Semiconductor Physics Division
Fachverband Halbleiterphysik (HL)

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Vice Chairs: Michael Jetter, University of Stuttgart, and Christoph Lienau, University of Oldenburg

Overview of Invited Talks and Sessions

(lecture rooms ER 164, ER 270, EW 015, EW 201, EW 202, and EW 203; Poster D)

Invited Talks

HL 3.1	Mon	9:30–10:00	ER 164	**Recent advances in ultrafast VECSELs and MIXSELs** — •Thomas Südmeyer, Valentin J. Wittwer, Oliver D. Sieber, Mario Mangold, Martin Hoffmann, Yohan Barbarin, Matthias Christoph Golling, Ursula Keller
HL 3.4	Mon	11:15–11:45	ER 164	**Novel wavelength VECSELs via intracavity Raman conversion and InP quantum dots** — •Jennifer E. Hastie, Peter J. Schlosser, Daniele C. Parrotta, Alan J. Kemp, Martin D. Dawson
HL 14.1	Mon	15:00–15:30	ER 164	**Growth and Device Integration of Site-Controlled Quantum Dots** — •Sven Höfling, Christian Schneider, Alexander Huggenberger, Vasilij Baumann, Micha Strauss, Thomas Sünner, Tobias Heindel, Lukas Worschech, Stephan Reitzenstein, Martin Kamp, Alfred Forchel
HL 14.4	Mon	16:45–17:15	ER 164	**Spatial and spectral control of self-assembled quantum dots.** — •Oliver G. Schmidt
HL 31.1	Tue	9:30–10:00	EW 203	**Quantum structures on ultra clean electron gases** — •Clemens Rössler, Stephan Baer, Thomas Ihn, Klaus Ensslin, Christian Reichl, Werner Wegscheider
HL 42.1	Tue	14:45–15:15	EW 201	**Excitons in organic semiconductors and organic/inorganic hybrid systems: Insight from many-body perturbation theory** — •Claudia Draxl
HL 46.1	Wed	9:30–10:00	ER 164	**AlN-based technology for electronics and optoelectronics** — •Zlatko Sitar, Ramon Collazo, Raoul Schlesser, Spalding Craft, Baxter Moody, Seiji Mita, Jinqiao Xie, Anthony Rice, James Tweedy
HL 67.1	Wed	17:15–17:45	ER 270	**Excitons in Artificial Light-Harvesting Antenna Systems** — •Dorthe M. Eisele, Dylan H. Arias, Colby P. Steiner, Robert J. Silbey, Xiaofeng Fu, Daniela Nicastro, Keith A. Nelson, Moungi G. Bawendi
HL 74.1	Thu	9:30–10:00	ER 164	**A highly efficient single photon - single quantum dot interface** — •P. Senellart, O. Gazzano, S. Michaelis de Vasconcellos, C. Arnold, V. Loo, A. Nowak, A. Dousse, A. Lemaitre, I. Sagnes, J. Bloch, P. Voisin, L. Lanco
HL 74.4	Thu	11:30–12:00	ER 164	**Semiconductor photonics for quantum information applications** — •Andrew Shields
HL 75.1	Thu	9:30–10:00	EW 201	**Weak and strong coupling in wide-gap semiconductor based monolithic microcavities** — •Kathrin Sebald
HL 82.1	Thu	15:00–15:30	ER 164	**Quantum dot - nanocavity QED for quantum information processing** — •Jelena Vuckovic
HL 83.1	Thu	15:00–15:30	EW 201	**Compositional instability in InGaN and InAlN thick films with high indium content** — •Fernando Ponce
HL 83.4	Thu	16:45–17:15	EW 201	**Low Temperature Growth Methods for Overcoming Perceived Limitations in III-Nitride Epitaxy** — •W. Alan Doolittle, Michael Moseley, Brendan Gunning

HL 96.5	Fri	11:45–12:15	ER 164	**Atomistic insights and controls for compound semiconductor growth by STMBE: STM obseration during MBE growth** — •Shiro Tsukamoto
HL 96.6	Fri	12:15–12:45	ER 164	**In situ synchrotron x-ray studies during metal-organic chemical vapor deposition of semiconductors** — •Carol Thompson, Matthew J. Highland, Edith Perret, Marie-Ingrid Richard, Paul H. Fuoss, Stephen K. Streiffer, G. Brian Stephenson

Invited talks of the joint symposium SYTI

See SYTI for the full program of the symposium.

SYTI 1.1	Tue	9:30–10:00	H 0105	**Search for Majorana fermions in topological insulators** — •Carlo Beenakker
SYTI 1.2	Tue	10:00–10:30	H 0105	**Cooper Pairs in Topological Insulator Bi_2Se_3 Thin Films Induced by Proximity Effect** — •Jinfeng Jia
SYTI 1.3	Tue	10:30–11:00	H 0105	**Gate tunable normal and superconducting transport through a 3D topological insulator** — •Alberto Morpurgo
SYTI 1.4	Tue	11:00–11:30	H 0105	**Weyl Metal States and Surface Fermi Arcs in Iridates** — •Sergey Savrasov
SYTI 1.5	Tue	11:30–12:00	H 0105	**Engineering a Room-Temperature Quantum Spin Hall State in Graphene via Adatom Deposition** — •Marcel Franz

Invited talks of the joint symposium SYNM

See SYNM for the full program of the symposium.

SYNM 1.1	Wed	15:00–15:30	H 0105	**Mechanical resonators in the quantum regime** — •Andrew N. Cleland
SYNM 1.2	Wed	15:30–16:00	H 0105	**Quantum optomechanics: exploring the interface between quantum physics and gravity** — •Markus Aspelmeyer
SYNM 1.3	Wed	16:00–16:30	H 0105	**Integrated transduction and coherent control of high Q nanomechanical systems using dielectric gradient forces** — •Eva M. Weig
SYNM 1.4	Wed	16:30–17:00	H 0105	**Cavity optomechanics with microwave photons** — •John Teufel
SYNM 1.5	Wed	17:00–17:30	H 0105	**Optomechanical crystals** — •Oskar Painter

Invited talks of the joint symposium SYRS

See SYRS for the full program of the symposium.

SYRS 1.1	Thu	15:00–15:30	H 0105	**Redox-based resistive memories - recent progress** — •Rainer Waser
SYRS 1.2	Thu	15:30–16:00	H 0105	**Electric Formation of Metal/$SrTiO_3$ Junctions and its Correlation to Multi-Dimensional Defects** — •Dirk C. Meyer, Hartmut Stöcker, Juliane Hanzig, Florian Hanzig, Matthias Zschornak, Barbara Abendroth, Sibylle Gemming
SYRS 1.3	Thu	16:00–16:30	H 0105	**The Connecting between the Properties of Memristive Material Systems and Application Requirements** — •Thomas Mikolajick, Stefan Slesazeck, Hannes Mehne
SYRS 1.4	Thu	16:30–17:00	H 0105	**Mechanism of resistive switching in bipolar transition metal oxides** — •Marcelo Rozenberg
SYRS 1.5	Thu	17:00–17:30	H 0105	**Resistive switching memories: Mechanisms, modeling and scaling** — •Daniele Ielmini

Sessions

HL 1.1–1.3	Sun	16:00–17:55	EW 201	**Tutorial: Attosecond Electron Dynamics**
HL 2.1–2.11	Mon	9:30–13:15	ER 270	**Focus Session: Structural Ordering and Electronic Transport I (jointly with CPP)**
HL 3.1–3.6	Mon	9:30–12:45	ER 164	**Focus Session: VECSEL**
HL 4.1–4.9	Mon	9:30–11:45	EW 201	**GaN: Preparation and Characterization I (mainly Optics)**

HL 5.1–5.6	Mon	9:30–11:00	EW 202	**Quantum Dots and Wires: Preparation and Characterization I**
HL 6.1–6.8	Mon	9:30–11:30	EW 203	**Ge/Si I**
HL 7.1–7.8	Mon	9:30–11:30	EW 015	**"New" Materials and New Physics in "Old" Materials I**
HL 8.1–8.12	Mon	9:30–12:45	BH 243	**Transport: Quantum Coherence and Quantum Information Systems 1 (jointly with TT, MA)**
HL 9.1–9.13	Mon	9:30–13:00	H 3010	**Transport: Topological Insulators 1 (jointly with TT, MA)**
HL 10.1–10.8	Mon	11:15–13:15	EW 202	**Quantum Dots and Wires: Preparation and Characterization II (mainly Arsenides)**
HL 11.1–11.9	Mon	11:45–14:00	EW 203	**Carbon: Nanotubes, Diamond and Silicon Carbid**
HL 12.1–12.9	Mon	11:45–14:00	EW 015	**"New" Materials and New Physics in "Old" Materials II**
HL 13.1–13.8	Mon	15:00–17:30	ER 270	**Focus Session: Structural Ordering and Electronic Transport II (jointly with CPP)**
HL 14.1–14.6	Mon	15:00–18:15	ER 164	**Focus Session: Site-selective Growth of single Quantum Dots**
HL 15.1–15.8	Mon	15:00–17:00	EW 201	**Graphene: Structure and Theory I**
HL 16.1–16.5	Mon	15:00–16:15	EW 202	**II-VI Semiconductors I**
HL 17.1–17.7	Mon	15:00–16:45	EW 203	**Plasmonic Systems**
HL 18.1–18.9	Mon	15:00–17:30	BH 243	**Transport: Quantum Coherence and Quantum Information Systems 2 (jointly with TT, MA)**
HL 19.1–19.6	Mon	15:00–16:30	H 3005	**Transport: Topological Insulators 2 (jointly with TT, MA)**
HL 20.1–20.7	Mon	16:30–18:15	EW 202	**Focus Session: Magnetic Semiconductors (jointly with MA)**
HL 21.1–21.5	Mon	17:00–18:15	EW 203	**Photonic Crystals I**
HL 22.1–22.7	Mon	17:15–19:00	EW 201	**Graphene: Structure and Theory II**
HL 23.1–23.6	Mon	17:45–19:15	H 1012	**Topological Insulators I (jointly with MA, DS, O, TT)**
HL 24.1–24.25	Mon	16:00–19:00	Poster D	**Poster Session: Ge/Si/SiC / III - V Semiconductors**
HL 25.1–25.27	Mon	16:00–19:00	Poster D	**Poster Session: GaN - Optical Properties & Preparation and Characterization & Devices**
HL 26.1–26.15	Mon	16:00–19:00	Poster D	**Poster Session: Heterostructures - Preparation and Characterization - Impurities / Amorphous Semiconductors**
HL 27.1–27.6	Tue	9:30–11:00	ER 270	**Photovoltaics: Innovative Material Systems**
HL 28.1–28.4	Tue	9:30–10:30	ER 164	**Focus Session: Topological Insulators (jointly with MA, TT)**
HL 29.1–29.11	Tue	9:30–12:30	EW 201	**III-V Semiconductors I (mainly Nitrides)**
HL 30.1–30.7	Tue	9:30–11:15	EW 202	**ZnO and Relatives I**
HL 31.1–31.1	Tue	9:30–10:00	EW 203	**Invited Talk: Clemens Rössler**
HL 32.1–32.12	Tue	10:00–13:15	EW 203	**Transport Properties I (mainly Spin Physics and Magnetic Fields)**
HL 33.1–33.7	Tue	9:30–11:15	EW 015	**Ge/Si II**
HL 34.1–34.7	Tue	9:30–11:15	H 2032	**Organic Electronics and Photovoltaics: Simulations and Optics I (jointly with DS, CPP, O)**
HL 35.1–35.8	Tue	9:30–12:15	BH 243	**Transport: Quantum Coherence and Quantum Information Systems 3 (jointly with TT, MA)**
HL 36.1–36.12	Tue	9:30–12:45	H 0112	**Magnetic Semiconductors (jointly with MA)**
HL 37.1–37.10	Tue	10:45–13:15	ER 164	**Quantum Dots and Wires: Optical Properties I (mainly InGaAs Dots)**
HL 38.1–38.8	Tue	11:15–13:15	ER 270	**Photovoltaics: CIGS and related Materials**
HL 39.1–39.7	Tue	11:30–13:15	EW 202	**ZnO and Relatives II**
HL 40.1–40.7	Tue	11:30–13:15	EW 015	**Impurities / Amorphous Semiconductors**
HL 41.1–41.6	Tue	11:30–13:00	H 2032	**Organic Electronics and Photovoltaics: Simulations and Optics II (jointly with DS, CPP, O)**
HL 42.1–42.1	Tue	14:45–15:15	EW 201	**Invited Talk: Claudia Draxl**
HL 43.1–43.28	Tue	9:30–12:30	Poster D	**Poster Session: Quantum Dots and Wires - Preparation and Characterization / Devices (incl. Laser) / Ultrafast Phenomena**
HL 44.1–44.22	Tue	9:30–12:30	Poster D	**Poster Session: Quantum Dots and Wires - Transport & Optical Properties**
HL 45.1–45.6	Wed	9:30–11:00	ER 270	**Photovoltaics: Silicon-based Systems I**
HL 46.1–46.6	Wed	9:30–12:45	ER 164	**Focus Session: AlGaN Materials for UV Emitters**
HL 47.1–47.1	Wed	9:30–10:00	EW 201	**Invited Talk: Dieter Weiss**
HL 48.1–48.12	Wed	10:00–13:15	EW 201	**Focus Session: Spintronics (jointly with MA)**
HL 49.1–49.9	Wed	9:30–11:45	EW 202	**Ultrafast Phenomena**
HL 50.1–50.5	Wed	9:30–10:45	EW 203	**III-V Semiconductors II (mainly Arsenides)**

HL 51.1–51.13	Wed	9:30–13:00	EB 301	**Topological Insulators II (jointly with MA, DS, O, TT)**
HL 52.1–52.7	Wed	9:30–11:15	H 2032	**Organic Electronics and Photovoltaics: Electronic Properties I (jointly with DS, CPP, O)**
HL 53.1–53.13	Wed	9:30–13:00	BH 334	**Transport: Topological Insulators 3 (jointly with TT, MA)**
HL 54.1–54.7	Wed	11:00–12:45	EW 203	**Optical Properties**
HL 55.1–55.6	Wed	11:15–12:45	ER 270	**Photovoltaics: Silicon-based Systems II**
HL 56.1–56.6	Wed	11:30–13:00	H 2032	**Organic Electronics and Photovoltaics: Electronic Properties II (jointly with DS, CPP, O)**
HL 57.1–57.5	Wed	12:00–13:15	EW 202	**Photonic Crystals II**
HL 58.1–58.8	Wed	15:00–17:00	ER 270	**Focus Session: Structure and Transport in Organic Photovoltaics III (jointly with CPP)**
HL 59.1–59.1	Wed	15:00–15:30	ER 164	**Invited Talk: Jonathan Eroms**
HL 60.1–60.5	Wed	15:30–16:45	ER 164	**Graphene: Raman Spectroscopy**
HL 61.1–61.5	Wed	15:00–16:15	EW 202	**GaN: Preparation and Characterization II (mainly structural)**
HL 62.1–62.8	Wed	15:00–17:00	EW 203	**Quantum Dots and Wires: Transport Properties I (mainly Quantum Wires)**
HL 63.1–63.8	Wed	15:00–17:00	EW 015	**Devices I**
HL 64.1–64.8	Wed	16:30–18:30	EW 202	**GaN: Preparation and Characterization III**
HL 65.1–65.5	Wed	17:00–18:15	ER 164	**Transport Properties II (Theory)**
HL 66.1–66.5	Wed	18:15–19:30	ER 164	**Transport Properties III (Experiments)**
HL 67.1–67.1	Wed	17:15–17:45	ER 270	**Invited Talk: Dörthe Eisele**
HL 68.1–68.7	Wed	17:45–19:30	ER 270	**Photovoltaics: Organic Semiconductors**
HL 69.1–69.8	Wed	17:15–19:15	EW 203	**Quantum Dots and Wires: Transport Properties II (mainly Quantum Dots)**
HL 70.1–70.7	Wed	17:15–19:00	EW 015	**Devices II**
HL 71.1–71.30	Wed	16:00–19:00	Poster D	**Poster Session: Graphene / Topological Insulators / Interfaces and Surfaces**
HL 72.1–72.32	Wed	16:00–19:00	Poster D	**Poster Session: Si-based Photovoltaics / Inorganic Photovoltaics / Structure and Transport in Organic Photovoltaics / Organic Semiconductors**
HL 73.1–73.6	Thu	9:30–11:00	ER 270	**GaN: Preparation and Characterization IV**
HL 74.1–74.5	Thu	9:30–12:30	ER 164	**Focus Session: Semiconductor-based Quantum Communication I**
HL 75.1–75.1	Thu	9:30–10:00	EW 201	**Invited Talk: Kathrin Sebald**
HL 76.1–76.6	Thu	9:30–11:00	EW 202	**Heterostructures**
HL 77.1–77.8	Thu	9:30–11:30	EW 203	**Quantum Dots and Wires: Optical Properties II (mainly Luminescence and Electronic Structure)**
HL 78.1–78.13	Thu	9:30–13:00	BH 334	**Transport: Graphene 1 (jointly with TT, MA, DY, DS, O)**
HL 79.1–79.6	Thu	10:30–12:00	EW 201	**Photovoltaics: General Aspects**
HL 80.1–80.9	Thu	11:15–13:30	ER 270	**GaN: Preparation and Characterization V (mainly Cathodoluminescence)**
HL 81.1–81.7	Thu	15:00–16:45	ER 270	**Graphene: Transport incl. Spin Physics and Magnetic Fields I**
HL 82.1–82.3	Thu	15:00–16:30	ER 164	**Focus Session: Semiconductor-based Quantum Communication II**
HL 83.1–83.6	Thu	15:00–18:15	EW 201	**Focus Session: III-Nitride Heterostructures for Optoelectronics - Polarization Reduction, Green Gap and High In-containing Alloys**
HL 84.1–84.5	Thu	15:00–16:15	EW 202	**Quantum Dots and Wires: Transport Properties III (mainly Thermal Gradients)**
HL 85.1–85.9	Thu	15:00–17:30	EW 203	**Organic Semiconductors: Transistors and OLEDS**
HL 86.1–86.10	Thu	15:00–17:45	EW 015	**Semiconductor Lasers**
HL 87.1–87.4	Thu	15:00–16:45	H 1012	**Graphen: Spin Transport (jointly with MA, DS, DY, O, TT)**
HL 88.1–88.7	Thu	16:30–18:15	EW 202	**Quantum Dots and Wires: Transport Properties IV (mainly Double Dots and Point Contacts)**
HL 89.1–89.6	Thu	16:45–18:15	ER 164	**Focus Session: Quantum Information Systems (jointly with MA,TT)**
HL 90.1–90.6	Thu	17:00–18:30	ER 270	**Graphene: Transport incl. Spin Physics and Magnetic Fields II**

HL 91.1–91.19	Thu	16:00–19:00	Poster D	**Poster Session: Spintronics / Magnetic Semiconductors / Transport**
HL 92.1–92.27	Thu	16:00–19:00	Poster D	**Poster Session: II-VI Semiconductors & ZnO and related Materials**
HL 93.1–93.23	Thu	16:00–19:00	Poster D	**Poster Session: Metal-Semiconductor Hybrid Systems, Plasmonic Systems / Photonic Crystals / Carbon: Diamond & CNT / Quantum Information Systems**
HL 94.1–94.1	Fri	9:30–10:00	ER 270	**Invited Talk: Martin Eickhoff**
HL 95.1–95.8	Fri	9:30–11:30	EW 201	**Quantum Dots and Wires: Optical Properties III (mainly Cavities and Ultrafast Response)**
HL 96.1–96.6	Fri	9:30–12:45	ER 164	**Focus Session: Semiconductor Nanophotonics - Characterization on the Atomic Scale**
HL 97.1–97.6	Fri	10:00–11:30	ER 270	**Quantum Dots and Wires: Optical Properties IV (mainly Nitrides)**
HL 98.1–98.11	Fri	9:30–12:30	EW 202	**Electronic Structure Theory**
HL 99.1–99.11	Fri	9:30–12:30	EW 203	**Organic Semiconductors: Transport**
HL 100.1–100.5	Fri	9:30–10:45	H 0111	**Resistive Switching I (jointly with DS, DF, KR)**
HL 101.1–101.9	Fri	9:30–12:00	BH 243	**Transport: Nanoelectronics II - Spintronics and Magnetotransport (jointly with TT, MA)**
HL 102.1–102.12	Fri	9:30–12:45	BH 334	**Transport: Graphene 2 (jointly with TT, MA, DY, DS, O)**
HL 103.1–103.6	Fri	11:00–12:30	H 0111	**Resistive Switching II (jointly with DS, DF, KR)**
HL 104.1–104.9	Fri	11:45–14:00	EW 201	**Quantum Dots and Wires: Optical Properties V (mainly Indiviual Photons)**

Annual General Meeting of the Semiconductor Physics Division

Thursday 18:30 in EW 202

HL 1: Tutorial: Attosecond Electron Dynamics

Attosecond physics aims at probing and manipulating electronic motion driven by strong laser fields on nanometer length and extremely short time scales. For some years, this field has captured the attention of atomic and molecular physicists. Very recently, several experimental and theoretical studies have started to explore strong-field attosecond electron dynamics in solid state nanostructures. It is the aim of this tutorial to give an introduction into this emerging field, to connect gas-phase and solid state attosecond science and to give perspectives for future work, in particular - but not exclusively - for young scientists. (Organizer: Christoph Lienau, University of Oldenburg)

Time: Sunday 16:00–17:55 Location: EW 201

Tutorial HL 1.1 Sun 16:00 EW 201

Time delays in ionization: real, imaginary, and imagined — •Misha Ivanov — Department of Physics, Imperial College London, South Kensington Campus, London, UK

I will review recent work on trying to understand how much time does it take to liberate an electron from an atom or a molecule. I will focus on two ionization regimes: one-photon and tunneling, and on different ways to address this question both technically and conceptually. In particular, I will show how our attempts to tag an electron as it becomes free after tunneling have led to a better understanding of attosecond core rearrangement during tunneling.

Short Break (5 min)

Tutorial HL 1.2 Sun 16:40 EW 201

Control of Electron Emission from Nanoscopic Systems by Ultrashort Laser Pulses — •Eckart Rühl — Physikalische Chemie, Freie Universität Berlin, Takustr. 3, 14195 Berlin, Germany

Recent progress in control of electron emission from nanoscopic dielectric systems by ultrashort laser pulses and related work is reviewed. Coherent control strategies of laser-induced processes of gas phase species have been established before. Such gas phase species are not limited to atoms, molecules, or clusters. More recently it has been shown that intense nanoparticle beams can be prepared in narrow size distributions as gas phase targets. Ultrashort, intense, and carrier envelope phase-stabilized laser pulses of 4-6 fs in the near infrared regime lead to novel electron emission processes as well as the control of electron motion in the attosecond time regime. This goes beyond well-known photoemission induced by one-photon absorption of ionizing radiation, where the electron spectra of nanoparticles and macroscopic condensed matter are dominated by low kinetic energy, inelastically scattered electrons. In contrast, few-cycle laser pulses yield electron spectra with phase-dependent emission of high kinetic energy electrons. This process has been shown to be unique for condensed matter and is not possible for atomic species. Details of the processes occurring on ultra-short time scales have been assigned by using semiclassical Monte-Carlo simulations. These results indicate that tunnel ionization, the laser field, dielectric near-field enhancement, and the Coulomb field of the liberated charges contribute. Prospects of these results are briefly discussed.

Short Break (5 min)

Tutorial HL 1.3 Sun 17:20 EW 201

Attosecond science at nanometric needle tips — •Peter Hommelhoff — Max-Planck-Institut für Quantenoptik

Attosecond science, namely the steering of electrons with the electric field of well-controlled femtosecond laser pulses, has led to the generation of high-harmonic radiation, even to the generation of single isolated extreme-ultraviolet pulses with durations below 100 attoseconds ($1\,\text{as} = 10^{-18}\,\text{s}$), as well as to the measurement of intramolecular dynamics and ultrafast electron holography. These effects have been observed with atoms, molecules and clusters in the gas phase. We will report on the steering of electrons emitted from *nanoscale metal tips* with the help of phase-controlled low-power few-cycle femtosecond laser pulses. We will highlight the commonalities as well as the differences to the atomic physics system, and will give an outlook on future techniques such as ultrafast surface imaging.

HL 2: Focus Session: Structural Ordering and Electronic Transport I (jointly with CPP)

As yet, there is no complete picture describing the influence of morphology on the transport of excitons and charge in organic semiconductors. This lack of understanding is in part due to the very complex and inhomogeneous morphology of these layers. This session aims to discuss the influence of molecular order, especially intramolecular and intermolecular order in crystalline and amorphous regions, on transport in conjugated molecular systems. Among other subjects, different model systems will be compared, ranging from ordered monolayers in UHV to macroscopic single crystals. (Organizers: Günter Reiter, Dieter Neher, Veit Wagner)

Time: Monday 9:30–13:15 Location: ER 270

Invited Talk HL 2.1 Mon 9:30 ER 270

Neither crystalline nor amorphous: how charge transport is affected by order in organic semiconductors — •Alberto Salleo — Stanford University, Stanford, USA

From the fundamental standpoint, organic semiconductors are fascinating as they are neither crystalline nor amorphous and their microstructure plays a central role in governing charge transport. I will show that understanding disorder is the key to determining charge transport mechanism. Using advanced synchrotron-based X-ray characterization techniques we are able to define and measure structural order at different length-scales. We are particularly interested in cumulative disorder (paracrystallinity), where the lattice parameter takes on a Gaussian distribution about its mean value. The disorder parameter g allows us to rank materials quantitatively on a continuous scale, from a perfectly crystalline material (g<1%) to an amorphous one (g>10%). Using disorder as a ranking parameter, I will discuss the differences in transport between small molecule and polymer films as well as their respective inherent limitations and bottlenecks. This work may help devising design rules for new materials with desirable transport properties for polarons and excitons.

HL 2.2 Mon 10:00 ER 270

Influence of Alkyl Side Chain Length on the Self-organization of RT and Low Temperature Cast Poly(3-alkylthiophene) Thin Films — •Shabi Thankaraj Salammal[1], Souren Grigorian[1], Ullrich Pietsch[1], Martin Brinkmann[2], Navaphun Kayunkid[2], Nils Koenen[3], and Ullrich Scherf[3] — [1]University of Siegen — [2]CNRS, Strasbourg — [3]University of Wuppertal

An enhancement of in-plane stacking of poly(3-alkylthiophene)s (P3ATs) with decrease of alkyl side chain length has been thoroughly analyzed using X-ray and electron diffraction (ED)technique. Thin films of poly(3-pentylthiophene), poly(3-hexylthiophene), poly(3-heptylthiophene), and poly(3-octylthiophene) (P3OT) were cast at

23°C(RT) and low (-30°C) temperature. Thin films prepared using the lowest concentration (1mg/14ml) envisages that the P3OT crystallites can provide highly edge-on oriented and bigger crystallites by casting at low temperature. The X-ray and electron diffraction patterns collected for the same films shows the poor in in-plane ordering of P3AT crystallites as the side chain length increases due to the augment in steric hindrance between the alkyl side chains. It subsequently reduces the photoluminescence (PL) efficiency as well as the field effect mobility of organic field effect transistors. The reduction in cast temperature together with the reduction of alkyl side chain length is resulting three distinct PL peaks with defined linewidths. The absence of face-on oriented crystallites while casting at -30°C can be explained by the prolongation of growth time caused by the reduced evaporation of solvent (Chloroform).

HL 2.3 Mon 10:15 ER 270

Determination of the Crystallinity of Semicrystalline Poly(3-hexyl thiophene) by Means of Wide Angle X-Ray Scattering — •Jens Balko[1], Ruth Lohwasser[2], Michael Sommer[3], Mukundan Thelakkat[2], and Thomas Thurn-Albrecht[1] — [1]Institute of Physics, Martin-Luther-University Halle-Wittenberg, 06120 Halle — [2]Applied Functional Materials, Macromolecular Chemistry I, University of Bayreuth, 95440 Bayreuth — [3]Melville Laboratory for Polymer Synthesis, Department of Chemistry, University of Cambridge, Cambridge

Poly(3-hexyl thiophene) (P3HT) is a common polymer semiconductor, often used as material or component in organic field effect transistors or solar cells. The crystallinity of this semicrystalline material is among other parameters governing the electronic mobility. However, at present there is no routine method available to determine an absolute value for the crystallinity, and the values given in the literature e.g. for the enthalpy of melting vary by a factor of three. Wide Angle X-Ray Scattering (WAXS) probes the crystals as well the amorphous parts of the sample and there exists an established procedure to measure the crystallinity (RULAND, 1961) based on scattering data. The result is used for a reliable calibration of the melting enthalpy that can serve as a reference value for more convenient calorimetric techniques. We compare the crystallinity for a number of chemically well-defined samples, with different molecular weight and a typical commercial sample with broad molecular weight distribution. In addition, for some selected samples we study the influence of temperature on crystallinity.

HL 2.4 Mon 10:30 ER 270

Formation of Single Crystals of Conjugated Polymers — •Khosrow Rahimi[1], Ioan Botiz[1,2], Natalie Stingelin[2,3], and Günter Reiter[1,2] — [1]Institute of Physics, University of Freiburg — [2]Freiburg Research Institute for Advanced Studies (FRIAS) — [3]Imperial College London

In order to improve optoelectronic properties of conjugated polymers, a profound understanding of the excitonic and electronic transport with respect to structure is crucial. By gaining a precise control over both molecular conformations and morphology we aim to obtain a correlation between orders at a macromolecular level to charge transport properties. The best controlled system for such a study is a single crystal which is free of grain boundaries and molecular disorder/defects.

Here, we report the preparation and structural properties of Poly(3-hexylthiophene) single-crystal grown by crystallization in dilute solutions. By employing a self-seeding approach, we were able to circumvent the nucleation process. To this end, we first dissolved all but a few small thermodynamically stable crystals, which then act as nuclei (seed crystals) for the subsequent crystallization step at higher polymer concentrations or at lower temperatures. This approach extends the accessible range for crystallization to lower degrees of supersaturation or supercooling. Using such conditions, we could control crystal size in all three dimensions as well as aspect ratio.

HL 2.5 Mon 10:45 ER 270

Developing hybrid simulation schemes for mesoscale modeling of morphologies in organic semiconductors — •Kostas Daoulas[1,2], Victor Ruehle[1,3], and Kurt Kremer[1] — [1]Max Planck Institute for Polymer Research, Mainz, Germany — [2]Innovation Lab GmbH, Heidelberg, Germany — [3]Department of Chemistry, University of Cambridge, United Kingdom

Hybrid simulations use a particle-based description while defining some interactions via collective variables. These degrees of freedom are soft; thus significant speedups of simulations are possible and large systems can be addressed. However, this softness of interactions poses challenges in modeling organic semiconductors where the local liquid structuring (e.g. pi-pi stacking) affects the mesoscale properties. As a first step in developing hybrid approaches incorporating this interplay, we consider here Monte Carlo simulations of homopolymer melts with nematic liquid-crystalline (LC) behavior. The polymers are described as discrete worm-like chains, a simple density functional controls the compressibility, and a functional of the local segmental orientation tensor captures the LC ordering. We illustrate that the method can address large systems parameterized according to volumetric and conformational properties representative of semiconductor materials by establishing a rough correspondence with regiorandom P3HT melts. Chain conformations and the effect of the molecular weight on the isotropic-nematic transition are studied. The formation of the nematic phase is addressed within the Rouse-like dynamics realized by the current model. We discuss directions of further methodological developments.

HL 2.6 Mon 11:00 ER 270

Structure determination beyond crystallinity — •Chris Elschner[1], Sebastian Radke[2], Gianaurelio Cuniberti[2], Karl Leo[1], and Moritz Riede[1] — [1]Institut für Angewandte Photophysik (IAPP), TU Dresden, 01069 Dresden, Germany — [2]Institute for Materials Science and Max Bergmann Center of Biomaterials, TU Dresden, 01062 Dresden, Germany

Organic semiconducting materials allow novel optoelectronic devices, combining the excellent optical properties of organic dyes with semiconductor behavior. Organic Light Emitting Diodes and Organic Solar Cells are successful examples in this field. Many organic materials grow strongly disordered or even amorphous in thin films. To distinguish between crystalline or amorphous thin films, X-ray diffraction measurements can be used. If Bragg reflections are missing, organic films are simply classified as amorphous in literature without any specification. We show that it is possible to extract short range order informations even from amorphous organic layers. Using a special grazing incidence X-ray diffraction method [1] it is possible to measure the diffuse scattering of amorphous DBP organic layers. A structural model of the short range order within a few nm gives insight of the molecular stacking in the amorphous layer. The structural model is used as starting configuration for mobility calculations based on Monte Carlo simulations. Finally, the correlation between short range molecule stacking and charge transport is investigated.

[1] C. Elschner et al. Journal of Applied Crystallography 44, 983-990(2011).

30 min break: Possibility for discussions

Invited Talk HL 2.7 Mon 11:45 ER 270

Charge transport and recombination in organic light-emitting diodes — •Paul Blom — TNO Holst Centre, Eindhoven, Netherlands

Charge transport and charge recombination are recognized as key ingredients in the performance of polymer light emitting diodes (PLEDs). We observe that in conjugated polymers the electron transport is limited by traps that are Gaussianly distributed in energy within the band gap. Remarkably, we show that the electron trap distribution is identical for a large variety of polymers, hinting at a common origin for electron traps. Photogenerated current measurements on PLED device structures reveal that next to the known Langevin recombination also trap-assisted recombination is an important recombination channel in PLEDs. The dependence of the open-circuit voltage on light intensity enables us to determine the strength of this process. Numerical modeling of the current-voltage characteristics incorporating both Langevin and trap-assisted recombination yields a correct and consistent description of the PLED, without the traditional correction of the Langevin pre-factor. At low bias voltage the trap-assisted recombination rate is found to be dominant over the free carrier recombination rate. As a result, we show that the ideality factor in the diffusion regime of a bipolar diode is governed by the recombination of trapped electrons with free holes.

HL 2.8 Mon 12:15 ER 270

Investigations of charge generation, transport and recombination on organic solar cells based on merocyanines — •Steven Graf[1], Vera Steinmann[1], Nils Kronenberg[1], Martin Lenze[1], Dirk Hertel[1], Frank Würthner[2], and Klaus Meerholz[1] — [1]Institut für Physikalische Chemie, Universität zu Köln, Luxemburger Str. 116, 50939 Köln (Germany) — [2]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074

Würzburg

Organic photovoltaics offer a very promising green energy alternative. Highly efficient organic solar cells can be produced by cost-effective methods such as coating from solution (SOL) or depositing under high vacuum conditions (VAC).

We investigate merocyanines (MC), a class of low-molecular-weight colorants, as donor material in organic solar cells. These molecules are processable via both deposition techniques, showing remarkable power conversion efficiencies (PCE) beyond 4% for SOL- and 6% for VAC-processed devices.

Towards even higher PCEs it is imperative to gain a better understanding of the fundamental processes of charge carrier generation, transport and recombination in MC solar cells. We carried out a detailed study of these processes using steady- state and time-resolved photoluminescence spectroscopy and current-voltage measurements. The influence of morphology on fundamental processes is elucidated by varying the deposition conditions as well as the fabrication method. The investigations are supported by temperature- and electric-field-dependent studies of charge recombination and transport.

HL 2.9 Mon 12:30 ER 270

Morphology triggered impact of charge carrier recombination on the current–voltage response of organic solar cells — •Alexander Foertig[1], Markus Gluecker[1], Alexander Wagenpfahl[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius-Maximilians-University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Bavarian Centre for Applied Energy Research (ZAE Bayern e.V.), Am Hubland, 97074 Würzburg, Germany

In view of a commercialization the efficiency of organic solar cells still has to be improved. Therefor a proper understanding of the fundamental physical processes is required. The non-geminate loss mechanisms of photo-generated charges in polymer:fullerene bulk heterojunction solar cells are studied using the complementary measurement techniques charge extraction (CE), transient photovoltage (TPV) and transient photocurrent (TPC). From voltage dependent charge carrier densities $n(V)$ a loss current $j_{loss}(V)$ can be determined. For systems predominately based on a voltage independent charge photo-generation this analysis successfully allows to reconstruct the measured I/V response. Devices based on the promising copolymer PTB7 blended with $PC_{71}BM$ are used to study the influence of morphology on the recombination dynamics and thus the I/V characteristics. Furthermore we applied macroscopic device simulations to analyse the influence of the spatial distribution of charges in the active layer which can not be accounted for in the experiment.

HL 2.10 Mon 12:45 ER 270

Temperature and carrier concentration dependent analysis of charge transport in Poly (3-hexylthiophene) based organic field effect transistors — •Hippolyte Hirwa and Veit Wagner — School of Engineering and Science Jacobs University Bremen Campusring 1, D-28759 Bremen (Germany)

A crucial step of organic electronics towards applications is the understanding and exploiting of their charge transport mechanisms. Several models have been previously developed in order to explain the behavior of organic semiconductors. These proposed models (e.g. Vissenberg Matters model, multiple trapping and release model and Neldel Meyer rule) try to include effects like temperature dependence, charge carrier concentration dependence and field dependence. However, these models can not fully explain our experimental data obtained on P3HT based organic field effect transistors manufactured on flexible PET foils. The Neldel Meyer rule hardly showed agreement with our experimental data. The Vissenberg and Matters model and the multiple trapping and release model showed a good agreement but only over a limited temperature range. For temperatures below 170K an additional transport mechanism is observed which is explained by a modification of the Vissenberg and Matters model.

HL 2.11 Mon 13:00 ER 270

Morphology controlled charge transport in diblock copolymer based solar cells — •Chetan Raj Singh[1], Ruth Lohwasser[2], Olesia Synooka[1], Mukundan Thelakkat[2], Gerhard Gobsch[1], and Harald Hoppe[1] — [1]Institute of Physics, TU Ilmenau, Germany — [2]Applied Functional Polymers, University of Bayreuth, Germany

The block copolymers as an active material have been sought after in solar cells to realize scalable and morphologically stable polymer solar cells. We report here the charge carrier mobilities of holes and electrons in the studied diblock copolymer (P3HT-b-PPerAcr) and in its constituting homopolymers, P3HT and PPerAcr. We discuss the effects of charge carrier mobility imbalance and its consequence on solar cell properties. In the study, the morphology of the diblock copolymer is altered by blending donor component and subsequent thermal treatments which have given rise to up to two orders of magnitude increase in charge carrier mobilities. Furthermore, the influence of morphology and achieved charge carrier mobility balance are studied on solar cell devices.

HL 3: Focus Session: VECSEL

Vertical-external-cavity surface-emitting lasers (VECSELs) or optically pumped semiconductor disk laser perfectly combine the excellent beam quality of surface emitters and the high output power of edge-emitting diode-lasers. VECSELs are available in a broad spectral range. Their external-cavity design offers large versatility such as efficient intra-cavity frequency mixing, multi-color operation, frequency stabilization, or ultrafast operation, only to name a few. At the same time, typical advantages of semiconductor devices like solid-state on-chip fabrication, small packaging dimensions, and the spectral tunability are maintained. (Organizers: Sangam Chatterjee, University of Marburg and Michael Jetter, University of Stuttgart)

Time: Monday 9:30–12:45 Location: ER 164

Invited Talk HL 3.1 Mon 9:30 ER 164

Recent advances in ultrafast VECSELs and MIXSELs — •Thomas Südmeyer[1,2], Valentin J. Wittwer[2], Oliver D. Sieber[2], Mario Mangold[2], Martin Hoffmann[2], Yohan Barbarin[2], Matthias Christoph Golling[2], and Ursula Keller[2] — [1]ETH Zurich, Switzerland — [2]University of Neuchatel, Switzerland

Ultrafast VECSELs and MIXELS are promising cost-efficient, reliable, and compact ltrafast laser sources. Modelocked VECSELs can achieve low-noise operation and >1 W in sub-picosecond pulses have been reported. The highest average powers are obtained from MIXSELs, VECSELs with integrated saturable absorber. Recent developments in these devices are reported.

Topical Talk HL 3.2 Mon 10:00 ER 164

Intra-cavity frequency doubling in visible VECSELs towards high efficiency UV laser emission — •Thomas Schwarzbäck, Hermann Kahle, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Center SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Since the pioneering work of Kuznetsov et al. in 1997, vertical external cavity surface-emitting lasers (VECSELs) have excited growing interest in science. These kinds of lasers combine some advantages, which none of the remaining semiconductor laser sources can offer. High continuous-wave (cw) output power and near-diffraction-limited beam quality with a TEM_{00} Gaussian beam profile are somewhat unique. Furthermore the possibility of bandgap engineering make VECSELs predestinated for lots of applications in various fields such as medicine, life sciences, display or projection applications and in research. Besides these compelling arguments, the VECSEL offers an additional feature resulting from the external cavity. Using optical elements in the external resonator like frequency selecting filters allow for spectral tuning

and with non-linear crystals efficient intra-cavity frequency doubling can be provided. The fundamental laser emission is provided by a red emitting VECSEL fabricated via metal-organic vapour-phase epitaxy. Using a compact v-shaped cavity, it is possible to generate UV laser emission at a wavelength of 330 nm with output powers in the 100 mW regime with a tuning range of several nanometers.

Topical Talk HL 3.3 Mon 10:30 ER 164
GaSb-based VECSELs for the $2-3\,\mu$m wavelength range — •Marcel Rattunde, Sebastian Kaspar, Tino Töpper, Christian Manz, Klaus Köhler, and Joachim Wagner — Fraunhofer Institut für Angewandte Festkörperphysik (IAF), Tullastr. 72, 79108 Freiburg, Germany

In recent years, vertical external cavity surface emitting lasers (VECSELs) have attracted increasing interest due to their capability of delivering simultaneously high output power and excellent beam quality, together with their suitability for the realization of tunable and single-frequency laser emission. Recently, the realization of high-performance VECSELs based on the (AlGaIn)(AsSb) material system with emission wavelengths around 2 μm and above has been reported. Such high-brightness laser sources are of interest for a range of applications such as long range sensing, medical therapy and diagnostics as well as seeding and pumping of solid state or fiber lasers. In this report we will present recent advances achieved using our GaSb-based VECSEL technology. In a high-power configuration, up to 10 W output power in CW-operation were demonstrated at 2.0 μm. With intracavity filters, tunable single-frequency laser modules were realized with a tuning range of 70-120 nm (depending on the cavity details). The emission linewidth (measured with a heterodyne beat note setup) was below 100 kHz (100 μs sampling time) at an output power above 1 W in CW operation. These results highlight the versatility of this concept for high-power, tunable and narrow-linewidth lasers in the $2-3\,\mu$m wavelength range.

Coffee Break (15 min)

Invited Talk HL 3.4 Mon 11:15 ER 164
Novel wavelength VECSELs via intracavity Raman conversion and InP quantum dots — •Jennifer E. Hastie, Peter J. Schlosser, Daniele C. Parrotta, Alan J. Kemp, and Martin D. Dawson — Institute of Photonics, University of Strathclyde, 106 Rottenrow, Glasgow G4 0NW, UK

In this talk we will present our recent work demonstrating intracavity Raman conversion of VECSELs, a nonlinear means to red-shift the emission wavelength of these high brightness semiconductor lasers. Practically, this involves the development of low-loss CW crystalline Raman lasers pumped by the VECSEL intracavity field, with tuning of the Raman laser achieved via tuning of the VECSEL oscillation wavelength. We reported a KGW Raman laser emitting around 1150nm, and more recently a diamond Raman laser with broad tuning around 1230nm, both pumped within the high finesse cavity of an InGaAs-based VECSEL. Multi-Watt Raman laser output power has been achieved with efficiency >14% w.r.t. diode pump power absorbed by the VECSEL. As well as addressing gaps in spectral coverage, Raman conversion is potentially an attractive alternative to the use of highly strained gain structures or less robust materials required for direct emission at longer wavelengths, without significant cost to power and efficiency.

The extension of VECSEL spectral coverage via novel semiconductor materials and gain structure design remains an important focus of our research, in parallel to our work on nonlinear conversion, and during the talk we will also briefly review our work on directly visible VECSELs utilising AlGaInP quantum wells and InP quantum dots.

Topical Talk HL 3.5 Mon 11:45 ER 164
Quantum-dot VECSEL — •Tim David Germann — Institut für Festkörperphysik EW 5-2, Technische Universität Berlin, Deutschland

Optical pumped vertical external-cavity surface-emitting lasers (VECSEL) based on multiple quantum well active regions have demonstrated multi-watt cw-operation and gaussian beam profiles enabling a bunch of new applications [1]. By introducing quantum-dot (QD) based active regions inside VECSEL new functionalities for such devices are enabled. A broader feasible wavelength range, higher temperature stability, and decreased threshold power densities are demonstrated. In order to achieve sufficient gain for high-power QD-based VECSEL stacking of many QD layers is required. For epitaxial growth processes the challenge is to maintain pseudomorphic growth and constant QD properties throughout the gain section while each QD layer induces a laterally inhomogeneous strain field. Thus QD overgrowth parameters are crucial to recover a smooth growth surface.

Here two conceptually different (In,Ga)As-based approaches for novel VECSEL gain media are demonstrated. Either the Stranski-Krastanow growth mode for QD fabrication or cycled sub-monolayer deposition of InAs embedded into GaAs is used aiming at a spectrally broad gain range or at high modal gain respectively. VECSELs for wavelengths ranging from 950 nm to 1210 nm are fabricated by stacking up to 30 active layers. Up to 1.4 W continuous wave output power and ultra low threshold of only 2.4 kW/cm^2 are achieved.

[1] A. C. Tropper and S. Hoogland, *Extended cavity surface-emitting semiconductor lasers*, Progress in Quantum Electronics **30**, 1 (2006).

Topical Talk HL 3.6 Mon 12:15 ER 164
Vertical-external-cavity surface-emitting lasers for high-power applications — •Alexej Chernikov[1], Jens Hermann[1], Bernadette Kunert[1], Wolfgang Stolz[1], Tsuei-Lian Wang[2], Joe M. Yarborough[2], Joerg Hader[2], Jerome V. Moloney[2], Martin Koch[1], Sangam Chatterjee[1], and Stephan W. Koch[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Germany — [2]College of Optical Sciences, The University of Arizona, Tucson, USA

Developed in the late 90s, vertical-external-cavity surface-emitting lasers combine the high output power of the edge-emitting diode lasers with the excellent beam quality of the surface-emitters. In addition, the external-cavity design offers additional advantages, faciliating frequency mixing applications as well as the operation of the device in a pulsed regime. Here, the high-power potential of the vertical-external-cavity surface-emitting lasers is discussed. Different cooling concepts are studied and the limits of the power-scaling are investigated by spacially resolved temperature measurements.

HL 4: GaN: Preparation and Characterization I (mainly Optics)

Time: Monday 9:30–11:45 Location: EW 201

HL 4.1 Mon 9:30 EW 201
Study of site symmetry from Europium (Eu^{+3}) luminescence in Europium-implanted p-GaN — •Jayanta Kumar Mishra[1], Torsten Langer[1], Uwe Rossow[1], Kirill Trunov[2], Andreas Wieck[2], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, TU Braunschweig — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Rare earth ions implanted into nitrides are promising for optoelectronic applications. In GaN, Europium is in a 3+ charge state. We studied the Eu^{3+} luminescence in Mg doped GaN. The most prominent luminescence is observed from the transition $^5D_0 \rightarrow {}^7F_2$. This transition further splits into several lines as the degeneracy of the ground state has been lifted. The contributions to this transition were found to be not only from a single Europium center but rather it is composed of different Europium centers in GaN. Considering the number of peaks from $^5D_0 \rightarrow {}^7F_2$ transition it would imply that Eu might not have occupied C_{3v} symmetry site, the Ga substitutional position.

We observed higher Eu^{3+} luminescence and more peaks for $^5D_0 \rightarrow {}^7F_2$ transition from Mg doped GaN:Eu than from undoped GaN:Eu. In Mg doped GaN more Eu sites contribute to $^5D_0 \rightarrow {}^7F_2$ transition.

The intensities of the split peaks of the $^5D_0 \rightarrow {}^7F_2$ transition are varying differently with temperature, which is further evidence for the presence of different Eu sites in Mg doped GaN:Eu.

HL 4.2 Mon 9:45 EW 201
Evidence for strain-induced defects as dominant nonradiative recombination centers in GaInN/GaN quantum wells — •Torsten Langer, Markus Göthlich, Andreas Kruse, Holger

Jönen, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, TU Braunschweig

Via temperature-dependent time-resolved photoluminescence spectroscopy we investigate the recombination dynamics in low-pressure MOCVD-grown GaInN/GaN single and multiple quantum well (SQW, MQW) structures. The temperature dependence of the intensities and decay times is used to separate the effect of radiative and nonradiative recombination mechanisms with the aim to understand the dominant loss mechanisms in green light emitters. We previously showed that there is a strong shortening of nonradiative lifetimes at 300 K from >4 ns down to ≈100 ps when the indium concentration exceeds 25% in 5-fold QW structures. In this contribution we show evidence that these limiting loss mechanisms for green emitters are caused by strain-induced defects: The strain energy density increases with the square of the lattice mismatch towards higher indium concentrations. We observe an exponential shortening of nonradiative lifetimes with increasing cumulative 2D strain energy density. This holds both for MQW and for SQW structures. A mere growth temperature related defect (e.g. point defects due to poor dissociation of ammonia at low T_{growth}) is not consistent with our data.

HL 4.3 Mon 10:00 EW 201

Angle resolved XPS for investigation of surface band-bending of III-nitrides — •Robert Metzner[1], Bernd Garke[1], Martin Feneberg[1], Stephanie Fritze[2], Armin Dadgar[2], Alois Krost[2], and Rüdiger Goldhahn[1] — [1]Otto-von-Guericke-Universität Magdeburg, Institut für Experimentelle Physik, Abteilung Materialphysik — [2]Otto-von-Guericke-Universität Magdeburg, Institut für Experimentelle Physik, Abteilung Halbleiterepitaxie

Due to surface donor states, III-nitrides suffer from Fermi level pinning at the surface leading to band-bending. To investigate this effect we establish angle resolved X-ray Photoelectron Spectroscopy (XPS) for determining size and direction of this fields. Variation of observation angles leads to different sampling depths and finally to a shift of the XPS peaks. With direction and size of these shifts, band-bending at the surface can be estimated. Samples which are expected to employ different surface band-bendings are investigated, especially c-oriented polar InN and GaN samples with various bulk doping levels. The measurements are finally compared to model calculations showing the principal applicability of the method.

HL 4.4 Mon 10:15 EW 201

Optical Investigation of Mg-doped AlGaN layers — •Sarah Osterburg[1], Martin Feneberg[1], María Fátima Romero[1], Bernd Garke[1], Jianchang Yan[2], Jianping Zeng[2], Junxi Wang[2], and Rüdiger Goldhahn[1] — [1]Otto-von-Guericke-Universität Magdeburg, Institut für Experimentelle Physik, Abteilung für Materialphysik, Deutschland — [2]Semiconductor Lighting R&D Center, Institute of Semiconductors, Chinese Academy of Sciences. P.O. Box 912. Beijing 100083, P.R.China

The emission and absorption features of Al-rich Mg-doped $Al_xGa_{1-x}N$ films ($0.58 \leq x \leq 0.735$) around the band edge were determined by different experimental techniques. We employed Photoluminescence (PL), synchrotron-based Photoluminescence Excitation Spectroscopy, synchrotron-based Spectroscopic Ellipsometry (SSE) and conventional Spectroscopic Ellipsometry at several temperatures between 5 K and room temperature. The data were compared to get a detailed view about the interband transitions taking place in the range from 4 eV to 6 eV. We analyze the Stokes shift of the different samples and clarify the influence of statistical alloy fluctuations on carrier localization.

HL 4.5 Mon 10:30 EW 201

Systematic optical characterization of InAlN/GaN heterostructures with different In content — •María Fátima Romero, Martin Feneberg, Rüdiger Goldhahn, Pascal Moser, Armin Dadgar, and Alois Krost — Institut für Experimentelle Physik, Otto-von-Guericke-Universität, Magdeburg, Germany

The luminescence properties of $In_xAl_{1-x}N$/GaN heterostructures are systematically investigated as a function of the In content (6.7 %-20.8 %). The recombination between the electrons confined in the two-dimensional-electron-gas (2DEG) at the heterointerface, and the photoexcited holes in the GaN buffer is identified and analyzed. We find a systematic shift of the recombination with the In content from about 80 meV below the GaN exciton emission (for x=0.067), to only few meV with increasing In concentration. These results are compared with theoretical model calculations and can be understood with changing band alignment and polarization offset between AlInN and GaN.

HL 4.6 Mon 10:45 EW 201

Optical studies on doped and nominally undoped AlN layers — •Benjamin Neuschl[1], Martin Feneberg[2], María Fátima Romero[2], Rüdiger Goldhahn[2], Zhihong Yang[3], Thomas Wunderer[3], Jinquiao Xie[4], Seiji Mita[4], Anthony Rice[5], Ramón Collazo[5], Zlatko Sitar[5], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Group Semiconductor Physics, University of Ulm, Ulm — [2]Institut für Experimentelle Physik, Abteilung Materialphysik, Otto-von-Guericke-Universität Magdeburg, Magdeburg — [3]Palo Alto Research Center Inc., Palo Alto, California, USA — [4]HexaTech Inc., Morrisville, North Carolina, USA — [5]Department of Materials Science and Engineering, North Carolina State University, Raleigh, North Carolina, USA

We present optical spectroscopy studies in the near band edge region on high quality c-plane aluminum nitride (AlN) samples grown homoepitaxially by MOCVD on bulk AlN substrates. We analyze the near band edge region in detail by highly energy resolved photoluminescence, reflectivity and photoluminescence excitation spectroscopy. The linewidth of the bound exciton emission peak is as low as 500 μeV and demonstrates thus the excellent crystalline quality of the samples. Multiple sharp emission bands were found in the range from the free exciton to the bound excitons and their replicas. Correlations allow for a direct calculation of defect binding energies. Beyond, spectral contributions from excited exciton states and excitons with holes from the deeper valence band are analyzed.

HL 4.7 Mon 11:00 EW 201

Raman spectroscopic characterization of freestanding GaN layers — •Christian Röder[1], Frank Lipski[2], Cameliu Himcinschi[1], Jens Kortus[1], and Ferdinand Scholz[2] — [1]TU Bergakademie Freiberg, Institute of Theoretical Physics, Leipziger Str. 23, D-09596 Freiberg, Germany — [2]Ulm University, Institute of Optoelectronics, Albert-Einstein-Allee 45, D-89081 Ulm, Germany

In contrast to established growth techniques of other semiconductor materials, GaN technology is currently based on heteroepitaxy on foreign substrates like sapphire (0001), 6H-SiC (0001) or silicon (111). Due to the lattice mismatch and the difference in the thermal expansion coefficients between GaN and substrates there are serious problems such as a large density of defects and structural imperfections as well as high induced stress. In this work we investigated several GaN layers separated from the sapphire substrate during cool-down from growth temperature. This allows to avoid thermal stress induced by mismatch of the thermal expansion coefficients. Using confocal Raman spectroscopy we obtained depth spatial information. We have chosen to analyze the position of the non-polar E_2(high) phonon mode which is only affected by strains. Assuming a planar stress state the determined wavenumber shifts were converted to stress values. Additionally, photoluminescence (PL) measurements were performed at 87 K being in good agreement with the Raman results.
The authors would like to thank the European Union (EFRE) as well as the Free State of Saxony for financial support within the ADDE project.

HL 4.8 Mon 11:15 EW 201

Local changes in the growth of the active region on semipolar templates produced by ELO — •Clemens Waechter, Julian Mack, Ulrich Rengstl, Elisabeth Koroknay, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen und Research Center SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart

The growth on semipolar substrates is in the focus of material research as the active regions grown on semipolar substrates are less influenced by the Quantum Confined Stark Effect (QCSE). Since the production of native semipolar substrates is still very resource (and therefore cost) intensive, the growth on semipolar templates produced by epitaxial lateral overgrowth (ELO) on sapphire substrates offers a less expensive approach. Next to this, the properties of the grown template change the local growth conditions of the following layers. For example, the different strain situations for InGaN layers grown on pyramidal GaN templates lead to an increased Indium incorporation on the edges and apex. Also, depending on the locally available growth area, there are local changes in the growth conditions due to transport processes in the gas phase. For this contribution, pyramidal templates were produced by ELO. The size and density of the pyramids are controlled by the growth mask. After the growth, photoluminescence measurements

(PL) were performed. In these measurements, we observe a strong influence of the pyramid density on the local emission spectra of the InGaN layer. The results of these measurements shall be presented and discussed in this contribution.

HL 4.9 Mon 11:30 EW 201

Structural and optical quality of GaN films grown on $Sc_2O_3/Y_2O_3/Si(111)$ — •Lidia Tarnawska[1], Peter Zaumseil[1], Peter Storck[2], and Thomas Schroeder[1] — [1]IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]SILTRONIC AG, Hanns-Seidel Platz 4, 81737 Munchen, Germany

Growth of GaN on Si wafers is intensively pursued to provide high quality cost effective GaN virtual substrates for electronic and optoelectronic applications. The direct deposition of GaN layers on Si is, however, a big challenge due to high reactivity of the Si surface with nitrogen, large lattice mismatch, and difference in thermal expansion coefficients. To solve the integration problems different semiconducting and insulating buffer layers were used in the past. We present a novel approach for the integration of GaN on Si(111) via Sc_2O_3/Y_2O_3 bilayer buffer system. Samples were prepared in a multichamber molecular beam epitaxy system on 4-inch Si(111) wafers. To obtain complete information on the quality of $GaN/Sc_2O_3/Y_2O_3/Si(111)$ heterostructures in-situ (RHEED and XPS) and ex-situ (XRD, SEM, TEM, EDX and PL) measurements were performed.Our studies show that the oxides buffer approach provides a template of high structural quality for GaN overgrowth. XRD analysis prove that the growth of single crystalline, wurzite GaN layers are achieved. The main defects in 900 nm-thick GaN layers are threading dislocations, with density in the order of 10^{10} cm^{-2}, and stacking faults, resulting in cubic inclusions within the hexagonal matrix. 10K photoluminescence show a relatively sharp (FWHM of 22 meV) donor bound exciton line at 3.45 eV.

HL 5: Quantum Dots and Wires: Preparation and Characterization I

Time: Monday 9:30–11:00 Location: EW 202

HL 5.1 Mon 9:30 EW 202

Phonon frequency shift in strain-engineered nanowire multi-quantum wells — •Martin Wölz, Manfred Ramsteiner, Vladimir M. Kaganer, Oliver Brandt, Lutz Geelhaar, and Henning Riechert — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin, Germany

Technologically relevant epitaxial semiconductor films are biaxially strained if the substrate has a different lattice constant. In planar layers, strain is maximum for coherent growth and can relax only through the formation of crystal defects. In contrast, axial nanowire (NW) heterostructures allow for elastic strain relaxation at the free sidewalls. By choosing appropriate heights of the NW segments, strained insertions can be grown free of defects with arbitrary strain state.

We grew self-induced GaN nanowires (NWs) containing axial (In,Ga)N heterostructures by plasma-assisted molecular beam epitaxy. By varying the heigth of the GaN barriers, we obtained (In,Ga)N insertions with different strain states between the pseudomorphic case and full elastic relaxation.

Linear elastic theory reveals a progressive relaxation from the center of the NW to the sidewall. The resulting broadening of phonon spectra is quantified based on published deformation potentials. We show that resonant Raman spectroscopy can be used to determine the variation of the (In,Ga)N strain state in NW segments.

Finally, we discuss the impact of such strain relaxation in the active region of (In,Ga)N NW light-emitting diodes, where a benefit over conventional planar devices is expected.

HL 5.2 Mon 9:45 EW 202

Stranski-Krastanov growth of InGaN quantum dots — •Konrad Bellmann, Abdul Kadir, Markus Pristovsek, and Michael Kneissl — TU Berlin, Berlin, Deutschland

InGaN based devices with high Indium content suffer from inhomogeneities and high defect densities. InGaN quantum dots (QD) have the opportunity to overcome these drawbacks and could realize green light emitting diodes and laser diodes. We have investigated the growth of capped and uncapped InGaN QDs on GaN templates by metal organic vapor epitaxy (MOVPE). For uncapped InGaN samples with increasing InGaN thickness and Indium contents above 20 % a growth mode transition from 2D to 3D occurs, i.e. Stranski-Krastanov growth mode. The density of QDs increases with increasing amount of InGaN beyond the wetting layer.

As the indium content is increased the wetting layer thickness is reduced. All InGaN layers up to 6nm are fully strained with indium content from 20 % to 30 %.

Overgrowth at low temperature obtains the InGaN QDs. However, overgrowth at higher temperature increases the Indium diffusion and change the QD morphology.

HL 5.3 Mon 10:00 EW 202

Nucleation of self-assembled GaN nanowires on diamond — •Fabian Schuster[1], Florian Furtmayr[1], Andrea Winnerl[1], Reza Zamani[2,3], Joan R. Morante[3], Jordi Arbiol[2,4], Jose Garrido[1], and Martin Stutzmann[1] — [1]Walter Schottky Institut, Technische Universität München, 85748 Garching, Germany — [2]Institut de Ciència de Materials de Barcelona, ICMAB-CSIC, 08193 Bellaterra, Spain — [3]Catalonia Institute for Energy Research, IREC, 08930 Sant Adrià del Besòs, Spain — [4]Institucio Catalana de Recerca i Estudis Avancats, ICREA, 08010 Barcelona, Spain

Diamond with its wide bandgap of 5.48 eV and its reliable p-type doping with boron is a perfect complement to the nitride material system with respect to optoelectronic devices operating in the UV spectral range. Therefore, we demonstrate the nucleation of high-quality, self-assembled, epitaxial GaN nanowires (NWs) on (111) single-crystalline diamond (SCD) substrates without using a catalyst or buffer layer. HRTEM measurements on released NWs show an excellent crystalline quality of the wurtzite crystal structure with m-plane faceting, a low defect density and axial growth along the polar c-axis. X-ray diffraction confirms single domain growth with an in-plane epitaxial relationship of $(10\bar{1}0)_{GaN} \parallel (01\bar{1})_{Diamond}$ as well as some biaxial tensile strain induced by thermal expansion mismatch. In photoluminescence, a strong and sharp excitonic emission reveals excellent optical properties with a comparably low defect recombination.

HL 5.4 Mon 10:15 EW 202

Dotiereffizienz phosphordotierter Silizium-Nanokristalle in einer Siliziumdioxidmatrix — •Sebastian Gutsch, Andreas Hartel, Daniel Hiller und Margit Zacharias — Albert-Ludwigs-Universität (IMTEK/Nanotechnologie), Freiburg, Deutschland

Silizium Nanokristalle (SiNCs) eingebettet in einer Siliziumoxynitridmatrix wurden mittels PECVD und anschließender Temperung bei 1150°C in Inertgasatmosphäre hergestellt [1]. Die Kristallisation erfolgte größenkontrolliert über einen Superlattice-Ansatz [2], wobei ein alternierender Schichtstapel bestehend aus 3.5 nm dicken siliziumreichen Oxinitridschichten (SRON) und 4 nm dicken Siliziumdioxidschichten abgeschieden wurde. Aus TEM Messungen wurde eine durchschnittliche Größe von 3.5+/-0.5 nm ermittelt. Die Dotierung wurde durch Beimischung von geringen Mengen Phosphin im Prozessgas erreicht. Die Stöchiometriebestimmung der SRON Schichten und Phosphorquantifizierung erfolgte durch kombinierte XPS und dynamische SIMS Messungen. Ein Modell basierend auf einer Poissonverteilung von PL-nichtstrahlenden Defekten und P-Dotanden ermöglicht die Berechnung von Defekten und P-Dotanden pro SiNC als Funktion der Dotierkonzentration. Dazu werden werden zusätzlich Photolumineszenz-Spektren von mit Wasserstoff passivierten und unpassivierten Proben verglichen. Eine Abschätzung der Dotiereffizienz der Silizium Nanokristalle wird aus der Kombination von Modell und Messung vorgenommen und diskutiert.

[1] Hartel et al., TSF, 520, 121 (2011)
[2] Zacharias et al., APL, 80, 661 (2002)

HL 5.5 Mon 10:30 EW 202

Thermodynamic theory of the phase separation in nonstoichiometric silicon oxide films — •Andrey Sarikov[1] and Magrit Zacharias[2] — [1]V. Lashkarev Institute of Semiconductor Physics NAS Ukraine, Kiev, Ukraine — [2]IMTEK, University of Freiburg, Freiburg im Breisgau, Germany

Nonstoichiometric silicon oxide films (SiOx, x < 2) are perspective for

optoelectronic applications due to the temperature stimulated phase separation in them and the formation of amorphous or crystalline Si nanoinclusions capable of light emission, in the silicon oxide matrix.

In this work, a thermodynamic theory of the phase separation in nonstoichiometric silicon oxide films is proposed. The expressions for the free energy of nonstoichiometric silicon oxide and silicon oxide with amorphous and crystalline Si nanoinclusions are derived. The free energy of amorphous Si / Si oxide and crystalline Si / Si oxide systems as a function of the relative concentration of separated silicon, the initial silicon oxide stoichiometry, and the temperature is studied. By the free energy minimization, the equilibrium stoichiometries of silicon oxide and the solubilities of Si in SiO2 in contact with amorphous and crystalline silicon are determined. An especial attention is given to the strain appearing as a result of phase separation. The account of strain contribution to the free energy of Si / Si oxide systems enables a comprehensive description of the dependence of the equilibrium stoichiometry of phase separated silicon oxide films on the initial silicon oxide composition and the temperature.

HL 5.6 Mon 10:45 EW 202

Raman study of zinc blende and wurtzite CdSe/CdS heterostructures — •Amelie Biermann[1], Raquel Gomes[2], Holger Lange[1], Zeger Hens[2], and Christian Thomsen[1] — [1]TU Berlin, Institut für Festkörperphysik, EW5-4, 10623 Berlin, Germany — [2]University of Ghent, Physics and Chemistry of Nanostructures, Krijgslaan 281-S3, Ghent, B-9000, Belgium

CdSe based heteronanocrystals offer a wide range of potential applications in the field of optoelectronics. Especially colloidal CdSe-CdS core-shell nanocrystals are currently of high interest because they offer new technics of application, e.g. printing of devices from a solution. The possibility to synthesize defined nanocrystals with a precise control over their size enables the use in systems like biological sensors, LEDs, lasers and solar cells.

The magnitude of the coupling of excited carriers to phonons in the CdSe core contributes to the time scales of different photophysical processes of high significance for those applications. These processes include for example carrier multiplication rates, and relaxation times and are strongly influenced by the states in the interface region of core and shell. In our contribution we present a systematic Raman study of wurtzite and zinc blende CdSe/CdS core-shell structures, revealing the structural details of the sample as well as the exciton-phonon coupling strength via the Huang-Rhys factor.

HL 6: Ge/Si I

Time: Monday 9:30–11:30 Location: EW 203

HL 6.1 Mon 9:30 EW 203

Heterostructure growth study for GaP collector integration in SiGe HBT technology — •Oliver Skibitzki[1], Fariba Hatami[2], Yuji Yamamoto[1], Peter Zaumseil[1], M. Andreas Schubert[1], Bernd Tillack[1,3], W. Ted Masselink[2], and Thomas Schroeder[1] — [1]IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]Humboldt Universität zu Berlin, MNF1, Newtonstrasse 15, 12489 Berlin, Germany — [3]Technische Universität Berlin, HFT4, Einsteinufer 25, 10587 Berlin, Germany

A heterostructure growth study of GaP on pseudomorphic 4° off-oriented $Si_{0.8}Ge_{0.2}$/Si(001) substrates was performed to develop a III/V wide band gap collector concept for future SiGe heterobipolar transistor performance increase. Before pseudomorphic GaP/$Si_{0.8}Ge_{0.2}$/Si(001)) heterostructure growth, critical thickness of GaP on Si and maximum thermal budget for GaP deposition were evaluated by preliminary investigations. Using XRD, AFM and TEM for structure and defect characterization, we were able to report single crystalline 170 nm GaP growth on 20 nm $Si_{0.8}Ge_{0.2}$/Si(001) substrates. Results show that 20 nm $Si_{0.8}Ge_{0.2}$/Si(001) can be overgrown by 170 nm GaP without affecting the pseudomorphism of the $Si_{0.8}Ge_{0.2}$/Si(001) layer. However, due to defect nucleation at the GaP/ $Si_{0.8}Ge_{0.2}$ interface during initial island coalescence, the GaP layer grows partially relaxed. The achievement of 2D GaP growth conditions on $Si_{0.8}Ge_{0.2}$/Si(001) systems is thus a crucial step for achieving fully pseudomorphic heterostructures. APD-free GaP growth is observed for film thicknesses beyond 70 nm.

HL 6.2 Mon 9:45 EW 203

Picosecond hole scattering and cooling dynamics in Ge/SiGe quantum wells. — •Kolja Kolata[1], Sebastian Imhof[2], Niko Köster[1], Giovanni Isella[3], Daniel Chrastina[3], John E. Sipe[4], Angela Thränhardt[2], and Sangam Chatterjee[1] — [1]Fachbereich Physik, Philipps Universität Marburg, Germany — [2]Technische Universität Chemnitz, Fakultät für Naturwissenschaften, Germany — [3]Dip. di Fisica del Politecnico di Milano, L-NESS, Polo di Como, Italy — [4]Department of Physics, University of Toronto, Canada

We investigated the hole scattering and cooling dynamics in Ge/SiGe quantum wells on a picosecond time scale. Time-resolved pump-probe experiments show an efficient scattering process between the electron and hole systems in the L- and Γ-valley, respectively. The Ge quantum wells are excited 10 meV above the band edge and probed with a white-light supercontinuum. After optical excitation, the electrons scatter from the Γ-valley into the lower lying L-valleys within a few hundreds of fs. At later times, only the hole system is investigated as photons can only access vanishing momenta. We observe a hot hole system with a temperature far beyond what is expected from the excess energy of the excitation. The additional heating is due to efficient energy transfer from the electron system in the L-valley which heats the hole-system in the Γ-valley mediated by Coulomb-interaction. The dependence on excitation energy as well as carrier density support this explanation. Our findings are corroborated by semiconductor Bloch equations calculations of the absorption spectra for various hole-system carrier-densities and temperatures.

HL 6.3 Mon 10:00 EW 203

Ultra-fast intersubband-relaxation and the evidence of non-thermal carrier distribution in Ge/SiGe quantum wells — •Alexej Chernikov[1], Verena Bornwasser[1], Martin Koch[1], Niko Köster[1], Ronja Woscholski[1], Sangam Chatterjee[1], Eleonora Gatti[2], Emanuele Grilli[2], Mario Guzzi[2], Danny Chrastina[3], and Giovanni Isella[3] — [1]Faculty of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany — [2]L-NESS and Dipartimento di Scienza dei Materiali, Università di Milano-Bicocca, via Cozzi 53, I - 20125 Milano, Italy — [3]L-NESS and Dipartimento di Fisica, Politecnico di Milano, Polo Territoriale di Como, via Anzani 42, I - 22100 Como, Italy

In the last decade, optical properties of Ge/SiGe-heterostructures have received much attention in the scientific community being a possible candidate for the realization of a semiconductor laser on Si-substrates. In addition, the optical properties of the material system are of fundamental interest due to the combination of a direct transition only slightly higher in energy than the indirect band-gap. Further advantages are the enhancement of the light-matter coupling as well as the tunability of the band strucure, both inherent for the low-dimensional systems. Here, we present a systematic study of carrier relaxation in Ge/SiGe quantum wells applying photoluminescence and pump-probe spectroscopy. Ultra-fast intersubband-relaxation on a 100 fs time-scale and the presence of a non-thermal carrier distribution are found to strongly influence the optical response of the material.

HL 6.4 Mon 10:15 EW 203

On the strain partitioning phenomenon in Ge clusters on free-standing Si(001) nanopillars — •Grzegorz Kozlowski[1], Peter Zaumseil[1], Andreas Schubert[1], Yuji Yamamoto[1], Joachim Bauer[1], Tobias Schulli[2], Bernd Tillack[1,3], and Thomas Schroeder[1,4] — [1]IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]European Synchrotron Radiation Facility, BP 220, F-38043 Grenoble Cedex, France — [3]Technische Universität Berlin, HFT4, Einsteinufer 25, Berlin 10587, Germany — [4]Brandenburgische Technische Universität, Konrad-Wachsmann-Allee 1, 03046 Cottbus, Germany

Ge is attracting increasing interest to integrate photonic modules within Si chip baseline technology. The major stumble block is given by the 4.2% lattice mismatch. The theory of nanoheteroepitaxy (NHE) offers the vision to shift the critical thickness for defect nucleation in

Ge to infinity by the so-called strain partitioning phenomenon. We report on the structural characterization of Ge clusters selectively grown by chemical vapor deposition on free-standing Si(001) nanopillars of 50 nm width. Synchrotron based x-ray diffraction studies and transmission electron microscopy were performed to experimentally verify NHE theory as a technique to grow high quality Ge on Si(001). Although the structure dimensions are comparable to the theoretical values required for the strain partitioning phenomenon, the compliant character of Si is not unambiguously proven. In consequence, the strain is relieved by nucleation of misfit dislocations at the Ge/Si interface. By gliding out of threading arms, high quality Ge nanostructures are achieved.

HL 6.5 Mon 10:30 EW 203

Kelvin probe force microscopy imaging on horizontal locally doped silicon nanowires — •Christine Baumgart[1], Stefan Habicht[2], Sebastian Feste[2], Manfred Helm[1], Siegfried Mantl[2], and Heidemarie Schmidt[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institut für Ionenstrahlphysik und Materialforschung, P.O. Box 510119, 01314 Dresden, Germany — [2]Peter Grünberg Institute 9 (PGI 9-IT), and JARA-Fundamentals of Future Information Technology, Forschungszentrum Jülich, 52425 Jülich, Germany

Kelvin probe force microscopy (KPFM) [1] has been used for the electrical characterization of silicon nanowires (NWs). Arrays of horizontal Si NWs [2] with widths down to 10 nm have been prepared from a silicon-on-insulator (SOI) starting material. After transferring the NW structures into the Si top layer by conventional top-down approach, the samples have been locally implanted with B and As. Quantitative dopant profiling by means of KPFM is successfully employed to locate the junctions along the B-doped and As-doped Si NWs. In addition, the influence of local intrinsic electric fields [3] is discussed for the investigated SOI structures.

[1] C. Baumgart, M. Helm, H. Schmidt, Phys. Rev. B 80, 085305 (2009).

[2] S. F. Feste, J. Knoch, S. Habicht, D. Buca, Q.-T. Zhao, S. Mantl, Solid-State Electronics 53, 1257 (2009).

[3] C. Baumgart, A.-D. Müller, F. Müller, and H. Schmidt, Phys. Stat. Sol. A 208, 777 (2011).

HL 6.6 Mon 10:45 EW 203

Raman scattering study of hydrogen-induced defects in ion-implanted Si — •Sebastian Socher, Edward V. Lavrov, and Jörg Weber — Technische Universität Dresden, 01069 Dresden

A Raman scattering study of single crystalline silicon implanted with ^{28}Si and subsequently treated in a rf hydrogen plasma at 200 °C is presented. Such a treatment results in a broad band at 3830 cm^{-1} (60 K) previously assigned to the vibrational $Q(J)$ transitions of hydrogen molecules trapped in Si multivacancies [Ishioka *et al.*, Phys. Rev. B **60**, 10852-10854 (1999)]. Here, J is the rotational quantum number. The 3830 cm^{-1} band reveals a substructure, which is assigned to at least two different types of the molecules. The H_2 signals are shown to correlate with the Si–H vibrational modes at 1888, 1930, and 1964 cm^{-1}. A quantitative analysis of the 3830 cm^{-1} band revealed the splitting of the $Q(1)$ modes of H_2 by the trapping potential. Ortho to para conversion rates of the hydrogen molecules at 77 K and room temperature were found to be 62 ± 15 and 8 ± 2 hours, respectively.

HL 6.7 Mon 11:00 EW 203

Cobalt-related defects in silicon: A deep level transient spectroscopy study — •Leopold Scheffler, Vladimir Kolkovsky, and Jörg Weber — Technische Universität Dresden, 01069 Dresden, Deutschland

In the present work cobalt-doped p- and n-type silicon samples were studied by means of deep level transient spectroscopy (DLTS) and Laplace-DLTS (LDLTS). We demonstrate that two dominant DLTS peaks previously assigned to an interstitial Co defect show different annealing behaviour and seem to belong to different defects. After wet chemical etching three other peaks (E90, E140 and H170) were observed in the samples. The intensity of the peaks becomes larger in the H-plasma treated samples. This together with depth profiling demonstrate that the peaks are hydrogen-related defects. The origin of the peaks will be discussed.

HL 6.8 Mon 11:15 EW 203

Observation of the oxygen precipitation in CZ-silicon by X-ray diffraction — •Christoph Bergmann, Johannes Will, Groeschel Alexander, and Magerl Andreas — Chair for Crystallography and Structural Physics, FAU Erlangen-Nuremberg, Erlangen-Germany

We investigated the formation, kinetics and final dissolution of oxygen precipitates in single crystalline silicon as a function of the temperature applied (up to 1200°C). The knowledge about and the control of such processes is one of the major challenges during the fabrication of integrated circuits. With the means of x-ray diffraction we examined the integrated intensity of a Bragg peak which is a direct function of the stress inventory introduced by the growing oxygen particles.

Samples cut in such a way that we were able to examine the whole radius of a 12" single CZ-Si crystal at once were illuminated with highly energetic X-radiation. Both in-situ and ex-situ measurements enabled us to follow the precipitation what gave strong indications for thermal donor formation, different point defect regimes along the radius ("V/G-model") and their influence on the precipitation regarding size, morphology and density of the precipitates grown.

A fit of the time-dependent evolution of the integrated intensity with a growth function given by the model of diffusion limited precipitation gave values for the precipitate density which excellently reproduce the values obtained by defect etching.

HL 7: "New" Materials and New Physics in "Old" Materials I

Time: Monday 9:30–11:30 Location: EW 015

HL 7.1 Mon 9:30 EW 015

Electronic and optical properties of Copper Oxides from first principles — •Markus Heinemann, Bianca Eifert, and Christian Heiliger — I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany

The copper oxide phases Cupric oxide (CuO), Cuprous oxide (Cu_2O), and Paramelaconite (Cu_4O_3) are of rising interest in the field of optoelectronics and solar technology. We investigate the phase stability of these copper oxide phases in different temperature and pressure domains within the framework of density functional theory. An *ab initio* approach to the LDA+U method is employed to calculate the electronic structure of all phases from first principles. Further, we study the optical properties of these materials by calculating the dielectric function. The results are compared to experimental measurements of sputtered Cu_2O thin films.

HL 7.2 Mon 9:45 EW 015

Deposition of copper oxide by a modified Radio-Frequency Ion Thruster (RIT) as Ion-Beam-Sputter-Source — •Martin Becker, Philipp Hering, Angelika Polity, Davar Feili, and Bruno K. Meyer — I. Physikalisches Institut, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany

Radio-Frequency-Ion-Thrusters, as designed for propulsion applications, are also qualified for thin film deposition and surface etching, because different gas mixtures, extraction voltages and rf power can be applied.

Copper oxide thin films were grown by ion beam sputter deposition using a 4 inch ceramic cuprous oxide target. Different aspects of the thin film growth and properties of the copper oxides were investigated in relation to growth parameters such as substrate temperature, supplied rf power and flux of oxygen.

Results of first investigations on thin films grown by this methodology will be compared to those obtained by "cold" rf-sputtered samples post-annealed in nitrogen atmosphere. Analysis of structural, optical and electrical properties will be shown.

HL 7.3 Mon 10:00 EW 015

Optical and electrical properties of different copper oxide phases deposited by magnetron sputtering — •Daniel Reppin, Angelika Polity, and Bruno K. Meyer — I. Physikalisches Institut, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 16, 35392

Giessen, Germany

Copper oxides Cu_xO_y are attractive materials for solar cell applications; that is due to the fact that the bandgaps of the different oxides lie in the range from 1.6 eV (CuO) to 2.17 eV (Cu_2O). Beside these two "main" phases of copper-oxide there are at least two phases which are more or less discussed in the literature: the metastable Cu_4O_3 and Cu_3O_2 known from low temperature oxidation experiments.

We will show that it is possible to obtain the different copper oxides by magnetron sputtering under different oxygen flows without substrate heating. A correlation will be given for structural, optical and electrical properties with the phase changes between the copper oxides. The obtained properties of the films will be discussed in terms of phase purity and stoichiometry.

HL 7.4 Mon 10:15 EW 015

Network of SnO2 nanowires for gas sensing application — •Elise Brunet, Giorgio Cataldo Mutinati, Stephan Steinhauer, and Anton koeck — Health & Environment Department, Molecular Diagnostics, AIT Austrian Institute of Technology GmbH, 1220 Vienna, Austria

SnO2 is an n-type semiconductor particularly used in metal oxide gas sensors, whose principle relies on changes of electrical conductance due to interactions between the surrounding gas and the sensing layer. We present a gas sensor device, whose sensing layer is reduced to a bundle of SnO2 nanowires. The surface to volume ratio is increased, which enlarges the number of interactions between the gas molecules and the SnO2 surface and improves the sensitivity of the sensor device.

A SnO2 thin film is deposited by spray pyrolysis on SiO2/Si substrates coated with CuO. The SnO2 film is then cleaved in two pieces, which are glued together on a support plate with a distance of about 150 micrometers. A thermal treatment of this assembly at 900°C in Ar-atmosphere results in the growth of single crystalline SnO2 nanowires on each of the two SnO2-coated substrates. The nanowires grown on the edges are long enough to interconnect and bridge the gap between the two substrates. The sensing performance of this network of SnO2 nanowires is investigated in the presence of small concentrations of CO, CO2, H2 and H2S in the low ppm range and compared with those of a single nanowire sensor device.

HL 7.5 Mon 10:30 EW 015

Switchable nanothermochromic VO_2 diffraction gratings defined by site selective ion implantation — •Johannes Zimmer, Hubert Krenner, Helmut Karl, and Achim Wixforth — Institut für Physik, Universität Augsburg, Universitätsstr. 2, 86159 Augsburg

The metal-insulator transition (MIT) of vanadium dioxide has been studied in great detail over the past 50 years, showing both structural and electronic phase changes. The bulk materials electric conductivity rises drastically at T=68°C, when heated from the isolating phase at room temperature to the metallic phase. Additionally optical properties of VO_2 exhibit significant changes during the MIT on sub-picosecond timescales. We examined the near-infrared thermochromic behaviour of VO_2 nanocrystals, which were synthesised by high-dose ion implantation through optically structured masks. Fused silica was chosen as matrix material for the fabrication of the diffractive optical elements, leaving the VO_2 crystals inert to structural degradation when undergoing the MIT. Two different processes were used to define diffraction gratings containing VO_2 nanocrystals. The first was direct implantation of VO_2 through masks into the host material and the second was site-selective bombardement of already synthesised nanocrystals, with argon ions in order to suppress the metallic phase in those regimes. While undergoing the phase transition, the gratings showed switching in diffraction efficiencies by factors of 3 for the directly synthesised gratings and more than one order of magnitude for the Ar-deactivated gratings. All gratings show broad thermal hysteresis extending down to room temperature.

HL 7.6 Mon 10:45 EW 015

Low-temperature photocarrier dynamics in single-layer MoS_2 — •Tobias Korn, Gerd Plechinger, Stefanie Heydrich, Johannes Schmutzler, Michael Hirmer, and Christian Schüller — Institut für Experimentelle und Angewandte Physik, Universität Regensburg

The dichalcogenide MoS_2, which is an indirect-gap semiconductor in its bulk form, was recently shown to become an efficient emitter of photoluminescence as it is thinned to a single layer [1], indicating a transition to a direct-gap semiconductor due to confinement effects. Here, we present scanning Raman and time-resolved photoluminescence studies of few- and single-layer MoS_2 flakes [2]. Scanning Raman spectroscopy reveals the intensity and spectral position of the characteristic Raman vibration modes of the flake. Photoluminescence (PL) measurements are performed on single-layer areas of a flake. We clearly see two PL peaks at low temperatures, which we may assign to bound and free exciton transitions. Time-resolved PL traces reveal photocarrier recombination on the few-picosecond timescale at low temperatures. For temperatures above 150 K, we observe a longer-lived component of the PL, which we attribute to increased carrier-phonon interaction at higher temperatures.

[1] K. F. Mak et al., Phys. Rev. Lett. **105**,136805 (2010).
[2] T. Korn et al., Appl. Phys. Lett. **99**, 102109 (2011).

HL 7.7 Mon 11:00 EW 015

Electronic and vibrational properties of single- and few-layer MoS_2 — •Gerd Plechinger, Stefanie Heydrich, Johannes Schmutzler, Franz-Xaver Schrettenbrunner, Jonathan Eroms, Dieter Weiss, Christian Schüller, and Tobias Korn — Institut für experimentelle und angewandte Physik, Universität Regensburg, 93040 Regensburg, Germany

The layered transition-metal dichalcogenide MoS_2 has attracted great interest because of good optical properties and as alternative to graphene for nanoelectronic applications. With the transparent tape liftoff method, single- and few-layer MoS_2 flakes were prepared. By annealing the samples in vacuum, photoluminescence peak intensity positions varying by about 20 meV at room temperature, were made uniform. Low temperature photoluminescence measurements on single-layer MoS_2 flakes show an additional low-energy peak. It can be attributed to a surface-bound exciton, because samples with a HfO_2 or Al_2O_3 coating do not show the low-energy peak.

In Raman-measurements, we have identified an interlayer shear mode at $30\,cm^{-1}$ in bulk material. We observed a decrease in wavenumber with decreasing layer number. By scanning an area on the sample, we can distinguish regions of different layer numbers by mapping the spectral position of the shear mode.

HL 7.8 Mon 11:15 EW 015

Atomically thin layers of transition metal dichalcogenides investigated by ab initio methods — •Kerstin Hummer and Georg Kresse — University of Vienna, Computational Materials Physics, Vienna, Austria

The advances in the fabrication of atomically thin layered materials has enabled investigations of new physical properties inherent to low dimensional structures. Transition metal dichalcogenides (TMX_2) crystallize in a quasi-two-dimensional structure that allows for low dimensional structuring. Among them, the prototype material molybdenum disulfide (MoS_2), has attracted intense interest because of its distinct electronic and optical properties that enable its application in photovoltaics and photocatalysis. A key issue regarding the applicability in efficient opto-electronic devices is the energy gap that should match the solar spectrum (1-3 eV). Bulk TMX_2 with TM = Mo, W and X = S, Se, Te have band gaps between 1 and 1.5 eV, but their fundamental gaps are indirect and thus optically forbidden. However, a transition from an indirect to an direct gap semiconductor was achieved in MoS_2, when going from bulk to atomically thin layers.

In this work, we present density functional theory studies of thin layer TMX_2 with TM = Mo, W and X = S, Se, and Te. Accurate band structures are obtained with the modified Becke-Johnson exchange potential in combination with LDA correlation. Particular emphasis is put on the variation of the band gap with layer thickness as well as the influence of the substrate present in experiment.

HL 8: Transport: Quantum Coherence and Quantum Information Systems 1 (jointly with TT, MA)

Time: Monday 9:30–12:45 Location: BH 243

HL 8.1 Mon 9:30 BH 243

Coherence in a transmon qubit with epitaxial tunnel junctions — •Martin Weides[1,4], Jeffrey Kline[1], Michael Vissers[1], Martin Sandberg[1], David Wisbey[1,2], Blake Johnson[3], Thomas Ohki[3], and David Pappas[1] — [1]National Institute of Standards and Technology, Boulder, Colorado 80305, USA — [2]Saint Louis University, St. Louis, Missouri 63103, USA — [3]Raytheon BBN Technologies, Cambridge, Massachusetts 02138, USA — [4]Karlsruhe Institute of Technology, Germany

Transmon qubits based on epitaxial tunnel junctions and interdigitated capacitors were developed. This multileveled qubit, patterned by use of all-optical lithography, is a step towards scalable qubits with a high integration density. The relaxation time T_1 is $.72-.86$ μsec and the ensemble dephasing time T_2^* is slightly larger than T_1. The dephasing time T_2 (1.36 μsec) is nearly energy-relaxation-limited. Qubit spectroscopy yields weaker level splitting than observed in qubits with amorphous barriers in equivalent-size junctions. The qubit's inferred microwave loss closely matches the weighted losses of the individual elements (junction, wiring dielectric, and interdigitated capacitor), determined by independent resonator measurements.

HL 8.2 Mon 9:45 BH 243

Single atom lasing of a dressed flux qubit — •Gregor Oelsner[1], Pascal Macha[1], Miroslav Grajcar[2], Oleg Astafiev[3], Boris Ivanov[1], Evgeni Il'ichev[1], Uwe Hübner[1], Solveig Anders[1], and Hans-Georg Meyer[1] — [1]Institute of Photonic Technology, PO Box 100239, D-07702 Jena, Germany — [2]Department of Solid State Physics, Comenius University, SK-84248 Bratislava, Slovakia — [3]NEC Nano Electronics Research Laboratories. Tsukuba, Ibaraki, 305-8501, Japan

We study a strongly driven superconducting flux qubit coupled to a high-quality coplanar waveguide resonator. In the frame of the dressed state approach, the energy of the Rabi splitting depends on the amplitude of the microwave field and the detuning between the qubit and the microwave frequency, which also controls the level occupation. If, for a certain detuning and amplitude, this splitting is in resonance with the fundamental mode of the resonator, a lasing (damping) effect is expected. Indeed we experimentally observe an increase in the transmission amplitude as well as line width narrowing, which proofs the predicted phenomena.

HL 8.3 Mon 10:00 BH 243

Gradiometric persistent current flux qubit with tunable tunnel coupling — •Manuel Johannes Schwarz[1,2], Jan Goetz[1,2], Zhaohai Jiang[1,2], Frank Deppe[1,2], Achim Marx[1], and Rudolf Gross[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching — [2]Physik Department, TU München, Garching

The persistent current flux qubit is a Josephson junction based superconducting circuit exhibiting strong anharmonicity and excellent coherence time of more than 10 μs. However, quantum coherence deteriorates drastically away from an optimal operation point. Moreover, a controlled adjustment of the transition frequency at the optimal point requires excellent stability of the fabrication process. Here, we present the spectroscopic analysis of a gradiometric flux qubit, where the minimal transition frequency, the qubit gap, can be tuned in situ while staying at the point of optimal coherence. We show a tunability of the qubit gap from a few hundreds of megahertz to several gigahertz, making the system suitable for future experiments with coupled qubit-resonator systems.

This work is supported by the DFG via SFB 631 and by the German Excellence Initiative via NIM.

HL 8.4 Mon 10:15 BH 243

Four-level lasing in the two-qubit system — •Sergey Shevchenko[1,2], Simon van der Ploeg[2], Miroslav Grajcar[2,3], Evgeniy Temchenko[1], Alexandr Omelyanchouk[1], Evgeniy Il'ichev[2], and Hans-Georg Meyer[2] — [1]Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine — [2]Institute of Photonic Technology, Jena, Germany — [3]Comenius University, Bratislava, Slovakia

The system of two coupled qubits can be described as a quantum four-level system. To make it useful for applications, e.g. for lasing, the hierarchy of relaxation times is needed. Such a situation occurs naturally in a case of two coupled superconducting qubits [1]. We have studied both experimentally and theoretically resonant excitation and relaxation in this system [1,2]. Two types of the multi-photon transitions were demonstrated: the direct and the ladder-type ones. This can be used for the creation of the inverse population, which was discussed in relation to the possibility of three- and four-level lasing in the system [2].

[1] E. Il'ichev, S.N. Shevchenko, S.H.W. van der Ploeg, M. Grajcar, E.A. Temchenko, A.N. Omelyanchouk, and H.-G. Meyer, Phys. Rev. B 81, 012506 (2010).
[2] E. A. Temchenko, S. N. Shevchenko, A. N. Omelyanchouk, Phys. Rev. B 83, 144507 (2011).

HL 8.5 Mon 10:30 BH 243

Observation of the Geometric Phase of a Harmonic Oscillator in Circuit Quantum Electrodynamics — •Stefan Filipp, Marek Pechal, Simon Berger, Abdufarrukh A. Abdumalikov, and Andreas Wallraff — ETH Zurich, Department of Physics, 8093 Zurich, Switzerland

Transporting a quantum harmonic oscillator state along a closed path in Hilbert space leads to a path-dependent geometric phase. However, the linearity of the system precludes its observation without a nonlinear quantum probe. We therefore make use of a superconducting qubit serving as an interferometer to measure the geometric phase of a harmonic oscillator realized as an on-chip transmission line resonator [1]. We demonstrate the proportionality of the geometric phase to the enclosed area for a variety of path shapes. At the transition to the non-adiabatic regime, we analyze corrections to the geometric phase and show how entanglement between the two-level system and the harmonic oscillator leads to dephasing. This system provides a versatile tool to study adiabatic and non-adiabatic geometric phases in open quantum systems and as a resource for quantum information processing.

[1] M. Pechal, S. Berger, A.A. Abdumalikov, A. Wallraff and S. Filipp, arxiv:1109.1157 [quant-ph] (2011)

HL 8.6 Mon 10:45 BH 243

High cooperativity in a microwave resonator coupled to YIG — Hans Huebl[1], •Johannes Lotze[1], Christoph Zollitsch[1,2], Fredrik Hocke[1], Sebastian T. B. Goennenwein[1], and Rudolf Gross[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany

Understanding the coupling of magnetic moments (spins) to light fields (photons) on a quantum level is of fundamental interest. Recent work [1,2] on paramagnetic samples coupled to superconducting resonators has shown coherent coupling between microwave photons and electron spins. This coupling is enhanced compared to a single spin by a factor of $\sqrt{N}$, where N is the number of spins in the ensemble. Here, we study a bulk ferrimagnetic Ga-doped yttrium iron garnet (YIG) crystal coupled to a superconducting niobium resonator operating at 6 GHz. Measuring the transmission through the resonator in a magnetic field, we observe an anticrossing of the spin and photon dispersions with a splitting of 450 MHz. Analyzing the magnetic field dependence of the resonance linewidths in this system in the interaction regime, we find that the coupling clearly dominates the intrinsic loss rates of the spin system and the resonator, an important requirement for studying the magnon-photon interaction in the strong coupling regime. The impact of microwave power and system temperature will be critically discussed.

[1] D. I. Schuster *et al.*, Phys. Rev. Lett. **105**, 140501 (2010)
[2] Y. Kubo *et al.*, Phys. Rev. Lett. **105**, 140502 (2010)

15 min. break.

HL 8.7 Mon 11:15 BH 243

Measurement scheme for the Lamb shift in a superconducting circuit with broadband environment — •Vera Gramich[1],

Paolo Solinas[2,3], Mikko Möttönen[2,3], Jukka Pekola[3], and Joachim Ankerhold[1] — [1]Institut für Theoretische Physik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany — [2]Department of Applied Physics/COMP, Aalto University, P.O. Box 14100, FI-00076 Aalto, Finland — [3]Low Temperature Laboratory, Aalto University, P.O. Box 13500, FI-00076 Aalto, Finland

Motivated by recent experiments on quantum mechanical charge pumping in a Cooper pair sluice [1], we present a measurement scheme for observing shifts of transition frequencies in two-level quantum systems induced by broadband environmental fluctuations. In contrast to quantum optical and related setups based on cavities, the impact of a thermal phase reservoir is considered. The experimental protocol to measure the Lamb shift in experimentally feasible superconducting circuits is analyzed in detail and supported by numerical simulations [2]. Therefore, we turn our attention to a brief description of the actual setup followed by an analysis of the detection proposal.

[1] A. O. Niskanen, J. P. Pekola, and H. Seppä, Phys. Rev. Lett. 91, 177003 (2003).
[2] V. Gramich, P. Solinas, M. Möttönen, J. P. Pekola, and J. Ankerhold, Phys. Rev. A 84, 052103 (2011).

HL 8.8 Mon 11:30 BH 243

Lasing, trapping states, and multistability in circuit quantum electrodynamical analog of a single-atom injection maser — •Michael Marthaler[1], Juha Leppäkangas[1,2], and Jared Cole[1,3] — [1]Institut für Theoretische Festkörperphysik and DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany — [2]Applied Quantum Physics Laboratory, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden — [3]Chemical and Quantum Physics, School of Applied Sciences, RMIT University, Melbourne 3001, Australia

We study a superconducting single-electron transistor (SSET) which is coupled to a LC oscillator via the phase difference across one of the Josephson junctions. This leads to a strongly anharmonic coupling between the SSET and the oscillator. The coupling can oscillate with the number of photons, which makes this system very similar to the single-atom injection maser. However, the advantage of a design based on superconducting circuits is the strong coupling and existence of standard methods to measure the radiation field in the oscillator. This makes it possible to study many effects that have been predicted for the single-atom injection maser in a circuit quantum electrodynamics setup.

HL 8.9 Mon 11:45 BH 243

Towards photon quantum gates in circuit qed — •Lukas Neumeier, Martin Leib, and Michael Hartmann — TU München, Munich,Germany

Quantum information processing can be decomposed into quantum channels and quantum gates. Photons are well suited for transferring information whereas stationary qubits offer better perspectives for implementing gates. Traditionally in circuit qed quantum gates are therefore realized by interactions between stationary superconducting qubits. As opposed to this we analyze a circuit qed setup where itinerant microwave photons, confined to two one dimensional transmission-lines, interact at a localized superconducting qubit. We provide results for reflection and transmission spectra and photon measurement probabilities for both waveguides which depend on the incoming single or two-photon pulses.

HL 8.10 Mon 12:00 BH 243

Bose-Hubbard dynamics in a chain of nonlinear superconducting transmission-line resonators — •Martin Leib and Michael J. Hartmann — TU München,Munich,Germany

Quantum mechanical many body physics offers many interesting phenomena and its simulation in well controlable experimental setups is therefore attracting increasing attention. We propose a superconducting circuit setup where microwave photons in an array of transmission line resonators interact due to an intrinsic nonlinearity of the resonators. We show that a transmission line resonator which is intersected by a Josephson junction can be approximatly described as a harmonic oscillator with a Kerr nonlinearity, making the whole array of resonators a quantum simulator for a Bose-Hubbard Hamiltonian. Strong nonlinearities and long coherence times can be easily achieved in superconducting circuits and in addition individual readout and control of resonators can be realized with current state of the art experimental techniques.

HL 8.11 Mon 12:15 BH 243

Backaction of Microwave Photon Detection by a Strongly Coupled Josephson Junction — •Emily Pritchett[1], Luke Govia[2], Seth Merkel[3], and Frank Wilhelm[1] — [1]Saarland University, Saarbrucken, Deutschland — [2]University of Waterloo, Waterloo, Canada — [3]IBM Watson Research Center, Yorktown Heights, USA

We analyze the functionality of on-chip Josephson junctions as single microwave photon detectors, as has been demonstrated recently [1]. The Josephson junction device, which we refer to as a Josephson Photomultiplier (JPM), acts as a nearly perfect binary detectors of microwave photons by undergoing an observable switching event when there are one or more photons in an incident cavity. We analyze the backaction of this switching event on the state of incident light, including the energy dissipation and dephasing affecting an imperfect JPM. This analysis improves the efficiency and fidelity with which a JPM reconstructs the state of light in an incident transmission line 'cavity', which are commonly used to store and transfer quantum states in implementations of circuit-QED.

[1] Chen et al., arXiv:1011.4329

HL 8.12 Mon 12:30 BH 243

Time-resolved qubit readout via nonlinear Josephson inductance — •Georg Michael Reuther[1], Peter Hänggi[1], and Sigmund Kohler[2] — [1]Institut für Physik, Universität Augsburg, Universitätsstr. 1, 86159 Augsburg, Germany — [2]Instituto de Ciencia de Materiales de Madrid (CSIC) C/Sor Juana Inés de la Cruz 3, Cantoblanco 28049 Madrid, Spain

We propose a generalization of dispersive qubit readout which provides the time evolution of a flux qubit observable. Our proposal relies on the non-linear coupling of the qubit to a harmonic oscillator with high frequency, representing a dc-SQUID. Information about the qubit dynamics is obtained by recording the oscillator response to resonant driving and subsequent lock-in detection. We simulate this measurement process for the example of coherent qubit oscillations and, in doing so, we corroborate the underlying measurement relation. In addition, we derive a quantum master equation for the qubit alone. With this at hand, we investigate the dependence of qubit dephasing on the measurement backaction that is induced by the oscillator driving [1].

[1] Georg M. Reuther, David Zueco, Peter Hänggi, and Sigmund Kohler, New J. Phys. 13, 093022 (2011)

HL 9: Transport: Topological Insulators 1 (jointly with TT, MA)

Time: Monday 9:30–13:00 Location: H 3010

HL 9.1 Mon 9:30 H 3010

Quantum point contact as a probe of a topological superconductor — •Michael Wimmer, Anton Akhmerov, Jan Dahlhaus, and Carlo Beenakker — Instituut-Lorentz, Universiteit Leiden, The Netherlands

We calculate the conductance of a ballistic point contact to a superconducting wire, produced by the s-wave proximity effect in a semiconductor with spin-orbit coupling in a parallel magnetic field. The conductance G as a function of contact width or Fermi energy shows plateaus at half-integer multiples of $4e^2/h$ if the superconductor is in a topologically nontrivial phase, supporting Majorana fermions. In contrast, the plateaus are at the usual integer multiples in the topologically trivial phase (without Majorana fermions). Disorder destroys all plateaus except the first, which remains precisely quantized, consistent with previous results for a tunnel contact. The advantage of a ballistic contact over a tunnel contact as a probe of the topological phase is the strongly reduced sensitivity to

HL 9.2 Mon 9:45 H 3010

Interaction and trapping effects on a 2D topological insulator in an optical lattice. — •Daniel Cocks[1], Peter P. Orth[2], Michael Buchhold[1], Stephan Rachel[3], Karyn Le Hur[4,3], and

Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität Frankfurt — [2]Institut für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie — [3]Department of Physics, Yale University, New Haven — [4]Center for Theoretical Physics, École Polytechnique, Palaiseau

We investigate effects of interaction, disorder and trapping of a 2D system that exhibits topologically insulating phases in an optical square lattice using both real-space dynamical mean-field theory (R-DMFT) and analytical techniques. The tunability of this system allows for a large degree of freedom, and by adjusting the size of the magnetic unit cell, along with the strength of a spin-orbit coupling that does not preserve the S_z spin component and a staggered super-lattice potential, topologically non-trivial regions have been identified.

Using R-DMFT, we determine the interacting phase diagram as a function of Hubbard U. We observe interaction driven transitions between the topological and normal insulating phase, as well as dependence of transitions to magnetically ordered phases on the flux parameter. We also analyze trapping effects that are relevant to experimental conditions and identify ideal trapping potentials that preserve the topological phases. This system is realizable (Goldman et al. PRL 105, 255302, 2010) as an effective Hamiltonian by generating a synthetic non-Abelian gauge field on the surface of an atom chip.

HL 9.3 Mon 10:00 H 3010

Phonon induced backscattering in helical edge states — •Patrik Recher[1], Jan C. Budich[2], Fabrizio Dolcini[3], and Bjoern Trauzettel[2] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [3]Dipartimento di Fisica del Politecnico di Torino, I-10129 Torino, Italy

A single pair of helical edge states as realized at the boundary of a quantum spin Hall insulator is known to be robust against elastic single particle backscattering as long as time reversal symmetry is preserved. However, there is no symmetry preventing inelastic backscattering as brought about by phonons in the presence of Rashba spin orbit coupling. In this talk, we show that the quantized conductivity of a single channel of helical Dirac electrons is protected even against this inelastic mechanism to leading order. We further demonstrate that this result remains valid even when Coulomb interaction is included in the framework of a helical Tomonaga Luttinger liquid.

HL 9.4 Mon 10:15 H 3010

Electromagnetically induced topological charge on the surface of a topological insulator due to magnetization dynamics — •Flavio Nogueira and Ilya Eremin — Institut für Theoretische Physik III, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany

A topologically non-trivial solution of the Landau-Lifshitz-Gilbert equation is obtained. Such a solution induces electric and magnetic fields and implies a topological current at the surface of a topological insulator which is proportional to $\mathbf{E}\cdot\mathbf{B}$. The values of the topological charge in our solution are $Q=-1,0,1$. The spin current density plays in this scenario the role of a non-Abelian gauge field and the topological charge is reminiscent of the 't Hooft-Polyakov construction of the magnetic monopole. We discuss the physical consequences of our theory, including the role of topological spin transport on the surface of a topological insulator.

HL 9.5 Mon 10:30 H 3010

Interplay of bulk and edge states in transport of topological insulators — •Rolf W. Reinthaler and Ewelina M. Hankiewicz — Faculty of Physics and Astrophysics, University of Würzburg, Würzburg, Germany

We study ballistic transport in two-terminal metal/quantum spin-Hall insulator (QSHI)/metal junctions within the effective four band model (conduction/heavy hole bands) [1, 2]. We show that the conductance signals originating from the bulk and the edge contributions are not additive. While for a long junction the transport is determined by the edge states contribution, for a short junction, the conductance signal is built from both, bulk and edge states, in the ratio which depends on the width of the sample. Further, the conductance for short junctions shows a non-monotonic behavior as a function of the sample lenght in topological insulator regime [3]. Suprisingly this non-monotonic behavior of conductance can be traced to the formation of an effectively propagating solution which is robust against scalar disorder. Our predictions should be experimentally verifiable in HgTe QWs and BiSe thin films.

We acknowledge the financial support of the German DFG Grant HA5893/1-2 .

[1] B. A. Bernevig et al., Science, 314(5806):1757, 2006.
[2] D G Rothe et al., New Journal of Physics, 12(6):065012, 2010.
[3] E. G. Novik et al., Phys. Rev. B, 81(24):241303, 2010.

HL 9.6 Mon 10:45 H 3010

Landau levels in a topological insulator — •Peter Schwab and Michael Dzierzawa — Institut für Physik, Universität Augsburg, 86135 Augsburg, Germany

Two recent experiments successfully observed Landau levels in the tunneling spectra of the topological insulator Bi_2Se_3. To mimic the influence of a scanning tunneling microscope tip on the Landau levels we solve the two-dimensional Dirac equation in the presence of a localized electrostatic potential. We find [1] that the STM tip not only shifts the Landau levels, but also suppresses for a realistic choice of parameters the negative branch of Landau levels.

[1] P. Schwab and M. Dzierzawa, arXiv:1107.0827

HL 9.7 Mon 11:00 H 3010

Surface flat bands in gapless topological phases — •Andreas Schnyder — Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, D-70569 Stuttgart, Germany

In this talk we discuss a classification of Fermi surfaces, Fermi lines and Fermi points, as well as nodal lines and nodal points in superconductors in terms of discrete symmetries and Fermi surface codimension. By use of a bulk-boundary correspondence, we determine the types of topologically protected zero-energy states that appear at the boundary of these gapless topological systems. As concrete examples we examine the polar state of 3He, the nodal non-centrosymmetric superconductor Li2Pt3B, and the ferromagnetic superconductor URhGe. For the latter two systems, we examine the signatures of the protected surface states in tunneling-conductance measurements and in Fourier transformed scanning tunneling spectra. Furthermore, we study the appearance of gapless modes located on topological defects in gapless topological phases.

15 min. break.

HL 9.8 Mon 11:30 H 3010

Weak antilocalization in HgTe quantum wells and topological surface states: Massive versus massless Dirac fermions — •Ewelina Hankiewicz and Grigory Tkachov — Wuerzburg University

HgTe quantum wells and surfaces of three-dimensional topological insulators support Dirac fermions with a single-valley band dispersion. In this work we conduct a comparative theoretical study of the weak antilocalization in HgTe quantum wells (QWs) and topological surface states. The difference between these two single-valley systems comes from a finite band gap (effective Dirac mass) in HgTe quantum wells in contrast to gapless (massless) surface states in topological insulators. The finite effective Dirac mass implies a broken internal symmetry, leading to suppression of the weak antilocalization in HgTe quantum wells and transition to the weak localization regime as a function of the gap or carrier density. Further we show how the difference in the behavior of the weak localization corrections for HgTe QWs allows to distinguish topological versus normal insulators. On the other hand, the topological surface states exhibit specific weak-antilocalization magnetoconductivity in a parallel magnetic field due to their exponential decay in the bulk. The relevant experiments will be discussed.

We acknowledge the financial support of the German DFG Grant HA5893/1-2 .

HL 9.9 Mon 11:45 H 3010

Coulomb blockade signatures of the topological phase transition in semiconductor-superconductor nanowires — •Björn Zocher[1,2], Mats Horsdal[1,3], and Bernd Rosenow[1] — [1]Institut für Theoretische Physik, Universität Leipzig, Germany — [2]Max Planck Institut für Mathematik in den Naturwissenschaften, Leipzig, Germany — [3]Max Planck Institut für Festkörperforschung, Stuttgart, Germany

In semiconductor-superconductor hybrid structures a topological phase transition is expected as a function of chemical potential or magnetic field strength. We show that signatures of this transition can

be observed in nonlinear Coulomb blockaded transport through a ring shaped structure. In particular, for a fixed electron parity of the ring, the flux periodicity of the neutral excitation spectrum changes from the usual $h/2e$-periodicity to a characteristic h/e-periodicity when tuning the system from the topologically trivial to the nontrivial phase. We relate the h/e-periodicity to the recently predicted 4π-periodicity of the Josephson current across a junction formed by two topological superconductors.

HL 9.10 Mon 12:00 H 3010

Tuning the Fermi velocity of Dirac cones: Towards an anomalous quantum Hall effect on the surfaces of topological insulators? — •Lars Fritz, Matthias Sitte, and Achim Rosch — Universität zu Köln, Institut für theoretische Physik, Zülpicher Strasse 77, 50937 Köln

Long-range Coulomb interaction can trigger an instability of two-dimensional Dirac fermions, the so-called chiral symmetry breaking. Three-dimensional topological insulators host two-dimensional helical Dirac fermions on their surfaces. We investigate whether long-range Coulomb interaction, controlled by the dimensionless coupling constant $\alpha = e^2/(\hbar\epsilon_r\epsilon_0 v_F)$, can induce surface ferromagnetism thereby gapping the surface metal. This is accompanied by an anomalous quantum Hall effect *without* explicit breaking of time-reversal invariance by an external magnetic field. We find that the prerequisite for observing this effect is to reduce the Fermi velocity v_F of the surface Dirac fermions while keeping the bulk dielectric constant ϵ_r finite. We discuss under which conditions this can be achieved.

HL 9.11 Mon 12:15 H 3010

Supersymmetry and Ballistic Transport in Topological Insulators with Ferromagnetic Domain-walls — •Christian Wickles and Wolfgang Belzig — Universität Konstanz, Fachbereich Physik, 78457 Konstanz, Germany

We consider the surface Dirac Fermions of a topological insulator with a proximity induced ferromagnetic domain wall (DW). We present an exact analytical treatment to discuss the spectrum, bound states and the ballistic conductance of the system with a DW in the in-plane and out-of-plane configuration. In the latter case of the "mass" DW, we find oscillations in the conducatance as a function of the wall width and we find for certain widths the DW to be completely reflectionless. We will use the language of supersymmetry to reveal that the dispersion of the surface Dirac Fermions together with the specific DW profile gives rise to these interesting features.

HL 9.12 Mon 12:30 H 3010

Aspects of electron-electron interactions and spin-conservation in topological insulators — •Stephan Rachel — Department of Physics, Yale University, New Haven, CT 06520, USA

We consider topological insulators on the honeycomb lattice and investigate the effect of electron-electron interactions and breaking of S_z spin-symmetry. We compare (i) non-interacting bandstructures with and without conserved spin, (ii) the regime of moderate interactions as well as (iii) the corresponding spin models. We find in all interaction-regimes qualitative differences between conserved and broken S_z spin-symmetry. The origin of these differences is explained. Eventually we discuss which of the effects are generic and which are specific for the honeycomb lattice.

HL 9.13 Mon 12:45 H 3010

Luttinger Liquid Physics and Spin-Flip Scattering on Helical Edges — •Martin Hohenadler and Fakher Assaad — Institut für Theoretische Physik und Astrophysik, Universität Würzburg, Würzburg, Deutschland

We investigate electronic correlation effects on edge states of quantum spin Hall insulators within the Kane-Mele-Hubbard model by means of quantum Monte Carlo simulations. In accordance with Luttinger liquid theory, we find dominant transverse spin fluctuations with an interaction dependent power law and the expected doping dependence. For strong electronic correlations, bulk states become important, and high-energy spectral features beyond Luttinger liquid theory emerge. Inelastic spin-flip scattering leads to graphene-like edge state signatures, and transfers spectral weight from low to high energies causing a suppression of charge transport.

HL 10: Quantum Dots and Wires: Preparation and Characterization II (mainly Arsenides)

Time: Monday 11:15–13:15 Location: EW 202

HL 10.1 Mon 11:15 EW 202

Crystal Structure Tuning of Au-catalyzed Nanowires grown by MBE — Andreas Rudolph, Marcello Soda, Dieter Schuh, Josef Zweck, Dominique Bougeard, and •Elisabeth Reiger — Institute for Experimental and Applied Physics, University of Regensburg

GaAs nanowires were grown by MBE using a thin Au layer as catalyst material. For individual nanowires we study the size and the chemical composition of the (post-growth) Au-Ga catalyst droplets as well as the crystal structure by HRTEM and EDX. We estimate the Ga-concentration of the catalyst droplets during growth and relate this value to the adopted crystal structure of the nanowires. Depending on the Ga-concentration we observe two different growth modes. For low Ga content the nanowires exhibit wurtzite crystal structure. For higher Ga concentrations (>60%) zincblende segments within a wurtzite matrix are formed. By adjusting the growth parameters of this second (pseudo-Ga) growth mode pure zincblende nanowires - as typically observed by the self-catalyzed / Ga-assisted growth technique - can be obtained

HL 10.2 Mon 11:30 EW 202

GaAs/InAs - core/shell nanowires grown by SA-MOVPE — •Fabian Haas[1,2], Kamil Sladek[1,2], Andreas Winden[1,2], Martina von der Ahe[1,2], Thomas Weirich[2,3], Hilde Hardtdegen[1,2], and Detlev Grützmacher[1,2] — [1]Peter Grünberg Institute-9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]GFE, Gemeinschaftslabor für Elektronenmikroskopie, 52074 Aachen, Germany

GaAs/InAs - core/shell nanowires could show interesting low-dimensional phenomena because of the expected intrinsic conductivity in the tubular low-bandgap InAs shells. However, suitable parameters for homogeneous radial growth of InAs on GaAs nanowires are still to be developed.

In this contribution we report on the heteroepitaxial growth of GaAs/InAs - core/shell nanowires via selective-area metalorganic vapor phase epitaxy (SA-MOVPE). GaAs core nanowires were grown on hole-patterned SiO_2/GaAs($\overline{111}$)B templates, structured by thermal nanoimprint lithography, and subsequently covered with a conformal InAs shell. The influence of the growth temperature (400°C to 650°C) on shell morphology, homogeneity and crystal structure was investigated by scanning and transmission electron microscopy.

It was found that the desired homogeneous and uniform InAs overgrowth is achieved at lower growth temperatures. The InAs shell adopted the morphology and crystal structure of the underlying GaAs core and dislocations at the GaAs/InAs interface were observed. At higher temperatures, the shell formed additional sidewall facets.

HL 10.3 Mon 11:45 EW 202

Growth of an InAs shell around GaAs nanowires — •Torsten Rieger[1,2], Mihail Ion Lepsa[1,2], Thomas Schäpers[1,2], and Detlev Grützmacher[1,2] — [1]Peter Grünberg Institute - 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology

Due to the small dimensions, nanowires are promising candidates for the combination of highly lattice mismatched materials such as GaAs and InAs. We present the growth of GaAs/InAs core/shell nanowires (NWs) by molecular beam epitaxy. The GaAs NW core is grown using the self-cataylzed growth method and has an almost pure zinc blende crystal structure. The growth of the InAs shell is analyzed using scanning and transmission electron microscopy. The As_4 beam flux is found to be crucial for the growth of a continuous shell. The growth of InAs starts with islands along the NW, which merge and form a continuous layer after around 5 nm thickness. The strain due to the lattice mismatch of 7% is accommodated by the formation of misfit dislocations. Relaxation along the growth direction ([111]B) saturates at

about 80%. Depending on the core diameter, the core/shell NWs bend during the growth. Special emphasis is given to different defects in the InAs shell. Apart from the pure core/shell NWs, we discuss briefly about some correlated structures: free-standing InAs nanotubes and GaAs NWs which are covered only on one side by InAs.

HL 10.4 Mon 12:00 EW 202

Fabrication of ultra-low density GaAs quantum dots by filling of self-organized nanoholes — •David Sonnenberg, Andreas Graf, Vera Paulava, Achim Küster, Christian Heyn, and Wolfgang Hansen — Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

We use the local droplet etching (LDE) technique to drill self-organized nanoholes into AlGaAs surfaces using molecular beam epitaxy. We fabricate quantum dots (QDs) by subsequent filling of these nanoholes. Here, we report on the control of the nanohole density to fabricate ultra-low densitiy QDs down to $6 \cdot 10^6$ cm^{-2}. Using Al droplets for etching, non-optimized process parameters yield a broad hole depth distribution with shallow (depth of some nanometers) and deep (deeper than 10 nm) holes. By optimizing the arsenic background flux, the generation of shallow holes can be suppressed and only deep holes (>20 nm) remain with a strongly reduced density. Ultra-low density GaAs QDs generated by filling of the nanoholes demonstrate intensive optical emission and clear excitonic features.

HL 10.5 Mon 12:15 EW 202

Einfluss eines vergrabenen Stressors auf das Wachstum von InGaAs mit MOCVD — •David Quandt, Jan-Hindrik Schulze, Tim David Germann, André Strittmatter, Udo Pohl und Dieter Bimberg — Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, D-10623 Berlin

Das Wachstum von InGaAs ist abhängig vom Verspannungsfeld der Wachstumsoberfläche. Durch Einsatz einer vergrabenen Oxidapertur kann die Oberflächenverspannung lateral moduliert werden. Hierzu werden Mesen oder Steifen mit einer AlGaAs-Schicht und einer GaAs-Deckschicht hergestellt. Durch selektive Oxidation erfährt das AlGaAs eine Volumenreduktion, wodurch die GaAs-Deckschicht verspannt wird. Wird auf eine solche Oberfläche InGaAs abgeschieden kommt es zu lateral unterschiedlichen Wachstumsraten für GaAs und InAs. Wird die Oberflächenverspannung relativ zur Gitterkonstante von GaAs betrachtet, so ist das InAs-Wachstum an Stellen mit tensiler Verspannung begünstigt und das GaAs-Wachstum an unverspannten Stellen. Durch diese lokale Variation der Wachstumsraten weißt die InGaAs-Schicht sowohl eine Dicken- wie auch Kompositionsvariation auf.

Die Wirkung dieser Wachstumsmodulation wird sowohl zum selektiven Wachstum von Quantenpunkten als auch zur lateralen Modulation von InGaAs-Quantenfilmen verwendet. Die Anwendung dieser Methode in optoelektronischen Bauelementen wird diskutiert.

HL 10.6 Mon 12:30 EW 202

MOVPE grown InAs quantum dots on InGaAs strain reducing layers — •Matthias Paul, Jan Kettler, Elisabeth Koroknay, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, University Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Self-assembled semiconductor quantum dots (QDs) have been studied extensively due to their potential application in the field of quantum information processing. Therefore, optically addressable single quantum dots are needed on a mass production scale using metal-organic vaporphase epitaxy (MOVPE). By burying InAs QDs in InGaAs strain-reducing layers (SRL) their emission wavelength can be shifted to the infrared region. Of special interest are the telecom wavelength bands around 1.3 μm and 1.55 μm of optical fibers where losses are reduced to a minimum. In contrast to high densities for laser applications, low densities of QDs will allow for single-photon sources, one key device in quantum information networks. The approach pursued to reach emission wavelengths of 1.3 μm is depositing InAs QDs between two InGaAs SRLs grown on GaAs substrates. Reduced strain and increased QD size cause a red-shift of the emission wavelength. Photoluminescence (PL) experiments and scanning electron microcopy (SEM) are used to characterize the InGaAs layers. Furthermore, PL and μ-PL measurements are performed to investigate optical properties of the InAs QDs, as well as, atomic force microscopy (AFM) to determine structural properties, e.g. density and size.

HL 10.7 Mon 12:45 EW 202

Prepatterning of GaAs substrates using microsphere photolithography for the site-controlled growth of InP quantum dots — •Ulrich Rengstl, Elisabeth Koroknay, Moritz Bommer, Michael Jetter, and Peter Michler — Universität Stuttgart, Institut für Halbleiteroptik und Funktionelle Grenzflächen, Allmandring 3, D-70569 Stuttgart and Research Center SCoPE

To use quantum dots (QDs) in single photon applications, we are working on separate addressable, site-controlled QDs. For this, we generate surface potential modulations by patterning a GaAs buffer before the overgrowth in a metal-organic vapor-phase epitaxy system (MOVPE). Instead of using expensive conventional patterning techniques, such as electron beam lithography, we use microsphere photolithography for the fast and periodic patterning of large areas [1]. A hexagonal closepacked microsphere monolayer is used as an array of microlenses to focus UV light on a UV-sensitive photoresist. We obtain structures with controllable diameters of 300 to 700 nm in the photoresist, which can be used as an etching mask for isotropic wet chemical etching to generate holes in the GaAs buffer. Due to the later overgrowth of the patterned samples, it is crucial to sustain a clean surface with low roughness. This is traced by atomic force microscopy, which shows atomic steps between the holes in the (100) on-axis surface. After overgrowth we observe face-selective growth of GaAs and a preferred InP deposition inside the holes, which leads to the formation of site-controlled InP islands. This can be observed in a spatial photoluminescence mapping.

[1] W. Wu et al., Nanotechnology 18, 485302 (2007)

HL 10.8 Mon 13:00 EW 202

Relaxation of excited charge carriers in silicon nanocrystals embedded in silicon dioxide — •Andrey Moskalenko[1], Jamal Berakdar[1], Alexander Poddubny[2], Alexei Prokofiev[2], Irina Yassievich[2], and Serguei Goupalov[2,3] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Germany — [2]Ioffe Physical-Technical Institute of RAS, St. Petersburg, Russia — [3]Department of Physics, Jackson State University, USA

We study different mechanisms of the charge carrier relaxation in silicon nanocrystals embedded in silicon dioxide. In our work we assume the spherical shape of the nanocrystals and use the single carrier states obtained in the framework of the multiband effective mass approximation [1]. We find that the relaxation is dominated by the phonon-induced transitions. For small nanocrystals, generally, several phonons needed to be emitted due to the relatively large interlevel energy spacings for both electrons and holes. The corresponding transition rates of the multiphonon transitions are calculated in dependence on the nanocrystal size and temperature. Typically, these rates vary in a broad range from nanoseconds to picoseconds for an ensemble of nanocrystals with a certain size distribution, leading to the multiexponential decay of the carrier populations that should be observed.

[1] A. S. Moskalenko, J. Berakdar, A. A. Prokofiev, and I. N. Yassievich, Phys. Rev. B **76**, 085427 (2007).

HL 11: Carbon: Nanotubes, Diamond and Silicon Carbid

Time: Monday 11:45–14:00 Location: EW 203

HL 11.1 Mon 11:45 EW 203

Electronic properties of silicon carbide surfaces and interfaces — •Andre Konopka, Tim Baumgarten, Siegmund Greulich-Weber, Eva Rauls, Wolf Gero Schmidt, and Uwe Gerstmann — Physics, University of Paderborn, Paderborn, Germany

Micro- and nanocrystalline materials provide new applications not only because of their potential to shrink devices, but also due to their new electrical and optical properties. Understanding the origin of these properties is essential to design and optimize these materials and the resulting devices. In these systems properties of surfaces and interfaces can dominated that of the bulk. Microcrystalline silicon carbide (μc-SiC) have become an attractive new class of advanced microstructured

materials for optoelectronic applications due to their wide band gap and advanced chemical and mechanical properties. We use a sol-gel process for growing μc-SiC allowing arbitrary doping. To understand the origin of our experimental results [1,2] we performed theoretical calculations in the framework of density functional theory (DFT). In this work we present the results of different surfaces of SiC. We discuss how the electronic properties of the different surfaces interact with n- and p-type doping of SiC. Based on this calculations we propose a model that explains the charge transfer at an interface between SiC and an organic semiconductor. The calculated surface band structures can also help to understand other experimental results, like conductivity and EPR signatures.

[1] A. Konopka et al (2010) IOP Conf. Ser.: Mater. Sci. Eng. 15 012013, [2] A. Konopka et al (2011). MRS Proceedings, 1322

HL 11.2 Mon 12:00 EW 203

Electrical and Chemical Passivation of 6H-SiC Surfaces by Chlorine Termination — Sebastian Schoell, •Matthias Sachsenhauser, John Howgate, Jose Garrido, Martin Brandt, Martin Stutzmann, and Ian Sharp — Walter Schottky Institut, Technische Universitaet Muenchen, Garching, Germany

In recent years, growth and processing of SiC has considerably improved. However, practical ways of chemical and electrical passivation of SiC surfaces are still rare. In particular, etching in HF yields hydroxylated surfaces with high defect densities. Here, we utilize plasma processing methods to achieve chlorine-terminated n-type (0001) 6H-SiC surfaces. Static water contact angle and atomic force microscopy show a transition of the wetting behavior from hydrophilic to hydrophobic surfaces following chlorine termination without affecting the surface roughness. Accordingly, X-ray photoelectron spectroscopy reveals an increased chlorine core level intensity together with a significant reduction of oxygen. Chlorine desorption at elevated temperatures of up to 425°C suggests saturation of terminal atoms rather than near surface incorporation of chlorine. The electronic properties of the plasma treated surfaces are examined with contact potential difference and surface photovoltage measurements and show the formation of negative surface dipoles as well as approximately flat band surface potentials, indicative of a successful termination of electrically active surface defect sites. Finally, we demonstrate that the halogenated surfaces enable the formation of functional self-assembled monolayers providing controlled chemical functionalities for bioelectronic and biosensor applications.

HL 11.3 Mon 12:15 EW 203

H and Si interaction with 4H-SiC surfaces — •Elwira Wachowicz[1,2] and Adam Kiejna[1] — [1]Institute of Experimental Physics, University of Wrocław, Wrocław, Poland — [2]Interdisciplinary Centre for Materials Modeling, Warsaw, Poland

Silicon carbide due to its wide band gap, it is suitable for applications related to high power, high frequencies, and high temperatures. The most commonly precursor for silicon in homoepitaxial VPE-growth of SiC is silane. Therefore, the understanding of the Si and H interaction with SiC surfaces is essential to gain better control over the crystal growth process. In this paper the ab initio calculations of the interaction of Si and H atoms with Si- and C-terminated SiC surfaces are presented. The only stable adsorption site on the stechiometric 4H-(0001) and (000$\bar{1}$) surfaces is situated on top of the topmost surface atom for H coverages ranging from 0.11 to 1 monolayer (ML). H atom binds stronger on the (000$\bar{1}$) with adsorption energy about -6 eV independent of the H coverage. The H adsorption energy on Si-terminated (0001) surface changes from -5.6 eV at 0.11 ML to -5.2 eV at 1 ML. The changes in the first interlayer distances are linear with respect to the H coverage for both surfaces. The molecular dynamic simulations show dissociative adsorption of H_2 molecule. Consequently, the study of Si adsorption on partially H covered or H saturated surfaces are performed. Those allow to identify the most favourable Si adsorption sites. The influence of the Si and H coadsorption on the atomic and electronic structure of the 4H-SiC(0001) and (0001) surfaces is analysed.

HL 11.4 Mon 12:30 EW 203

Towards a quantum point contact on hydrogen-terminated single-crystalline diamond — •Moritz Hauf, Patrick Simon, Max Seifert, Markus Stallhofer, Martin Stutzmann, Alexander Holleitner, and Jose A. Garrido — Walter Schottky Institut and Zentrum für Nanotechnologie und Nanomaterialien, Am Coulombwall 4, 85748 Garching

The two-dimensional hole gas which forms at the surface of hydrogen-terminated diamond has already been used for the fabrication of in-plane gated field effect transistors in the past. Until now, no quantum effects have been observed in these structures. However, the two-dimensional nature of the hole gas offers a good starting point for the fabrication of lower-dimensional structures, similar to GaN/AlGaN heterostructures.

In this work we use e-beam lithography to selectively oxidize the H-terminated diamond surface in order to create conductive channels with nano-scale dimensions. We show Coulomb-blockade on surface-conductive channels with a width of 100nm. Furthermore, in-plane gate structures are used to approach conductance quantization in this material system at temperatures below 4K. Varying the gate voltage, we observe stepwise changes of the conductance in channels with widths of 100nm, 150nm, 200nm, and a length of 100nm. We discuss the origin of the conductance quantization in terms of the dimensionality of the hole-gas and possible Coulomb blockade effects at the surface of H-terminated diamond.

HL 11.5 Mon 12:45 EW 203

Charge transfer in diamond-based biohybrid systems for energy harvesting applications — •Michael Metzger, Roberta Caterino, Matthias Sachsenhauser, Martin Stutzmann, and Jose Antonio Garrido — Walter Schottky Institut, Technische Universität München, Germany

The understanding of charge transfer on the nanometer scale is of fundamental interest for a multitude of applications like molecular electronics, sensing, and catalysis. In addition, the energy conversion processes involved in photosynthesis represent a blueprint for future nanoscaled bioelectronics.

Our research aims at the immobilization of photosynthetic reaction centers (RCs) on diamond substrates for the study of direct charge transfer under photo excitation. For the covalent immobilization of RCs, we will discuss a novel functionalization concept which has been extensively investigated using a variety of redox species. Aminocaproic acid molecules were grafted onto H-terminated boron-doped polycrystalline diamond surfaces in order to introduce functional carboxylic groups which can be used for tethering redox species and biomolecules via covalent amide bonds. Cyclic voltammetry, square wave voltammetry, and electric impedance spectroscopy were employed to characterize the grafting of several molecules and biomolecules such as aminomethyl ferrocene, horseradish peroxidase, and cytochrome c. We have investigated the spectrally resolved photocurrent of RCs immobilized on boron-doped polycrystalline diamond, as well as on gold substrates.

HL 11.6 Mon 13:00 EW 203

Carbon nanotube Fermi energy shifts upon deposition on a substrate revealed by Raman spectroscopy — •Benjamin Hatting[1], Sebastian Heeg[1], Frank Hennrich[2], Ralph Krupke[2], and Stephanie Reich[1] — [1]Freie Universität Berlin, Berlin, Germany — [2]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Raman spectroscopy of single-walled carbon nanotubes (SWNTs) reveals a variety of information about the samples under study, such as their composition in terms of chirality and the amount of defects. Additionally, the lower-frequency component of the high-energy modes (HEM) in metallic tubes is sensitive to the position of the Fermi level. This component arises from longitudinal optical (LO) vibrations. It appears at lowered frequencies of about 1550cm^{-1} when the Fermi energy is at its intrinsic value due to the presence of a Kohn anomaly at the Γ point in the LO phonon branch.[1] We report the observation of a downshift of the metallic LO peak along with a broadening of its width upon deposition of a chirality-enriched tube sample[2] on a Si substrate. We explain our observations in terms of two Fermi energy shifts. The results imply that simple inspection of the HEM lineshape is insufficient to judge the presence of metallic tubes in a sample with an unknown chirality distribution.

HL 11.7 Mon 13:15 EW 203

Two-color pump-probe study of single-walled carbon nanotubes — •Olga A. Dyatlova[1], Christopher Koehler[2], Ermin Malic[2], Jordi Gomis-Bresco[1], Janina Maultzsch[3], Andrey Tsagan-Mandzhiev[1], Tobias Watermann[2], Andreas Knorr[2], and Ulrike Woggon[1] — [1]Institut fuer Optik und Atomare Physik, Technische Universitaet Berlin, 10623 Berlin, Germany — [2]Institut fuer Theoretische Physik, Technische Universitaet Berlin, 10623 Berlin, Germany — [3]Institut fuer Festkoerperphysik, Technische Universitaet Berlin, 10623 Berlin, Germany

Due to their remarkable properties carbon nanotubes (CNT) have big

application potential which is already implemented in some real devices and products. A better understanding of the ultrafast relaxation dynamics of optically excited carriers in single walled carbon nanotubes is of crucial importance for the realization of their application potential. In this work, we perform two-color pump-probe experiments to determine the decay behavior of (8,7), (10,2), (11,3), and (12,1) nanotubes. We find the relaxation dynamics to be characterized by three decay times in ps, tens of ps and few hundreds of ps ranges. Our results are modeled within a microscopic approach based on the density matrix formalism. Our calculations reveal that the component in the range of 5-10 ps is due to the intraband carrier-phonon scattering.

HL 11.8 Mon 13:30 EW 203

Permanent Dipole Moments of Localized Carbon Nanotube Excitons — •Jan Glückert, Matthias Hofmann, and Alexander Högele — Fakultät für Physik and Center for Nano Science (CeNS), Ludwig-Maximilians-Universität, München, Germany

Semiconducting single-walled carbon nanotubes exhibit photoluminescence emission in the near infrared due to recombination of excitons [1-3]. Recent observation of photon anti-bunching in the cryogenic photoluminescence of individual nanotubes suggests that exciton localization at low temperatures dominates the spectral response [4].

We investigate the emission spectra of individual CoMoCat nanotubes as a function of external electric field. We fabricated a sample that allows us to apply static electric fields perpendicular to the nanotube axis and record their spectral response in a confocal microluminescence setup at cryogenic temperatures.

We observe spectral shifts up to several linewidths and a linear dependence of the emission energy on the electric field. We interpret our findings in terms of a linear DC Stark effect due to permanent dipole moments of localized excitons. From the linear slope we deduce values for the exciton dipole moments and find a sub-Angstrom electron-hole separation.

[1] M. J. O'Connell et al., Science 297, 593 (2002).
[2] J. Maultzsch et al., Physical Review B 72, 241402 (2005).
[3] F. Wang et al., Science 308, 838 (2005).
[4] A. Högele et al., Physical Review Letters 100, 217401 (2008).

HL 11.9 Mon 13:45 EW 203

Photoluminescence of pristine carbon nanotubes — •Matthias Hofmann, Jan Glückert, and Alexander Högele — Fakultät für Physik and CeNS, Ludwig-Maximilians-Universität München, Geschwister-Scholl-Platz 1, D-80539 München, Germany

Semiconducting carbon nanotubes are an ideal material for the study of optical phenomena in one-dimensional systems. Recent experiments have shown that nanotubes exhibit the quantum optical effect of strong photon anti-bunching [1]. However, photoluminescence studies also revealed that the intrinsic optical properties of the commonly used material are partly masked due to the surrounding environment and defects in the nanotube crystalline structure.

By means of chemical vapour deposition we fabricated samples with freely suspended pristine carbon nanotubes with diameters in the subnanometer range. In contrast to commercial material of same chirality the photoluminescence of our suspended nanotubes reveals suppressed spectral diffusion and emission linewidths below the resolution limit of our spectrometer ($<100\,\mu$eV). Furthermore, photoluminescence lifetimes of several nanoseconds are no longer limited by rapid quenching - now exceeding previously reported decay times [2] by one order of magnitude in accordance with *ab initio* theory predictions [3].

[1] A. Högele *et al.*, Phys. Rev. Lett. **100**, 217401 (2008)
[2] A. Hagen *et al.*, Phys. Rev. Lett. **95**, 197401 (2005)
[3] C. D. Spataru *et al.*, Phys. Rev. Lett. **95**, 247402 (2005)

HL 12: "New" Materials and New Physics in "Old" Materials II

Time: Monday 11:45–14:00 Location: EW 015

HL 12.1 Mon 11:45 EW 015

HAXPES investigation of vacuum evaporated Bi_2S_3 thin films — •Sebastian ten Haaf[1], Benjamin Balke[2], Claudia Felser[2], and Gerhard Jakob[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany — [2]Institut für Anorganische Chemie und Analytische Chemie, Johannes Gutenberg-Universität, 55099 Mainz, Germany

In order to explore new absorber materials for photovoltaics, polycrystalline Bi_2S_3 thin films were prepared and investigated for their usability for solar cell fabrication.

Amorphous Bi_2S_3 thin films were deposited by thermal evaporation of bismuth trisulphide compound under ultra-high vacuum conditions on various substrates. An amorphous-to-crystalline transition could be observed after heat treatment in argon atmosphere at different temperatures.

The first measurements with hard X-ray photoelectron spectroscopy (HAXPES) on Bi_2S_3 were performed. Clear effects of annealing on valence band states could be observed, in addition to this, the thin films were characterized with regard to their optical and electrical properties as well as their morphology.

HL 12.2 Mon 12:00 EW 015

Radial distribution function analysis of ultra low-k interlayer dielectric from electron diffraction — •Pradeep Singh[1], Sven Zimmermann[2], Steffen Schulze[2,3], Stefan Schulz[1], and Michael Hietschold[1] — [1]Chemnitz University of Technology, Institute of Physics, D-09107 Chemnitz, Germany — [2]FraunhoferInstitute for Electronic Nano Systems (Fraunhofer ENAS), Dept. BEOL, D-09107 Chemnitz, Germany — [3]Chemnitz University of Technology, Center for Microtechnologies, D-09107 Chemnitz, Germany

The continuous scaling of transistor size towards deep submicron level needs an inevitable replacement of SiO2 with a low-k dielectric material. In this study we choose three different low-k dielectric materials to determine their structural arrangement by Selected Area Electron Diffraction (SAED). The SAED analysis for the local short-range ordering has been carried out with homemade software package BEUG having been developed in our group by S. Schulze. Using BEUG, it is possible to Fourier transform the diffracted intensity distribution ending up with the radial distribution function (RDF).The bond lengths calculated from RDF between the Si-O, O-O and Si-Si have a significant change in low-k materials as compared to the corresponding lengths in bulk amorphous SiO2. These changes in bond lengths have a reasonable impact on the binding energy of the corresponding elements. We observed an inverse relation between bond lengths and binding energies for the elements present in the materials. Further the local densities of the materials have also been derived from the RDF curve.

HL 12.3 Mon 12:15 EW 015

Growth and Analysis of Fe and FeCo on GaAs — •Tobias Nickel, Boris Landgraf, Sören Meyer, Taras Slobodskyy, and Wolfgang Hansen — Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

The injection of highly spin-polarized electrons from ferromagnetic metals into semiconductor systems is an important part of spintronic applications. The main problem encountered when building such spintronic devices is the loss of spin-polarization of electrons at the metal/semiconductor interface [1]. This obstacle may be avoided by introducing a tunnel barrier between metal and semiconductor. We therefore investigate epitaxial growth as well as structural, magnetical, and electrical properties of ferromagnet/semiconductor hybrid systems. Here, we analyze the epitaxial growth of Fe and FeCo on GaAs(001) and on modulation-doped InAs heterostructures with and without a MgO layer in between. The MgO layer works as a tunnel barrier [2] for spin-injection into the semiconductor and as a diffusion-barrier to avoid intermixing at the interface.

[1] G. Schmidt et al., *Physical Review B* R4790-R4793 (2000).
[2] X. Jiang et al., *Physical Review Letters* 94, 1-4 (2005).

HL 12.4 Mon 12:30 EW 015

Disorder-parameters in Ga(AsBi) — •Christian Wagner[1], Sebastian Imhof[1], Alexej Chernikov[2], Martin Koch[2], Nico S. Köster[2], Kolja Kolata[2], Sangam Chatterjee[2], Stefan W. Koch[2], Xianfeng Lu[3], Shane R. Johnson[3], Dan A. Beaton[4], Thomas Tiedje[5], Oleg Rubel[6,7], and Angela Thränhardt[1] — [1]Institut für Physik, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [2]Fachbereich Physik, Philipps-Universität Mar-

burg, 35032 Marburg, Germany — [3]Department of Electrical Engineering, Arizona State University, Tempe, Arizona 85287-6206, USA — [4]Department of Physics and Astronomy, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada — [5]Department of Electrical and Computer Engineering, University of Victoria, Victoria, British Columbia V8W 3P6, Canada — [6]Thunder Bay Regional Research Institute, Thunder Bay, Ontario P7A 7T1, Canada — [7]Department of Physics, Lakehead University, Thunder Bay, Ontario P7B 5E1, Canada

In recent years, Ga(AsBi) has been shown to be an interesting material for laser applications since its band gap can be varied over a wide frequency range. The growth process, however, is still challenging and carrier dynamics remains governed by hopping processes. We show that emission spectra and temporal behavior are well described by a two-scale disorder model (S. Imhof et al., Appl. Phys. Lett. 96, 131115 (2010), S. Imhof et al, Appl. Phys. Lett. 98 161104 (2011)) and discuss accessible parameters from measurements. Theory and experiment can be brought into agreement with physically meaningful parameters.

HL 12.5 Mon 12:45 EW 015

Chemical Composition of Novel III/V-alloys — •Tatjana Wegele, Vivien Vossebürger, Rafael Fritz, Kakhaber Jandieri, and Kerstin Volz — Faculty of Physics and Material Sciences Centre, Philipps-University Marburg, D-35032 Marburg

Low-priced and high-efficient solar cells are possible through combination of silicon technologies and III/V-ternary or -quaternary semiconductors. The conditions for high efficiency are a suitable band gap and high crystal quality. The latter implies good lattice-matching and consequently a specific chemical composition of III/V-alloys as well as the homogeneity of the distribution of the chemical constituents.

Cross-sectional dark-field transmission electron microscopy is a good opportunity to determine chemical composition using chemical sensitive reflections on the nanometre scale. For quantitative interpretations of these micrographs it has to be taken into account, that the chemical constituents, which have different covalent radius, induce a local strain and therefore impact the intensity of the respective dark-field image.

We study dilute ternary B- or N-containing compound semiconductors based on GaP and GaAs as well as novel quaternary alloys like (BGa)(AsP) and summarise the results of quantitative TEM imaging using chemical sensitive reflections in combination with structure factor calculation.

HL 12.6 Mon 13:00 EW 015

Wachstum und Charakterisierung von verdünnt - stickstoffhaltigem (GaIn)(NAs) auf InP mittels MOVPE — •Peter Ludewig, Katharina Werner, Wolfgang Stolz und Kerstin Volz — Fachbereich Physik und Wissenschaftliches Zentrum für Materialwissenschaften, Philipps-Universität Marburg

Aktuelle optoelektronische Bauelemente mit einer Emissionswellenlänge von 1,55um bestehen aus (GaIn)(AsP)/(GaIn)(AsP)-MQW Strukturen, abgeschieden auf InP Substrat. Die Energieeffizienz und thermische Stabilität dieser Bauelemente ist allerdings sehr gering und externe Kühlung notwendig.

Durch das Ersetzen der aktiven (GaIn)(AsP) Schicht aktueller Bauelemente durch verdünnt stickstoffhaltiges (GaIn)(NAs) kann eine höhere thermische Stabilität der Bauelemente erreicht werden.

Es wurden (GaIn)(NAs)/(GaIn)(AsP)-MQW Strukturen mittels metallorganischer Gasphasenepitaxie (MOVPE) auf InP-Substrat abgeschieden. Dabei wurden Wachstumstemperaturen von 450°C und 500°C verwendet. Die optischen wie strukturellen Eigenschaften wurden mittels Photolumineszenz-Spektroskopie sowie hochauflösender Röntgenbeugung (HR-XRD) und Transmissionselektronenmikroskopie (TEM) untersucht. Die Experimente zeigen, dass ein Stickstoffeinbau von bis zu 2% bei einem Indiumgehalt von ca. 40% erreicht werden kann. Mit steigender Stickstoffkonzentration ergibt sich eine Rotverschiebung der Emissionswellenlänge sowie eine Abnahme der integrierten Photolumineszenz-Intensität. HR-XRD wie TEM Untersuchungen weisen auf eine sehr gute Qualität der Schichten hin.

HL 12.7 Mon 13:15 EW 015

Time-resolved photoluminescence and optical gain in Ga(NAsP) pseudomorphically grown on silicon — Nektarios Koukourakis[1], Max Klimasch[1], •Nils C. Gerhardt[1], Martin R. Hofmann[1], Sven Liebich[2], Daniel Trusheim[2], Martin Zimprich[2], Kerstin Volz[2], Wolfgang Stolz[2], and Bernardette Kunert[3] — [1]Photonics and Terahertztechnology, Ruhr-University Bochum, Bochum, Germany — [2]Material Science Center and Faculty of Physics, Philipps-University Marburg, Marburg, Germany — [3]NAsP III/V GmbH, Marburg, Germany

The development of optoelectronic integrated circuits (OEICs) on silicon using the advanced complementary metal oxide semiconductor technology is one of the most important challenges in photonics today. However the realization of the key component, a reliable electrically pumped semiconductor laser grown on silicon, remains a huge challenge. The novel dilute nitride material Ga(NAsP) is a very promising candidate to fill this gap. Because of its direct nature and the capability for pseudomorphical growth on exactly oriented (001) silicon substrate Ga(NAsP) is perfectly qualified as an active material for lasers on silicon. Here we investigate the optical properties of Ga(NAsP) samples grown lattice matched on Si substrates using time-resolved photoluminescence and optical gain spectroscopy. The results indicate a significant impact of disorder-induced localization effects, which depends strongly on N content and growth conditions. However, optical gain measurements reveal high modal gain values at room temperature and demonstrate the suitability of Ga(NAsP) for laser devices on silicon.

HL 12.8 Mon 13:30 EW 015

Graphene Solution-Gated Field Effect Transistors for Bioelectronics — •Lucas Hess[1], Max Seifert[1], Michael Jansen[2], Vanessa Maybeck[2], Amel Bendali[3], Serge Picaud[3], Andreas Offenhäusser[2], Martin Stutzmann[1], Ian D. Sharp[1], and Jose A. Garrido[1] — [1]Walter Schottky Institut, TU München — [2]FZ Jülich — [3]Institut de la Vision, Paris

For medical applications in neuroprostheses as well as for fundamental research on neuron communication, it is of utmost importance to develop a new generation of electronic devices which can effectively detect the electrical activity of nerve cells. The relatively high electronic noise and the poor stability of silicon biosensors have motivated the search for more suitable materials. In this respect, the outstanding electronic and electrochemical performance of graphene holds great promise for bioelectronic applications.

Here, we report on arrays of graphene solution-gated field effect transistors (G-SGFETs) which can detect the electrical activity of electrogenic cells. G-SGFETs were fabricated using graphene films, which were grown by CVD on Cu and then transferred to insulating substrates where arrays of transistors were processed. We have investigated the ability of these transistors to detect the electrical activity of electrogenic cells. To this end, cardiomyocyte-like HL-1 cells have been cultured on G-SGFET arrays. Employing the transistors beneath, we were able to detect and resolve the action potentials generated by the cells. Our results clearly show that graphene transistors can outperform state-of-the-art devices for bioelectronic applications by far.

HL 12.9 Mon 13:45 EW 015

Sensing with graphene solution-gated field effect transistors — •Benno Blaschke, Lucas H. Hess, Max Seifert, Martin Stutzmann, and Jose A. Garrido — Walter Schottky Institut, Technische Universität München, Germany

Graphene based solution-gated field effect transistors (SGFETs) are promising candidates for high-sensitivity biosensors due to the outstanding electronic and chemical properties of graphene such as the high charge carrier mobility and the good biocompatibility. Sensors for various analytes as well as cell action potentials have already been realized based on graphene SGFETs.

In this work, an array of graphene SGFETs is fabricated on large-scale CVD-grown graphene using optical lithography. We present an electrical characterization of the graphene SGFETs and report on their long-term stability. Hall-effect measurements are performed to obtain more detail on the charge carrier density and mobility of the graphene under electrolytic gate.

In order to use graphene SGFETs for sensing applications, the influence of the electrolyte composition on the transistor needs to be investigated and understood. Therefore, the effect of pH and different ion species on the transistor current is analyzed. These experimental results are compared to a model describing the graphene-electrolyte interface.

HL 13: Focus Session: Structural Ordering and Electronic Transport II (jointly with CPP)

Time: Monday 15:00–17:30 Location: ER 270

Invited Talk HL 13.1 Mon 15:00 ER 270

Single-Molecule Spectroscopy of Conjugated Polymers: Unravelling Chain Conformations from the Bottom Up — •John Lupton — Institut für Experimentelle und Angewandte Physik, Universität Regensburg — Department of Physics and Astronomy, University of Utah, Salt Lake City

When considering molecular morphology in the context of plastic electronics, one usually refers to the level of intermolecular order. Yet because of the large molecular weight and the interplay between intrinsically flexible and stiff molecular bonds, intramolecular morphology is crucial in determining the overall macroscopic properties of a material. Single-molecule fluorescence spectroscopy offers a unique approach to quantifying intrachain order and disorder, rigidity and shape, and the respective influence on electronic structure so as to construct a microscopic understanding of a functional material from the bottom up. Examples where the technique has proven particularly successful include polyfluorene, which can display a wide range of intrachain conformations including the extraordinary case of perfect defect-free pi-chains; and in polyhexylthiophene, which exhibits a uniquely broad range of conjugation lengths which can be directly mapped on the single-chain level.

HL 13.2 Mon 15:30 ER 270

Rod-coil transitions in the polymers MEH-PPV and PFO — •Anna Köhler — Universität Bayreuth, Bayreuth, Germany

In the current work we explore the effect of aggregation of three conjugated polymers, MEH-PPV , PFO and MeLPPP, dissolved in MeTHF. In MEH-PPV, the absorption spectra are a superposition of a broad ("blue") band and a vibrationally well resolved spectrum at lower energies (the "red"-phase)that appears at 190 K and grows at the expense of the blue phase. Obviously there is a temperature-induced transformation from the blue to the red phase. While this is observed in solutions of 5 x 10-6 mol/L , the red-phase is absent in a 10-7 mol/L solution. This proves that the formation of the red-phase requires aggregation. A similarly temperature dependent superposition of blue and red features can also observed for PFO, but upon dilution only the red feature survives. Finally for MeLPPP, the absorption and fluorescence spectra are mono-modal at all temperatures.The results are indicative of a rod-coil transition in the case of MEH-PPV and PFO with a temperature dependence that is characteristic of a order-disorder transition, albeit with different driving forces. In the case of MEH-PPV the planarization of the chain requires chain aggregation. Quantum chemical calculations show the potential for torsional motion of the repeat units is so shallow that the motion the solvent molecules above the glass temperature is sufficient to prevent chain elongation unless chain pairing occurs. In PFO, however, the tendency towards chain planarization is obviously strong enough to facilitate the elongation of single chains and inter-chain interaction obstructs rather than helps chain elongation.

HL 13.3 Mon 15:45 ER 270

Aggregation in a High Mobility n-type Low Bandgap Copolymer: Implications on Morphology and Charge Transport — •Robert Steyrleuthner[1], Marcel Schubert[1], Ian Howard[2], Christian Schilling[3], Bastian Klaumünzer[4], Zhihua Chen[5], Peter Saalfrank[4], Frederique Laquai[2], Antonio Facchetti[5], and Dieter Neher[1] — [1]University of Potsdam, Institute of Physics — [2]MPI for Polymer Research, Mainz — [3]Nanolytics GmbH, Potsdam — [4]University of Potsdam, Institute of Chemistry — [5]Polyera Corporation, Illinois

The prominent copolymer P(NDI2OD-T2) exhibits very high electron OFET mobility of 0.85 cm2/Vs. Recent X-ray studies on P(NDI2OD-T2) revealed an exceptional in-plane order with distinct pi-stacking of the NDI cores (Rivnay et al.) while GIXD and NEXAFS measurements suggested a significant fraction of amorphous content (Schuettfort et al.). By investigating steady state and time dependent UV-Vis absorption/fluorescence spectroscopy on solutions of P(NDI2OD-T2), we identified distinct absorbing species and assigned them to intrachain CT-excitons on disorderd chains and to interchain excitations on aggregated chains. These results were confirmed by DFT calculations on individual and stacked chains. Analytical ultracentrifugation showed that aggregation in solution proceeds via the collapse of individual polymer coils. The analysis of chain aggregation in solution allowed for the quantitative deconvolution of the thin film absorption, yielding the aggregate content. Finally we find that the vertical transport (electron-only devices) is largely affected by the layer crystallinity.

HL 13.4 Mon 16:00 ER 270

Probing Exciton and Charge Dynamics in Low-Bandgap Polymer:Fullerene Blends by NIR Transient Absorption Spectroscopy — Ian Howard, Fabian Etzold, Clare Dyer-Smith, Hannah Mangold, Ralf Mauer, Michael Meister, and •Frédéric Laquai — Max Planck Research Group for Organic Optoelectronics, Max Planck Institute for Polymer Research Mainz, Germany

Low-bandgap polymers are among the most promising donor materials for bulk heterojunction organic solar cells with efficiencies now exceeding 7 %. However, the photophysics of the pristine polymers and the mechanisms of charge generation and recombination in low-bandgap polymer:fullerene blends are still not entirely understood. In this contribution we compare the exciton and charge carrier dynamics of relevant low-bandgap polymers including PCDTBT, PCPDTBT and PTB-type polymers and their photovoltaic blends, which we study by broadband transient absorption (TA) spectroscopy covering a dynamic range from femto- to milliseconds. We present the previously unobserved near-infrared (NIR) spectral range up to 2000 nm, which we observe with our recently developed broadband NIR-TA setup. We show that by detecting the NIR spectral range we are able to distinguish between the spectral features of singlet and triplet excitons as well as charge-transfer states and mobile polarons and that we can study their generation and decay dynamics, which is difficult, if not impossible, by conventional broadband visible transient absorption spectroscopy.

Invited Talk HL 13.5 Mon 16:15 ER 270

Band dispersion and localized states in organic solids — Nobuo Ueno[1] and •Norbert Koch[2] — [1]Graduate School of Advanced Integration Science, Chiba University, Chiba, Japan — [2]Institut f. Physik, Humboldt-Universität zu Berlin, Berlin, Germany

Charge transport in solids is inevitably linked with structural properties. Organic molecular materials are characterized by two hierarchical levels of structure, i.e., the structure of an individual molecule and that of the molecular assembly. As a consequence, both affect the organic solid's electron density of states (DOS) and the mechanisms of charge transport. We give an overview of how photoelectron spectroscopy can be used to study the DOS of organic materials ranging from amorphous thin films to single crystals, and how the sample's structure (including defects) is reflected in localized (gap) states or delocalized dispersing bands. The influence of the molecular chemical structure and the dielectric environment on electron-vibron coupling strength will be discussed. We will address the impact of polymorphism and temperature on the band structure of prototypical organic solids, including tetracene, pentacene, and rubrene.

HL 13.6 Mon 16:45 ER 270

Elucidating excitonic coupling in supramolecular dye nanotubes — •Dorthe M. Eisele[1], Dylan H. Arias[1], Colby P. Steiner[1], Robert J. Silbey[1], Xiaofeng Fu[2], Daniela Nicastro[2], Keith A. Nelson[1], and Moungi G. Bawendi[1] — [1]MIT, USA — [2]Brandeis University, USA

Self-assembled molecular nanotubes, in particular those strongly absorbing visible light, are highly promising quasi-1d systems for opto-electronic and light harvesting (LH) applications. A detailed understanding of the energetics, dynamics, and couplings of excitonic states in these nanoscale systems is the key for further development of such applications. We report on a remarkable example of such a system, i.e., well-defined nanotubular aggregates of amphiphilic cyanine dyes [1]. By means of cryogenic electron microscopy and 2d electronic spectroscopy, we show that excitonic interactions in such nanoscale systems are not only highly sensitive to changes within the supramolecular structure, but also to changes in higher ordering [2]. This addresses the fundamental question of what physical properties control the energy transport processes in excitonic nanoscale systems, which are vital for new developments in opto-electronic applications.

[1] D.M. Eisele, *et al.*, Nature Nanotech. 4 (2009); D.M. Eisele, *et al.*, JACS Comm. 132 (2010); D.M. Eisele, C.M. Cone, E.A. Bloemsma, S.M. Vlaming, R.J. Silbey, M.G. Bawendi, J. Knoester, J.P. Rabe, and D.A. Vanden Bout (submitted);[2] D.M. Eisele, D.H. Arias, C.P. Steiner, X. Fu, D. Nicastro, K.A. Nelson, and M.G. Bawendi (to be submitted)

HL 13.7 Mon 17:00 ER 270

Intermolecular torsional motion of a π-aggregated dimer probed by two dimensional spectroscopy — •Joachim Seibt[1] and Alexander Eisfeld[1,2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden — [2]Department of Chemistry and Chemical Biology Harvard University, 12 Oxford Street, Cambridge, MA 02138

The energetic splitting of the two exciton states of a molecular dimer depends strongly on the relative orientation of the monomers with respect to each other. The curvature of the corresponding adiabatic potential energy surfaces can lead to torsional motion of the monomers. It has been suggested recently that this torsional motion could provide a possible relaxation mechanism for the upper state which proceeds via a crossing of the two excited state potentials. Another, competing, relaxation mechanism is provided by coupling to the environment, leading to direct exciton relaxation. Here we examine theoretically the combined dynamics of torsional motion and excitonic relaxation for a π-aggregated dimer. Using two dimensional (2D) spectroscopy it is shown how torsional motion through a crossing of the adiabatic excitonic potential surfaces could be distinguished from direct relaxation. For the calculations a mixed quantum/classical approach is used, where the torsional motion is treated by an Ehrenfest type of equation, while the excitonic dynamics including dephasing and direct relaxation is described by a quantum master equation.

HL 13.8 Mon 17:15 ER 270

Origins of low charge mobility in crystalline acceptor-substituted oligothiophenes — Manuel Schrader[1], Roland Fitzner[2], Moritz Hein[3], Chris Elschner[3], Bjoern Baumeier[1], Moritz Riede[3], Karl Leo[3], and •Denis Andrienko[1] — [1]Max Planck Institute for Polymer Research, Mainz, Germany — [2]Institute of Organic Chemistry II and Advanced Materials, Ulm, Germany — [3]Institute of Applied Photophysics, Dresden, Germany

In a small molecule-based organic solar cell, optical absorption in the visible spectrum, needed for efficient photon harvesting, and the relative donor-acceptor level alignment, required for efficient exciton dissociation, are currently achieved by tuning the electron affinity, the ionization potential, and the band gap of the donor material. In dicyanovinyl-substituted oligothiophenes this is realized by covalently binding an electron-withdrawing group (dicyanovinyl) to an electron-donating core (thiophene oligomer). Such an internal donor-acceptor molecular architecture, however, results in large local molecular dipole moments and thus substantial electrostatic energetic disorder, which leads to pronounced Poole-Frenkel behavior and low charge mobilities, even in a crystalline phase. Analyzing charge transport of dicyanovinyl-substituted oligothiophenes, we propose chemical design rules for the donor which offer a compromise between band gap and charge mobility engineering.

HL 14: Focus Session: Site-selective Growth of single Quantum Dots

The vision of semiconductor device operation based on the quantum mechanical properties of a single quantum dot is stimulating many activities towards site-selective growth of quantum dots in order to achieve deterministic device properties. Site-selective quantum dot growth simultaneously represents one of the most challenging frontiers for epitaxial growth today as it requires precise control over lateral assembly of a few thousands of atoms on a few tens of nanometers scale. Many details of the process affect quantum dot properties such as size, emission energies, and linewidth. This focus session highlights different approaches for site-selective quantum dot growth and discusses in-situ and ex-situ concepts for tailoring of their electronic properties. (Organizers: Andre Strittmatter, TU Berlin, and Armando Rastelli, Leibniz Institute for Solid State and Materials Research Dresden)

Time: Monday 15:00–18:15 Location: ER 164

Invited Talk HL 14.1 Mon 15:00 ER 164

Growth and Device Integration of Site-Controlled Quantum Dots — •Sven Höfling[1], Christian Schneider[1], Alexander Huggenberger[1], Vasilij Baumann[1], Micha Strauss[1], Thomas Sünner[1], Tobias Heindel[1], Lukas Worschech[1], Stephan Reitzenstein[1,2], Martin Kamp[1], and Alfred Forchel[1] — [1]Technische Physik, Physikalisches Institut and Wilhelm Conrad Röntgen-Center for Complex Material Systems, Würzburg University, Am Hubland, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany

Single semiconductor quantum dots (QDs) are very attractive candidates to control charge and spin carries at the quantum level. One of the major challenges regarding the scalable fabrication of single QD based devices is however the precise control of the QD position within device structures. Within this work, we present a site-controlled growth technique using pre-patterned nanohole templates for the controlled integration of site-controlled quantum dots into nanoscale devices. By combining this growth technique with a process capable of accurately aligning QDs relatively to subsequently fabricated device structures, several interesting devices could be fabricated based on positioned QDs. For instance, cavity enhanced emission of single site-controlled QDs that were deterministically placed within photonic crystal or micropillar cavities has been demonstrated. Single photon emission of a coupled QD-resonator system has been proven by photon auto-correlation measurements, thus underlining the promise of the devices for quantum communication technologies.

Topical Talk HL 14.2 Mon 15:30 ER 164

Growth and characterization of site-selective quantum dots — •Mathieu Helfrich[1], Philipp Schroth[2], Sergey Lazarev[2], Daniil Grigoriev[3], Taras Slobodskyy[4], Tilo Baumbach[2,3], and Daniel M. Schaadt[1,5] — [1]DFG-Centrum für funktionelle Nanostrukturen (DFG-CFN), Karlsruher Institut für Technologie (KIT), Wolfgang-Gaede-Str. 1a, 76131 Karlsruhe, Germany — [2]Institut für Synchrotronstrahlung / ANKA, Karlsruher Institut für Technologie (KIT), Hermann-von-Helmholtz-Platz 1 ,76344 Eggenstein-Leopoldshafen, Germany — [3]Laboratorium für Applikationen der Synchrotronstrahlung, Karlsruher Institut für Technologie (KIT), Engesserstraße 15, 76131 Karlsruhe, Germany — [4]Institut für Angewandte Physik, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg, Germany — [5]Institut für Energieforschung und Physikalische Technologien, Technische Universität Clausthal, Am Stollen 19B, 38640 Goslar, Germany

Site-selective quantum dots (QDs) can be fabricated by lateral self-alignment or pre-structuring substrates. The latter method allows for a high degree of control of different parameters such as QD locations, size and shape. We will present a quantitative analysis of site-selective InAs QDs grown on pre-structured GaAs substrates. We tested several fabrication parameters including different fabrication techniques. Furthermore, we investigated post growth annealing as means of additional control on above mentioned parameters.

Topical Talk HL 14.3 Mon 16:00 ER 164

Positioned growth and optical properties of InP/GaInP islands and coupled quantum dot structures — •Michael Jetter[1], Elisabeth Koroknay[1], Ulrich Rengstl[1], Moritz Bommer[1], Christian Kessler[1], Heinz Schweizer[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen und Research Center SCoPE, Universität Stuttgart, Deutschland — [2]4. Physikalisches Institut, Universität Stuttgart, Deutschland

In this talk we show a route towards the realization of laterally and vertically positioned quantum dot structures. The lateral positioning is achieved by self-assembled nucleation of InP islands on a regular patterned GaAs surface during the growth process in the metal-organic vapour-phase (MOVPE) system. A low-cost method, called microsphere photolithography, is presented to produce the regular hole pattern.

Next to this, strain driven vertically aligned asymmetric coupled quantum dots (QDs) were highlighted. By controlling the vertical distance between the single QD layers the electronic coupling between the nanostructures can be modified. Photoluminescence experiments reveal the phonon assisted tunneling behavior of either the electron or the whole exciton in dependence of the spacer distance between the dots.

Coffee Break (15 min)

Invited Talk HL 14.4 Mon 16:45 ER 164

Spatial and spectral control of self-assembled quantum dots. — •Oliver G. Schmidt — IFW Dresden, Germany

Two major challenges in the development of quantum dot (QD) based applications are addressed in this talk: First, the need to accurately position QDs and second feasible ways to fully control their spectral properties. The first challenge has been dealt with for several years and has already matured. The second point seems more challenging and postgrowth techniques need to be developed to tune single exciton emission either to the required absolute wavelength or relative to other excitonic recombination lines. To reach these goals self assembled QDs embedded in thin GaAs nanomembranes are transferred to piezo-substrates, where large amounts of strain can be applied to the quantum dots. This technique allows shifting single QD emission lines by more than 20meV and to tune excitonic and biexcitonic lines into resonance [1]. For instance, the single QD emission can be easily tuned into resonance with certain transition lines of Rubidium atoms [2], which is important to efficiently slow down single photons on demand [3]. If embedded into a nanomembrane p-i-n device including Bragg reflectors, the wavelength, emission intensity and charging state of the QDs can be independently controlled at will [4].

[1] F. Ding et al., Phys. Rev. Lett. 104, 067405 (2010) [2] S. Kumar et al., Appl. Phys. Lett. 99, 161118 (2011) [3] N. Akopian et al., Nature Photonics 5, 230 (2011) [4] R. Trotta, P. Atkinson, J. D. Plumhof, E. Zallo, R. Razaev, S. Kumar, S. Baunack, J. R. Schröter, A. Rastelli, O. G. Schmidt, unpublished.

Topical Talk HL 14.5 Mon 17:15 ER 164

Pre-patterned silicon and GaAs substrates for the growth of III-V nanostructures: morphological and optical properties — •Mohamed Benyoucef, Muhammad Usman, Tariq Al Zoubi, Aleksandar Gushterov, Tino Pfau, and Johann Peter Reithmaier — Institute of Nanostructure Technologies and Analytics (INA), Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Strasse 40, D-34132 Kassel, Germany

Light emission from direct growth of III-V quantum dots (QDs) on silicon (Si) is a future dream. However, the presence of high-density threading dislocations due to the lattice mismatch and the formation of antiphase boundaries due to the polar/non polar nature destroy the light emission. Growth on pre-patterned substrates could results in reducing or eliminating such defects due to size effect.

In this talk, we report on growth of site-controlled InAs QDs on pre-patterned GaAs and Si substrates based on dry and wet-chemical etching. In the first part, a review on the recent work on pre-patterned GaAs will be provided. Results of an optimized wet-chemically etching holes and a special MBE growth stack technique will be presented. GaAs based single QDs emissions is probed by micro-PL and reveals clear spectra with single lines. In the second part, we present the results of the optimized electron beam lithography and dry etching processes for the patterning of Si substrates. The MBE growth of QDs on patterned Si surface with highly selective formation of localized InAs nanostructures in patterned holes with 1 μm period will be discussed.

Topical Talk HL 14.6 Mon 17:45 ER 164

Lateral positioning of InGaAs quantum dots using a buried stressor — •André Strittmatter — Institut für Festkörperphysik, Technische Universität Berlin, Sekr. EW 5-2, Hardenbergstrasse 36, D-10623 Berlin, Germany

We present a bottom-up approach for the lateral alignment of semiconductor quantum dots (QDs) based on strain-driven self-organization. A buried stressor formed by partial oxidation of (Al,Ga)As layers is employed in order to create a locally varying strain field at a GaAs(001) growth surface. During subsequent strained layer growth, local self-organization of (In,Ga)As QDs is controlled by the contour shape of the stressor. Large vertical separation of the QD growth plane from the buried stressor interface of 150 nm is achieved enabling high optical quality of QDs. Optical characterization confirms narrow QD emission lines without spectral diffusion.

HL 15: Graphene: Structure and Theory I

Time: Monday 15:00–17:00 Location: EW 201

HL 15.1 Mon 15:00 EW 201

Functional Polymer Brushes on Graphene — •Max Seifert[1], Amelie Koch[1], Frank Deubel[2], Tobias Simmet[1], Lucas Hess[1], Martin Stutzmann[1], Ian Sharp[1], and Jose Antonio Garrido[1] — [1]Walter Schottky Institut, TU München, Germany — [2]Wacker-Lehrstuhl für Makromolekulare Chemie, TU München, Germany

The use of graphene in biosensing applications requires a well-defined functionalization method in order to introduce sensing specificity and improve device sensitivity. It has been shown that direct photografting and photo-polymerization of styrene yields covalently bound polystyrene brushes on graphene without significantly disrupting its basal plane conjugation. We have previously suggested that hydrogen-containing defects sites can act as initiation centers for the surface polymerization. In this contribution, we demonstrate by Raman spectroscopy that the density of such hydrogen defect sites can be finely controlled by exposing the pristine CVD grown graphene sheets to a hydrogen plasma at room temperature, resulting in a tunable polymer brush grafting density. However, pure polystyrene brushes exhibit very low chemical reactivity for further functionalization. Thus, we have developed a procedure for the copolymerization of styrene and different acrylates, paving the way towards a graphene-based platform for highly sensitive and specific biosensor devices.

HL 15.2 Mon 15:15 EW 201

Electronic structure of graphene on single crystal copper substrates — •Andrew Walter[1,2], Shu Nie[3], Aaron Bostwick[1], Keun Su Kim[1,4], Luca Moreschini[1], Young Jun Chang[1,2], Davide Innocenti[5], Karsten Horn[2], Kevin F. McCarty[3], and Eli Rotenberg[1] — [1]Advanced Light Source (ALS), E. O. Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA — [2]Department of Molecular Physics, Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany, — [3]Sandia National Laboratories, Livermore, California 94550, USA. — [4]Center for Atomic Wires and Layers, Pohang University of Science and Technology, Pohang 790-784, Korea. — [5]University of Rome (Tor Vergata), Rome 00173, Italy

The electronic structure of graphene on Cu(111) and Cu(100) single crystals is investigated using low energy electron microscopy, low energy electron diffraction and angle resolved photoemission spectroscopy. On both substrates the graphene is rotationally disordered and interactions between the graphene and substrate lead to a shift in the Dirac crossing. The graphene film is found to protect the surface state from air exposure, with no change in the effective mass observed.

HL 15.3 Mon 15:30 EW 201

Atomic structure and spectroscopy of graphene edges on Ir(111) — •Soo-hyon Phark[1], Jérôme Borme[1,2], Augusto León Vanegas[1], Marco Corbetta[1], Dirk Sander[1], and Jürgen Kirschner[1] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany — [2]International Iberian Nanotechnology Laboratory, Avenida Mestre José Veiga, 4715-310 Braga, Portugal

We performed scanning tunneling microscopy/spectroscopy (STM/S)

on monolayer graphene islands grown on Ir(111). The graphene islands show moiré patterns, which are induced by the lattice mismatch between graphene and Ir(111). The atomic structure at the edge of a graphene depends on the stacking configurations of the edge atoms. The edges of graphene islands terminate with a zigzag carbon configuration and show periodic kinks in the regions of the on-top stacking carbon rings. The periodicity is given by the moiré pattern of the graphene island. The termination of a graphene island at an Ir(111) step also leads to the formation of periodic kinks, of which the positions depend on the orientation of the step edge. We tentatively ascribe these observations to a strong electronic interaction, arising from the broken σ-bond of graphene, between carbon edge atoms and the Ir lattice. Spatially resolved tunnel spectroscopy indicates a considerably reduced density of states at the edges as compared to center regions of the islands.

HL 15.4 Mon 15:45 EW 201

Bernal graphite is a narrow gap semiconductor — Nicolas Garcia[1], •Pablo Esquinazi[2], Jose Barzola-Quiquia[2], and Srujana Dusari[2] — [1]Laboratorio de Física de Sistemas Pequeños y Nanotecnología, Consejo Superior de Investigaciones Científicas, E-28006 Madrid, Spain — [2]Division of Superconductivity and Magnetism, Institut für Experimentelle Physik II, Universität Leipzig, Linnéstraße 5, D-04103 Leipzig, Germany

We have studied the resistance of a large number of highly oriented graphite samples with areas ranging from several mm^2 to a few μm^2 and thickness from ~ 10 nm to several tens of micrometers. The measured resistance can be explained by the parallel contribution of semiconducting graphene layers with low carrier density $< 10^9$ cm^{-2} and the one from metalliclike internal interfaces. The results indicate that ideal graphite with Bernal stacking structure is a narrow-gap semiconductor with an energy gap $E_g \sim 40$ meV.

HL 15.5 Mon 16:00 EW 201

Effective screening and the plasmaron bands in Graphene — •Andrew Walter[1,2], Aaron Bostwick[1], Ki-Joon Jeon[3], Florian Speck[4], Marcus Ostler[4], Thomas Seyller[4], Luca Moreschini[1], Young Jun Chang[1,2], Marco Polini[5], Reza Asgari[6], Allan H. MacDonald[7], Karsten Horn[2], and Eli Rotenberg[1] — [1]Advanced Light Source (ALS), E. O. Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA, — [2]Department of Molecular Physics, Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany, — [3]School of Electrical Engineering, University of Ulsan, Namgu, Ulsan, 680-749, South Korea — [4]Lehrstuhl fur Technische Physik, Universitat Erlangen-Nurnberg, Erwin-Rommel-Strasse 1, 91058 Erlangen, Germany — [5]NEST, Istituto Nanoscienze-CNR and Scuola Normale Superiore, I-56126 Pisa, Italy. — [6]School of Physics, Institute for Research in Fundamental Sciences (IPM), Tehran 19395-5531, Iran. — [7]Dept. of Physics, Univ. of Texas at Austin, 1 University Station C1600, Austin TX 78712

Electron-plasmon coupling in graphene has recently been shown to give rise to a "plasmaron" quasiparticle excitation. The strength of this coupling is compared to the strength of enviromental screening for graphene on four different substrates. Comparison with G0W-RPA predictions are used to determine the effective dielectric constant of the underlying substrate layer indicating that plasmaron and electronic properties of graphene can be independently manipulated, an important aspect of a possible use in "plasmaronic" devices.

HL 15.6 Mon 16:15 EW 201

Opening of a tunable energy gap in disordered graphene nanoribbons — •George Pal, Walter Apel, and Ludwig Schweitzer — Physikalisch-Technische Bundesanstalt (PTB), Bundesalee 100, 38116 Braunschweig, Germany

The absence of an energy gap in the electronic band structure is the most severe impediment for the use of graphene in electronic device applications where large on-off currents are indispensable. Recently, we have proposed a mechanism to open a spectral gap by applying structured external electric potentials to the edge regions of graphene zig-zag nanoribbons [1]. Specifically, we show that an antisymmetric potential that acts selectively on the ribbon boundaries shifts the energies of the edge states in opposite directions and thus an energy gap opens up. To check the robustness of the proposed gap-opening mechanism against disorder, which is certainly present in real samples, we study the effect of different kinds of imperfections on the spectral and the transport properties. These include uncorrelated random on-site potentials, chiral-symmetry preserving bond disorder and edge disorder which may be due to edge passivation by randomly attached atoms that saturate the carbon dangling bonds. We find that all types of disorder merely reduce the spectral gap. Bulk disorder influences only slightly the edge states responsible for the gap, and its closing is mainly due to increasing the strength of edge disorder. Still, the energy gap remains finite as long as W<2V, where W is a measure of the disorder strength and V is the applied potential. [1] W. Apel, G. Pal and L. Schweitzer, PRB 83, 125431 (2011)

HL 15.7 Mon 16:30 EW 201

Perturbative analysis of the conductivity in disordered monolayer and bilayer graphene — •Andreas Sinner and Klaus Ziegler — Institut für Physik, Universität Augsburg, Germany

The DC conductivity of monolayer and bilayer graphene is studied perturbatively for different types of disorder. In the case of monolayer, an exact cancellation of logarithmic divergences occurs for all disorder types. The total conductivity correction for a random vector potential is zero, while for a random scalar potential and a random gap it acquires finite corrections. We identify the diagrams which are responsible for these corrections and extrapolate the finite contributions to higher orders which gives us general expressions for the conductivity of weakly disordered monolayer graphene. In the case of bilayer graphene, a cancellation of all contributions for all types of disorder takes place. Thus, the minimal conductivity of bilayer graphene turns out to be very robust against disorder.

Reference: arXiv:1110.3065, to appear with PRB.

HL 15.8 Mon 16:45 EW 201

Valley symmetry breaking and gap tuning in graphene by spin doping — •Antonio Hill, Andreas Sinner, and Klaus Ziegler — Institut für Physik, Universität Augsburg

We study graphene with an adsorbed spin texture, where the localized spins create a periodic magnetic flux. The latter produces gaps in the graphene spectrum and breaks the valley symmetry. The resulting effective electronic model, which is similar to Haldane's periodic flux model, allows us to tune the gap of one valley independently from that of the other valley. This leads to the formation of two Hall plateaux and a quantum Hall transition. We discuss the density of states, optical longitudinal and Hall conductivities for nonzero frequencies and nonzero temperatures. A robust logarithmic singularity appears in the Hall conductivity when the frequency of the external field agrees with the width of the gap.

HL 16: II-VI Semiconductors I

Time: Monday 15:00–16:15 Location: EW 202

HL 16.1 Mon 15:00 EW 202

Geometry effects of nonlinear optical properties in 0D-1D II-VI semiconductor nanocrystals — •Alexander W. Achtstein[1], Jonas Hennig[1], Anatol Prudnikau[2], Marya Hardzei[2], Mikhail Artemyev[2], and Ulrike Woggon[1] — [1]Institute of Optics and Atomic Physics, Technical University of Berlin, Berlin, Germany — [2]Institute for Physico-Chemical Problems, Belarussian State University, Minsk, Belarus

Semiconductor nanoparticles have unique properties due to spatial confinement and shape control also in the nonlinear optical regime. This work studies the optical nonlinearities in colloidal 0D and 1D zinc-blende- and wurtzite-type II-VI semiconductor nanocrystals. To understand nonlinear effects at a nanoscale, spatial confinement and its influence on the nonlinear optical properties are investigated. The expected strong geometry and size dependence of the two photon absorption (TPA) cross-section has been tested by a size series of colloidal CdS dots and rods starting from a near 0D system to long 1D nanorods in a z-scan setup. A pronounced change of volume normalized TPA

cross sections at the transition from dots to elongated rods has been found. While the bulk TPA coefficient of CdS is only 17GM/nm^3, it grows in spherical CdS nanocrystals to 140GM/nm^3 and becomes 2.3×10^3 GM/nm^3 in elongated CdS nanorods. The contributions of spatial confinement and local field effects of the dielectric environment are evaluated separately to get a deeper insight in the confinement effect on TPA. Additional Two-Photon Luminescence Excitation measurements reveal the spectral dependence of the TPA coefficients.

HL 16.2 Mon 15:15 EW 202

New approach towards backthinning and removal of MBE growth substrates — •Steffen Bieker, Michael Rüth, Tobias Kiessling, Wolfgang Ossau, and Laurens W. Molenkamp — Physikalisches Institut (EP3) der Universität Würzburg, 97074 Würzburg, Germany

Epitaxial lift-off techniques (ELO) have attracted interest since the late 1980s [1]. We report on a new two-step approach towards the removal of MBE growth substrates. Other than established ELO techniques, our process does not rely on a sacrificial release layer. Pure mechanical lapping allows for several micrometer of residual substrate thicknesses. Residue-free removal of the GaAs substrates from II-VI semimagnetic resonant tunnelling diodes (RTD) is demonstrated. HR-XRD analysis indicates that the crystalline integrity of complex RTD heterostructures is preserved if a silicon frame is mounted during the lapping step to decouple shear forces from the active device layers. Smoothing of interfaces due to strain relaxation allows to assess the microscopic origin of long-debatable transport characteristics.

[1] Yablonovitch et al., APL **51**, 2222 (1987)

HL 16.3 Mon 15:30 EW 202

Li-doping of cubic ZnS grown on GaP (001) by chemical vapour deposition — •Gunther Haas, Udo Roemer, Stefan Lautenschlaeger, Sebastian Eisermann, Andreas Laufer, Melanie Pinnisch, and Bruno Karl Meyer — 1st Physics Institute, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, DE-Germany

Chemical vapour deposition has been used to grow high quality zinc sulfide heteroepitaxial layers on GaP (001). The precursors of the growth process were metallic zinc and dihydrogen sulfide. Zinc sulfide is a wide band gap semiconductor, known to be challenging in terms of Li-doping with the purpose of p-type doping. In our experiments we used lithium amide as a lithium doping source. Our investigations of undoped as well as Li-doped layers show a clear dependence of the structural quality analyzed by X-Ray diffraction (XRD) and the surface morphology observed with atomic force microscopy (AFM) on the layer thickness. The surface morphology of undoped layers switches from nanometer scale crystallites to rough pyramid-like structures for layers thicker than ca. 1.8 μm, while Li-doped layers exhibit a rippled surface. The incorporation of Li and Na into the layers was confirmed by secondary ion mass spectrometry (SIMS) and correlates with the intensity of acceptor bound excitons found in low temperature photoluminescence measurements.

HL 16.4 Mon 15:45 EW 202

Optical characterization of CdSe/ZnTe type-II interfaces for photovoltaics — •Jan-Peter Richters[1], Lionel Gerard[2], Regis Andre[2], and Joel Bleuse[1] — [1]CEA-CNRS group "Nanophysique et semiconducteurs", CEA-Grenoble, INAC, SP2M, 17 rue des Martyrs, 38042 Grenoble, France — [2]CEA-CNRS group "Nanophysique et semiconducteurs", Institut Néel, CNRS, BP 166, 38042 Grenoble Cedex 9, France

Solar cells based on direct bandgap semiconductors (GaAs, CdTe, CdSe...) show an efficient light absorption compared to silicon solar cells. This is an advantage for material savings due to thinner absorbers, but it also comes with the drawback of higher losses due to efficient radiative electron-hole recombination. Such losses could be prevented through the use of type-II interfaces which separate electrons and holes within the active area, similar to a p-n junction. We report a study of CdSe/ZnTe samples showing such an interface. The CdSe bandgap (1.7 eV) is well adapted to the solar spectrum and its lattice parameter mismatch with ZnTe is exceptionally low. We have grown, by MBE, different kinds of samples like CdSe/ZnTe 2D interfaces and superlattices and present time-resolved spectroscopy results which specify the efficiency of the electron-hole separation in these type-II structures. The measured decay time can be above 100 ns for the interface optical transition, i.e. 3 orders of magnitude slower than the typical PL decay time for the constitutive materials taken separately.

HL 16.5 Mon 16:00 EW 202

A new model for the O_{Te}-V_{Cd} complex in CdTe — •Dirk Bastin[1], Edward Lavrov[1], Jörg Weber[1], Jürgen Schneider[2], Alex Fauler[2], and Michael Fiederle[2] — [1]Technische Universität Dresden, 01062 Dresden, Deutschland — [2]Freiburger Materialforschungszentrum, 79104 Freiburg, Deutschland

CdTe single crystals treated in $CdSO_4$ vapor at 850 °C are investigated by IR absorption. Two local vibrational modes (LVM) at 1096.8 (ν_1) and 1108.4 cm^{-1} (ν_2) appear in the sample as the result of the thermal treatment. The modes were previously identified by Chen *et al.* as vibrations of the O_{Te}-V_{Cd} complex [G. Chen *et al.*, Phys. Rev. Lett. **96**, 035508 (2006)]. We detect in our samples additional LVMs with intensities which match the natural abundance of the sulfur isotopes. The reported dependence of the absorption intensities of ν_1 and ν_2 from the oxygen concentration of the samples points to a model of an sulfur-oxygen complex of the vibrating center. From the intensities of the IR absorption involving the ^{18}O isotope, we conclude that two oxygen atoms contribute to the LVMs.

HL 17: Plasmonic Systems

Time: Monday 15:00–16:45 Location: EW 203

HL 17.1 Mon 15:00 EW 203

Observation of plasmonic mirages — •Felix Bleckmann[1], Johannes Lenz[2], Nikolas Grünwald[2], Stephan Irsen[2], and Stefan Linden[1] — [1]Physikalisches Institut, Universität Bonn, Nußallee 12, 53115 Bonn, Germany — [2]Research Center Caesar, Ludwig-Erhard-Allee 2, 53175 Bonn, Germany

Surface plasmon polaritons (SPPs) are electromagnetic waves propagating at the interface between a metal and an insulator. Recently, it has been demonstrated, that SPPs can be controlled by adding a dielectric film on top of the metal. The effective refractive index of the SPPs of such a three layer system depends on the thickness and the refractive index of the dielectric film. For PMMA on top of gold, the effective refractive index of the SPPs for near-infrared frequencies can be tuned between approximately 1.0 and 1.5 by changing the PMMA thickness from 0 nm to 200 nm.

Simple optical components like lenses and prisms can be fabricated by adding dielectric elements with constant thickness and appropriate shape on top of the metal. The local modification of the thickness of the dielectric film also allows for graded index profiles for propagating SPPs.

Here, we use grey-scale lithography to fabricated different functional elements for the manipulation of SPPs. We demonstrate that a dielectric gradient structure can be used to bend the propagation direction of a SPP mimicking the mirage effect.

HL 17.2 Mon 15:15 EW 203

Near-field Study on Plasmonic Oligomers — •Thorsten Weber[1,2], Felix von Cube[1,2], Stephan Irsen[2] und Stefan Linden[1,3] — [1]Physikalisches Institut, Universität Bonn, Nußallee 12, 53113 Bonn, Germany — [2]Research center caesar, Ludwig-Erhard-Allee 2, 53175 Bonn, Germany — [3]Intitut für Nanotechnologie, Karlsruher Institut für Technologie (KIT), 76021 Karlsruhe, Germany

Plasmonic nano-structures have recently been proposed to be a useful tool in sensing. The corresponding sensors are based on the spectral shift of a mode of the plasmonic nano-structure upon change of the refractive index of the surrounding medium. The interaction of metallic nano-particles, arranged in an oligomer-like structure, gives rise to Fano resonances. The small spectral width of the Fano resonance makes plasmonic oligomers an interesting candidate for sensing applications. Furthermore, Fano resonances can easily be tuned in frequency by rearranging the oligomer's nano-particles in space or size. So far,

interactions of the oligomer's particles have been mainly studied in optical far-field-measurements.

We employ electron energy loss spectroscopy in combination with scanning transmission electron microscopy to map the near-field of plasmonic oligomer structures for different energies. Our experiments give us a remarkable insight into the near-field interactions between the different particles of the oligomer. We study heptamers, which are six particles arranged around one central particle. Dissecting these into single particles, dimers, trimers, and hexamers allows a systematic study of how the separated parts of an oligomer interact.

HL 17.3 Mon 15:30 EW 203

Terahertz Metamaterials Based on Arrays of Rolled-Up Gold/(In)GaAs Tubes — •Andreas Rottler, Markus Bröll, Nils Gerken, Detlef Heitmann, and Stefan Mendach — Institute of Applied Physics, University of Hamburg, Germany

Metamaterials are artificial structures where permittivity and permeability can be designed on demand and may exhibit values which are not observed in nature. Recently it has been shown that three-dimensional metal/semiconductor microtube metamaterials with multiple rotations can be fabricated [1].

In this talk, we demonstrate with finite-integration technique simulations that arrays of rolled-up gold/(In)GaAs tubes with slightly more than one winding interact resonantly with the magnetic component of an incident electromagnetic field and exhibit a negative permeability at terahertz frequencies [2]. We show that the frequency interval of negative permeability can be tailored to desired values by changing the winding number. Additionally, we also demonstrate that this dependence can be removed, if desired, by the incorporation of an additional slit into the gold layer. In an experiment such a slit can be prepared by lithographic means prior to the rolling-up process.

We gratefully acknowledge support by the DFG via the Graduiertenkolleg 1286.

[1] S. Schwaiger et al., Phys. Rev. Lett. 102, 163903 (2009).

[2] A. Rottler et al., Opt. Lett. in press.

HL 17.4 Mon 15:45 EW 203

Rolled-up active plasmonic metamaterials — •Stephan Schwaiger, Aune Koitmäe, Lena Simone Fohrmann, Matthias Klingbeil, Andreas Rottler, Jochen Kerbst, Markus Bröll, Yuliya Stark, David Sonnenberg, Christian Heyn, Detlef Heitmann, and Stefan Mendach — Institut für Angewandte Physik, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg

Using the relaxation process of strained semiconductor layers [1] we fabricate microtubes whose wall represent three-dimensional metamaterials consisting of alternating layers of metal (Ag) and semiconductor (AlIn)GaAs. I will present the results of the optical investigations of these microtube metamaterials including our latest findings. Be means of transmission measurements and finite difference time domain simulations we could show that these microtube metamaterials are promising candidates for rolled-up hyperlenses [2]. Furthermore, we demonstrated that the transmission through the metamaterial can be enhanced by integrating an optically active quantum well into the semiconductor [3]. In the next step we embedded a grating into the metamaterial to investigate the interaction of the embedded quantum well and possible surface plasmon polariton excitation on the Ag grating. We gratefully acknowledge support from the Deutsche Forschungsgemeinschaft (DFG) through GrK 1286. [1] V. Ya. Prinz et al., Physica E 6, 828 (2000). [2] S. Schwaiger et al., Phys. Rev. Lett. 102, 163903 (2009). [3] S. Schwaiger et al., Phys. Rev. B 84, 155325 (2011).

HL 17.5 Mon 16:00 EW 203

Bandgap Tuning in Plasmonic Gratings — •Jens Ehlermann, Hoan Vu, Markus Bröll, Robert Blick, Detlef Heitmann, and Stefan Mendach — Institute of Applied Physics, University of Hamburg, Germany

We investigate plasmon excitations on thin goldfilms coated with PMMA grating structures both, in the near field, using a scanning nearfield optical microscope (SNOM), and in the far field. Particular interest is being paid to the characteristics of the bandgap at $k = 0$ in the plasmon dispersion relation.

The dependence of the bandgap's size and energetic position on structural parameters like grating height and filling factor f, i.e. the ratio between grating bar width and period, is examined. We discovered a shift of the bandgap's position to lower energies with increasing f and we noticed a significant change in the bandgap's size.

Our results enabled us to trace back the measured far field effects to the filling factor dependent variation of the effective refractive index.

Experimental data can be well modeled using FDTD and RCWA simulations. Based on these findings it is possible to manufacture structures with tailor-made plasmonic properties whose application covers a broad range of topics.

We gratefully acknowledge support by the University of Hamburg and the DFG through GrK 1286 and the LExI Cluster 'Nano Spintronics'.

HL 17.6 Mon 16:15 EW 203

Optical properties of metal-organic hybrid microcavities — •Robert Brückner, Markas Sudzius, Susanne Hintschich, Hartmut Fröb, Vadim Lyssenko, and Karl Leo — Institut für Angewandte Photophysik, Technische Universität Dresden, D-01062 Dresden, Germany

We investigate the impact of the incorporation of a thin silver layer into a planar dielectric microcavity (MC). The MC is composed of a $\frac{\lambda}{2}$-layer of the organic media Alq_3 doped with 2wt% DCM sandwiched between two dielectric distributed Bragg reflectors (21 alternating layers of TiO_2 and SiO_2). Using a μ-photoluminescence setup, we systematically study the transition from a single cavity mode into *two* optical Tamm states depending on the thickness of the embedded silver layer [1]. Even for a silver layer of 40 nm thickness both new modes are only slightly damped, enabling lasing in these metal organic hybrid devices. The eigenenergies of these modes strongly depend on both the thickness of the silver layer and the adjacent dielectric layers. We show that both resonances cannot have the same wavelength indicating a clear anticrossing behavior. We confirm the experimentally observed shift and splitting of the cavity mode into two anticrossing resonances via transfer matrix calculations.

[1] R. Brückner, *et al.* Phys. Rev. B, **83**, 033405 (2011).

HL 17.7 Mon 16:30 EW 203

Functionality and Dielectric Function Retrieval of a Rolled-Up Hyperlens — •Andreas Rottler, Stephan Schwaiger, Markus Bröll, Detlef Heitmann, and Stefan Mendach — Institute of Applied Physics, University of Hamburg, Germany

Three-dimensional metamaterials made of rolled-up metal/semiconductor microtubes have recently gained much attention due to their ability to work as hyperlenses in the visible regime [1]. In this talk we present finite-difference time-domain (FDTD) simulations to analyze the functionality of such hyperlens systems together with a dielectric function retrieval. The real and imaginary part of the dielectric function of a rolled-up metal/semiconductor hyperlens is retrieved from experimental reflection and transmission data and from data calculated by the transfer matrix formalism. The retrieved dielectric function is compared to a well-known effective medium model for metal/semiconductor superlattices [2]. It turned out that for the fabricated samples there is some agreement with the effective medium model for frequencies below the plasma frequency. However, for higher frequencies, the retrieved permittivity strongly deviates. In additional FDTD simulations we show that, interestingly, the hyperlens functionality of our realized structures is preserved, even far beyond the effective plasma frequency.

We gratefully acknowledge support by the DFG via the Graduiertenkolleg 1286.

[1] S. Schwaiger et al., Phys. Rev. Lett. 102, 163903 (2009).

[2] B. Wood et al., Phys. Rev. B 74, 115116 (2006).

HL 18: Transport: Quantum Coherence and Quantum Information Systems 2 (jointly with TT, MA)

Time: Monday 15:00–17:30 Location: BH 243

HL 18.1 Mon 15:00 BH 243

Control Pulse Engineering for Fast Controlled-Z Gates — •Daniel Egger, Seth Taylor Merkel, and Frank Wilhelm — Universität des Saarlandes, Saarbrücken, Germany

When manipulating quantum systems it is key to do so before decoherence destroys the fragile states. For quantum computing this sets a time within which the desired qubit manipulations can be done. To increase the number of computations, either the coherence times must be increased or the gate durations must be decreased with the help of Optimal Control Theory. In the following work we show how Gradient Pulse Shape Engineering [1] can be used to optimize the time taken to perform a controlled-Z gate in the framework of the RezQu architecture [2]: two qubits, sufficiently far apart, are coupled to a bus resonator. The only controls considered are the two qubit-bus detunings. All elements have three levels to account for leakage. Additionally the finite bandwidth of the electronics is taken into account though an impulse response function. We give a value of the critical time below which a high fidelity gate can no longer be realized and explore what affects the control pulses. For the case of phase qubits we find that a controlled-Z gate with an error of 10^{-4} can be realized in 27 ns. Furthermore, the found control pulses are ready to be tested experimentally.
[1] N. Khaneja, J. Magn. Reson. **172**, 296
[2] M. Mariantoni, Science **334**, 6052

HL 18.2 Mon 15:15 BH 243

Relaxation and decoherence dynamics in the spin-boson model — •Oleksiy Kashuba, Mikhail Pletyukhov, Dirk Schuricht, and Herbert Schoeller — Institut für Theorie der statistischen Physik, RWTH Aachen, D-52056 Aachen

We study the real-time dynamics of the ohmic spin-boson model using a nonequilibrium renormalisation group method [1] successfully applied to the anisotropic Kondo model [2] and the interacting resonant-level model [3]. We discuss the relaxation and decoherence channel w/o bias. In all regimes of the coupling α, we obtain power law time dependence from non-Markovian contributions but always accompanied by exponential decay. For $\alpha \sim 1/2$, we recover the well-known localization transition but obtain different power-law exponents for the time evolution in the biased case. Finally, for $\alpha \sim 1$, we discuss the time-evolution close to a quantum critical point.
[1] H. Schoeller, Eur. Phys. J. Spec. Top. 168, 179 (2009).
[2] M. Pletyukhov, D. Schuricht and H. Schoeller, Phys. Rev. Lett. 104, 106801 (2010).
[3] S. Andergassen, M. Pletyukhov, D. Schuricht, H. Schoeller, and L. Borda, Phys. Rev. B 83 205103 (2011).

HL 18.3 Mon 15:30 BH 243

Simple ways to avoid leakage in qubit systems — •Frank Wilhelm[1,2], Felix Motzoi[2], Seth Merkel[3], and Jay Gambetta[3] — [1]Theoretical Physics, Saarland University, Saarbrücken — [2]IQC and Department of Physics and Astronomy, University of Waterloo, Canada — [3]IBM Watson Research Laboratories, Yorktown Heights, NY, USA

No physical system is just a two-state qubit. Many qubit candidates are in fact weakly nonlinear oscillators with leakage transitions that lead outside the computational subspace that are spectrally close to the qubit transition. The simple DRAG pulse-shaping method allows to efficiently supress these leakage transitions. We will show that there is a whole family of DRAG pulses that also allow to enhance spectral selectivity through multiple channels, and that allow to selectively address qubits driven through a common control. These ideas are applied to superconducting phase qubits, Transmons, and circuit QED architectures.
[1] F. Motzoi, J.M. Gambetta, P. Rebentrost, and F.K. Wilhelm, Phys. Rev. Lett. 103, 110501 (2009)
[2] J.M. Gambetta, F. Motzoi, S.T. Merkel, and F.K. Wilhelm, Phys. Rev. A 2011

HL 18.4 Mon 15:45 BH 243

Non-equilibrium dynamics of the central spin model — •Alexandre Faribault and Dirk Schuricht — Institute for Theory of Statistical Physics RWTH Aachen Physikzentrum Sommerfeldstrasse 52074 Aachen Germany

A long standing proposal for a q-bit is to use the spin of a single electron trapped in a quantum dot. In such solid-state based systems, the dominant decoherence mechanism is the hyperfine coupling of the electron spin to the nuclear spins in the substrate. In this work, the Central spin model describing such a quantum system is studied numerically by exploiting its quantum integrability via the algebraic Bethe ansatz. In doing so, it becomes possible to efficiently compute exact eigenstates which we then use to study non-equilibrium dynamics in scenarios describing the relaxation and decoherence of prepared states.

HL 18.5 Mon 16:00 BH 243

Impurity entanglement via electron scattering in a magnetic field — Raoul Dillenschneider, •Alexandros Metavitsiadis, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Kaiserslautern, Germany

A possible mechanism to entangle two non-interacting magnetic moments is via successive electron scattering. Of particular interest is the case when the magnetic moments are considered as embedded impurities in a one dimensional lattice. The amount of entanglement can be modified by appropriately choosing the initial state of the system. Furthermore, the presence of a magnetic field may play a crucial role to the resulting entanglement. In this work, we present analytical as well as numerical results for the time dependence of the entanglement of magnetic moments, as manifested in the concurrence, especially stressing the role of external fields.

15 min. break.

HL 18.6 Mon 16:30 BH 243

Decoherence of a qubit in a non-Markovian environment formed through a spin cluster — •Wenling Qiao[1,2], Mohammad Ansari[2], and Frank Wilhelm-Mauch[1,2] — [1]Saarland University, Saarbrücken, Germany — [2]University of Waterloo, Waterloo, Canada

The error rate in quantum computing based on solid-state devices is mostly limited by the qubit decoherence behavior. While Markovian environments are well understood, the main experimental and theoretical challanges lie in the field of correlated non-Markovian noises. We study the quantum dynamics of a qubit in a toy non-Markovian environment model, a large spin cluster coupled to a thermal bath. By using the Holstein-Primokoff transformation,Bogoliubov transformation on the spin Hamiltonian and representing the master equation in phase space, we calculated the correlation function for the spin operator coupled to the qubit. This permits insight into the decoherence of the qubit.

HL 18.7 Mon 16:45 BH 243

Quantum state transfer in boundary-controlled and fully engineered spin chains — Analia Zwick[1,2], Gonzalo A. Álvarez[1], •Joachim Stolze[1], and Omar Osenda[2] — [1]Institut für Physik, TU Dortmund, Germany — [2]Facultad de Matemática, Astronomía y Física and Instituto de Física Enrique Gaviola, Universidad Nacional de Córdoba, Argentina

Quantum state transfer in presence of noise is one of the main challenges for building quantum computers. We compare the quantum state transfer properties for two classes of qubit chains under the influence of static randomness. In fully engineered chains all nearest-neighbor couplings are tuned in such a way that a single-qubit state can be transferred perfectly between the ends of the chain, while in boundary-controlled chains only the two couplings between the transmitting and receiving qubits and the remainder of the chain can be optimized. We study how the noise in the couplings affects the state transfer fidelity depending on the noise model and strength as well as the chain type and length. We show that the desired level of fidelity and transfer time are important factors in designing a chain. In particular we demonstrate that transfer efficiency comparable or better than that of the most robust engineered systems can also be reached

in boundary-controlled chains without the demanding engineering of a large number of couplings.

HL 18.8 Mon 17:00 BH 243

Pauli blockade for Kramers-qubit readout in carbon nanotubes — •Gábor Széchenyi and András Pályi — Institute of Physics, Eötvös University, Hungary

Carbon nanotube double quantum dots are promising candidates for a solid-state platform of quantum-information processing. In the ground state of the nanotube the physical qubit is a Kramers doublet, which involves two states with antiparallel alignment of spin and valley. To evaluate the potential in Pauli-blockade-based Kramers-qubit readout, we theoretically investigate electron transport in a situation where Pauli or spin-valley blockade is lifted by the combined effect of axial and transverse magnetic-field and short range disorder. We can identify a parameter regime where four-level (spin and valley) carbon nanotube quantum dot is reduced to an effective two-level system. We derive analytical formulas of the current as a function of applied transverse and axial magnetic field, which we compare with our numerical results.

HL 18.9 Mon 17:15 BH 243

Entanglement, Fluctuations, and Quantum Critical Points — •Stephan Rachel[1], Nicolas Laflorencie[2], H. Francis Song[1], and Karyn Le Hur[3,1] — [1]Department of Physics, Yale University, New Haven, CT 06520, USA — [2]Laboratoire de Physique Theorique, Universite de Toulouse, UPS, (IRSAMC), F-31062 Toulouse, France — [3]Center for Theoretical Physics, Ecole Polytechnique, 91128 Palaiseau Cedex, France

We show that bipartite fluctuations F can be considered an entanglement measure. We further demonstrate that the concept of bipartite fluctuations F provides a very efficient tool to detect quantum phase transitions in strongly correlated systems. We investigate paradigmatic examples for both quantum spins and bosons in one and two dimensions. As compared to the von Neumann entanglement entropy, we observe that F allows to find quantum critical points with a much better accuracy in one dimension. We further demonstrate that F can be successfully applied to the detection of quantum criticality in higher dimensions with no prior knowledge of the universality class of the transition. Promising approaches to experimentally access fluctuations are discussed for quantum antiferromagnets and cold gases.

HL 19: Transport: Topological Insulators 2 (jointly with TT, MA)

Time: Monday 15:00–16:30 Location: H 3005

HL 19.1 Mon 15:00 H 3005

Majorana end states in disordered topological superconducting wires — •Alessandro Romito, Piet Brouwer, Mathias Duckheim, and Felix von Oppen — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universit at Berlin, 14195 Berlin, Germany

Zeeman fields can drive semiconductor quantum wires with strong spin-orbit coupling and in proximity to s-wave superconductors into a topological phase. Such topological phases are characterized by the presence of Majorana Fermions which obey non-abelian statistics, and provide a possible platform for a topological quantum computer. So far Majorana Fermions have never been observed in experiments. However, semiconducting wires with strong spin-orbit coupling offer a promising path towards this goal. A key question, both for theory and experiment, is whether the topological phase is robust against the unavoidable presence of disorder.

Here, after brefly introducing the proposals for the realization and control of Majorana Fermions in quantum wires, I will mainly address their robustness against disorder showing that Majorana fermions persist in disordered wires up to a critical disorder strength which, remarkably, depends sensitively and non-monotonously on the Zeeman field applied to the wire. In finite length disordered wires the Majorana states combine into fermionic excitation at finite energy with large sample-to sample fluctuations. I will discuss the probability distribution of such low energy level and the consequences for the speed at which such topological quantum bits can be operated.

HL 19.2 Mon 15:15 H 3005

Competition between d-wave and topological p-wave superconductivity in the doped Kitaev-Heisenberg model — •Timo Hyart[1], Anthony Wright[1], Giniyat Khaliullin[2], and Bernd Rosenow[1] — [1]Institut für Theoretische Physik, Universität Leipzig, D-04103, Leipzig, Germany — [2]Max-Planck-Institut für Festkörperforschung, D-70569 Stuttgart, Germany

The competition between Kitaev and Heisenberg interactions away from half filling is studied for the hole-doped Kitaev-Heisenberg t-J_K-J_H model on a honeycomb lattice. While the isotropic Heisenberg coupling supports a time-reversal violating d-wave singlet state, we find that the Kitaev interaction favors a time-reversal invariant p-wave superconducting phase, which obeys the rotational symmetries of the microscopic model, and is robust for $J_H < J_K/2$. Within the p-wave superconducting phase, a critical chemical potential $\mu_c \approx t$ separates a topologically trivial phase for $|\mu| < \mu_c$ from a topologically non-trivial Z_2 time-reversal invariant spin-triplet phase for $|\mu| > \mu_c$.

HL 19.3 Mon 15:30 H 3005

s + p - wave proximity-induced superconductivity in impure topological insulators — •Grigory Tkachov, Pauli Virtanen, Florian Foohs, Patrik Recher, and Ewelina Hankiewicz — Universität Würzburg, Germany

In contacts with conventional s-wave superconductors (Ss), topological insulators (TIs) are expected to show both s- and p-wave superconducting correlations due to the spin-momentum locking on the surface. We analyze how the impurity scattering, extended defects (e.g. interfaces) and an external magnetic field influence such mixed proximity-induced superconductivity in topological insulators. As an example, we calculate a surface magnetosupercurrent through an S/TI/S Josephson junction.

HL 19.4 Mon 15:45 H 3005

Topologically protected zero-energy surface states of noncentrosymmetric superconductors — •Philip M. R. Brydon[1], Andreas P. Schnyder[2], and Carsten Timm[1] — [1]Technische Universität Dresden, Dresden, Germany — [2]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany

It has recently been pointed out that nodal noncentrosymmetric superconductors are topologically non-trivial, with the nodal rings possessing a non-zero topological charge [1]. In these systems a bulk-boundary correspondence can be developed, which guarantees the existence of a flat band of singly degenerate zero-energy states within the projection of the nodal lines onto the surface Brillouin zone. Using the quasiclassical method [2,3], we present results for the surface bound state spectra, and provide a condition for the existence of the zero-energy states in terms of the sign of the gaps, which is complementary to the topological condition. The zero-energy surface states are shown to leave distinct signatures in the tunneling conductance.

[1] A. P. Schnyder and S. Ryu, Phys. Rev. B 84, 060504(R) (2011).
[2] P. M. R. Brydon, A. P. Schnyder, and C. Timm, Phys. Rev. B 84, 020501(R) (2011).
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HL 19.5 Mon 16:00 H 3005

Quantum phase transitions in the Kane-Mele-Hubbard model — Martin Hohenadler[1], Zi Yang Meng[2], •Thomas C. Lang[3], Stefan Wessel[3], Alejandro Muramatsu[4], and Fakher F. Assaad[1] — [1]Universität Würzburg, Würzburg, Germany — [2]Louisiana State University, Baton Rouge, USA — [3]RWTH Aachen, Aachen, Germany — [4]Universität Stuttgart, Stuttgart, Germany

We study the two-dimensional Kane-Mele-Hubbard model at half filling by means of quantum Monte Carlo simulations. We present a refined phase boundary for the quantum spin liquid. The topological insulator at finite Hubbard interaction strength is adiabatically connected to the groundstate of the Kane-Mele model. In the presence of spin-orbit coupling, magnetic order at large Hubbard U is restricted to the transverse direction. The transition from the topological band insulator to the antiferromagnetic Mott insulator is in the universality class of the three-dimensional XY model. The numerical data suggest

that the spin liquid to topological insulator and spin liquid to Mott insulator transitions are both continuous.

HL 19.6 Mon 16:15 H 3005

Majorana fermions in strongly interacting helical liquids — •Eran Sela, Achim Rosch, and Alexander Altland — Koeln university, Germany

Majorana fermions were proposed to occur at edges and interfaces of gapped one-dimensional systems where phases with different topological character meet due to an interplay of spin-orbit coupling, proximity-induced superconductivity and external magnetic fields. Here we investigate the effect of strong particle interactions and show that a helical liquid offers a mechanism that protects the very existence of Majorana edge states: whereas moderate interactions close the proximity gap that supports the edge states, in helical liquids the gap reopens due to two-particle processes. However, gapless fermionic excitations occur at spatial proximity to the Majorana states at interfaces and may jeopardize their long-term Majorana coherence.

HL 20: Focus Session: Magnetic Semiconductors (jointly with MA)

Time: Monday 16:30–18:15 Location: EW 202

HL 20.1 Mon 16:30 EW 202

Cu-doped GaN: A ferromagnetic semiconductor — •Philipp R. Ganz[1], Christoph Sürgers[2,3], Gerda Fischer[3], and Daniel M. Schaadt[1,2,4] — [1]Karlsruhe Institute of Technology, Center for Functional Nanostructures, 76049 Karlsruhe, Germany — [2]Karlsruhe Institute of Technology, Institut für Angewandte Physik, 76049 Karlsruhe, Germany — [3]Karlsruhe Institute of Technology, Physikalisches Institut, 76049 Karlsruhe, Germany — [4]Institut für Energieforschung und Physikalische Technologien,TU Clausthal, 38640 Goslar, Germany

Nitride based spintronics has caused wide interest device applications due to the long and temperature-independent spin lifetime in InN quantum dots. For spin-injection in these quantum dots a ferromagnetic spin-aligner which yields high spin-polarization at room-temperature is necessary. Nitride based magnetic semiconductors are promising candidates. Because of possible clustering of magnetic dopands, non-magnetic dopands such as copper have raised interest over the last years. Theoretical predictions show the possibility of ferromagnetism and a high spinpolarization for Cu-doped GaN. We carried out a detailed study on the structural and magnetic properties for Cu-doped GaN, grown by plasma assisted molecular beam epitaxy, for various growth conditions. These films exhibit ferromagnetic behavior with a Curie temperature higher than 400 K in a small range of doping levels.

HL 20.2 Mon 16:45 EW 202

Magnetism and bound states of Fe in GaN : a hybrid DFT study — •Paola Alippi[1], Francesco Filippone[1], Giuseppe Mattioli[1], Aldo Amore Bonapasta[1], and Vincenzo Fiorentini[2] — [1]CNR-ISM, Rome, Italy — [2]CNR-IOM and U of Cagliari, Italy

Transition- metal (TM) impurities in GaN hold promise for room-temperature ferromagnetism. They are also under investigation because of suspected effects of electron correlation in the localized impurity d shell as well as in host p valence states. We studied therefore neutral and charged Ga-substitutional Fe impurities in GaN via spin-polarized density-functional-theory calculations using the hybrid GGA+Hartree-Fock HSE functional.

For the neutral state, Fe induces localized states in the lower valence band, and dispersed N-Fe hybrids in the majority upper valence band, and empty minority states resonant with the Ga-like conduction band. The –1 charge state occupies and shift the latter into the gap, resulting in a (0/–1) transition level near the observed value. The +1 state has a hyper-deep (+1/0) donor level associated to a bound hole on ligand N's, i.e. a Fe(III)+$\underline{L}$ state. This is the first theoretical evidence of such a state, supported by some as-yet-inconclusive experiments. A Bader analysis shows that Fe:GaN follows a "charge self-regulation" rule. In the –1 state, the Fe-like gap state is counterbalanced by depleted Fe valence states, and conversely the bound hole is an empty gap state appearing only in the +1 state. The population of resonant plus gap states, however, remains constant, and the charge residing on Fe hardly changes upon charging the impurity+host system.

HL 20.3 Mon 17:00 EW 202

Ferromagnetic Semiconductor-Metal Transition in Heterostructures of Europium Monoxide — •Tobias Stollenwerk and Johann Kroha — Physikalisches Institut der Universität Bonn, Deutschland

Experiments on thin films of electron doped europium monoxide show a simultaneous ferromagnetic semiconductor-metal transition which goes along with a huge drop in resistivity over several orders of magnitude. Therefore, this material is a very promising candidate for spintronics applications. We have developed a theory which correctly predicts the simultaneous phase transition in thin films of electron doped EuO and the increase of the Curie temperature T_C with doping concentration. The origin of the increased T_C lies in the enhanced RKKY interaction between the localized 4f moments of the Eu atoms. Therefore, the phase transition is controlled by the population of the conduction band. We investigate the influence of film thickness and interface effects on the population of the conduction band and on the magnetic and electronic properties of the EuO film.

HL 20.4 Mon 17:15 EW 202

Effects of disorder and hole tunneling transport on the ferromagnetism in GaMnAs quantum wells — •Christian Ertler and Walter Pötz — Institute of Physics, Karl-Franzens University Graz, Universitätsplatz 5, 8010 Graz, Austria

Recent experiments on heterostructures comprising GaMnAs quantum wells [1] evoke strong debates about the nearly absence of ferromagnetic order observed in these structures. Based on a tight-binding approach and the non-equilibrium Green's function formalism we investigate self-consistently the interplay between ferromagnetic order, structural defects, and hole tunnel current [2]. We find that disorder has a strong influence on the IV characteristic in efficiently washing out negative differential conductance as found in experiment [1]. The hole density in the well is established by tunneling from the p-doped GaAs leads, resulting in small exchange splittings in the well on the order of 10 meV for reasonable lead doping. We predict that for cleaner samples the ferromagnetic order in the well tends to be destroyed under resonance condition. This effect leads to a characteristic signature in the spin-polarization of the tunnel current available to experimental detection.

[1] S. Ohya, K. Takata and M. Tanaka, "Nearly non-magnetic valence band of the ferromagnetic semiconductor GaMnAs", Nature Physics, 7, 342 (2011).

[2] C. Ertler and W. Pötz, "Electrical control of ferromagnetism and bias anomaly in Mn-doped semiconductor heterostructures", Phys. Rev. B 84, 165309 (2011).

HL 20.5 Mon 17:30 EW 202

Influence of the interface structure on the magnetic proximity polarization in Fe/(Ga,Mn)As bilayers — •S. Polesya[1], S. Mankovsky[1], J. Minar[1], H. Ebert[1], M. Sperl[2], and C. Back[2] — [1]Universität München, Department Chemie, Butenandtstr. 5-13, D-81377 München, Germany — [2]Institut für Experimentelle Physik, Univ. Regensburg, Germany

We present the results of detailed investigations on the influence of various conditions at the interface on the magnetic proximity polarization effect for the Fe/($Ga_{0.95}Mn_{0.05}$)As system. The ab initio electronic structure calculations were performed using the TB-KKR Green's function method. These allow the calculation of the exchange coupling parameters between magnetic atoms in the system. The finite temperature magnetic properties were determined then by means of Monte Carlo simulations. The exchange coupling between Fe and Mn atoms in the vicinity of the Fe/(Ga,Mn)As interface is found to be strongly dependent on the Mn atom position in the lattice. In particular, the substitutional Mn is coupled antiferromagnetically to Fe for Ga- as well as As-terminated interfaces while the Mn at the interstitial positions is coupled ferromagnetically to Fe. As a result, the total magnetization of the (Ga,Mn)As film can be aligned ferromagnetically with Fe. This effect is larger for As-termination. In addition, presence of the Mn interstitials influences the interaction between substitutional Mn. It is shown that a complicated competition of FM and

AFM interactions between Mn atoms results in a disordered magnetic structure close to the interface with Fe.

HL 20.6 Mon 17:45 EW 202

Anomalous Hall effect in Mn doped, p-type InAs quantum wells — •Dieter Vogel, Christina Wensauer, Ursula Wurstbauer, Dieter Schuh, Werner Wegscheider, and Dieter Weiss — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

We measured the Hall resistivity in InAs:Mn quantum wells (QWs), containing a two-dimensional hole gas, as a function of temperature, carrier density and manganese concentration. Earlier experiments on these Mn doped InAs QWs indicated the important role of p-d exchange coupling between holes and Mn magnetic moments, giving rise to hysteretic magnetoresistance and thermal bistability of the longitudinal resistance [1]. In the present work we find that this paramagnetic two-dimensional system features a considerable anomalous Hall effect (AHE) whose size increases with decreasing temperature and increasing Mn concentration. Surprisingly, the sign of the anomalous Hall coefficient is negative. A first analysis of the data shows that the skew scattering contribution is rapidly suppressed as temperature increases. Furthermore, the empirical scaling between Hall and longitudinal conductivity in the bad-metal-hopping regime [2], $\sigma_{xy} \sim \sigma_{xx}^{\gamma}$, with $\gamma = 1.6$, seems to be valid also in our system. Finally, we discuss the possibility to separate the intrinsic and the extrinsic scattering contribution following recent work by [3].

[1] U. Wurstbauer et al., Nature Physics **6**, 955 (2010)
[2] N. Nagaosa et al., Rev. Mod Phys. **82**, 1539 (2010)
[3] A. Shitade and N. Nagaosa, ArXiv ID 1109.5463 (2011).

HL 20.7 Mon 18:00 EW 202

Magnetotransport in (Ga,Mn)As/GaAs core-shell nanowires — •Christian Butschkow[1], Elisabeth Reiger[1], Stefan Geissler[1], Alexander Eckrot[1], Andreas Rudolph[1], Marcello Soda[1], Dieter Schuh[1], Georg Woltersdorf[1], Werner Wegscheider[2], and Dieter Weiss[1] — [1]Universität Regensburg, Germany — [2]ETH Zürich, Switzerland

We investigate angle dependent the transport properties of individual ferromagnetic (Ga,Mn)As/GaAs core-shell nanowires in a magnetic field at cryogenic temperatures. The nanowires are grown self-assembled in a bottom up process using the vapor-liquid-solid (VLS) mechanism and molecular beam epitaxy (MBE). We observe a very pronounced response of the magnetoresistance on an applied magnetic field, which we attribute to the negative magnetoresistance effect (NMR) in combination with an effective magnetic field. This effective magnetic field, which is typically used to describe ferromagnetic resonance phenomena, is composed of the anisotropy field H_a and the external magnetic field. The shape of the resulting MR-traces can be used to derive the magnetic properties of single nanowires. This way we determine a Curie-Temperature of $T_C \approx 20$K and a strong uniaxial magnetic anisotropy with a magnetic easy axis pointing along the nanowire axis. We assume that this uniaxial magnetic anisotropy is related to strain relaxation similar to the observations on lithographically defined (Ga,Mn)As stripes. However we determine a uniaxial anisotropy constant K_U which is up to 5 times larger than K_U of the etched (Ga,Mn)As stripes.

HL 21: Photonic Crystals I

Time: Monday 17:00–18:15 Location: EW 203

HL 21.1 Mon 17:00 EW 203

Spectral compression of light by ultrafast tilting of the dispersion of a photonic crystal — •Tobias Kampfrath[1,2], Daryl Beggs[2], Thomas Krauss[3], and L. Kuipers[2] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]FOM Institute AMOLF, Amsterdam, The Netherlands — [3]University of St. Andrews, Scotland, UK

Photonic crystals are well known for their ability to control the dispersion relation $\omega(k)$ of light. Here, we demonstrate that $\omega(k)$ can even be tuned on ultrafast timescales by means of a femtosecond pump pulse exciting the silicon parts of a photonic-crystal waveguide. We shape the cross section of the pump beam with a nanometric shadow mask such that different waveguide eigenmodes acquire different spatial overlap with the perturbing pump. In this way, a local flattening of the dispersion curve by as much as 11 % is obtained. This value is two orders of magnitude higher than the relative pump-induced variations $\Delta n/n$ of the silicon refractive index.

We show that such partial mode perturbation can be used to adiabatically compress the spectrum of a light pulse traveling through the waveguide.

HL 21.2 Mon 17:15 EW 203

High frequency tuning of photonic crystal nanocavity modes using surface acoustic waves — •Daniel A. Fuhrmann[1,2,3], Susanna M. Thon[4], Hyochul Kim[3], Dirk Bouwmeester[4,5], Pierre M. Petroff[3], Achim Wixforth[1], and Hubert J. Krenner[1,2] — [1]Lehrstuhl für Experimentalphysik I, Universität Augsburg, Germany — [2]Emmy Noether Group, Universität Augsburg, Germany — [3]Materials Department, University of California, Santa Barbara, USA — [4]Physics Department, University of California, Santa Barbara, USA — [5]Huygens Laboratory, Leiden University, The Netherlands

We propose and demonstrate high frequency dynamic modulation of localized optical modes of photonic crystal membrane (PCM) defect nanocavities employing surface acoustic waves (SAWs). The mechanical deformation induced by SAW distorts the PCM periodicity and gives rise to pronounced modulation of the nanocavity mode. In time-integrated and SAW-phase resolved photoluminescence (PL) experiments we demonstrate tuning speeds > 1.7 GHz using this approach. In the experimental data we observe a pronounced sinusoidal shift of the cavity resonance over one cycle of the SAW. Shifts of more than 5 times the cavity linewidth are achieved. In addition, a high quality factor is preserved. These experimental observations are found in excellent agreement with FDTD simulations for the same cavity design and realistic SAW amplitudes. Our FDTD calculations show no resolvable shift of the field distribution of the cavity mode making our technique attractive for both real-time control of solid state cQED experiments and coherent mechanical excitation of cavity optomechanical systems.

HL 21.3 Mon 17:30 EW 203

Fast structural analysis of photonic crystals — •Rebecca Wagner, Lars Heerklotz, and Frank Cichos — Molecular Nanophotonics, University of Leipzig, Germany

Photonic crystals (PCs) are materials where the dielectric constant varies periodically on the length scale of visible wavelengths. This results in the formation of a photonic band structure, which gives one the possibility to modify the propagation of light.

Inexpensive and simple methods for the production of 3D PCs are based on self assembly of colloidal beads, leading to close packed structures. However, these methods usually create polycrystalline structures, with differently stacked domains and other defects.

These stacking faults are hidden in the 3D structure and difficult to characterize experimentally. However, the PC's optical properties depend on its structure. Therefore a method to locally characterize the 3D order of the PC is desirable.

Here we present a method for fast microscopic characterization of PCs based on back focal plane (BFP) imaging. After local excitation by a focused laser the luminescence from inside the PC is collected by a high NA objective. The BFP of the objective contains information about the angel dependence of the emission. When imaging it onto a CCD for a selected wavelength, stop bands are visible for certain directions, showing the local symmetry of the PC. Thus, a fast determination of the orientation of domains is possible. The change between different kinds of stacking (twin structure) can be observed.

HL 21.4 Mon 17:45 EW 203

Influence of cracks on photonic stop bands — •Lars Heerklotz, Rebecca Wagner, and Frank Cichos — Molecular Nanophotonics, University of Leipzig, Germany

Periodical spatial variations of a materials properties lead, via the Bloch condition, to the formation of bands, causing partial and total band gaps. That holds for electrons in a semiconductor, where the core potential is periodic, as well as for photons in a photonic crystal (PC), where the dielectric constant is periodic. In the photonic case

this means, that light cannot propagate in the stop band directions and thus the fractional density of states (fDOS) vanishes. To observe these features we produced face-centered cubic (fcc) PCs by vertical deposition. We used our home-built confocal setup to investigate the behavior of light emitted from the polystyrene inside the PC. Imaging the light of the objectives back focal plane onto a slit and afterwards onto a spectrometer leads to angle dependent spectra. The novel advantage is the acquisition of 100 spectra for up to 73.5° of emission in one measurement. This method, angle resolved fluorescence spectroscopy, is applied to measure the fDOS locally (lateral resolution of 300 nm) in order to observe the three folded structure of the first Brillouin-zone of the fcc-lattice. Due to non-confocal detection there is no resolution along the optical axis. We use this method to analyze the influences a crack has on the fDOS.

HL 21.5 Mon 18:00 EW 203

Photonic crystal slab based on nitride semiconductors — •Dominik Heinz[1,2], Robert A. R. Leute[1], Klaus Thonke[2], Frank Lipski[1], Tobias Meisch[1], Thomas Wunderer[3], Ingo Tischer[2], Matthias Hocker[2], and Ferdinand Scholz[1] — [1]Institute of Optoelectronics, Ulm University, Albert-Einstein-Allee 45, 89081 Ulm, Germany — [2]Institute of Quantum Matter / semiconductor physics group, Ulm University, Albert-Einstein-Allee 45, 89081 Ulm, Germany — [3]now at Palo Alto Research Center, Inc., 3333 Coyote Hill Road, Palo Alto, California 94304, USA

Photonic crystals are periodically modulated dielectric structures with a periodicity comparable to the considered wavelength regime. For realization of photonic crystals in the visible spectrum of light, sub-μm patterning is necessary. In this work, UV laser interference lithography has been used to realize photoresist structures with a periodicity of approximately 240 nm on areas of several square centimeters. These patterns were subsequently transfered to a mechanically stable titanium layer deposited on a gallium nitride (GaN) epitaxial layer using a lift-off technique. Finally, GaN-stripes with triangular cross section and GaInN quantum wells integrated on their side facets were grown by selective area metalorganic vapour phase epitaxy. For better selectivity, an in-situ nitridation step in hot ammonia atmosphere was performed before epitaxy. The resulting structures were characterized by angle resolved photoluminescence (ARPL) and cathodoluminescence. Directional modal extraction of guided light was observed in ARPL, and the respective photonic dispersion relation was determined.

HL 22: Graphene: Structure and Theory II

Time: Monday 17:15–19:00 Location: EW 201

HL 22.1 Mon 17:15 EW 201

DFT+CI calculations of quantum dots in graphene nanoribbons — •Tobias Burnus[1], Gustav Bihlmayer[1], Daniel Wortmann[1], Ersoy Sasioglu[1], Stefan Blügel[1], and Klaus Michael Indlekofer[2] — [1]Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Hochschule RheinMain, Unter den Eichen 5, 65195 Wiesbaden, Germany

Graphene nanoribbons (GNR) hold great future promise for field-effect transistors and quantum-dot devices. With gate electrodes an in-plane electric field can be generated, which localizes quantum-dot states in the bandgap of armchair GNR. Density-functional theory (DFT) calculations have been used to calculate GNR under an in-plane gate electric field, taking correctly the edge termination of the ribbon into account. The results obtained via DFT have been combined with the screened Coulomb interaction calculated within the random-phase approximation to setup a configuration interaction (CI) calculation for the quantum dot, which properly describes the multiplet states of the few electrons in the quantum dot. The results of this DFT+CI calculation can be used for a description of the time-dependent spin decoherence.

The work is supported by the DFG Research Unit 912 "Coherence and Relaxation Properties of Electron Spins".

HL 22.2 Mon 17:30 EW 201

Universal infrared absorbance of 2D honeycomb crystals — •Lars Matthes[1,2], Friedhelm Bechstedt[1], Olivia Pulci[2], and Paola Gori[3] — [1]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Dipartimento di Fisica, Università di Roma "Tor Vergata", via della Ricerca Scientifica 1, 00133 Rome, Italy — [3]CNR-ISM, Via Fosso del Cavaliere 100, 00133 Rome, Italy

Recently it has been demonstrated experimentally that the optical transparency of graphene is only determined by the Sommerfeld finestructure constant α. [1,2] This result is in agreement with the theory of non-interacting isotropic Dirac fermions with pseudospin and using the vector-potential gauge for the electromagnetic field. [1,3]

Using the complex dielectric function for optical interband transitions, we show the universal result that the low-frequency absorbance obtained for graphene also holds for the 2D group IV crystals silicene and germene, although they are not atomically flat. The result is derived by means of ab-initio electronic-structure calculations for two-dimensional crystals with honeycomb geometry without assuming chiral massless Dirac fermions. It does not depend on the group-IV atom, the sheet buckling, the orbital hybridization, and the gauge used to calculate the optical oscillator strength.

[1] R. R. Nair et al., Science 320, 1308 (2008)
[2] F. Maket al., Phys. Rev. Lett. 101, 196405 (2008)
[3] L. Yang et al., Phys. Rev. Lett. 103, 186802 (2009)

HL 22.3 Mon 17:45 EW 201

Electronic Structure of Graphene Twist Flakes — •Karla Türschmann, Wolfgang Landgraf, Sam Shallcross, and Oleg Pankratov — Theoretische Festkörperphysik, Universität Erlangen, Staudtstr. 7B2, 91058 Erlangen

The chemical exfoliation of graphene, that is the reduction of a highly ordered graphite crystal to single and multilayer graphene flakes via a wet chemical route, represents one of the most promising techniques for the mass production of high quality graphene. The bilayer flakes most probably consist of mutually rotated graphene layers, and in this work we describe the electronic properties of such systems. We use the tight-binding method in conjunction with Lanczos diagonalisation allowing us to access the required very large system sizes. For large twist angles we find an electronic decoupling of the flake layers, whereas for small angles we find a localisation of low energy quantum states associated with the moire pattern of AA and AB stacked regions of the twist flake.

HL 22.4 Mon 18:00 EW 201

The Self-similar Limit of the Graphene Twist Bilayer: Zero Mode and Wavefunction Localization — •Sam Shallcross and Oleg Pankratov — Theoretische Festkörperphysik, Universität Erlangen, Staudtstr. 7B2, 91058 Erlangen

The graphene bilayer consisting of mutually rotated layers shows a rich physics, including both a large angle electronic decoupling of the constituent layers, and a small angle regime characterised by an emergent length scale, the moiré length, and dramatic changes in the density of states near the Dirac point [1]. In this work we present tight-binding results for a complete range of twist angles (θ), demonstrating the existance of a small angle limit in which the system becomes *self-similar* with θ, i.e., reduction of θ leads to no changes in electronic properties when scaled by system size N. This regime is characterised by a zero mode consisting of states strongly localised on the AA patches of the lattice. In addition we present a low energy gauge theory of this self-similar regime, and demonstrate that it yields good agreement with the tight-binding results.

[1] S. Shallcross *et al.* Phys. Rev. B **81**, 165105 (2010)

HL 22.5 Mon 18:15 EW 201

Electron Scattering by Buffer Layer Acoustic Phonons in Graphene on SiC Si-face — •Nicolas Ray, Sam Shallcross, and Oleg Pankratov — Theoretische Festkörperphysik, Universität Erlangen, Staudtstr. 7B2, 91058 Erlangen

Graphene grown epitaxially on SiC presents one of the most promising routes towards the technological implementation of graphene, as well as being an interesting physical system in its own right. Key features of this system are a doping which places the Fermi level $\approx$ 450 meV above the Dirac point, and a much reduced electron mobility ($\approx$ 3000

cm^2/V.s at room temperature). In this work we describe a mechanism in which accoustic surface phonons modify the graphene-substrate separation resulting in a deformation potential and hence electron scattering. With this model we then calculate transport properties within the Boltzmann formalism, finding agreement with recent experimental work [1] demonstrating a remarkable *decrease* in the resistivity (ρ) near the Dirac with increasing temperature (T), a linear increase of ρ with T away from the Dirac point, and a good description of the graphene electron mobility.
[1] S. Tanabe *et al.* Phys. Rev. B **84**, 115458 (2011)

HL 22.6 Mon 18:30 EW 201

Density Oscillations in a Graphene Bilayer — •Nicolas Klier, Sam Shallcross, and Oleg Pankratov — Theoretische Festkörperphysik, Universität Erlangen, Staudtstr. 7B2, 91058 Erlangen

Density oscillations due to an impurity in graphene (Friedel oscillations) show a remarkable $1/r$ decay due to intervalley interference ($1/r^2$ is the expected envelope form for a two dimensional e-gas) [1]. In this work we describe Friedel oscillations in Bernal, AA, and twist graphene bilayers. We consider an ideal δ-function impurity in conjunction with a low energy Green's function of the bilayer system, and solve the Dyson equation exactly. We find that in addition to the Friedel oscilations in the local density of states, there is an additional long period modulation resulting from the interlayer coupling. Furthermore, we find the magnitude of such density oscillations are substantially increased near the Dirac point in Bernal stacked graphene as compared to single layer graphene.
[1] C. Bena, Phys. Rev. Lett., 100, 076601 (2008)

HL 22.7 Mon 18:45 EW 201

Graphene on Different SiC Polytypes — Oleg Pankratov, •Stephan Hensel, and Paul Götzfried — Theoretische Festkörperphysik, Universität Erlangen, Staudtstr. 7B2, 91058 Erlangen

Epitaxial graphene grows on different SiC polytypes, yet the influence of the substrate polytype on graphene Dirac spectrum has not been systematically studied. We address this question with ab initio calculations, comparing the electronic structure of a graphene epilayer on polytypes with different hexagonality, various terminations and buffer/epilayer stackings within the $(\sqrt{3}\times\sqrt{3})$R30 interface model. We find the Dirac point alignment relative to the valence band substantially varies depending on polytype, but the Fermi level pinning and hence the doping of the epilayer stay the same. For the most relevant case of a buffer/epilayer Bernal stacking (Si-face) the Dirac cone splits by $\varepsilon_g < 40\,\mathrm{meV}$, whereas it remains intact for the AA-stack. This can be understood within the analytical symmetry-based model, which allows to establish a direct connection between ε_g and the buffer/epilayer interaction potential.

HL 23: Topological Insulators I (jointly with MA, DS, O, TT)

Time: Monday 17:45–19:15 Location: H 1012

HL 23.1 Mon 17:45 H 1012

Atom-specific spin mapping and buried topological states in a homological series of topological insulators — Sergey V. Eremeev[1,2], Gabriel Landolt[3,4], Tatiana V. Menshchikova[1,2], Bartosz Slomski[3,4], Yury M. Koroteev[1,2], Ziya S. Aliev[5], Mahammad B. Babanly[5], •Jürgen Henk[6], Arthur Ernst[6], Luc Patthey[4], Andreas Eich[7], Alexander A. Khajetoorians[7], Julian Hagemeister[7], Oswald Pietzsch[7], Jens Wiebe[7], Roland Wiesendanger[7], Pedro M. Echenique[2], Stepan S. Tsirkin[1,2], Imamaddin R. Amiraslanov[8], J. Hugo Dil[3,4], and Evgueni V. Chulkov[2] — [1]Tomsk State University, Russian Federation — [2]Donostia International Physics Center, San Sebastián, Spain — [3]Universität Zürich, Switzerland — [4]Paul-Scherrer-Institut, Villigen, Switzerland — [5]Baku State University, Azerbaijan — [6]Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany — [7]Universität Hamburg, Germany — [8]Azerbaijan National Academy of Science, Baku, Azerbaijan

By *ab-initio* calculations and spin-resolved photoemission experiments we demonstrate that a homological series of topological insulators—the binary chalcogenides Bi_2Te_3, Bi_2Se_3, and Sb_2Te_3 with the addition of a group IV element—can be tuned in such a way that ideal and isolated Dirac cones are located within the topological transport regime [1]. These compounds exhibit exotic buried topological states strongly protected against surface perturbations and with complex spin textures.
[1] S. V. Eremeev *et al*, Nature Comm. (2011), in press.

HL 23.2 Mon 18:00 H 1012

In-plane anisotropy of Fe atoms on Bi_2Se_3(111) — J. Honolka[1], A. A. Khajetoorians[2], V. Sessi[3], T. O. Wehling[4], S. Stepanow[1], J. Mi[5], B. B. Iversen[5], •T. Schlenk[2], J. Wiebe[2], N. Brookes[3], A. I. Lichtenstein[4], P. Hofmann[5], K. Kern[1], and R. Wiesendanger[2] — [1]Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, 70569 Stuttgart, Germany — [2]Institute for Applied Physics, Universität Hamburg, D-20355 Hamburg, Germany — [3]ESRF, Grenoble, France — [4]1. Institut für Theoretische Physik I, Universität Hamburg, D-20355 Hamburg, Germany — [5]Interdisciplinary Nanoscience Center, Aarhus University, Denmark

Topological insulators exhibit a linearly dispersing gapless topological surface state where both the spin and momentum degrees of freedom are locked. The topological nature of this state results in interesting effects such as suppression of back-scattering. Recently, the robustness of these surface states against magnetic order has been investigated intensively. Here, we explore the magnetic properties of single Fe adatoms on the Bi_2Se_3 surface, in the coverage range $< 1\%$, with combined non-local x-ray magnetic circular dichroism techniques and local low temperature scanning tunneling spectroscopy. We show that the Fe adatoms relax into the surface and exhibit a magnetic easy axis within the surface-plane, contrary to recent reports. Futhermore, we show how *ab-initio* approaches can give a reorientation of the easy axis from out-of-plane to in-plane when considering the interplay of Coulomb interactions, spin orbit coupling, and dynamic hybridization effects.

HL 23.3 Mon 18:15 H 1012

Ab initio study of Rashba splitting of 2DEG at the surfaces of topological insulators — Sergey V. Eremeev[1,2], •Maia G. Vergniory[3,4], Tatiana V. Menshchikova[2], and Evgueni V. Chulkov[4,5,6] — [1]Institue of Strength and Materials Science, Tomsk, Russia — [2]Tomsk State University, Tomsk, Russia — [3]Max Planck Institute of Microstructure Physics, Halle, Germany — [4]Donostia International Physics Center, Donostia, Spain — [5]Departamento de Fisica de Materiales UPV/EHU, Donostia, Spain — [6]Centro de Fisica de Materiales CFM-MPC and Centro Mixto CSIC-UPV/EHU, Donostia, Spain

The surface of three dimensional topological insulators (TI) holds a metallic surface state (SS) with Dirac dispersion. Recently it has been demonstrated by using Angle Resolved Photoemission Spectroscopy (ARPES) that besides de Dirac cone 2D electron gas (2DEG) arise at the surface of Bi2Se3 and Bi2Te3 after a few hours of exposition in vacuum or upon deposition of atoms. In this work by means of DFT ab initio calculations we present a new interpretation for the driving mechanism of the simultaneous formation and evolution of the parabolic and M-shaped 2D electron gas (2DEG) bands at the surface of Topological Insulators. As it has been probed in previous publications [7,8] it might be due to an expansion of the van der Waals spacing produced by impurities intercalation. We will show the effect of these expansions on the spatial relocalization of the Dirac cone and we will compare our results with some experimental data for different binary and ternary compounds.

HL 23.4 Mon 18:30 H 1012

Reactive chemical doping of the Bi_2Se_3 topological insulator — •Hadj Mohamed Benia, Chengtian Lin, Klaus Kern, and Christian R. Ast — Max-Planck-Institut für Festkörperforschung, 70569 Stuttgart, Germany

We studied the evolution of the surface electronic structure of the topological insulator Bi_2Se_3 as a function of water vapor exposure using angle resolved photoemission spectroscopy. We find that a surface reaction with water induces a band bending, which shifts the Dirac point deep into the occupied states and creates quantum well states with a

strong Rashba-type splitting. The surface is thus not chemically inert, but the topological state remains protected. The band bending is traced back to Se-abstraction leaving positively charged vacancies at the surface. Due to the presence of water vapor, a similar effect takes place when Bi_2Se_3 crystals are left in vacuum or cleaved in air, which likely explains the aging effect observed in the Bi_2Se_3 band structure.

HL 23.5 Mon 18:45 H 1012

Unoccupied electronic states of topological insulators — •Christian Langenkämper[1], Anna Zumbülte[1], Sune N. P. Wissing[1], Anke B. Schmidt[1], Markus Donath[1], Peter Krüger[2], Richard C. Hatch[3], Philip Hofmann[3], Kenta Kuroda[4], Koji Miyamoto[5], and Akio Kimura[4] — [1]Physikalisches Institut, Westfälische Wilhelms-Universität Münster, Germany — [2]Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Germany — [3]Department of Physics and Astronomy, Aarhus University, Denmark — [4]Graduate School of Science, Hiroshima University, Japan — [5]Hiroshima Synchrotron Radiation Center, Hiroshima University, Japan

We report on the first investigation of the unoccupied electronic states of materials which are currently discussed in the context of topological insulators: $Bi_2Se_3(111)$, Sb(111) and $TlBiSe_2(111)$. First, different preparation methods (sputter-annealing, cleaving with scotch-tape) will be compared with regard to the surface quality of the samples, i.e. crystallographic order and chemical composition. Second, spin-resolved inverse-photoemission data will be presented. The experimental requirements concerning energy and momentum resolution will be addressed. Our first results show predominantly bulk-derived features with only small spin asymmetries. The experimental data will be discussed along with theoretical calculations for the unoccupied states.

HL 23.6 Mon 19:00 H 1012

Quantization of conduction and valence band states through adsorption of nonmagnetic impurities on Bi_2Se_3 — •Marco Bianchi[1], Richard Hatch[1], Zakaria Abd El-Fattah[3], Jianli Mi[2], Bo Brummerstedt Iversen[2], and Philip Hofmann[1] — [1]Department of Physics and Astronomy, Interdisciplinary Nanoscience Center, Aarhus University, 8000 Aarhus C, Denmark — [2]Departamento de Física de Materiales CSIC-UPV/EHU-Materials Physics Center, E-20018 Donostia-San Sebastián, Spain — [3]Center for Materials Crystallography, Department of Chemistry, Interdisciplinary Nanoscience Center, Aarhus University, 8000 Aarhus C, Denmark

Angle-resolved photoemission (ARPES) can give detailed information on the surface electronic structure of materials. Here we present an ARPES study of the adsorption-induced changes in the electronic structure of the topological insulator $Bi_2Se_3(111)$. Exposure to CO results in strong shifts of the features observed by ARPES. The spectral changes can be explained by a simultaneous confinement of the bulk conduction band and valence band states. This is only possible because of the unusual bulk electronic structure of Bi_2Se_3. The valence band quantization leads to spectral features which resemble those of a band gap opening at the Dirac point. Similar effects are observed when Rb is adsorbed on the surface. In this case up to seven quantum well states are found in the valence band, both above and below the Dirac point.

HL 24: Poster Session: Ge/Si/SiC / III - V Semiconductors

Time: Monday 16:00–19:00 Location: Poster D

HL 24.1 Mon 16:00 Poster D

Spin Noise Spectroscopy — •Fabian Berski, Carsten Schulte, Katharina-Sophie Isleif, Jens Hübner, and Michael Oestreich — Institute for Solid State Physics, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany

We study the spin dynamics of localized non interacting donor electrons in Gallium Arsenide at low temperatures by means of all optical spin noise spectroscopy (SNS) [1]. SNS avoids the generation of free carries by tuning the cw–probe laser light to the transparent regime of the semiconductor and is therefore a promising tool to reveal hyperfine interaction dominated dephasing processes, as they are expected in low doped semiconductor systems in thermal equilibrium. The experiment is carried out on a specially prepared, MBE–grown GaAs sample. The detected signal contains the longitudinal and transversal dephasing with respect to the effective stochastic magnetic field caused by nuclear spins. The fast transversal timescale is 4.5±3 ns, which is in good agreement with previous reported measurement [1]. The second dephasing time is about 127ns, which states a lower limit on the longitudinal spin dephasing time.

[1] G. M. Müller, M. Oestreich, M. Römer, and J. Hübner, Semiconductor spin noise spectroscopy: Fundamentals, accomplishments, and challenges, Physica E 43, 569 (2010).

HL 24.2 Mon 16:00 Poster D

Detection of high frequency spin dynamics via ultrafast spin noise spectroscopy — •Jan Gerrit Lonnemann, Fabian Berski, Hendrik Kuhn, Petrissa Zell, Georg Müller, Jens Hübner, and Michael Oestreich — Institute for Solid State Physics, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany

Semiconductor spin noise spectroscopy has proven to be a powerful experimental technique to explore spin dynamics in semiconductors [1], however, the bandwidth of the photoreceivers has been a limiting factor if trying to detect high frequency spin noise. In pioniering Experiments Müller et al. showed that this obstacle can be overcome by utilising pulsed lasers [2]. However this implementation is in general restricted to spin dephasing rates that are smaller than the laser repetition rate. We present the experimental relalization of a complementary technique [3] that is sensitive to spin dephasing rates that exceed the repetition rate of the laser system. Due to this spin lifetimes as short as 1 ns and lamor precession frequency above 40 GHz have been observed.

[1] Georg M. Müller, Michael Oestreich, Michael Römer, and Jens Hübner; Semiconductor spin noise spectroscopy: Fundamentals, accomplishments, and challenges; *Physica E*, 43; 569 - 587 (2010).

[2] Georg M. Müller, Michael Römer, Jens Hübner, and Michael Oestreich; Gigahertz spin noise spectroscopy in n -doped bulk GaAs; *Phys. Rev. B*, 81; 121202 (2010).

[3] Sebastian Starosielec and Daniel Hägele; Ultrafast spin noise spectroscopy; *Applied Physics Letters*, 93; 051116 (2008).

HL 24.3 Mon 16:00 Poster D

Hole spin dynamics in 2D GaAs/AlGaAs systems at low temperatures — •Michael Kugler[1], Kamil Korzekwa[2], Pawel Machnikowski[2], Christian Gradl[1], Stephan Furthmeier[1], Michael Griesbeck[1], Marika Hirmer[1], Dieter Schuh[1], Werner Wegscheider[3], Tillmann Kuhn[4], Christian Schüller[1] und Tobias Korn[1] — [1]Universität Regensburg, D-93040 Regensburg, Germany — [2]Wroclaw University of Technology, 50-370 Wroclaw, Poland — [3]ETH Zurich, 8093 Zurich, Switzerland — [4]Westfälische Wilhelms-Universität, D-48149 Münster, Germany

We performed time-resolved Kerr rotation measurements (TRKR) on p-doped GaAs/AlGaAs single wells to resolve the spin dynamics of hole ensembles, confined in so-called natural quantum dots. For long spin lifetimes, we employ the resonant spin amplification (RSA) technique. Hole spins in such systems may be a viable alternative to electron spins for solid-state quantum-bit systems. A key requirement for this is the generation of a resident hole spin polarization (RHSP).

Here, we report on a novel mechanism that leads to a RHSP after optical excitation. It is driven by quick relaxation of the hole spins in the first few ps after excitation. The recombination of electrons and holes with matching spin polarization leads then to a RHSP pointing in the opposite direction than the optically generated spins. It is greatly enhanced by increased temperature, excitation density and excess carrier energy provided by detuning the laser from resonant excitation. The interconnected e/h spin dynamics leading to this behavior are well reproduced theoretically for TRKR as well as for RSA setups.

HL 24.4 Mon 16:00 Poster D

Site-controlled In droplets on GaAs substrates by in situ focused ion beam implantation and droplet epitaxy — •Yu-Ying Hu, Dirk Reuter, and Andreas D. Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

We use a focused ion beam (FIB) to modify (100) GaAs surfaces so that subsequent molecular beam epitaxy (MBE) overgrowth forms In droplets at pre-selected sites. The droplets are then crystallized into InAs by supplying As. During the process of crystallization, In droplets can be transformed into InAs quantum dots or quantum rings by tuning substrate temperature and As flux. In this study, site-controlled single and paired In droplets have been fabricated with the sizes from 80 nm to 150 nm, depending on the focus and the ion fluence. The In amount is also an important parameter for the site-selected droplet formation. The distance between the paired droplets is so far closed to 150 nm by utilizing the ability of FIB patterning.

HL 24.5 Mon 16:00 Poster D

Influence of dilute amounts of Nitrogen in GaAs - A comparison of simulated and experimental STEM HAADF-Z-Contrast measurements — •Nikolai Knaub[1], Andreas Beyer[1], Vivien Vossebürger[1], Rafael Fritz[1], Kakhaber Jandieri[1], Markus Heidelmann[2], and Kerstin Volz[1] — [1]Faculty of Physics and Material Science Centre, Philipps Universität Marburg, D-35032 Marburg — [2]IFF and ER-C, Research Centre Jülich, D-52425 Jülich

The integration of small concentrations of nitrogen into III-V semiconductors such as GaAs and GaP has a big influence on their band gaps and electronic properties. Therefore dilute nitrides are very interesting for electronic and optoelectronic applications. A high crystal quality is necessary to ensure a high efficiency of these devices.

We used a high-angle annular dark field (HAADF) detector in a probe-corrected scanning transmission electron microscope (STEM) to investigate the influence of nitrogen on the structure of these materials. The small covalent radius of nitrogen compared with gallium or arsenic induces static atomic displacements (SADs), whose influence on the crystal-structure also can be measured by quantitative evaluation of HAADF images. An absorptive potential approximation and crystal input structures with and without SADs have been used for the simulation.

It will be shown, that for the low sample thicknesses used for high-resolution Z-contrast imaging, the absorptive potential approximation is valid and that simulation and experiment are in a good agreement, when we take SADs into account.

HL 24.6 Mon 16:00 Poster D

Evolution & optical characteristics of self assembled III-nitride nanowires formed by reactive ion etching — •Anna Haab[1,2], Martin Mikulics[1,2], Toma Stoica[1,2], Jürgen Moers[1,2], Eli Sutter[3], Beata Kardynal[1,2], Sally Riess[1,2], Andreas Winden[1,2], Hilde Hardtdegen[1,2], and Detlev Grützmacher[1,2] — [1]Peter Grünberg Institute-9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]Center for Functional Nanomaterials, Brookhaven National Laboratory, Upton, NY 11973, USA

In the past group III-nitrides have received increasing interest for photovoltaic applications (PV) due to their large band gap span in the visible range from 0.7 eV to 3.4 eV. An enhancement of photovoltaic cell performance could be achieved by using nanostructured material which has the possibility to absorb incoming photons more effectively. In this work we studied a simple method for nanostructure fabrication: reactive ion etching (RIE) without any lithographic procedure. The RIE process was optimized to achieve a dense array of nanowires with high aspect ratios. Metal-organic vapor phase epitaxy (MOVPE) was employed to deposit group III-N layers on c-plane sapphire. Subsequent maskless RIE yields a self assembled array of nanowires. Finally the structural and optical characteristics of the nanostructures were investigated. They exhibit intense bandgap emission in accordance with transmission electron microscopy investigations, which indicate that the nanostructures are without dislocations. RIE on unmasked GaN templates may be a viable route to obtain materials for PV.

HL 24.7 Mon 16:00 Poster D

Epitaxial GaN around ZnO nanopillars — •Mohamed Fikry[1], Manfred Madel[2], Ingo Tischer[2], Ren Zhe[1], Klaus Thonke[2], and Ferdinand Scholz[1] — [1]Institut für Optoelektronik, Universität Ulm, Albert-Einstein-Allee 45, 89081 Ulm — [2]Institut für Quantenmaterie, Gruppe Halbleiterphysik, Universität Ulm, Albert-Einstein-Allee 45, 89081 Ulm

We report on the investigation of the epitaxial quality of GaN layers forming non-polar m-plane facets grown coaxially around ordered ZnO nanopillars. The GaN layers were grown using Metal Organic Vapor Phase Epitaxy (MOVPE). For developing a scalable process, in a first step successful position control of single ZnO nanopillars grown on top of ordered GaN pyramids is achieved. At growth temperatures above 800°C and using hydrogen as a carrier gas, the ZnO nanopillars start to dissolve during the GaN growth, leaving hollow GaN nanotubes. A strong and broad luminescence at 2.8 eV indicates the presence of heavily Zinc doped GaN layers. Characterization involves photoluminescence, scanning electron microscopy, transmission electron microscopy and cathodoluminescence.

HL 24.8 Mon 16:00 Poster D

Band alignment between III-V polytypes — •abderrezak belabbes, Christian Panse, Jürgen Furthmüller, and Friedhelm Bechstedt — Friedrich-Schiller-Universität Jena Max-Wien-Platz 1 D-07743 Jena

Growth of III-V nanorods leads to several stackings and hence besides of 2H also to the formation of other polytypes (4H and 6H). The hexagonal polytypes 2H, 4H, and 6H give rise to a drastic changes of the bonding topology along the cubic [111] or hexagonal [0001] axis but also to significant changes of the electronic structure, e.g. the fundamental energy gap, with respect that of the cubic 3C polytype. Heterocrystalline but homomaterial junctions appear. The trials toward their understanding by means of almost first-principles calculations were basically restricted to the junction 3C-2H and the density functional theory (DFT) which however significantly underestimates the fundamental gaps. In this study, the electronic structure for a variety of polytypes of the Ga-V and In-V compounds (V = P, As, Sb) is computed using a recently developed approximate calculation scheme, the LDA-1/2 method, and taking into account the spin-orbit interaction. Clear trends for the resulting band gaps and band orderings are observed. The aligned electronic structures are used to explain properties of junctions between two polytypes. The gaps and offsets allow to discuss spectroscopic results found recently for such III-V nanowires.

HL 24.9 Mon 16:00 Poster D

Confinement effects and band gap tuning of III-Nitride nanowires — •Klaara Viisanen, Laura Oikkonen, Katri Laaksonen, Maria Ganchenkova, and Risto Nieminen — Aalto University School of Science, Espoo, Finland

Nanowires of semiconductor materials are expected to play an important role in future nanoscale technologies such as third generation photovoltaics and light emitting diodes. It is very important that the electronic properties of a wire can be modified by changing its size. This opens possibilities for band gap engineering without alloying, for which we need a clear understanding of the effect of confinement on the electronic properties of the nanostructures. One of the key choices for nanowire materials are group III-V compound semiconductors. The aim of this work is to computationally examine how the size of the structure affects the width of the band gap for three different materials: AlN, GaN and InN. In addition to the confinement, the band structures of nanowires are also affected by the treatment of their highly reactive surfaces. This has been taken into account by considering two types of surfaces: clean and hydrogen-passivated. The calculations are performed by using three different approaches: density-functional theory within the semilocal approximation (PBE), a range-separated hybrid functional (HSE06) and the GW approximation.

HL 24.10 Mon 16:00 Poster D

Growth mechanisms of thin GaN on AlN — •Konrad Bellmann, Abdul Kadir, Markus Pristovsek, and Michael Kneissl — TU Berlin, Berlin, Deutschland

GaN based QD devices are very promising to reach single photon emission at room temperature, because of their feasibility of higher electron confinement. The lattice mismatch of GaN and AlN is about 2.5%. However, overgrowth of AlN by GaN results in 2D growth at normal growth conditions. In order to achieve QDs in Stranski-Krastanov mode, a small parameter window at low V/III ratio with additional annealing step is needed.

An additional challenge for QD growth is smooth AlN surfaces. Therefore, we have varied the V/III ratio during AlN growth. Due to the high binding energy of AlN, aluminum has a low diffusibility on the surface. With lower ammonia partial pressure higher aluminum ad atom mobility was achieved, resulting in smoother surfaces. High V/III ratio results in spiral growth.

HL 24.11 Mon 16:00 Poster D

Morphology and atomic structure of InGaN surfaces — •Sabine Alamé[1], Christian Friedrich[1], Daria Skuridina[1], Duc

Dinh[1], Norbert Esser[2], Michael Kneissl[1], and Patrick Vogt[1] — [1]TU Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Leibniz-Institut für Analytische Wissenschaften-ISAS-e.V., Albert-Einstein-Str. 9, 12489 Berlin, Germany

Although $In_xGa_{1-x}N$ alloys have received much interest over the last years, there is still only limited knowledge about their atomic surface structure. We present a study on the morphology and electronic properties of group-III and group-V polar $In_xGa_{1-x}N$ surfaces with varying indium content ($0 \leq x \leq 100$), grown by metalorganic vapour phase epitaxy on sapphire substrate. In order to obtain clean surfaces, the samples were prepared by thermal annealing between 400°C and 800°C under ultra-high vacuum conditions and in nitrogen plasma. The surface morphology was measured by atomic force microscopy in tapping mode, surface symmetries were investigated by low energy electron diffraction. X-ray photoelectron spectroscopy (XPS) was used to study the binding configurations and electronic properties of the surface. We obtained contamination free $In_{0.15}Ga_{0.85}N$ (0001) surfaces within a temperature range of 600°C - 760°C, showing stable (1x1), (1+1/6), ($\sqrt{3}$x$\sqrt{3}$)R30°, and (2x2) reconstructions, respectively. The results show that the amount of surface indium plays a crucial role for the formation of the surface reconstructions. For further investigation we compared indium-rich $In_xGa_{1-x}N$ (000-1) layers ($0.3 \leq x \leq 0.8$) by means of numerically analyzed XPS core-level spectra.

HL 24.12 Mon 16:00 Poster D

Das Temperaturverhalten von Cd dotiertem $Al_xGa_{(x-1)}N$ — •Patrick Kessler[1], Sahar Hamidi[1], Sérgio Miranda[2], Katharina Lorenz[2] und Reiner Vianden[1] — [1]Helmholtz-Intstitut für Strahlen- und Kernphysik, Universität Bonn, Bonn, Deutschland — [2]Instituto Tecnológico e Nuclear, Sacavém, Portugal

Für verschiedene Anteile von Al wurde das Temperaturverhalten von Cd dotiertem AlGaN untersucht.

Mit der Methode der gestörten Winkelkorrelation wird der elektrische Feldgradient (EFG) in der Umgebung von Sondenatomen untersucht. Dazu werden radioaktive ^{111m}Cd und ^{117}Cd Isotope in dünne AlGaN Schichten auf Saphir Substrat mit einer Energie von 30 keV implantiert. Die dadurch verursachten Kristallschäden werden unter Stickstoffffluss bei einer Temperatur von 1220 K ausgeheilt.

Im Gegensatz zu ^{111}In, das zu ^{111}Cd zerfällt und zwei Sondenumgebungen in AlGaN zeigt, ist bei den Sonden ^{111m}Cd und ^{117}Cd nur eine definierte Umgebung beobachtbar. Mit steigender Temperatur und Al Anteil nimmt der dazugehörige EFG zu. Zusätzlich wird beobachtet. dass die Kristallqualität mit dem Al Anteil zunimmt.

HL 24.13 Mon 16:00 Poster D

Lifetime measurements on III-V solar cell relevant materials — •Anja Dobrich[1], Klaus Schwarzburg[1], Elias Martinez[1], Marinus Kunst[1], and Thomas Hannappel[1,2,3] — [1]Helmholtz-Zentrum Berlin, Institut Solare Brennstoffe und Energiespeichermaterialien, D-14109 Berlin — [2]TU Ilmenau, Institut für Physik, Fachgebiet Photovoltaik, D-98693 Ilmenau — [3]CiS Forschungsinstitut für Mikrosensorik und Photovoltaik, D-99099 Erfurt

The lifetime of minority charge carriers in III-V relevant solar cell absorber materials is essential for the performance of solar cells. Suitable nondestructive methods to get informations about the electronic quality of the grown layers are the time resolved photoluminescence (TRPL) and transient microwave photoconductivity (TRMC). The lifetime of minority charge carriers generated by a laser pulse is measured and gives direct results about the material quality. Both methods should lead to the same results under similar excess charge carrier density conditions and deliver informations about the bulk material quality and the interface quality as well. However, if electric fields are generated caused by growth conditions in the structures to be examined (i.e. on interfaces) or p-n junctions in solar cell structures are investigated, the assumption of a homogeneous charge carrier distribution is no more valid and leads to the false interpretation of the measured results. With the help of some examples the influences of these effects should be demonstrated for the measured minority charge carrier lifetimes of MOVPE grown InP/InGaAs /InP test structures and solar relevant absorbers and structures in generally.

HL 24.14 Mon 16:00 Poster D

Coherent phonon excitation in SiC — Toru Shimada[1], •Wiktor Pronobis[1], Martin Scheuch[1], Kamaraju Natarajan[1], Christian Frischkorn[2], Martin Wolf[1], and Tobias Kampfrath[1] — [1]Fritz-Haber-Institut der MPG, Faradayweg 4-6, 14195 Berlin — [2]Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin

Silicon carbide (SiC) is a prominent material for high-temperature, high-power, high-frequency and radiation-resistant devices. In view of these important applications, it is of great interest to characterize the basic solid-state properties of this material. Here, we consider coherent vibrations of the crystal lattice (coherent phonons) which we trigger by impulsive excitation with a femtosecond laser pulse (pump pulse). A second time-delayed laser pulse (probe pulse) is used to monitor the lattice vibration in the time domain by measuring the pump-induced birefringence of the sample as a function of the delay between pump and probe pulses. Based on the temperature dependence of their decay, we discuss the anharmonic coupling of the LO (29.3 THz) and the folded TO (23.8 THz) phonon mode in the 3C (cubic) and 6H (hexagonal) polytypes of SiC, respectively.

HL 24.15 Mon 16:00 Poster D

Sol-Gel-assembly of micro-crystalline silicon carbide and EPR-measurements — •Tim Baumgarten, Andre Konopka, Eva Rauls, Wolf-Gero Schmidt, Uwe Gerstmann, and Siegmund Greulich-Weber — Physics, University of Paderborn, Paderborn, Germany

Micro-crystalline semiconductor materials offer a huge amount of optical and electrical applications due to their vast surface to volume ratio. Silicon carbide (SiC) has become a material of interest in this field, because of its wide band gap and chemical stability, offering potential applications as semiconductor substrate and high power applications material, as well as chemical catalytic structure. In order to benefit from these abilities, it is most important to get a deep understanding of the crystalline structure and the electro-optical characteristics resulting from the large surface. In our sol-gel process we produce SiC microcrystals with various sizes and dopings. We performed Electron Paramagnetic Resonance measurements (EPR), to obtain information on the electronic structure of our samples, Debye-Scherrer X-Ray diffraction to analysis the crystalline parameters and optical spectroscopy to analysis the electro-optical characteristics. In order to get a deeper understanding of our experimental results, we performed calculations via density functional theory (DFT). In this contribution we present our results on the analysis of different surfaces of micro-crystaline SiC.

HL 24.16 Mon 16:00 Poster D

Light-induced electron spin resonance (LESR) studies of silicon vacancy centers in 6H-SiC — •Daniel Riedel[1], Andreas Sperlich[1], Hannes Kraus[1], Franziska Fuchs[1], Alexandra Soltamova[2], Pavel Baranov[2], Georgy Astakhov[1], and Vladimir Dyakonov[1,3] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]Ioffe Physical-Technical Institute, St. Petersburg, RU-194021 Russia — [3]ZAE Bayern, D-97074 Würzburg

The silicon vacancy V_{Si} centers in hexagonal polytypes of SiC, in particular 6H-SiC, have C_{3v} symmetry allowing for zero field splitting between spin sublevels in the ground state. Below-band-gap illumination of 6H-SiC samples results in nonequilibrium spin population, which is directly detected in our X-band (9.4 GHz) ESR setup. We investigated LESR as a function of temperature, illumination wavelength and intensity in order to find the most efficient conditions for initialization, manipulation and readout of the V_{Si} spin. The observed saturation of the LESR signal at relatively low illumination intensities and microwave powers indicates efficient optical spin pumping mechanism and long spin relaxation time, much longer than radiative lifetime in the excited states. Our observations suggest that V_{Si} centers are promising candidates for qubits.

HL 24.17 Mon 16:00 Poster D

Spatially-resolved photoluminescence of silicon vacancy centers in 6H-SiC — •Franziska Fuchs[1,2], Georgy Astakhov[1], Alexandra Soltamova[3], Pavel Baranov[3], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, D-97074 Würzburg — [3]Ioffe Physical-Technical Institute, St. Petersburg, RU-194021 Russia

Defects in silicon carbide (SiC) are considered as promising candidates for qubits operating at ambient conditions (i.e., room temperature and zero magnetic field). As a rule, defects in SiC are created by electron or neutron irradiation, which is extensive and therefore causes damage of the crystal lattice.

In this study we demonstrate that 6H-SiC monocrystals grown by

high temperature Lely technique contain silicon vacany (V_{Si}) defects, even without irradiation. We performed systematic studies of the V_{Si} photoluminescence (PL) as a function of temperature. Strong PL signal observed at room temperature confirms high crystalline quality of our SiC monocrystals. Moreover, using confocal arrangement we performed spatially resolved PL measurements and demonstrated homogeneous distribution of V_{Si} in all three dimensions throughout the samples.

Summarizing, the high temperature Lely growth technique seems to be an appropriate method for the fabrication of high quality SiC samples for quantum information processing.

HL 24.18 Mon 16:00 Poster D

Organic Functionalization of 3C-SiC Surfaces — •Matthias Sachsenhauser[1], Sebastian Schoell[1], Alexandra Oliveros[2], John Howgate[1], Martin Stutzmann[1], Stephen Saddow[2], and Ian Sharp[1] — [1]Walter Schottky Institut, Technische Universitaet Muenchen, Garching, Germany — [2]Electrical Engineering Department, University of South Florida, Tampa, FL, USA

3C-SiC is a promising substrate material for electronic and mechanical biosensing applications due to its exceptional stability, strength, and biocompatibility. Although the quality of epitaxially grown 3C-SiC on Si has significantly improved in recent years, only limited work has been devoted to establishing methods of bio-organic functionalization of its surfaces. Here, we utilize wet chemical processing techniques for the formation of self-assembled aminopropyldiethoxymethylsilane (APDEMS) and octadecyltrimethoxysilane (ODTMS) monolayers on n-type (100) and (111) 3C-SiC. Chemical activation of the surfaces is achieved by HF treatment in a first step, followed by reaction with ODTMS and APDEMS molecules. The structural and chemical properties of the surfaces are characterized using static water contact angle, atomic force microscopy, and X-ray photoelectron spectroscopy. These techniques verify the formation of covalently bound monolayers. Contact potential difference and surface photovoltage measurements are used to examine the near-surface band-bending and changes of interfacial dipoles due to chemical binding. Finally, ODTMS layers are micropatterned by means of lithographically-defined oxidation and the resulting changes of local wettability are illustrated.

HL 24.19 Mon 16:00 Poster D

Isotopically modulated silicon and its thermoelectric properties — •Soizic Eon[1], Nadine Wehmeier[1], Hartmut Bracht[1], Georg Bastian[2], Arne Vogelsang[2], Saeed M. Ullah[2], Anton Plech[3], Christian Heiliger[4], and Dietrich Wolf[5] — [1]WWU Münster — [2]U Rhine-Waal — [3]KIT Karlsruhe — [4]U Giessen — [5]U Duisburg-Essen

In order to use silicon (Si) for thermoelectric applications, it is necessary to increase the figure of merit ZT for example by decreasing the thermal conductivity. A promising approach is the use of isotopically modulated Si structures. Isotopically enriched Si multilayers were grown on natural Si substrates by means of molecular beam epitaxy. Homogeneously p- and n-type samples were fabricated and assembled to a thermoelectric module. Information about the thermal stability was gained by depth profiling before and after thermal treatments. The electrical conductivity was determined by Van de Pauw and current-voltage measurements after ohmic contact formation. Various methods were applied to determine the thermal conductivity of the multilayer structures. This includes measurements with time-domain thermoreflectance, time-resolved X-Ray scattering and the 3-ω-method. Our investigations reveal a reduced conductance due to phonon scattering at the isotopes interface while the electrical conductivity remains unchanged. Molecular dynamics and ab-initio calculations confirm a reduced thermal conductivity between Si layers of different isotopic composition. Further reduction is expected by optimizing the arrangement of the isotope layers and by an additional lateral confinement.

HL 24.20 Mon 16:00 Poster D

DLTS study on deep levels after aluminum gettering in FZ silicon — •Sarina Grevsmühl, Patricia Krenckel, Doaa Abdelbarey, and Michael Seibt — IV. Physikalisches Institut, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

In silicon device fabrication gettering is an important process for reducing metal contamination. In particular, iron is known to have detrimental effects on the electrical performance of these devices due to its deep levels in the silicon band gap which reduce minority carrier lifetime [1]. Recently it was reported that illumination after performing an aluminum gettering step on iron contaminated p-type FZ silicon introduces a deep level ("FeD") that has tentatively been attributed to an iron vacancy complex [2].

In this work aluminum gettering was performed after iron indiffusion into boron-doped FZ silicon. Additionally, the samples were exposed to white light. The material was characterized using deep level transient spectroscopy (DLTS) on Schottky contacts. Along with the signal corresponding to the FeD defect and the iron interstitial level, a level probably due to divacancies was observed with a concentration of $5 \cdot 10^{12}$ cm^{-3} in illuminated samples. Results on the effects of thermal annealing, illumination and Schottky contact preparation on these deep levels will be reported on this contribution.

This work was financially supported by the BMU.

[1] A. A. Istratov at al., Appl. Phys. A 70, 489-534 (2000)
[2] D. Abdelbarey et al., J. Appl. Phys. 108, 043519 (2010)

HL 24.21 Mon 16:00 Poster D

Measurement of the dependency of the defect density on the band gap in a-SiGe:H thin films — •Burkhard Gilles[1], Ulrich Heinzmann[1], Helmut Stiebig[2], Andreas Gondorf[2], Pavel Prunici[2], and Florian Maier[2] — [1]Molecular and Surface Physics, Bielefeld University, 33615 Bielefeld, Germany — [2]Malibu GmbH Co. KG, 33609 Bielefeld, Germany

Increasing the quality of the amorphous silicon [aSi] and Silicon-Germanium alloys [aSiGe] is a necessary task for solar energy conversion efficiency of thin film solar cells. The defect states of a-Si:H based materials - represented by the dangling bond density and the Urbach tail - depend on the applied deposition conditions and the composition of the layer. A deeper understanding of the defect state distribtion is a crucial requirement to further enhance the efficiency and the long term stability of thin film silicon based solar cells. The dependency of the defect density on the Fermi energy was already subject of many investigations. In this work, the dependency of the defect density on the band gap will be investigated. In order to determine the defect distribution a constant photocurrent measurement (CPM) setup was installed. CPM spectra from a-SiGe:H layers will be presented. The quality of the material and the dependency of the defect density on the band gap will be discussed.

HL 24.22 Mon 16:00 Poster D

Photoluminescence spectra of SiGe quantum islands grown on prepatterned Si substrates: evidence of carrier interaction and biexcitonic transitions — •Petr Klenovský[1,2], Moritz Brehm[3], Vlastimil Křápek[1,4], Elisabeth Lausecker[3], Florian Hackl[3], Thomas Fromherz[3], Günther Bauer[3], and Josef Humlíček[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]CEITEC - Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, 4040 Linz, Austria — [4]Institute of Physics, Academy of Sciences of the Czech republic, Cukrovarnická 10, Praha 6, 162 53, Czech Republic

The pumping intensity (I) dependence of the photoluminescence (PL) spectra of SiGe quantum dots grown on prepatterned Si(001) substrates was studied. Their analysis revealed up to seven spectral bands attributed to phonon-assisted recombinations, no-phonon recombinations of the ground and excited states of excitons, all showing linear dependencies of the peak intensity on I. At large values of I, additional lines with a quadratic dependence on I appear in he PL spectra that are assigned to biexciton transitions. The experimentally obtained energies of the no-phonon transitions are in good agreement with the exciton and biexciton energies calculated within the framework of a $\vec{k} \cdot \vec{p}$ theory. To the best of our knowledge this is the first clear evidence of the carrier interaction and biexcitonic transitions in SiGe/Si QDs.

HL 24.23 Mon 16:00 Poster D

Impact of p-type doping on Germanium self-diffusion — •Tobias Südkamp[1], Hartmut Bracht[1], Giorgia Scapellato[2], Elena Bruno[2], and Dominique Bougeard[3] — [1]Institut für Materialphysik, WWU-Münster, Germany — [2]Center MATIS CNR-IMM, University of Catania, Italy — [3]Institur für Experimentelle und Angewandte Physik, Universität Regensburg, Germany

Self-diffusion in germanium (Ge) under n-type doping has been recently investigated by means of Ge isotope multilayer structures. The n-type dopants of interest such as phosphorus, arsenic and antimony

were diffused from the surface into the isotope structure. The gradual change of the self-atom profile along the dopant profile reveals the dominance of doubly negatively charged vacancies. Similar experiments on the impact of p-type dopants on Ge self-diffusion are hampered by the slow diffusivity of acceptor dopants such as boron (B), aluminium and gallium. In order to study the self-diffusion of Ge under p-type doping we utilize a Ge isotope multilayer structure doped with B by implantation. Implantation of B was performed in an amorphous $\left({}^{nat}Ge/{}^{73}Ge\right)_{10}$-multilayer structure grown by molecular beam epitaxy on a preamorphized Ge wafer. The amorphous, B-implanted samples were recrystallized by annealing and subsequently used for diffusion anneals. First results of this approach to study self-diffusion in Ge under p-type doping are presented.

HL 24.24 Mon 16:00 Poster D

Glancing Angle Deposition: Structural Aspects and Growth Modelling — Christoph Grüner, •Jens Bauer, and Bernd Rauschenbach — Leibniz-Institut für Oberflächenmodifizierung, Permoserstrasse 15, D-04318 Leipzig, Germany

Recently, considerable progress in understanding ballistic deposition has been achieved. Over a long time the topic was inscrutable, since it was not possible to simulate the structure evolution properly. New results in kinetic Monte Carlo studies showed that the large variety of contradicting results originates from the so-called grid-effect in on lattice-simulations. To avoid this problem Tanto et al. [1] proposed the usage of cluster particles for ballistic deposition modelling. We applied this novel conception to generate a fast and easy experiment-adaptable Monte Carlo simulation code. The nanostructure evolution in glancing angle deposition and the influence of the deposition parameters on the structural properties were studied in comparison between experiment and simulation. Substrates with nanoscopic pre-patterns were successfully applied to form arranged fields of nanostructures. The temporal evolution of ordered and disordered nanocolumns was investigated in simulation and experiment. Regarding the nanostructured film porosity two contributions have to be considered: an interstructure contribution because of the spatial nanostructure separation and an innerstructure contribution originating from distinct density changes within the nanostructures. The results are applied to describe macroscopic film properties as the film density and the effective refractive index.

[1] B. Tanto, C. F. Doiron, T.-M. Lu: Phys. Rev. E 83 (2011) 016703

HL 24.25 Mon 16:00 Poster D

High throughput investigation of the thermoelectric properties of Si based compounds — •Ingo Opahle, Georg K. H. Madsen, and Ralf Drautz — ICAMS, Ruhr-Universität Bochum, Bochum, Germany

We have investigated the structural stability and electronic structure of a series of known and hypothetical Si based compounds. Calculations are performed in the framework of density functional theory using a recently developed High Throughput Environment (HTE). The HTE calculations are used for an efficient screening of candidate structures for enhanced thermoelectric properties. We discuss trends in the structural stability as well as the electronic and transport properties. Furthermore, details of the HTE implementation like an efficient prescreening of trial structures will be discussed.

HL 25: Poster Session: GaN - Optical Properties & Preparation and Characterization & Devices

Time: Monday 16:00–19:00 Location: Poster D

HL 25.1 Mon 16:00 Poster D

Feedback Control of a Quantum Dot Cavity-QED System — •Franz Schulze, Alexander Carmele, and Andreas Knorr — Institut für Theoretische Physik, Technische Unitversität Berlin, Germany

We investigate externally pumped quantum dots embedded in a nanocavity within an equation-of-motion-approach.[1] In the limit of many emitters and photons the standard cluster expansion scheme is a well-known factorization procedure to investigate quantum light emission.[2] A possible way of stabilizing this emission and its statistical properties is a time delayed self-feedback as it is described classically by the Lang-Kobayashi model.[3] Here, we discuss the transition from the classical [4] to the quantum mechanical model and present first steps toward a fully quantized feedback description.

[1] M. Richter *et al.*, Phys. Rev. Lett. **103**, 087407 (2009)
[2] C. Gies *et al.*, Phys. Rev. A **75**, 013803 (2007)
[3] R. Lang and K. Kobayashi, IEEE J. Quantum Electron. **16**, 347 (1980)
[4] C. Otto *et al.*, Phys. Status Solidi B **247**, 829 (2010)

HL 25.2 Mon 16:00 Poster D

Time Resolved Generallized Ellipsometry — •Christian Heinrichs, Chris Sturm, Helena Franke, Steve Linke, Tammo Böntgen, Rüdiger Schmidt-Grund, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig, Germany

For the investigation of optical switching processes, change of the polarization in perovskite-based heterostructure, and its realization in devices, the change of the dielectric function (DF) as a function of time in dependence on the excitation is important up to the ps time scale. Ellipsometry is a suitable and sensitive tool for the determination of the DF. Up to now, no commercial ellipsometers are available which allow to perform time resolved measurements in this time regime. Therefore, we present a custom made ellipsometer setup which allows such measurements and devote special emphasis to the calibration routine, the data acquisition techniques, and the accuracy of the obtained data.

Our setup contains a linear polarizer and a compensator for both, the preparation of the polarization state of light and its analysis after reflection from a sample. Thereby we can measure the Stokes vector and determine the complete Mueller matrix. The signal is detected by a streak camera system which allows a time-resolution down to the ps range. The setup also allows PL measurements without changing the detection area on the sample at nearly the same time as the ellipsometry measurements. This allows a correlation of the time dependence of the luminescence processes and the corresponding contribution of the electronic components in the DF.

HL 25.3 Mon 16:00 Poster D

Spectral signatures of excitonic BEC in Cu_2O — •Rico Schwartz[1], Siegfried Sobkowiak[1], Dirk Semkat[1], Thomas Koch[2], Holger Fehske[2], and Heinrich Stolz[1] — [1]Institut für Physik, Universität Rostock, D-18051 Rostock, Germany — [2]Institut für Physik, Ernst-Moritz-Arndt-Universität Greifswald, D-17489 Greifswald, Germany

When looking for an excitonic BEC one of the most important points to be clarified is the kind of spectral signatures of such a BEC. We present recent theoretical investigations for a weakly luminescing BEC of trapped excitons in Cu_2O. For exciton numbers below the critical density the spectrally resolved integrated intensity behaves Bose-like with a linear dependence on the exciton number. Above the critical number the spectrum consists of a Bose-like distribution (luminescence from thermalized excitons outside the condensate), two gaussian peaks with energetic position symmetrically around the chemical potential (contribution of the Bogoliubov quasiparticles in the condensate), and a third gaussian peak at the chemical potential (the weakly luminecing condensate). The dependence of the total integrated intensity shows a kink at the critical exciton number and has a different slope below and above this point. This results from the different luminescence efficiencies of excitons in a condensate and in thermal states. We also present recent experiments which confirm the theoretical predictions.

HL 25.4 Mon 16:00 Poster D

Resonance Raman and Selection Rules in Cuprous Oxide — •Ovidiu Dorin Gordan, Salvan Georgeta, Schäfer Philipp, Fronk Michael, and Dietrich R.T. Zahn — Semiconductor Physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany

Long known as a red pigment, cuprous oxide (Cu_2O) is one of the principal oxides of copper which crystallizes in a cubic structure. Even though Raman studies of Cu_2O in resonance conditions were reported

in several papers, the relative intensities and the origin of the spectral features is still under debate. In this work natural, one side polished (100), (110), and (111) terminated Cu_2O single crystals purchased from SurfaceNet GmbH are investigated using a micro-Raman configuration. The selection rules in resonance conditions are revisited using parallel and cross polarization configurations for two different excitation energies, 2.41 eV and 3.82 eV, which probe in resonance with different excitonic transitions.

HL 25.5 Mon 16:00 Poster D

Vibrational spectra of different phases of Cu_xO_y — •Christian Reindl, Thomas Sander, Daniel Reppin, Bruno K. Meyer, and Peter J. Klar — I. Physikalisches Institut, Justus Liebig University, Heinrich-Buff-Ring 16, 35392 Giessen

The vibrational spectra of different phases of copper oxide – CuO, Cu_2O and Cu_3O_4 – are investigated. The Raman spectra of the three phases differ in the number of Raman active modes and exhibit variations in the peak positions of the signals. To establish a relationship between growth condition and crystal phase obtained, a series of sputtered thin-film samples with varied oxygen concentrations was studied by Raman spectroscopy. The Raman spectra were recorded in backscattering geometry at room temperature using an 633 nm excitation laser. In addition, Raman spectra were obtained during in-situ tempering to study the stability of the various phases. Raman depth scans were performed to investigate changes of the copper oxide phase as a function of sample thickness.

HL 25.6 Mon 16:00 Poster D

Photoluminescence investigations of differently annealed and doped SrTiO3 single crystals in varying atmospheres — •Juliane Hanzig, Barbara Abendroth, Florian Hanzig, Hartmut Stöcker, and Dirk C. Meyer — TU Bergakademie Freiberg, Institut für Experimentelle Physik, Leipziger Straße 23, 09596 Freiberg

Strontium titanate is a well-known transition metal oxide for memory applications, which also exhibits interesting optical properties. Here, we utilized intrinsic and extrinsic doping of strontium titanate single crystals, e. g. oxygen vacancies, niobium and lanthanum. To introduce oxygen vacancies, $SrTiO_3$ single crystals were vacuum-annealed. The existence of free charge carriers was controlled by means of infrared (IR) spectroscopy. A model to extract the electron density will be figured out. The determination of defect levels in the band gap related to surface and bulk oxygen vacancies was performed by photoluminescence (PL) measurements. The interaction between surface defects and atmosphere is highlighted by using different temperatures and gases. We found a time dependence of the photoluminescence intensity, which was attributed to oxygen incorporation at the surface during laser exposure. In addition, surface sensitive investigation methods like elastic recoil detection analysis (ERDA) and X-ray photoelectron spectroscopy (XPS) were used to clarify surface absorption effects under different ambient conditions. Implications for the situation at metal-oxide contacts will be presented.

HL 25.7 Mon 16:00 Poster D

Energy transfer dynamics of the Mn $3d^5$ and Tb $4f^8$ luminescence in ZnS:Mn,Tb nanostructures — •Uwe Kaiser[1], Sebastian Gies[1], Limei Chen[1], Wolfram Heimbrodt[1], Sebastian Geburt[2], and Carsten Ronning[2] — [1]Dept. of Physics, Philipps-University Marburg — [2]Institute of Solid State Physics, Friedrich-Schiller University

The photoluminescence (PL) decay characteristics of ZnS nanostructures doped with different luminescence centers can be described by a modified Förster model taking into account the concentration quenching as well as the dimensionality of the nanostructures. To check the general validity of this model, nanostructures of diverse morphology were doped with two different luminescence centers, namely Terbium and Manganese with concentrations of $4{\cdot}10^{-6}$% to 4% by ion implantation. The PL transients of the internal $Tb^{2+}(4f^8)$ and the $Mn^{2+}(3d^5)$ transitions were measured over four orders of magnitude.
For wires as well as for belts an enhancement of the effective dimensionality could be observed for increasing Mn concentration at 10K. Measurements at room temperature indicate, however, again a reduction of the effective dimensionality, due to the enhanced transfer probability inside the subsystem of the luminescence centers. Temperature treatment and ion irradiation were used to incorporate additional defects for a thorough investigation of the energy transfer influenced by nonradiative killer centers.

HL 25.8 Mon 16:00 Poster D

Investigation of Parametrizations for the Valence Band Structure of GaN — •Felix Schwarz, Steve Lenk, and Erich Runge — Institut für Physik und Institut für Mikro- und Nanotechnologien, Technische Universität Ilmenau, 98693 Ilmenau, Germany

We calculate the dielectric function of hexagonal GaN including the A-, B-, and C-excitons using a multi-valence band formalism. The importance of excitons for the interpretation of reflectance spectroscopy of GaN was emphasized by several experimental groups, but only recently theoretical calculations were presented [1]. We obtain the dielectric function from a numerical solution of an initial-value problem [2] via an exponential split-operator method, taking into account the full 6x6 valence band structures of several parametrizations calculated by other groups. We present the complex dielectric function as well as the deduced reflectivity spectra of the excitons in GaN. After comparing the results to recent experimental spectra, we present an semi-empirically adapted parametrization for the valence band structure.

[1] A. T. Winzer, G. Gobsch, and R. Goldhahn, Phys. Rev. B **74**, 125207 (2006).

[2] S. Glutsch, *Excitons in Low−Dimensional Semiconductors*, Springer Heidelberg (2004).

HL 25.9 Mon 16:00 Poster D

Optical second harmonic spectroscopy of GaAs excitons in crossed electric and magnetic fields — •David Brunne[1], Marco Lafrentz[1], Victor Pavlov[2], Roman Pisarev[2], Dmitri Yakovlev[1], and Manfred Bayer[1] — [1]Experimentelle Physik 2, TU Dortmund, D-44221 Dortmund, Germany — [2]Ioffe Physical-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

Optical second harmonic generation is a powerful tool to investigate exciton resonances in semiconductors. Recent measurements on GaAs in an external magnetic field have revealed a rich spectrum of magneto-excitons related to carrier Landau levels with numbers up to eight[1]. In the present work we extend this research by additional application of an electric field, which modifies considerably the spectrum of magneto-excitons detected via second harmonic generation (SHG). Electric and magnetic fields are applied perpendicular to each other and to the (001) crystal axis of a GaAs sample. In the absence of these fields SHG intensity is zero as the nonlinear process is forbidden in the electric-dipole approximation. Polarization characteristics are analyzed. We discuss the rich spectrum of magneto-excitons which stems from the complex energy and spin structure of the valence band.
[1] V. V. Pavlov, A. M. Kalashnikova, R. V. Pisarev, I. Sänger, D. R. Yakovlev, and M. Bayer, Phys. Rev. Lett. **94**, 157404 (2005)

HL 25.10 Mon 16:00 Poster D

Long-range transport of indirect excitons by moving strain dots in a GaAs double quantum wells — •Snežana Lazić, Rudolf Hey, and Paulo Santos — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

We report on the acoustic transport of spatially indirect (inter-well) excitons in a GaAs/AlGaAs double quantum well. The photo-excited excitons are trapped within an array of moving strain dots with a spatial periodicity of a few μm. These dynamic potential dots are formed by interfering two surface acoustic waves (SAWs) propagating along orthogonal non-piezoelectric crystallographic directions. The trapping mechanism relies on a dynamic type-I modulation of the band edges via the deformation potential interaction. The exciton lifetime is voltage-tunable via the top semi-transparent gate and is substantially longer than the SAW period. We show that such system offers a controllable way for artificially producing cold exciton gases for the investigation of quantum collective effects.

Using spectrally and spatially resolved low-temperature photoluminescence measurements, we have observed the formation of a luminescence ring around the laser illumination spot, which is discussed in terms of thermalization of long-living indirect excitons. Under acoustic excitation, we demonstrate the long-range transport (of the order of 100 μm) followed by recombination at the inter-well exciton transition energy. These experiments allow us to determine the distribution of indirect excitons as well as to probe the exciton-exciton interactions within the dot array.

HL 25.11 Mon 16:00 Poster D

Photoluminescence line shape features of carbon delta-doped GaAs heterostructures — Jürgen Schuster[1], •Tae Yang

Kim[1], Edwin Batke[1], Dirk Reuter[2], and Andreas Wieck[2] — [1]Physikalisches Institut der Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstrasse 150, D-44780 Bochum, Germany

The PL line shape properties of quasi two-dimensional electron gas (2DEG) in setback delta doped GaAs heterostructure at liquid helium temperature are studied. We illuminated the sample with two different excitation energies, below and above the band gap of AlGaAs. The whole density of states of 2DEG can be directly visible due to the relaxation of k-selection rule. We observed clearly the ground and the first excited 2D subbands. A simple fit to the line shape including broadening demonstrated that there is an exponential low-energy tail associated with the ground subband. The fit precisely reveals the subband bottom energies, the quasi Fermi-energy, the electron temperature and the integrated strengths, enabling an accurate determination of the subband populations and the transition probability. A self-consistent calculation of subband properties including the potential contribution of the delta doping reproduces the subband separations and recombination intensities well. The dependence of excitation intensity, temperature and magnetic field strength on the PL line shape is studied.

HL 25.12 Mon 16:00 Poster D

Near-field scanning optical microscopy of infrared emitting semiconductor nanostructures — •Alexander Senichev[1], Uri Givan[1], Oussama Moutanabbir[1], Vadim Talalaev[2], and Peter Werner[1] — [1]Max Planck Institute of Microstructure Physics, Weinberg 2, D-06120 Halle (Saale), Germany — [2]Centre for Innovation Competence SiLi-nano, Martin-Luther-University, Karl-Freiherr-von-Fritsch-Str. 3, 06120 Halle (Saale), Germany

The fabrication of low-dimensional semiconductor materials with controlled variation of structural parameters in nanometer scale is fascinating activity in solid-state research. These structures are interested for study the fundamental physical properties and possibilities of their application in advanced optoelectronic devices as well. Optical spectroscopy is one of the most powerful tools for investigation of electronic and optical properties of low-dimensional semiconductor nanostructures which are determined by quantum-mechanical confinement of electronic wave functions. Using near-field scanning optical microscopy (NSOM) allows one to study these properties of single nanostructures with sub-wavelength spatial resolution.

In this work we address abilities of our NSOM technique to perform space resolved experiments at low temperature. We will report on results of a near-field optical study of semiconductor nanostructures, e.g. single Si nanowires and InGaAs nanoclusters. The combination of NSOM data with TEM, SEM, and Raman spectroscopy opens the possibility to get complete information about properties of low-dimensional nanostructures.

HL 25.13 Mon 16:00 Poster D

Direct determination of piezoelectric coefficients for GaN by AFM — •Uwe Röder[1], Frank Lipski[2], Martin Feneberg[3], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University — [2]Institute of Optoelectronics, Ulm University — [3]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg

For the piezoelectric coefficients of GaN a broad range can be found in literature (d_{33} = 2...4 pm/V; d_{15} = 2.9...3.3 pm/V). Mostly, these parameters have been determined from polycrystalline thin layers. We present here data obtained on thick semi-insulating Fe doped GaN layers grown by HVPE. By applying AC voltages with varying amplitude and frequency to top and bottom contacts, and measuring the elongation of the thick GaN layer with an AFM tip in contact mode and lock-in technique to record the phase-correlated periodic change of the quadrature diode signal, we get a direct measure of the piezoelectric constant d_{33}. We obtain a value of $d_{33} = (2.2 \pm 0.3)$ pm/V. Similarly, d_{15} could be obtained by recording the shear displacement. Effects of mechanical sample resonances etc. have to be carefully avoided.

HL 25.14 Mon 16:00 Poster D

Low voltage spatially resolved cathodoluminescence measurements on nitride semiconductors — •Matthias Hocker[1], Ingo Tischer[1], Robert A.R. Leute[2], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institut für Quantenmaterie, Gruppe Halbleiterphysik, Universität Ulm, 89069 Ulm — [2]Institut für Optoelektronik, Universität Ulm, 89069 Ulm

Cathodoluminescence (CL) measurements with very low acceleration voltages can drastically improve spatial resolution. For low electron energies of $550 - 2000$ eV and small working distances of $2 - 4$ mm in the scanning electron microscope, we achieve a spatial resolution down to the diffusion length of the generated excitons. We demonstrate the application of low voltage CL measurements to InGaN quantum wells, and compare the results to Monte Carlo simulations.

HL 25.15 Mon 16:00 Poster D

Untersuchung von InGaN-basierten Quantenpunktsystemen mittels STEM Z-Kontrast — •Alexander Würfel[1], Thorsten Mehrtens[1], Christian Tessarek[2], Timo Aschenbrenner[2], Detlef Hommel[2] und Andreas Rosenauer[1] — [1]AG Elektronenmikroskopie — [2]AG Halbleiterepitaxie, Institut für Festkörperphysik, Universität Bremen, Deutschland

InGaN-basierte (Laser-)Dioden emittieren im blauen bis grünen Spektralbereich. Die Verwendung von Quantenpunkten (QPe) in der aktiven Schicht verbessert die Effizienz und ermöglicht neue Anwendungen wie z.B. Einzelphotonemitter.

Es werden InGaN/GaN-Strukturen untersucht, die mittels MOVPE unter Verwendung komplexer Temperaturprofile gewachsen wurden. Die spinodale und binodale Entmischung wird als treibende Kraft für die QP-Bildung vorgeschlagen. Unüberwachsene Proben zeigen große In-reiche Inseln auf der Oberfläche, die sich beim Überwachsen auflösen. Zusätzlich bildet sich eine Meanderstruktur (ca. 20% In), aus der beim Überwachsen die QPe hervorgehen.

Die aufgenommenen hochauflösenden HAADF-STEM-Bilder werden quantitativ ausgewertet. Dazu wird die von der Kernladungszahl Z abhängende Intensität mit simulierten Bildern verglichen, um die In-Konzentration zu bestimmen.

Die QPe sind als Fluktuationen mit höherer In-Konzentration sichtbar und aus ihrer Ausdehnung lässt sich die Konzentration im QP abschätzen. Zusätzlich ist bei einigen Proben eine zweite InGaN Schicht zu erkennen, die beim Überwachsen mit GaN entstanden ist.

HL 25.16 Mon 16:00 Poster D

Photoluminescence of cubic AlGaN layers — •Florian Hörich[1], Sarah Osterburg[1], María Fátima Romero[1], Martin Feneberg[1], Thorsten Schupp[2], Christian Mietze[2], Donat J. As[2], and Rüdiger Goldhahn[1] — [1]Otto-von-Guericke University Magdeburg, Germany — [2]Universität Paderborn, Department Physik, Paderborn, Germany

Thin cubic AlGaN layers grown by melcular beam epitaxy were investigated by photoluminescence (PL) at variable temperatures. Excitation was provided by λ=193nm ArF*-excimer laser pulses. We study localization properties of the ternary alloy over the whole composition range by analyzing PL peak position, full width at half maximum, and intensity. Model calculations are presented and compared to the experimental data yielding parameters like the characteristic localization energy. The evolution from direct (GaN) to indirect (AlN) semiconductor is explored.

HL 25.17 Mon 16:00 Poster D

Ultraviolet photoluminescence spectroscopy of homo- and heteroepitaxially grown AlN — •Christoph Reich[1], Viola Küller[2], Arne Knauer[2], Martin Feneberg[3], Jessica Schlegel[1], Markus Weyers[2], Rüdiger Goldhahn[3], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany — [3]Otto-von-Guericke-Universität, Abteilung Materialphysik, Universitätsplatz 2, 39106 Magdeburg, Germany

For high power deep UV LEDs, high quality AlN templates are required. However, heteroepitaxial growth of AlN on sapphire substrates leads to high threading dislocation densities (TDD) of $10^{10}\,\mathrm{cm}^{-2}$, which significantly deteriorate the internal quantum efficiency of LEDs. The optical properties of homoepitaxially grown AlN layers on bulk AlN and heteroepitaxially grown AlN layers on patterned and unpatterned AlN/sapphire templates have been investigated by low temperature photoluminescence spectroscopy (PL), temperature dependent PL and excitation density dependent PL. High quality AlN layers are grown homoepitaxially on bulk AlN substrates (TDD $< 10^8\mathrm{cm}^{-2}$) or epitaxial lateral overgrowth (ELO) of patterned AlN/sapphire templates (TDD $< 10^9\mathrm{cm}^{-2}$) by metalorganic vapour phase epitaxy (MOVPE). The recombination of free excitons and several donor bound excitons has been observed. Exciton emission energies, exciton linewidths and the temperature dependence PL for different substrate

materials will be compared.

HL 25.18 Mon 16:00 Poster D

Effect of growth parameters and annealing on the p-doping of GaN:Mg — •Gunnar Kusch, Martin Frentrup, Tim Kolbe, Tim Wernicke, Markus Pristovsek, and Michael Kneissl — Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany

One of the key challenges limiting the output power of group-III-nitride light emitting diodes (LEDs) and laser diodes is the p-doping of (Al)GaN with magnesium (Mg). During growth of GaN:Mg by metal-organic vapor phase epitaxy compensating defects are incorporated such as nitrogen vacancies, Mg-H-N complexes and inversion domains. The high activation energy is a further obstacle for effective p-doping with hole concentrations $> 1 \cdot 10^{18}\ cm^{-3}$. We have investigated Mg incorporation in GaN in the range of 10^{19} to $10^{20}\ cm^{-3}$ as well as ex-situ activation and the influence of activation on LEDs. Variation of the Mg/III ratio showed a strong influence on the hole concentration. The lower limit is given by the n-type background doping below a II/III ratio of $15 \cdot 10^{-3}$ and the upper limit by compensating defects above a II/III ratio of $25 \cdot 10^{-3}$. The resulting growth window for p-doping is in good agreement with calculations and literature. Other growth parameters, such as V/III ratio, growth rate and growth temperature show lesser influence. Annealing studies at different temperatures show a lower limit for full activation at 600 °C.

HL 25.19 Mon 16:00 Poster D

Optimization of the internal and external quantum efficiency of high In content GaInN LED structures — •Fedor Alexej Ketzer, Holger Jönen, Ailun Zhao, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, TU Braunschweig

We investigate high indium content GaInN based light emitting diodes grown via low pressure MOVPE. The efficiency of such structures is rather small due to the high indium content. In order to improve the efficiency we study the growth of the p-doped GaN layer and rapid thermal annealing (RTA), needed to activate the p-dopants (Mg). Due to the high thermal load these processes influence the quantum well (QW) and therefore the internal quantum efficiency (IQE). These influences appear to raise with higher indium content.

For this purpose the IQE before and after RTA is compared with the external quantum effiency (EQE). Also conditions during RTA and growth of the layers following the QW were modified to examine changes in emission spectra and efficiency. The IQE was determined by temperature dependent photoluminescence and the EQE was determined by electroluminescence. With these results the growth conditions of the active region and their following layers can be optimized for high internal and external quantum efficiencies.

HL 25.20 Mon 16:00 Poster D

MBE growth and characterization of group III/N quantum dots on various templates — •Christopher Hein, Andreas Kraus, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, TU Braunschweig

Devices based on quantum dots are expected to overcome some of the limitations of quantum well based structures opening the way to applications such as laser diodes and single photon sources. Our experiments include RF MBE (Riber 32) grown self-organized group III/N dots using Stranski-Krastanov (SK) growth mode under metal rich conditions. Various templates including AlN were used with sapphire and SiC as substrates. Afterwards the dots were capped, allowing studies of the optical properties.

In situ RHEED reveals a dotty pattern indicating 3D island formation and therefore SK growth mode. AFM characterization of the samples hints at rough surface morphology with dot-like features. The structural properties were investigated with XRD. Concerning the AlN buffer layer XRD revealed an improvement for optimized growth conditions. The optical properties were investigated using a UV photoluminescence setup. We discuss PL studies of the samples as well as the optimization of dot formation via adjusted growth conditions.

HL 25.21 Mon 16:00 Poster D

Investigation of the incorporation of Mg as p-dopant in GaN grown by metal modulated epitaxy — •Thorsten Klein[1], Stephan Figge[1], Tomasz Krajewski[2], Marek Godlewski[2], and Detlef Hommel[1] — [1]Institute of Solid State Physics, University of Bremen, Germany — [2]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

Group III-nitrides are of high interest for use in optoelectronic devices such as light emitting diodes or laser diodes. However, one of the main challenges remains the growth of highly p-doped GaN:Mg to achieve higher efficiencies of such devices. In our work we present an approach of low-temperature GaN-growth by metal modulated epitaxy (MME) which was reported in the literature to strongly increase the doping level up to $4{\times}10^{19}\,\mathrm{cm}^{-3}$. During MME the metal shutters (Ga, Mg) are periodically opened and closed while the N-shutter remains constantly open. This method is used to optimize the incorporation of Mg into the structure while preserving a smooth surface. The growth takes place under metal-rich conditions and is monitored in-situ by RHEED. The substrate temperature is 550 °C. AFM investigations reveal RMS values of 1.9 nm. The surface shows holes with a depth of about 30 nm, in between them RMS values of 0.7 nm indicate an atomically flat surface. Hall effect measurements were performed to determine the doping level. Charge carrier densities up to $1.6{\times}10^{19}\,\mathrm{cm}^{-3}$ are achieved, which remain almost constant over a temperature range between 50 - 400 K. Activation energies of 10 - 12 meV as well as mobilities around $30\,\mathrm{cm}^2/\mathrm{Vs}$ indicate electron conductivity.

HL 25.22 Mon 16:00 Poster D

Implantation studies on silicon doped group-III nitride semiconductors — Ronnie Simon[1], •Reiner Vianden[1], and Klaus Köhler[2] — [1]Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn — [2]Fraunhofer Institut für angewandte Festkörperphysik, Freiburg

Silicon doped GaN layers grown by low-pressure metal-organic vapor-phase epitaxy with Si concentrations ranging from $2{*}10^{17}$ atoms/cm^3 to $9.2{*}10^{18}$ atoms/cm^3 were investigated by means of the perturbed angulat correlation (PAC) technique applied to implanted ^{111}In(Cd). An undoped GaN film is used as a reference. The Si-atoms replace Ga-atoms in the lattice and silicon, being a group-IV element, acts as a donor on the Ga-site and contributes one extra electron to the conduction band. Hall effect measurements confirmed that the free charge carrier density is essentially increased and of the order of the silicon concentration. PAC investigations of the annealing behavior after implantation of the ^{111}In probes shows that best recovery is achieved after annealing at 1200 K and that high silicon concentrations make GaN films more stable at high temperatures. Further, it was found that the temperature dependence of the electric field gradient is reduced by increasing Si concentrations.

HL 25.23 Mon 16:00 Poster D

External oxidation of GaN studied by Perturbed Angular Correlations — •Michael Steffens[1], Reiner Vianden[1], and Alberto Pasquevich[2] — [1]Helmholtz-Institut für Strahlen- und Kernphysik, Universität of Bonn, Bonn, Germany — [2]Departamento de Física, Facultad de Ciencias Exactas, UNLP, La Plata, Argentina

A sample of 7 μm GaN was heated in air at 1273 K in steps of 5 min for a total of 80 min. During this treatment, external oxidation of the sample occured. After each oxidation step, perturbed angular correlation measurements were performed at room temperature. The growth of the oxide will be discussed.

β-Ga_2O_3 can be used for transparent conductors or electronic devices. Thin films were already achieved with external oxidation, but the feasibility of these films for UV-photo diode production is largely reduced, possibly because of surface defects like oxygen vacancies [1].

The perturbed angular correlation (PAC) is an important tool to study point defects or lattice deformations in semiconductors. It is based on the hyperfine interaction between the intermediate state of a probe nucleus undergoing a γ-γ-cascade and an electric field gradient (EFG) generated by the electronic conditions in the sample. The strong dependence of the EFG to its origin makes PAC ideal for studies on the nanoscale.

[1] Weng et al., IEEE Sensors Journal, 11, 999 (2011)

HL 25.24 Mon 16:00 Poster D

Electrochemical characterization of Si- and Mg- doped GaN nanowire electrodes — •Jens Wallys[1], Florian Furtmayr[1,2], Jörg Teubert[1], Wladimir Schäfer[1], Jörg Schörmann[1], and Martin Eickhoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen — [2]Walter Schottky Institut, Technische Universität München

Recent progress in the field of GaN nanowire (NW) growth, in particular the possibility to realize both p- and n-type doping, suggest their

use as novel electrodes for chemical and biological sensors or in the field of photo catalysis. However, the knowledge about their electrochemical properties and the influence of doping is still very limited.

We investigated ensembles of undoped, Si-doped and Mg-doped GaN NWs with different doping concentrations and average diameters grown on Si (111) substrates by plasma assisted molecular beam epitaxy. The samples were analyzed using bias dependent electrochemical impedance spectroscopy measurements under physiological electrolyte conditions. By fitting the results to an equivalent circuit model the electronic properties of GaN NW ensembles could be extracted. According to these results a classification of the NWs into conducting and depleted ones is suggested and verified by cyclic voltamogramms in the presence of a redox couple and correlated to scanning electron microscope images.

HL 25.25 Mon 16:00 Poster D

Investigation of efficiency of blue and green GaN based LEDs — •Ailun Zhao, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik TU Braunschweig

GaN based light-emitting diodes (LEDs) have been attracting much attentions due to their promising and wide application in display and lighting during the past decades. In spite of significant improvements in their performance, there still remain many technical challenges impeding further applications of LEDs, an important one of which is the efficiency droop. The efficiency droop includes two aspects: one is the efficiency decreasing with increasing injection current and another is the decrease with longer wavelength. We grow blue and green LEDs strutures on sapphire substrate along c-direction by MOVPE. As we are mainly interested in effects related to the internal efficiency, simple on-wafer processing is used, providing small but fairly well-known extraction efficiency. The samples were characterized by electroluminescence. We investigated the series resistance, external quantum efficiency (EQE), efficiency droop and peak emission wavelength of our samples. We observe that, generally, LEDs showing strong efficiency droop also show a strong injection blue shift. We discuss the implications on the possible droop mechanism.

HL 25.26 Mon 16:00 Poster D

Current-injection and carrier confinement in InAlGaN ultraviolet light emitting diodes — •M.-A. Rothe, T. Kolbe, J. Stellmach, F. Mehnke, T Wernicke, P. Vogt, and M. Kneissl — Institute of Solid State Physics, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Ultraviolet (UV) light emitting diodes (LEDs) have attracted great interest in recent years because of their potential applications in phototherapy and sensing. However the external quantum efficiency (EQE) of these LEDs is only in low percentage range. One of the key challenges to improve the EQE is the carrier injection in to the active region. Therefore, an optimisation of the electron blocking layer (EBL) is very important to prevent an electron leakage into the p-layers of the LED with a simultaneous unhindered hole injection. In this work we have investigated 320 nm LEDs with different $Al_xGa_{1-x}N$:Mg EBLs. The devices were grown by metalorganic vapour phase epitaxy on (0001) sapphire substrates. A combination of electroluminescence measurements and simulations of the LED heterostructure were performed to investigate the carrier injection in the active region of the LEDs. We will compare LEDs with AlGaN EBLs with an aluminum content between 37 % and 48 % and show that the highest EQE is obtained for LEDs with an $Al_{0.44}Ga_{0.56}N$ EBL. This is in a good agreement with our simulation results. The temperature effect on the performance of LEDs with different EBLs is investigated by temperature dependent electroluminescence measurements which shows a clear influence of the temperature on the electron leakage current of the UV LEDs.

HL 25.27 Mon 16:00 Poster D

Performance Enhancement of InAlN/AlN GaN-HEMTs by using In-Situ SiN Passivation for High Temperature Applications — •Alexander Alexewicz[1], Paul Marko[1], Mohammed Alomari[2], Hannes Behmenburg[3,4], Christoph Giesen[3], Michael Heuken[3,4], Dionyz Pogany[1], Erhard Kohn[2], and Gottfried Strasser[1] — [1]TU Wien — [2]Universität Ulm — [3]AIXTRON SE, Herzogenrath — [4]RWTH Aachen

We present InAlGaN/AlN GaN high electron mobility transistors (HEMTs) with an optimized MOCVD-grown (metal organic chemical vapor deposition) SiN passivation, compared to the standard PECVD (plasma enhanced CVD)-SiN. Passivating the devices effectively reduces electronically active surface states, which can deteriorate the device performance drastically. In this work, GaN HEMTs are processed on SiC substrate with MOCVD-SiN passivation layers of different thicknesses (5 nm, 30 nm, no passivation). SiN is grown in the same run (in-situ) as the InAlGaN/AlN/GaN heterostructure, before the actual processing of the device, what enhances the interface quality by avoiding surface contamination before deposition of the passivation. The non-passivated devices show a maximum drain current of 0.8 A/mm in DC and 0.5 A/mm in pulsed mode at a gate voltage of 3 V. The 5 nm and 30 nm passivated devices exhibit an improvement of these values by 25 % and 50 % in DC, and 80 % and 140 % in pulsed mode, as well as a strongly reduced electron trapping related current collapse. Due to the better interface quality, this kind of passivation has great potential for high temperature device applications.

HL 26: Poster Session: Heterostructures - Preparation and Characterization - Impurities / Amorphous Semiconductors

Time: Monday 16:00–19:00 Location: Poster D

HL 26.1 Mon 16:00 Poster D

MOVPE growth of lattice-matched GaNP/Si(100) for photoelectrochemistry — •Oliver Supplie[1], Matthias M. May[1], Henning Döscher[1,2], and Thomas Hannappel[1,2,3] — [1]Helmholtz-Zentrum Berlin, Institut Solare Brennstoffe und Energiespeichermaterialien, D-14109 Berlin — [2]TU Ilmenau, Institut für Physik, Fachgebiet Photovoltaik, D-98693 Ilmenau — [3]CiS Forschungsinstitut für Mikrosensorik und Photovoltaik, D-99099 Erfurt

III-V dilute nitrides grown lattice matched on Si(100) are considered as a candidate for both hydrogen and oxygen evolution within one single photoelectrochemical tandem device. Heteroepitaxial GaP/Si(100) quasisubstrates combine high quality and inexpensive silicon technology on the one hand (with a band gap close to the optimum for tandem solar cell applications) and a high band gap III-V film with low lattice mismatch to Si on the other hand. Incorporation of N and As in GaP films allows band gap engineering [1] for higher absorbtion and perfect lattice matching to silicon.
We applied reflection anisotropy spectroscopy (RAS) in situ in vapor phase ambient to study both the surface preparation of Si(100), GaP/Si(100) and GaNP/Si(100) as well the growth of the GaNP films. We correlate RA spectra to UHV based surface science techniques accessible via a contamination-free transfer system. For instance, III- and V-rich surface terminations exhibit characteristic RA spectra corresponding to specific surface reconstructions measured with low energy electron diffraction.
[1] Wu et al., PRB **65**(2002)241303.; Geisz et al., EPVSEC **19**(2004).

HL 26.2 Mon 16:00 Poster D

Using of solid solution and rust of AlGaAs for creating optoelectronic devices — •Lia Trapaidze[1], Raphiel Chikovani[2], Gela Goderdzishvili[2], and Maia Jgenti[2] — [1]Dep. of Physics, Tbilisi State University, 3 Chavchavadze Ave 0128, Tbilisi, Georgia — [2]Dep. of Physics, Georgian Technical University, 77 Kostava 0175, Tbilisi, Georgia

Among the semoconductive devices one of the important are many elements indicators of light emission. High efficiency of indicators emission and increasing of quality elements was investigated. For increasing efficiency of indicators emission very perspective using heterostructures based on AlGaAs. It is recommended to use own thermal rust of GaAs and GaAlAs in the GaAs-AlAs heterostructures. Method of thermal treatment is very interesting to use in integral optics, because GaAs and GaAlAs has very important properties.

HL 26.3 Mon 16:00 Poster D

Laser-induced lattice distortions in III-V and II-VI quantum heterostructures — •Sebastian Tiemeyer[1], Michael Bombeck[2], Michael Paulus[1], Christian Sternemann[1], Florian J. Wirkert[1], Johannes Möller[1], Julia Nase[1], Oliver H. Seeck[3], Manfred Bayer[2], and Metin Tolan[1] — [1]Fakultät Physik / DELTA, TU Dortmund, D-44221 Dortmund, Germany — [2]Experimentelle Physik II, TU Dortmund, D-44221 Dortmund, Germany — [3]HASYLAB, DESY, D-22607 Hamburg, Germany

Optically excited low dimensional semiconductor heterostructures have shown strong evidence for lattice distortions triggered by exciton-phonon interactions. This effect was observed for the III-V group systems InAs/GaAs and InN/GaN by means of high resolution continuous wave or non-linear time-resolved optical spectroscopy. A local change in the lattice constant due to the creation of electron-hole pairs was as well monitored for II-VI quantum structures.

We have investigated the laser-induced lattice distortions in InAs/GaAs quantum dots and CdSe/CdS core/shell quantum rods by means of anomalous x-ray single crystal diffraction and x-ray powder diffraction, respectively. The presented data were collected at the beamlines BL9 (DELTA, TU Dortmund) and P08 (HASYLAB, DESY Hamburg).

HL 26.4 Mon 16:00 Poster D

The absorption spectra of PrSb2 thin films of golden colour — •Ia Trapaidze[1], Zaur Jabua[1], Iago Kupreishvili[1], Akaki Gigineishvili[1], Giorgi Iluridze[1], Tamaz Minashvili[1], and Ketevan Davitadze[2] — [1]Dep.of physics,GeorgianTechnical University,77 kostava,Tbilisi,Georgia — [2]Georgian Aviation University,Tbilisi,Georgia

Single-phase crystalline films of PrSb2 were prepared by vacuum thermal evaporation from two independence sources on various substrate. That is shown the temperature of Sb evaporator influence on colour and accordingly on valence of Pr ion of PrSb2 thin films. The films have golden, black and blue dark colour. Absorption spectra of golden colour of PrSb2 thin films were measured at 300 K and photon energy was 0.05-5.5 eV.

HL 26.5 Mon 16:00 Poster D

Noise spectroscopy of two-dimensional-electron systems in GaAs/AlGaAs heterostructures — •Berit Körbitzer[1], Pintu Das[1], Y. Ohno[2], H. Ohno[2], and Jens Müller[1] — [1]Goethe-Universität, Frankfurt am Main, Germany — [2]Tohoku University, Sendai, Japan

Because of their high mobility, two-dimensional-electron gases (2DEG) formed at the heterostructure interface of GaAs/AlGaAs are often used as high-resolution Hall magnetometers. Since the noise level has a considerable influence on the sensitivity of these sensors, it is important to study their noise characteristics. Therefore, we have investigated the low-frequency dynamics of charge carriers in such 2DEGs in the temperature range of 10 K to 300 K by using fluctuation spectroscopy. This technique allows to gain information about the energetics of different defects, as e.g. the well-known DX centers [1, 2].

In this work we have measured resistance and Hall-voltage noise as a function of the size of Hall structures, which were prepared by standard photolithography techniques. We will also discuss the dependence of the fluctuation properties on the gate voltage.

[1] Jens Müller et al., PRL **96**, 186601 (2006)
[2] Jens Müller et al., PRB **74**, 125310 (2006)

HL 26.6 Mon 16:00 Poster D

Investigation of the polarisation properties of the polariton emission — Steve Linke, •Steffen Richter, Chris Sturm, Helena Franke, Rüdiger Schmidt-Grund, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig, Germany

Strong light-matter coupling between excitons and photons leads to the formation of exciton-polaritons revealing a modified dispersion relation with respect to the pure excitonic or photonic ones. Stokes-vector analysis of the emission from non-resonantly excited exciton-polaritons in a ZnO-based microcavity was used to obtain information about their spin polarisation. The TE-TM splitting of the lower polariton branch (LPB) and the Stokes vector of its emission were investigated in angular-resolved photoluminescence spectra as a function of temperature and detuning.

Resulting from a large TE-TM splitting of the cavity mode, the LPB shows a separation of the two orthogonal linear polarisation states of up to 12meV. The splitting increases with more negative detuning, i.e. a more photonic-like character of the polaritons. The contribution of elliptical polarisation follows roughly the k-dependent behavior of the TE-TM splitting. It increases also with more negative detunings. This elliptically polarised contribution is most likely caused by coherent TE-TM state interactions and/or in a non-negligible coupling with the neighboring D^0X donor bound exciton. For a given detuning, the degree of circular polarisation decreases with increasing temperature, probably connected with a higher scattering rate into the ground state.

HL 26.7 Mon 16:00 Poster D

Electronmicroscopical preparation of nanowires grown perpendicular to the substrate without loss of orientation information — •Sally Riess[1,2], Martin Mikulics[1,2], Beata Kardynal[1,2], Anna Haab[1,2], Fabian Haas[1,2], Hilde Hardtdegen[1,2], and Detlev Grützmacher[1,2] — [1]Peter Grünberg Institut - 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology

The structural properties of nanowires and the templates they are attached to give insights into their formation process. It is therefore important to analyze the wires by transmission electron microscopy (TEM) without removing them from their initial position. To this end the nanowire samples need to be transparent to the electron beam and are therefore thinned down to a few tens of nanometers. They are filled up first with a preferably conductive material for mechanical stability. Thin lamellae are then prepared by focused ion beam methods (FIB). Usually metals are used as the filling material - a time consuming and complex procedure. Additionally the metals could unintentionally alter the sample and impair the investigation of other metals on the wires‘ surfaces. A fast and inexpensive alternative process to fill up the wires is by spin-coating the sample with a conductive polymer. We will present the development of this process as well as the result after optimization: a lamella with nanowires fully encompassed in conductive polymer produced in only a few minutes time. The method may also be employed in future in contacting schemes for nanowires.

HL 26.8 Mon 16:00 Poster D

Electronic and transport properties of In_2O_3 single crystals — •Valentina Scherer[1], Christoph Janowitz[1], Alica Krapf[1], Dorothee Braun[1], Helmut Dwelk[1], Klaus Irmscher[2], Zbigniew Galazka[2], and Recardo Manzke[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, Berlin, Germany — [2]Leibniz-Institut für Kristallzüchtung, Max-Born-Str. 2, Berlin, Germany

The macroscopic and microscopic electronic properties of high quality In_2O_3 single crystals grown by two methods, namely chemical vapor transport (CVT) and melt growth, were investigated. The temperature dependent transport properties such as resistivity and Hall coefficient were compared. Additionally the In_2O_3 crystals were annealed in oxygen flow for different time spans to study effects on the doping due to different oxygen contents. Subsequently the temperature dependent mobility and resistivity of the annealed crystals were compared. Furthermore the electronic properties of In_2O_3 crystals from the melt and from CVT growth were investigated using angle resolved photoemission (ARPES), enabling a comparison of the band structure. In_2O_3 crystals from both growth methods revealed very similar band structure with a very broad valence band and a partially filled conduction band (CB) at the Γ-point. The partially filled CB bent below the Fermi energy is characteristic of a degenerate semiconductor. Additionally the temperature dependence of the band structure and the band gap were determined by ARPES.

HL 26.9 Mon 16:00 Poster D

Preparation of donor doped $ZnO_{1-x}S_x$ layers and their application in hetero diode structures — •Achim Kronenberger, Julian Benz, Angelika Polity, Peter J. Klar, and Bruno K. Meyer — I. Physics Institute, Justus-Liebig-University, Heinrich-Buff-Ring 16, 35392 Giessen, Germany

The ternary system $ZnO_{1-x}S_x$ can be prepared without any miscibility gap by sputter deposition techniques. ZnO1-xSx shows a strong band gap bowing which is caused by variations of the energetic position of the valence and conduction band. This can be utilized to minimize or eliminate disturbing band offset effects in hetero structure solar cells or to control the emission energy of light emitting hetero diodes. In our work aluminum and gallium doped $ZnO_{1-x}S_x$ thin films were deposited from ceramic targets by radio frequency sputtering on glass, sapphire and p-type GaN substrates. Using oxygen as reactive gas

in the sputtering process allowed to adjust the composition of the alloy. We present our results on the structural, optical and electrical properties of the $ZnO_{1-x}S_x$ films and report on the performance of $ZnO_{1-x}S_x$/GaN hetero diodes.

HL 26.10 Mon 16:00 Poster D

Deposition and characterization of zincoxynitride — •Elisabeth A. Zolnowski, Johannes Bieber, Gunther Haas, Andreas Laufer, Sebastian Eisermann, Stefan Lautenschläger, and Bruno K. Meyer — I. Physikalisches Institut Giessen, Justus-Liebig-Universität, Heinrich-Buff-Ring 16, 35392 Giessen, DE-Germany

The first solely ZnO based light-emitting diode was produced in 2005 with PLD on $ScAlMgO_4$-substrates by the group of Tsukazaki et al. For special applications, like blue or ultraviolet diodes, p-type ZnO is necessary. But the acceptor doping of ZnO and the production in industrial scales and methods, like chemical vapor deposition (CVD), is still a current problem. A promising approach is to incorporate group V impurities into the ZnO lattice. Due to its ionic and covalent radii nitrogen seems to be the most promising candidate. Thus, we tried to deposit highly doped ZnO:N with a homebuilt CVD setup by varying the type of substrate, the substrate temperature, the oxygen precursor and its flow. We investigated the epitaxialy grown ZnO:N layers by secondary ion mass spectrometry (SIMS), raman spectroscopy and x-ray diffraction (XRD).

HL 26.11 Mon 16:00 Poster D

Thermally oxidized copper thin films — •Philipp Hering, Martin Becker, Philipp Schurig, and Bruno K. Meyer — 1. phys. Inst., JLU Giessen, Heinrich-Buff-Ring 16, 35392 Giessen

Cuprous oxide (Cu2O) constitutes, despite the relatively large band gap (2.17 eV), a very promising absorber material in photovoltaic devices due to the high absorption coefficient, non-toxicity and great abundance of the composing elements. To investigate high quality cuprous oxide films, copper was deposited on quartz substrates via sputtering and then oxidized in a controlled nitrogen/oxygen atmosphere at temperatures ranging from 800 to 1050 °C. The resulting film quality was analyzed by XRD, AFM and Raman measurements. Electrical properties were investigated with Hall and admittance measurements.

HL 26.12 Mon 16:00 Poster D

Cu_2O thin films grown by chemical vapour deposition — •Johannes Bieber, Sebastian Eisermann, Stefan Lautenschläger, Achim Kronenberger, Andreas Laufer, Gunther Haas, and Bruno K. Meyer — I. Physics Institute, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, DE-Germany

Today the world energy demand is mainly covered by limited resources, like oil, coal or gas. So it becomes more and more important to find an alternative, renewable energy source. Solar cells could be the solution or a part of it, when they are cheap, sustainable and clean. The p-type semiconductor cuprous oxide (copper(I) oxide, Cu_2O) with a direct band gap of 2.17 eV is a suitable candidate, because it is a cheap and nontoxic optoelectronic material system. The theoretical efficiency is approximately 23 % which makes it a possible candidate for a top cell in cascade solar cells. For that reason the aim of this study was to investigate the heteroepitaxial growth of cuprous oxide by CVD with different copper and oxygen precursors, various growth parameters and different substrates. The effects of different growth conditions on the crystalline, electrical, optical and vibrational properties as well as the incorporated impurities were examined.

HL 26.13 Mon 16:00 Poster D

Ab-initio phase diagram of the copper-oxygen system — •Bianca Eifert, Markus Heinemann, and Christian Heiliger — I. Physikalisches Institut, Justus Liebig University Giessen, D-35392, Germany

The different oxides of copper are of great interest as semiconductor materials, but it is experimentally challenging to produce the desired stoichiometry. The copper-oxygen system consists of metallic copper, gaseous oxygen and the three oxide phases cuprite (Cu2O), tenorite (CuO) and paramelaconite (Cu4O3). Full structural relaxations of all phases were performed employing first-principles density functional theory (DFT) calculations with different exchange-correlation functionals, and phase diagrams were constructed from these results. The *ab-initio* approach allows us to examine phases at chemical potentials at which they are not thermodynamically stable in order to better understand the energetic situation of the system.

HL 26.14 Mon 16:00 Poster D

Hall Mobility Measurements on Amorphous Phase-Change Materials — •Matthias Kaes, Hanno Volker, and Matthias Wuttig — I. Physikalisches Institut (IA), RWTH Aachen, 52056 Aachen

Phase-change materials (PCMs) exhibit a rapid crystallization of their amorphous phase and a related change in electrical conductivity of several orders of magnitude. Studies of the electronic structure in the crystalline phase have revealed a surprising tendency of quasibinary PCM alloys $(GeTe)_x(Sb2Te3)_{1-x}$ to display a disorder-induced metal-insulator transition ([1]). In contrast, the study of electronical properties of amorphous-phase change materials has, so far, been confined to the study of DC-conductivity and photoconductivity, which have revealed p-type conduction as well as the presence of deep defects and shallow defects in the mobility gap ([2]).

Here, we present Hall measurements on amorphous quasibinary PCM-alloys employing an AC-Hall technique. Modulating not only the external magnetic field but also the voltage applied on the sample, an excellent signal to noise ratio can be achieved. The extracted Hall mobilities are anomalously signed and in the range of 0.1 cm^2/Vs at 300 K. In addition, the Hall mobility increases with temperature and displays stoichiometric trends. The results are discussed in light of two-channel and small-polaron transport models.

[1] T. Siegrist et al., Nature Materials 10, p. 202-8 (2011).
[2] J. Luckas et al., Journal of Applied Physics 110, p. 013719 (2011).

HL 26.15 Mon 16:00 Poster D

Electronic and optical properties of amorphous semiconductors: a-SiO_2 and a-TiO_2 bulk, solid solution, and interface — •Marc Landmann[1], Thomas Köhler[2], Eva Rauls[1], Thomas Frauenheim[2], and Wolf Gero Schmidt[1] — [1]Lehrstuhl für Theoretische Physik, Universität Paderborn, 33095 Paderborn — [2]Bremen Center for Computational Materials Science, Universität Bremen, 28359 Bremen

Both titania (TiO_2) and silica (SiO_2) are oxides whose extraordinary physical and chemical properties are demonstrated by manifold traditional fields of application. For gaining a basic estimation of the technological potential of SiO_2/TiO_2 hybrid materials a detailed understanding of the electronic and optical properties of such materials is required. Here, we have calculated the electronic structure and optical response of the SiO_2 and TiO_2 crystalline and amorphous bulk [1,2], solid solution, and interface. The calculations have been done by standard (PBE) and hybrid (HSE06) exchange-correlation functional density-functional theory (DFT). The HSE06 hybrid functional's suitability to correct for a large part of the DFT intrinsic band gap underestimation and to give a reliable approximation of quasiparticle properties is demonstrated. The optical spectra are calculated in independent particle approximation (IPA) from the DFT band structure and compared to existing experimental data.

[1] M. Landmann et al., submitted to PRB (2011).
[2] M. Landmann et al., to be published.

HL 27: Photovoltaics: Innovative Material Systems

Time: Tuesday 9:30–11:00 Location: ER 270

HL 27.1 Tue 9:30 ER 270

Iron based photovoltaic devices: $FeSi_2$ and FeS_2 from first principles — •Timo Schena, Pengxiang Xu, Gustav Bihlmayer, Markus Betzinger, Martin Schlipf, Christoph Friedrich, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany

Photovoltaic devices are one of the most attractive power supplies for the future. To expand their proliferation and guarantee long-term power supply, we explore the possibility to move away from CdTe or In-based cells by researching solar cells from abundant materials as, for example, Fe, Si, S, Zr, Cu.

In this talk we present first-principles results for the electronic structure of the semiconductors β-$FeSi_2$ and the pyrite structure of FeS_2. The calculations have been performed with the `FLEUR` code [www.flapw.de], based on density-functional theory using a full-potential linearized augmented-plane-wave basis set. The bulk structure is examined with different exchange-correlation functionals (LDA, PBE, HSE, PBE0, EXX), also including a one-shot GW calculation, carried out with the `SPEX` code, for describing quasi-particle energies, from which the dielectric function can be extracted. To determine the most stable surface configurations for future calculations, various surfaces of different crystallographic orientations and terminations are compared in energy. We gratefully acknowledge funding from BMBF of the NADNuM project 03SF0402A.

HL 27.2 Tue 9:45 ER 270

Colloidal zinc oxide nanoparticles in organic and hybrid photovoltaic applications — •Sebastian Wilken, Dorothea Scheunemann, Verena Wilkens, Holger Borchert, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, Carl-von-Ossietzky-Str. 9-11, 26129 Oldenburg, Germany

In recent years, zinc oxide (ZnO) reached much interest in photovoltaics as a low cost, non-toxic and easy to process n-type semiconductor with a large band-gap of about 3.3 eV. Here, we present a detailed study of wet chemically derived colloidal ZnO nanorods (NRs) with a length and width of about 20 nm and 8 nm, respectively. Homogeneous nanoparticular films, deposited by solution-based techniques, were widely characterized using electron microscopy, X-ray diffraction, optical spectroscopy, and cyclic voltammetry.

As one possible application, we present inverted indium tin oxide-free polymer/fullerene solar cells based on poly(3-hexylthiophene) with an electron-selective interlayer of ZnO NRs, incorporated between the cathode and absorber layer. In the case of an aluminum/chromium cathode a strong increase in power conversion efficiency was achieved compared to cells without interlayer. We attribute this result to optimized contact properties and an enhanced symmetry breaking. Furthermore, we show that our ZnO NRs are also suitable as acceptor material in hybrid polymer/nanoparticle solar cells.

HL 27.3 Tue 10:00 ER 270

Insights into the growing mechanism of electrocrystallised ZnO — •Miriam Schwarz, Karolis Parfeniukas, and Veit Wagner — School of Engineering and Science, Jacobs University Bremen, Campusring 1, D-28759 Bremen (Germany)

Hybrid approaches to solar cells, offer the combined advantage of high mobilities of inorganics with tailored design of organic / polymeric materials in one device. A well designed inorganic scaffold is desired in which the organic material can be embedded. This scaffold requires on one hand, a dense inorganic layer as blocking layer at the interface to the cathode, on the other hand, rods of a high aspect ratio and proper spacing on top to offer a large interface to the organic material. Such well designed hybrid solar cells are expected to outperform fully organic photovoltaics by minimizing tortuous pathways for charges to the appropriate electrodes, typical for organic devices. In this context, we report on the morphological control of crystalline ZnO deposited by electrochemistry at low temperatures (< 100 °C). We relate the time dependent deposition current of the main deposition parameters to certain stages of ZnO growth. Since nucleation occurs extremely fast, the first few seconds (< 15 s) are of special interest. Thus, the analysis of the growing mechanism reveals a rather weak voltage and a strong temperature and concentration dependence. Consequently, tuning the temperature and concentration allows to design the crystal density and shape of the ZnO nanostructures for appropriate hybrid solar cell application.

HL 27.4 Tue 10:15 ER 270

Radiative recombination in kesterite Cu2ZnSnS4 single crystals — •Sergej Levcenko[1], Viktor Tezlevan[1], Ernest Arushanov[1], Susan Schorr[2], and Thomas Unold[2] — [1]Institute of Applied Physics, Academy of Sciences of Moldova, Chisinau, MD 2028, Moldova — [2]Helmholtz Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany

Among the quaternary chalcogenides, Cu2ZnSnS4 (CZTS) semiconductor has attracted much attention due to their potential photovoltaic application. A recent record conversion efficiency value of 8.2% has been achieved on CZTS-solar cell devices [1]. Although there are a number of studies discussing the development of thin film CZTS based solar cells, there are only a few reports concerning the basic material properties of CZTS. Here, we report a detailed study on the emission properties of the CZTS single crystals by photoluminescence (PL) spectroscopy. CZTS single crystals were grown by chemical vapor transport technique using iodine as a transport agent. At low temperature the PL spectrum shows one broad asymmetric band peaked at around 1.29 eV. Temperature and excitation intensities dependences of the PL band indicate that it is due to a free to bound recombination type recombination mechanism that involves a free electron and a trapped hole in the acceptor state with an activation energy of 150 meV. We attribute this acceptor level to Cu on Zn antisite defects.

[1] B. Schin, O. Gunawan, Y. Zhu, N.A. Bojarczuk, S. J. Chey, S. Guha, Prog. Photovolt: Res. Appl. (2011).

HL 27.5 Tue 10:30 ER 270

Radiative recombination in Cu_2ZnSnS_4 thin films with varying composition — •Steffen Kretzschmar, Sergej Levcenco, Justus Just, Bjoern Schubert, and Thomas Unold — Helmholtz-Zentrum Berlin, Institut für Technologie, Hahn-Meitner Platz 1, 14109 Berlin

The quarternary compound Cu_2ZnSnS_4 may be used as an absorber material for thin film solar cells. Although current conversion efficiencies are much lower than for $Cu(In, Ga)Se_2$-based solar cells, 8.4% have been demonstrated recently. Currently, little is known about the optical and electronic properties of this materials, in particular about defects and radiatiative recombination behaviour. In this work Cu_2ZnSnS_4 thin films with widely varying composition, grown by co-evaporation, are investigated by photoluminescence spectroscopy. At low temperature shallow and deep transitions are observed. By temperature and intensity dependent measurements the nature of these transitions are identified.

HL 27.6 Tue 10:45 ER 270

Tiefenprofilierung von Fremdphasen in Cu_2ZnSnS_4 mit winkelaufgelöster Röntgenabsorptionspektroskopie — •Justus Just[1,2], Thomas Unold[2], Dirk Lützenkirchen-Hecht[1], Steffen Kretzschmar[2], Ole Zander[2] und Ronald Frahm[1] — [1]Bergische Universität Wuppertal — [2]Helmholtz-Zentrum-Berlin, Institut für Technologie E-I3

Cu_2ZnSnS_4 (CZTS) in Chalkopyrit-verwandter Kesterit-Struktur bietet sich als alternatives Absorbermaterial für Dünnschichtsolarzellen an. Alle enthaltenen Elemente bzw. deren Verbindungen sind ungiftig und zur Genüge in der Erdkruste enthalten. CZTS und dessen strukturverwandte Fremdphasen werden mittels Nahkanten-Röntgenabsorptionsspektroskopie (XANES) bezüglich ihrer elektronischen Struktur nahe der Leitungsbandkante untersucht. Dies ermöglicht u. A. eine quantitative Identifikation von Fremdphasen in den mittels Ko-Verdampfung hergestellten Dünnschichten. Durch Messung der Röntgenabsorptionsfeinstruktur bei unterschiedlichen Einfallswinkeln wird unter Ausnutzung der Selbstabsorption von Röntgenstrahlung in der Probe eine Tiefenprofilierung von Fremdphasen möglich. Messungen an Probenserien unterschiedlichen Fremdphasengehaltes zeigen Oberflächenfremdphasen, die einige nm dick sind und den Heteroübergang zwischen Absorber und Puffer signifikant beeinflussen können.

HL 28: Focus Session: Topological Insulators (jointly with MA, TT)

Time: Tuesday 9:30–10:30 Location: ER 164

HL 28.1 Tue 9:30 ER 164

Edge channel mixing in HgTe/HgCdTe Quantum point contacts — •Mathias J. Mühlbauer, Timo Wagner, Philipp Leubner, Christopher Ames, Christoph Brüne, Hartmut Buhmann, and Laurens W. Molenkamp — Physikalisches Institut (EP3), Universität Würzburg, 97074 Würzburg, Germany

In this project we study the properties of Quantum Point Contacts (QPCs) that were fabricated in HgTe/HgCdTe high mobility inverted quantum well structures, using e-beam lithography and dry-etching techniques. However, the realization of QPCs in these structures is not trivial due to the narrow band gap and the presence of the Quantum Spin Hall Effect (QSHE) [1]. We demonstrate that these structures are controllable using top gate electrodes and confirm this by low temperature conductance measurements at 4 K and 1.8 K, which indicate steps in $2e^2/h$. The residual conductance in these measurements can be explained by the helical Quantum Spin Hall edge channels which are still present during the transition from the n-conducting region to the p-conducting part. Deviations of ideal conductance plateau values could be explained with the changing transmission probability due to the mixing of these channels because of their finite extension [2].

[1] M. König, S. Wiedmann, C. Brüne, A. Roth, H. Buhmann, L. W. Molenkamp, X-L. Qi, S. C. Zhang, Science, 318, 766, (2007).

[2] Zhou, B., Lu, H-Z., Chu, R-L., Shen, S-Q. & Niu, Q., Phys. Rev. Lett. 101, 246807 (2008)

HL 28.2 Tue 9:45 ER 164

Topological surface states in a strained three-dimensional HgTe — •Elena G. Novik[1], Chaoxing Liu[1], Christoph Brüne[1], Ewelina M. Hankiewicz[2], Hartmut Buhmann[1], Shoucheng Zhang[3], and Laurens W. Molenkamp[1] — [1]Physikalisches Institut (EP3), University of Würzburg, 97074 Würzburg — [2]Institut für Theoretische Physik und Astrophysik, University of Würzburg, 97074 Würzburg — [3]Department of Physics, McCullough Building, Stanford University, Stanford, California 94305-4045, USA

Three-dimensional (3D) HgTe is a semimetal which is charge-neutral when the Fermi energy is at the touching point between the light-hole and heavy-hole Γ8 bands at the Brillouin zone center. With applied strain a gap of about 20 meV opens up between the light-hole and heavy-hole bands, so that strained 3D HgTe is expected to be a 3D topological insulator with Dirac-like surface states [1]. In most of 3D topological insulators the observation of surface charge transport is obscured by the bulk conductivity. The voltage applied to the gate on top of the HgTe structure allows the suppression of the bulk transport contribution, thus only the surface electrons can be accessed in transport when the Fermi energy is shifted into the gap. The self-consistent calculations of the band structure and density of states for a strained HgTe layer have been done for different values of the gate voltage.

[1] C. Brüne et al. Phys. Rev. Lett. 106, 126803 (2011).

HL 28.3 Tue 10:00 ER 164

Induced superconductivity in the surface state of mercury telluride (HgTe) — •Luis Maier, Daniel Knott, Christopher Armes, Christoph Brüne, Philipp Leubner, Jeroen Oostinga, Hartmut Buhmann, and Laurens W. Molenkamp — Physikalisches Institut (EP3), Universität Würzburg, 97074 Würzburg

It has been recently shown that the strained epitaxial growth of bulk HgTe layers opens a band gap in the normally semi-metallic material [1]. This means that strained HgTe meets all prerequisites of a topological insulator, i.e. surface states and an insulating bulk, which does not contribute to transport measurements. The interfaces between topological insulators and superconductors are especially interesting due to the possibility of creation and detection of majorana fermions [2].

Our current work is focussing on investigating contacts between strained HgTe and Nb as a superconducting material. First results show proximity effect and multiple sub gap features which will be discussed in detail.

[1] C. Brüne et al. Phys. Rev. Lett. 106, 126803 (2011)

[2] L. Fu and C. L. Kane, Phys. Rev. Lett. 100, 096407 (2008)

HL 28.4 Tue 10:15 ER 164

Cyclotron resonance of two-dimensional Dirac fermions in HgTe-based quantum well structures — Z.D. Kvon[1,2], S.N. Danilov[3], D.A. Kozlov[1,2], •C. Zoth[3], N.N. Mikhailov[1], S.A. Dvoretsky[1], V.V. Bel'kov[4], and S.D. Ganichev[3] — [1]Institute of Semiconductor Physics, Novosibirsk, Russia — [2]Novosibirsk State University, Novosibirsk, Russia — [3]Terahertz Center, Rgensburg, Germany — [4]Ioffe Institute, St. Petersburg, Russia

We report on the observation and investigation of cyclotron resonance (CR) of one-valley two-dimensional Dirac fermions in HgTe-based quantum well (QW) structures [1]. Terahertz photoconductivity was measured in (013)-grown QWs with widths of 6.4 and 6.6 nm, which are close to the critical thickness, when the band structure changes from normal to inverted. We show that these QWs are characterized by a linear energy dispersion and, consequently, by nonequidistant Landau levels. Our experiments show a shift by a factor of three of resonance position to smaller magnetic fields in comparison to larger QW widths having a parabolic energy spectrum. Moreover, our data demonstrates that the CR position changes by a factor of three upon variation of carrier density. This observation provides a further proof for nonequidistant Landau levels in our samples. The role of fluctuations of structure parameters, such as QW thickness and magnitude of impurity potential is discussed.

[1] Z.D. Kvon, S.N. Danilov, D.A. Kozlov *et al.*, *Pis'ma ZhETF* **94**, 895 (2011) (*JETP Lett.* in print)

HL 29: III-V Semiconductors I (mainly Nitrides)

Time: Tuesday 9:30–12:30 Location: EW 201

HL 29.1 Tue 9:30 EW 201

Coupled LO-Phonon-Plasmon Modes in Si- and Ge-doped GaN — •Max Bügler[1], Stephanie Fritze[2], Armin Dadgar[2], Alois Krost[2], and Axel Hoffmann[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Berlin, Germany — [2]Otto-von-Guericke-Universität Magdeburg, Institut für Experimentelle Physik, Magdeburg, Germany

Results of Raman spectroscopy on highly silicon and germanium doped GaN epilayers showing longitudinal-optical phonon-plasmon coupled modes are presented. Micro-Raman spectroscopy allows for spatially resolved probing of carrier concentration without the need to process electrical contacts. While it is inherently challenging to achieve high carrier concentrations ($>5{\cdot}10^{19}\mathrm{cm}^{-3}$) in GaN by doping with Si, doping with Ge allows for carrier concentrations up to at least $2{\cdot}10^{20}\mathrm{cm}^{-3}$ without deterioration of the layers surface and crystalline quality. Raman spectroscopy is utilized to determine spatial fluctuations in the incorporation of Si and to proof homogeneity of doping by Ge. Results on films with carrier concentrations ranging from $3{\cdot}10^{18}\mathrm{cm}^{-3}$ to $6{\cdot}10^{19}\mathrm{cm}^{-3}$ for Si-doping and up to $2{\cdot}10^{20}\mathrm{cm}^{-3}$ for Ge-doping are presented. The observed dependence of the LPP^--mode position on the carrier concentration is discussed and compared to theoretical predictions. To support the interpretation of the Raman results photoluminescence and photoluminescence excitation spectroscopy experiments are presented and discussed.

HL 29.2 Tue 9:45 EW 201

Influence of electron beam annealing on the structural and optical properties of GaN:Mg — •Christian Nenstiel[1,3], Marc Hoffmann[2,3], Trevor Manning[3], Gordon Callsen[1], Ramon Collazo[2], James Twiedie[2], Zlatko Sitar[2], Matthew Phillips[3], and Axel Hoffmann[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Germany — [2]North Carolina State University, Materials Science and Engineering, USA — [3]University of Technology Sydney, Department of Physics and Advanced Materials, Australia

The chemical and structural origin of the in Magnesium doped GaN observed donor acceptor pair transitions (DAP) is not yet fully understood. Furthermore, the dynamics of Hydrogen during the commonly applied thermal activation process of MOCVD grown GaN:Mg are still a matter of active debate. To investigate these questions we grew 700 nm thick GaN:Mg layers. The samples exhibit Magnesium concentrations from 5E17 to 2E19 cm-3 and thermal annealing was before between 450 and 650 °C. Under electron beam exposure in CL measurements at 10 K we observed an increase of the intensity of the DAP luminescence until saturation after a few seconds which is then followed by rather complex shifting and quenching dynamics of the DAP luminescence. Additionally, we observed the quenching of acceptor bound excitons over time. None of these effects can be observed by Photoluminescence measurements , not even in the high excitation regime which allows us to derive electron beam induced technologically relevant dynamics of Hydrongen in GaN:Mg.

HL 29.3 Tue 10:00 EW 201

Surface states and band alignment of polar and nonpolar InN films studied by in-situ photoelectron spectroscopy — •Marcel Himmerlich, Anja Eisenhardt, and Stefan Krischok — Institut für Physik and Institut für Mikro- und Nanotechnologien, TU Ilmenau, PF 100565, 98684 Ilmenau, Germany

The chemical and electronic properties of (0001), (000$\bar{1}$), (1$\bar{1}$00) and (11$\bar{2}$0) InN surfaces are analysed for stoichiometric and metal-rich growth conditions. Thin InN films were grown by PAMBE on GaN/Al_2O_3(0001), GaN/6H-SiC(000$\bar{1}$) and m/a-plane bulk GaN substrates, respectively, and characterised in-situ using XPS and UPS. The energy distance between surface valence band maximum and Fermi level (VBM-E_F) as well as the work function are dependent on crystal orientation. In general, In-rich growth leads to the formation of In adlayers which reduce VBM-E_F and result in the existence of a broad band of electron states inside the band gap. For stoichiometric (000$\bar{1}$), (1$\bar{1}$00) and (11$\bar{2}$0) InN surfaces, the band bending is strongly reduced compared to the (0001) configuration, pointing to nearly flat band conditions. The InN(0001) surface exhibits an In-induced (2×2) reconstruction and a surface state at the Fermi edge is detected, while for the growth on the other crystallographic orientations, no superstructure was formed and the occupied surface states are located at the valence band edge. The trends of variation of the surface band alignment as well as the observed occupied states agree with results of DFT calculations by D. Segev and C. G. Van de Walle (Europhys. Lett. 76, 305 (2006) & J. Appl. Phys. 101, 081704 (2007)).

HL 29.4 Tue 10:15 EW 201

Non-linear piezoelectric polarization in III-V semiconductors — •Pierre-Yves Prodhomme, Annie Beya-Wakata, and Gabriel Bester — Max-Planck Institut, Stuttgart, Deutschland

Piezoelectricity can be important for the electronic and optical properties of quantum well and quantum dots based devices such as lasers, light emitting diodes, infrared photodetectors. In particular it has been shown to be important in III-V and nitride semiconductors. The piezoelectric effect in quantum Well or in Quantum Dots is usually taken into account by neglecting the non linear term in the piezoelectric tensor. We have calculated the second order piezoelectric tensor for all the III-V (including the nitrides) semiconductors in the Wurtzite and Zincblende structure. And we have derived a relation between the proper and the improper second order piezoelectric coefficients. This relation is used to calculate the proper coefficients which are the experimentally measurable ones. We have calculated the piezoelectric field in several Quantum wells and compare our values to experiment. We show that the second order can be so large for Zinc-Blende materials that it cancels the first order term, we demonstrate also that for Nitrides this effect is much lower. However we show that for severely strained structure such as quantum dots or thin films, the second order piezoelectric effect can even exceed the spontaneous polarization in the nitrides.

HL 29.5 Tue 10:30 EW 201

Understanding and controlling In incorporation on InGaN surfaces: An ab initio approach — •Andrew Duff, Liverios Lymperakis, and Jörg Neugebauer — Max-Planck-Institut für Eisenforschung GmbH, Max-Planck-Straβe 1, 40237 Düsseldorf, Germany.

A first step in achieving full control on the growth and properties of {000$\bar{1}$} (N-polar) InGaN surfaces is to gather a fundamental understanding of the relevant atomistic surface processes as well as to identify and investigate the differences in the growth of the N-polar face compared to the {0001} (Ga-polar) face. In this work, the incorporation of In into N- and Ga-polar surfaces is investigated using density functional theory (DFT) calculations. Total energies for an extensive range of reconstructions on the technologically relevant Ga-polar and N-polar surfaces are calculated and surface phase diagrams are constructed showing the most stable structures as a function of growth conditions. A substantially stronger binding for In adlayer/s and In adlayer/s with sub-surface In is found for N-polar compared to Ga-polar. Kinetic DFT calculations are also performed to address the competing effect of In segregation, with the surface segregation effect found to be weakest for the N-polar surface. Based on these results, the mechanisms of In incorporation, In segregation and also the self surfactant effect will be discussed in detail.

HL 29.6 Tue 10:45 EW 201

Excitonic effects and optical properties of $In_xGa_{1-x}N$ and $In_xAl_{1-x}N$ alloys: A first-principle study — •Luiz Claudio de Carvalho, Jürgen Furthmüller, and Friedhelm Bechstedt — Institüt für Festkörpertheorie und -optiK, Max Wien Platz 1, 07743 Jena, Germany

Optical properties of group-III nitrides and of their alloys are of increasing interest. This holds especially for the emission properties in the so called green gap. A much deeper understanding of the interplay of clustering and composition fluctuations on the optical properties is needed. Random alloy and many-body theory can give an important contribution. In the present work, the optical properties and excitonic effects of wurtzite $In_xX_{1-x}N$ (X = Ga, Al) alloys and those of the end components are studied using a combination of methods. The alloys are described within the cluster expansion approximation. The optical spectra and the underlying excitonic effects are studied using a state-of-the-art treatment of the quasiparticle electronic structure and the solution of the Bethe-Salpeter equation (BSE). Explicitly we use the Vienna Ab-initio Simulation Package (VASP) in order to compute the electronic structure for each local cation fraction. Based on the electronic structures, the BSE is solved and the optical absorption spectra, exciton binding energies, and electron-energy-loss spectra are computed and compared with available experimental data. At least, two different cluster statistics are investigated.

Coffee Break (15 min)

HL 29.7 Tue 11:15 EW 201

MOVPE growth of semi-polar GaN LED structures on planar Si(112) and Si(113) substrates — •Roghaiyeh Ravash, Armin Dadgar, Anja Dempewolf, Peter Veit, Thomas Hempel, Jürgen Bläsing, Jürgen Christen, and Alois Krost — Otto-von-Guericke-Universität Magdeburg, Institut für Experimentelle Physik, Fakultät für Naturwissenschaften,Universitätsplatz 2, 39106 Magdeburg, Germany

We present semi-polar GaN LED structures grown on non-patterned Si(112) and Si(113) substrates by MOVPE to improve light emitter efficiency. The samples were investigated by X-ray diffraction measurements, photoluminescence (PL), cathodoluminescence (CL) as well as field emission scanning electron microscopy (FE-SEM). In samples, which were simultaneously grown on Si(112) and Si(113), we observed that structures on Si(112) consist of a relatively smooth surface but those on Si(113) have a V-pit dominated surface with a three dimensional growth mode of the GaN layers resulting in a rough GaN surface. The low temperature CL spectra of the sample grown on Si(112) exhibit a dominant InGaN/GaN MQWs emission. But CL spectra of the MQWs grown on Si(113) show two peaks related to the rough surface resulting in inhomogeneous indium incorporation and / or thickness fluctuations in the MQWs. For an optimized sample grown on Si(113), the surface undulation of a first GaN layer is strongly reduced obtaining a LT-AlN interlayer nearly parallel to the substrate surface. There, CL measurements show only one dominant MQWs emission.

HL 29.8 Tue 11:30 EW 201

Surface atomic arrangements of polar (000-1) and semipolar (11-22) InN layers. — •Daria Skuridina, Sabine Alamé, Duc Dinh, Michael Kneissl, and Patrick Vogt — TU Berlin, Institute of Solid State Physics, Hardenbergstr. 36, EW6-1, 10623 Berlin, Germany

InN surface studies and their related electronic properties still lack a fundamental understanding, despite their great technological rele-

vance. We performed surface studies on N-polar (000-1) InN layers grown directly on (0001) sapphire and semipolar (11-22) InN layers grown on (11-22) GaN templates by MOVPE. Morphology, atomic structure and surface symmetry of InN samples were measured by scanning tunneling microscopy (STM) and low energy electron diffraction (LEED), respectively. Moreover, Auger electron spectroscopy was used for chemical composition analysis of the layers. The oxidized surfaces were annealed at 450°C under UHV conditions resulting in a significant reduction of the surface carbon and oxygen contaminations. Single atomic steps were observed on the clean (000-1) InN surface. Surface reconstruction (1x1) was observed by LEED and confirmed by the atom-resolved STM image. Scanning tunneling spectroscopy showed a metallic behavior on the N-polar InN that is in good agreement with predicted metal adlayer on the surface. The atomic arrangement of (11-22) InN layers showed no evidence of dimers or adatoms on the surface but the presence of In monolayer in agreement with the calculations by Yamashita et al. [1].

[1] Yamashita et al., Jpn. J. Appl. Phys. 48, 120201, (2009)

HL 29.9 Tue 11:45 EW 201

Growth of (20$\bar{2}$1) AlGaN, GaN and InGaN by metal organic vapor phase epitaxy — •S. Ploch[1], T. Wernicke[1], J. Rass[1], M. Pristovsek[1], M. Weyers[2], and M. Kneissl[1,2] — [1]TU Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin — [2]Ferdinand-Braun-Institut Leibniz Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

Green InGaN-based laser diodes on (20$\bar{2}$1) GaN substrates have recently demonstrated performances exceeding those of conventional (0001) oriented devices. However little is known regarding the growth parameters. We have investigated growth of AlGaN, GaN and InGaN on (20$\bar{2}$1) GaN substrates by MOVPE. Smooth GaN layers with a rms roughness <0.5 nm were obtained by low growth temperatures and reactor pressures. The layers exhibit undulations along [10$\bar{1}$4] similar to the GaN substrate. AlGaN and InGaN layers exhibit an increased surface roughness. Undulation bunching was observed and attributed to reduced adatom surface mobility due to the binding energy of Al and the low growth temperature for InGaN respectively or strain relaxation. AlGaN and InGaN heterostructures on (20$\bar{2}$1) GaN relax by layer tilt accompanied by formation of misfit dislocations, due to shear strain of the unit cell. This relaxation mechanism leads to a reduced critical layer thickness of (20$\bar{2}$1) AlGaN layers and InGaN multi quantum wells (MQW) in comparison to (0001). PL spectral broadening of 230 meV of (20$\bar{2}$1) InGaN single QWs emitting at 415 nm can be reduced by increased growth temperature or increased number of QWs with reduced thickness.

HL 29.10 Tue 12:00 EW 201

Active region design and MOVPE growth of UV–B light emitting diodes — •F. Mehnke, J. Stellmach, T. Kolbe, M.-A. Rothe, C. Reich, T. Wernicke, M. Pristovsek, and M. Kneissl — Institute of Solid State Physics, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The external quantum efficiency of AlGaN–based ultraviolet (UV) light emitting diodes (LED) decreases with shorter emission wavelength. This is attributed to a higher defect density, carrier localization, increased magnesium acceptor ionization energy and an enhanced incorporation of impurities.

We studied the influence of active region and electron blocking layer (EBL) design on the injection efficiency. UV LEDs were grown by metalorganic vapour phase epitaxy (MOVPE) in a spectral range between 320 nm and 290 nm. The devices were characterized by electro– and photoluminescence spectroscopy and XRD. With increasing aluminium content in the active region i.e. decreasing emission wavelength we observe for an $Al_{0.6}Ga_{0.4}N$ EBL a decrease of output power and increase of p–side luminescence. This indicates decreasing injection–efficiency due to a lower effective barrier height of the EBL. We will discuss the effect of the barrier height and magnesium doping on the injection efficiency and compare the results with 1D–drift–diffusion simulation.

HL 29.11 Tue 12:15 EW 201

Crystal field investigations of rare earth doped aluminum nitride — •Ulrich Vetter[1], Tristan Koppe[1], Takashi Taniguchi[2], John B. Gruber[3], Gary W. Burdick[4], and Hans Hofsäss[1] — [1]2. Physikalisches Institut, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen — [2]National Institute for Materials Science, Namiki 1 - 1, Tsukuba, Ibaraki 305-0044, Japan — [3]Department of Physics and Astronomy, The University of Texas at San Antonio, San Antonio, 4 Texas 78249-0697, USA — [4]Department of Physics, Andrews University, Berrien Springs, Michigan 49104-0380, USA

Aluminum nitride belongs to the most promising semiconducting rare earth hosts due to its large band gap of around 6.2 eV and its high thermal conductivity, thus showing properties which make it useful for high power light emitting devices. In this work we are comparing the optical properties of aluminum nitride doped with rare earths during high-temperature, high-pressure synthesis to aluminum nitride doped by ion implantation, in detail considering the crystal field analyses for selected rare earth ions. Additionally the influence of co-doping with e.g. oxygen and fluorine on the optical properties of the host matrix and the rare earth intra-4f electron transitions is discussed, together with issues regarding electrical contacts.

HL 30: ZnO and Relatives I

Time: Tuesday 9:30–11:15 Location: EW 202

HL 30.1 Tue 9:30 EW 202

Resonant phonon and exciton dynamics in ZnO — •Markus R. Wagner[1,2], Juan Sebastian Reparaz[1], Ronny Kirste[1], Gordon Callsen[1], Christian Thomsen[1], Axel Hoffmann[1], and Matthew R. Phillips[2] — [1]Institute of Solid State Physics, Technische Universitaet Berlin, Berlin, Germany — [2]Department of Physics and Advanced Materials, University of Technology Sydney, Sydney, Australia

The optical transitions and dynamics of excitons, phonons, and defects in ZnO are reviewed. The influence of resonant and non-resonant excitation on the decay dynamics of phonons and excitons is studied. A strong resonance enhancement of the second order LO Raman modes is observed for excitation energies in resonance with the dominating bound exciton states. This enhancement is caused by the wave vector dependent Fröhlich interaction which leads to a pronounced coupling of excitons with LO phonons. Time resolved energy dispersive luminescence and Raman measurements enable the differentiation between the resonantly enhanced coherent Raman process and the non-coherent luminescence process. It is shown that the 2LO phonon lifetime greatly depends on the excitation energy and is mainly governed by the lifetime of the real excitonic state under resonant excitation reaching lifetimes of up to 200ps. In addition, temperature dependent time resolved measurements demonstrate that the dissociation of bound excitons at elevated temperatures correlates with a decrease of the resonantly enhanced lifetime of the 2LO Raman modes.

HL 30.2 Tue 9:45 EW 202

Surface band gap of non-polar ZnO(11-20) cleavage surfaces determined by scanning tunneling spectroscopy — •Philipp Ebert[1], Aizhan Sabitova[1], Andrea Lenz[2], Sarah Schaafhausen[1], Lena Ivanova[2], Mario Daehne[2], Axel Hoffmann[2], Rafal E. Dunin-Borkowski[1], and Holger Eisele[2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Germany

The energetic position of intrinsic surface states and the size of the surface band gap on non-polar ZnO surfaces are highly debated. Therefore, we investigated the electronic properties of ZnO(11-20) cleavage surfaces by scanning tunneling microscopy. Since all previous STM measurements were done on sputter and annealed surface having high defect concentrations, we focus on highly stepped cleavage surface. Scanning tunneling spectroscopy yields that in addition to the classical tunnel current arising from electrons tunneling out or into the valence and conduction bands, respectively, a significant defect-related tunnel current exists. The defect related tunnel current arises from step-induced gap states that lead to an apparent narrowing of the band gap. The measurements indicate that no intrinsic surface states are in the fundamental band gap and the surface band gap is identical to the bulk band gap.

HL 30.3 Tue 10:00 EW 202

Spin noise spectroscopy on ZnO — •Hauke Horn[1], Andrea Balocchi[2], Xavier Marie[2], Andrey Bakin[3], Andreas Waag[3], Jens Hübner[1], and Michael Oestreich[1] — [1]Institute for Solid State Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover, Germany — [2]INSA-CNRS-UPS, LPCNO, Université de Toulouse, 135 Av. de Rangueil, 31077 Toulouse, France — [3]Institut für Halbleitertechnik, Technische Universität Braunschweig, Hans-Sommer-Straße 66, 38106 Braunschweig, Germany

We measure the fluctuating magnetization noise of an ensemble of localized donor electrons in ZnO with high sensitivity spin noise spectroscopy. The measurement technique allows us to probe the equilibrium spin dynamics of our sample by nearly dissipation free, below band gap Faraday rotation. In our measurements an additional magnetic field applied in Voigt geometry modulates the spin noise signal with the Larmor frequency $\omega_L = g^* \mu_B B/\hbar$ where g^* is the electron g–factor, μ_B the Bohr magneton and B the magnetic field.

We probe the Faraday rotation noise of the equilibrium donor electron spins. The T_2^* time is shortened to 20 ns due to the inhomogeneous hyperfine interaction. This HF interaction becomes negligible when a longitudinal magnetic field is applied and hence the T_1 (and T_2) time becomes measurable. We further investigate the effects of laser light excitation on the spin dynamics of free electrons and reveal clear differences between intrinsic spin lifetime measurements and excitation effects.

HL 30.4 Tue 10:15 EW 202

Patterned growth of ZnO nanopillars on GaN — •Manfred Madel[1], Mohamed Fikry[2], Ingo Tischer[1], Benjamin Neuschl[1], Uwe Röder[1], Martin Feneberg[1], Tobias Meisch[2], Frank Lipski[2], Dominik Heinz[1], Martin Dickel[1], Robert Leute[2], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institut für Quantenmaterie / Gruppe Halbleiterphysik, Universität Ulm — [2]Institut für Optoelektronik, Universität Ulm

Well ordered arrays of ZnO nanopillars are grown on GaN layers. For the patterning we employ self-assembling polystyrene (PS) spheres, laser interference, and photo lithography. As a patterning mask a thin layer of SiO_2 is deposited onto the epitaxial GaN layer. Using selective reactive ion etching, holes in the SiO_2 layer are created, through which ZnO nanopillars are grown by CVD. For spacings in the 250nm range laser interference lithography and evaporation of Ti as a growth mask is used. To get nanopillars with homogeneous distances of several μm, GaN pyramids are first grown in hexagonal arrangements using photolithography. In a subsequent ZnO growth process, one single nanopillar on each pyramid could be generated. The nanopillars have diameters between 200 and 800nm and uniform length up to 5μm. Very good crystal perfection and excellent structural definition is shown in SEM characterization as well as in PL, CL, and HRXRD measurements.

HL 30.5 Tue 10:30 EW 202

Photoluminescence studies on zinc oxide surfaces modified with ultrashort pulses — •Andreas Schneider, Kathrin Sebald, and Tobias Voss — Institute of Solid State Physics, University of Bremen, Bremen, Germany

Ultrashort laser pulses can be used to modify the surface morphology of semiconductors resulting in improved properties for applications such as solar cells and photodiodes. Recent studies showed that the modified surface layer can drastically change its absorption characteristics. This is generally attributed to the formation of defects and the transformation of single-crystalline to amorphous and polycrystalline material.

We have applied ultrashort laser pulses to crystalline ZnO wafers in order to change the surface morphology. The influence of variable laser fluences and applied number of laser pulses on the surface structures is identified by scanning electron microscopy. Multi-pulse interaction with the surface layer near its ablation threshold leads to the formation of laser-induced periodic ripples out of the planar sample. In addition, the impact of laser ablation under ambient N_2, O_2 and medium vacuum atmospheres on the optical properties is studied. The dominant exciton recombination line observed is the donor bound I_4 line. Upon varying the laser parameters the peak is broadened and shifted to lower energies. This is accompanied by an overall decrease of the integrated PL intensities. Different line broadening and peak shift mechanisms in the band edge emission must be considered and will be discussed. Finally, the effect of post annealing of fs-laser processed samples on photoluminescence will be presented.

HL 30.6 Tue 10:45 EW 202

Oxygen-controlled photoconductivity in hybrid ZnO-nanowire/CdSe-quantum-dot devices — •dongchao hou, apurba dev, and tobias voss — Semiconductor Optics, Institute of Solid State Physics, University of Bremen

Modern nanotechnology has interest in the assembly and study of hybrid structures composed of different materials that offer enhanced properties or achieve new functions through the interactions between different constituents. We built a hybrid assembly using ZnO nanowire (NW) arrays decorated with colloidal CdSe quantum dots (QDs) which has a potential application in photovoltaics. QDs were synthesized with an aqueous precipitation method and stabilized with mercaptopropionic acid (MPA), through which the QDs are chemically linked to the nanowire surface. A dense and clustered coating of the QDs on the ZnO nanowire surface was achieved via partial removal of the MPA stabilizers. The photoconductivity of this NW/QD assembly was investigated in multiple gas environments using an argon laser to selectively excite electron-hole pairs in the QDs. The photoconductivity was significantly enhanced under laser irradiation. The enhancement achieved in vacuum was more than 6-fold higher than in air. The operation mechanism involving electron transfer between the QDs and the nanowires as well as the surface oxygen desorption was analyzed, which reveals that the passivation of the QD surface defects by oxygen adsorption has significant influence on the relaxation and transfer dynamics of the photo-excited electrons in QDs.

HL 30.7 Tue 11:00 EW 202

Biofunctionalization of ZnO Nanowires for DNA sensing applications — •Slowik Irma[1], Barbara Seise[2], Christian Leiterer[2], Raphael Niepelt[1], Ulrich Schröder[2], Davide Cammi[1], Wolfgang Fritzsche[2], and Carsten Ronning[1] — [1]Friedrich-Schiller-Universität, Jena, Deutschland — [2]Institut für Photonische Hochtechnologie, Jena, Deutschland

Reliable and efficient identification of DNA is a major goal in modern medical diagnostics. Here, we present a promising alternative approach to conventional fluorescence labeled DNA sensors. Bottom up fabricated ZnO nanowires were chemically modified to attach probe DNA on the surface of the nanowire. Successful binding and hybridization with the complementary DNA was shown using fluorescence labeled target DNA. Due to the quasi-one-dimensional geometry of the nanowires and the large surface-to-volume ratio, surface-induced effects can have a big impact on the electrical transport properties. Changes in surface composition that occur during absorption of molecules lead to significant changes in nanowire conductivity. The effect can be utilized to create an electrical device out of biofunctionalized nanowires for label-free specific sensing of biomolecules with high sensitivity. Electrical contacting of the nanowires can be conducted either by photolithography or dielectrophoresis.

HL 31: Invited Talk: Clemens Rössler

Time: Tuesday 9:30–10:00 Location: EW 203

Invited Talk HL 31.1 Tue 9:30 EW 203

Quantum structures on ultra clean electron gases — •Clemens Rössler, Stephan Baer, Thomas Ihn, Klaus Ensslin, Christian Reichl, and Werner Wegscheider — Solid State Physics Laboratory, ETH Zurich, 8093 Zurich, Switzerland

Since the first observation of the quantum Hall effect, the quality and the mobility of two-dimensional electron gases (2DEGs) have undergone tremendous improvements. 2DEGs defined in $Al_xGa_{1-x}As$ heterostructures can reach mobilities exceeding $\mu = 10^7\,cm^2/Vs$ at low temperatures, facilitating the observation of fascinating phenomena like the microwave-induced zero-resistance states, the $\nu = 5/2$ quantum Hall state, and interactions between composite fermions.

We investigate the transport properties of nano structures fabricated in high-mobility 2DEGs. Quantum point contacts (QPCs) profit from a strongly suppressed disorder potential, giving rise to the appearance of transport features that are obscured in standard 2DEGs. Within these conceptually simple structures, we find already a rich variety of effects like the 0.7-feature, enhanced g-factors and Aharonov-Bohm interference between edge channels forming near the QPCs. By combining two QPCs, we define quantum dots and Fabry-Perot interferometers which are investigated in the (fractional) quantum Hall regime.

HL 32: Transport Properties I (mainly Spin Physics and Magnetic Fields)

Time: Tuesday 10:00–13:15 Location: EW 203

HL 32.1 Tue 10:00 EW 203

A quantized 5/2 state in a two-subband electron system — •Johannes Nuebler[1], Benedikt Friess[1], Vladimir Umansky[2], Bernd Rosenow[3], Moty Heiblum[2], Klaus von Klitzing[1], and Jurgen Smet[1] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart — [2]Braun Centre for Semiconductor Research, Weizmann Institute of Science, Rehovot, Israel — [3]Institute for Theoretical Physics, University of Leipzig

We investigate the fractional quantum Hall effect in wide quantum well heterostructures with tunable electron density. In contrast to previous measurements [1] we observe that upon population of the second subband the two subbands show independent quantum Hall states [2]. In particular, the fully quantized 5/2 state of the lower subband is surprisingly unaffected by the presence of the additional second subband electron system whose density we can vary over a wide range. We use tilted magnetic fields to modify the subband interaction.

[1] J. Shabani et al., Phys. Rev. Lett. 105, 246805 (2010).
[2] J. Nuebler et al., accepted for publication in PRL.

HL 32.2 Tue 10:15 EW 203

Interaction-Induced Huge Magnetoresistance in a High Mobility Two-Dimensional Electron Gas — •Lina Bockhorn[1], Aida Hodai[1], Igor V. Gornyi[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover — [2]Institut für Nanotechnologie, Forschungszentrum Karlsruhe, 76021 Karlsruhe

We study magneto transport in a high mobility two-dimensional electron gas (2DEG). Hall geometries are created by photolithography on a GaAs/GaAlAs quantum well containing a 2DEG. The 2DEG has an electron density of n_e=3.1·10^{11}cm^{-2} and a mobility of μ_e=11.9·10^{6}cm^2/Vs at a temperature of 1.5 K. We observe a strong negative magnetoresistance at zero magnetic field. In lowering the electron density the magnetoresistance gets more pronounced and reaches values of more than 300 % [1]. We demonstrate that the negative magnetoresistance consists of a small peak induced by a combination of at least two types of disorder [2] and a huge magnetoresistance explained by the interaction correction to the conductivity for mixed disorder [3,4]. The huge magnetoresistance vanishes for increasing the temperature from 100 mK to 800 mK while the small peak remains unchanged.

[1] L. Bockhorn *et al.*, Phys. Rev. B 83, 113301 (2011)
[2] A. D. Mirlin *et al.*, Phys. Rev. Lett. 87, 126805 (2001).
[3] I. V. Gornyi and A. D. Mirlin, Phys. Rev. Lett. 90, 076801 (2003)
[4] I. V. Gornyi and A. D. Mirlin, Phys. Rev. B 69, 045313 (2004)

HL 32.3 Tue 10:30 EW 203

Magnetotransport of (Zn,Mn)Se:Cl under hydrostatic pressure — •Steve Petznick[1], Michael Hetterich[2], and Peter J. Klar[1] — [1]Institute of Experimental Physics I, Justus-Liebig University of Giessen, Germany — [2]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), Germany

As material n-doped MBE-grown (Zn,Mn)Se:Cl on an undoped (100) GaAs substrate was used. The manganese concentration of the 1050 nm thick layer was about 2 % and the carrier concentration at room temperature was $n = (4.3 \pm 0.3) \cdot 10^{17}\,\mathrm{cm}^{-3}$. For the hydrostatic pressure experiments the sample was mounted in a clamp pressure cell. For different pressure values between 0 and 16.5 kbar transport measurements were obtained at different temperatures between 1.6 K and 280 K in Van der Pauw geometry and in applied magnetic fields up to 10 T.

The dependence of the magnetoresistance and the carrier concentration are shown and discussed. The splitting of the spin-up and spin-down states hinders the hopping conductivity between the donor states and results in a high magnetoresistance at low temperatures. Moreover, at high pressure a sudden decrease of the carrier concentration is observed. It is likely that this behavior is due to carrier trapping, which occurs when the band gap is in resonance with inner d-shell transitions of the Mn^{2+} ions.

HL 32.4 Tue 10:45 EW 203

Ultrafast Spin Noise Spectroscopy — •Hendrik Kuhn, Fabian Berski, Jan G. Lonnemann, Petrissa Zell, Jens Hübner, and Michael Oestreich — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover

Semiconductor spin noise spectroscopy (SNS) has evolved as a powerful experimental technique to explore the dynamics of carrier spins close to thermal equilibrium [1]. However, with the standard continous-wave (cw) laser probing scheme the detectable temporal spin dynamic is limited by the bandwidth of the photoreceiver. We advance SNS to detection bandwidths of several hundred gigahertz by replacing cw probe light with light from two ultrafast oscillators. The two oscillators are mode-locked with an adjustable phase which enables subsequent scanning of the temporal spin correlations via below band gap Faraday rotation. Our first measurements on highly n-doped (10^{17} cm^{-3}) bulk GaAs perfectly demonstrate the feasibility of SNS for spin lifetimes down to the order of a few ten picoseconds without the loss of information. These measurements pave the way for future experiments where optical excitation poses an obstacle for the detection of the true spin dynamics.

[1] G. M. Müller, M. Oestreich, M. Römer and J. Hübner, Physica E 43, 569 (2010).

HL 32.5 Tue 11:00 EW 203

Top Gates for InAs/InAlGaAs Heterostructures — •Jens S. Kienitz[1], Lasse Cornils[1], Till Benter[1], Christian Heyn[1], Katrin Groth[1], Dirk Reuter[2], Andreas Wieck[2], Ulrich Merkt[1], and Jan Jacob[1] — [1]Universität Hamburg, Institut für Angewandte Physik, Jungiusstraße 11, 20355 Hamburg — [2]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44780 Bochum

The intrinsic spin-Hall effect allows filtering of the electron spins in quasi one-dimensional electron systems. However the spin-Hall effect is only effective when the occupation of the transport modes is restricted to a small number. Hence control of the electron density is decisive. At the same time it is mandatory to keep the electron mobility high and to leave the spin-orbit coupling constant or to tune it in a precise and reproducible way. At liquid helium temperatures we determine from the Shubnikov-de Haas effect and the Hall effect the densities, the mobilities and the Rashba spin-orbit parameters [1] of electrons in InAs/InAlGaAs heterostructures with metallic top gates. The top gates are evaporated on insulating hydrogen silsesquioxane layers spun before onto the semiconductors. Our investigation includes InAs/InAlGaAs heterostructures with different innate electron densities and mobilities. The thickness of the InAlAs capping layer above the conducting InAs channel and the thickness of the insulating layer are also varied. [1] A. D. Wieck et al., Phys. Rev. Lett. **53**, 493 (1984)

Coffee Break (15 min)

HL 32.6 Tue 11:30 EW 203

Strain and Electric Field Control of the Spin-Dynamics in GaAs/AlGaAs Quantum Wells — •David English[1], Peter Eldridge[3], Jens Hübner[1], Richard Harley[2], and Michael Oestreich[1] — [1]Institute for Solid State Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover, Germany — [2]School of Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, UK — [3]Foundation for Research and Technology, IESL, PO Box 1527, 71110, Heraklion, Crete, Greece

We measure by spin quantum beat spectroscopy the anisotropy of the electron Landé g-factor and the spin relaxation rate, Γ^s, in (001) AlGaAs/GaAs quantum wells. The anisotropy is either induced by an applied electric field, applied strain or an asymmetrically grown quantum well. The anisotropy of g and Γ^s are produced by different microscopic mechanisms. In general an anisotropic g-factor implies an asymmetric conduction electron wavefunction, whereas the anisotropic spin relaxation rate requires a non-zero expectation value of the valence band potential gradient on the conduction band states. Therefore, a comparison of the two in-plane anisotropies provides insight into the effects on the band edges induced by the different perturbations.

We find that an electric field generates anisotropy of both g and Γ^s. However, it is shown that an asymmetric potential produces anisotropy in g but not Γ^s while the opposite occurs for strain which induces an in-plane anisotropy of Γ^s but leaves the g-factor isotropic. Therefore, we unambiguously reveal the different microscopic mechanisms of the three perturbations.

HL 32.7 Tue 11:45 EW 203

Electron Transport in Side-Gated Quantum-Point Contacts on InAs/InAlGaAs Heterostructures — •Jens S. Kienitz[1], Hauke Lehmann[1], Christian Heyn[1], Dirk Reuter[2], Andreas D. Wieck[2], Ulrich Merkt[1], and Jan Jacob[1] — [1]Universität Hamburg, Institut für Angewandte Physik, Jungiusstraße 11, 20355 Hamburg — [2]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44780 Bochum

Quantum-point contacts exhibiting conductance quantization of quasi one-dimensional electron systems have been studied extensively in GaAs/GaAlAs heterostructures [1], but not so in InAs/InAlGaAs heterostructures. The spin-orbit interaction in InAs is much stronger than in GaAs. Thus for applications in spintronics InAs is the material of choice. Nevertheless spin-dependent phenomena are only visible when few or just one transport modes contribute. In order to be able to count the number of occupied transport modes, well-defined conductance steps are mandatory. We define quantum-point contacts by side gates of different widths along InAs quantum wires and of different distances to these wires. Transport measurements at different temperatures between 15 mK and 4 K in high magnetic fields are presented. They hint at a stronger quantization for lower temperatures and higher magnetic fields. [1] B. van Wees et al., Phys. Rev. Lett. **60**, 848 (1988)

HL 32.8 Tue 12:00 EW 203

Dyakonov-Perel electron spin relaxation in a wurtzite semiconductor: From the nondegenerate to the highly degenerate regime — •Jörg Rudolph[1], Jan Heye Buss[1], Sebastian Starosielec[1], Arne Schaefer[1], Fabrice Semond[2], and Daniel Hägele[1] — [1]AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, Bochum, Germany — [2]Centre de Recherche sur l'Hétéro-Epitaxie et ses Applications, Valbonne, France

The doping density dependence of the electron spin lifetime in n-type semiconductors gives insight into the interplay between spin-orbit coupling, phase space filling and momentum scattering. We measure electron spin lifetimes in bulk n-type GaN as a prototypical semiconductor with wurtzite structure by time-resolved Kerr-rotation spectroscopy for a wide range of doping densities from 5×10^{15} to 1.5×10^{19} cm^{-3}. The spin lifetime follows a non-monotonic density dependence with a maximum at the onset of degeneracy. The maximum is found to shift toward higher densities for increasing lattice temperature. The additional determination of momentum scattering times in the degenerate regime allows for a direct comparison to an analytical expression for the density-dependent spin relaxation tensor for wurtzite semiconductors. Quantitative agreement is found up to the highest densities without any fitting parameter.[1]

[1] J. H. Buß *et al.*, Phys. Rev. B **84**, 153202 (2011)

HL 32.9 Tue 12:15 EW 203

Electrical Spin Injection into Semiconductor Nanowires — •Sebastian Heedt[1,3], Isabel Wehrmann[1,3], Torsten Rieger[1,3], Kamil Sladek[1,3], Daniel Bürgler[2,3], Detlev Grützmacher[1,3], and Thomas Schäpers[1,3,4] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, 52425 Jülich, Germany — [3]JARA-Fundamentals of Future Information Technology — [4]II. Physikalisches Institut, RWTH Aachen, 52056 Aachen, Germany

In order to drive a spin-polarized current into InAs nanowires prepared in a bottom-up approach, ferromagnetic injector and detector electrodes are deposited onto the semiconductor structures. To ensure a well-defined magnetization axis a novel contact preparation process has been conceived employing hydrogen silsesquioxane resist in order to planarize the nanowires. By means of doping and the application of a gate voltage the carrier concentration in the nanowires can be controlled. The spin accumulation is probed in a four terminal non-local measurement geometry. To this end, controlling the interface resistance between the ferromagnet (Co) and the nanowire is of outmost importance. Native indium oxide is removed by in situ Ar^+ sputtering. Subsequently an ultra-thin layer of Al_2O_3 (or MgO respectively) is evaporated in order to overcome the conductivity mismatch between the semiconductor beneath and the ferromagnetic metal above the tunnel barrier. A further unequivocal evidence of spin injection is aspired by measuring the dephasing of the injected spin ensemble in a Hanle setup.

HL 32.10 Tue 12:30 EW 203

Interplay of spin and orbital magnetogyrotropic photogalvanic effects in InSb-based quantum wells — •Sebastian Stachel[1], Peter Olbrich[1], Christina Zoth[1], Ursula Hagner[1], Thomas Stangl[1], Cynthia Karl[1], Peter Lutz[1], Vasily Bel'kov[2], Leonid Golub[2], Steve K. Clowes[3], Tim Ashley[4], Adam M. Gilbertson[5], and Sergey D. Ganichev[1] — [1]Terahertz Center, University of Regensburg, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia — [3]Advanced Technology Institute and SEPNet, University of Surrey, UK — [4]School of Engineering, University of Warwick, UK — [5]Blackett Laboratory, Imperial College, UK

Here we report on the observation and detailed study of the magnetic-field induced photocurrents in n-doped InSb/InAlSb quantum wells (QWs). We show that the intraband absorption of terahertz radiation in QWs causes a *dc* electric current in the presence of an in-plane magnetic field. While at moderate magnetic fields B the photocurrent depends linear on B, at high magnetic fields it becomes nonlinear and inverses its sign. The generation of this current is analyzed in terms of electron gas heating and asymmetric scattering in k-space [1]. We show that due to the narrow gap, strong magnetic proberty and strong spin-orbit coupling this effect is substantially enhanced compared to other III-V materials. It is demonstrated that the strong nonlinear behavior is due to a nonlinear Zeeman spin splitting. [1] V.V. Belkov and S.D. Ganichev, Sem. Sci. Tec. **23**, 114003 (2008)

HL 32.11 Tue 12:45 EW 203

Exchange interaction of electrons with Mn in hybrid AlSb/InAs/ZnMnTe structures — •P. Olbrich[1], C. Zoth[1], Ya. V. Terent'ev[2], V. V. Bel'kov[2], C. Drexler[1], V. Lechner[1], P. Lutz[1], M. S. Mukhin[2], S. A. Tarasenko[2], A. N. Semenov[2], V. A. Solov'ev[2], G. V. Klimko[2], T. A. Komissarova[2], S. V. Ivanov[2], and S. D. Ganichev[1] — [1]University of Regensburg, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia

Here we report on the fabrication an investigation of Manganese modulation doped structures with an InAs two-dimensional electron gas (2DEG) channel. The quantum wells were grown applying III-V/II-VI "hybrid" technique and Mn layers have been inserted into the II-VI barrier. To explore the magnetic properties of the 2DEG we investigated spin polarized electric currents induced by microwave (mw) and terahertz (THz) radiation [1]. Our measurements show that hybrid AlSb/InAs/(Zn,Mn)Te QWs are characterized by enhanced magnetic properties which can be changed by tuning of the spatial position of the Mn-doping layer as well as by the variation of temperature. We demonstrate that the exchange interaction is due to penetration of the electronic wave function into the (Zn,Mn)Te layer and can be controllably varied by the position and density of Mn^{2+} ions [2].

[1] S. D. Ganichev *et al.*, *Phys. Rev. Lett.* **102**, 156602 (2009)
[2] Ya. V. Terent'ev *et al.*, *Appl. Phys. Lett.* **99**, 072111 (2011)

HL 32.12 Tue 13:00 EW 203

Realization of a persistent spin helix in InGaAs/InAlAs quantum wells — •V. Lechner[1], M. Kohda[2], Y. Kunihashi[2], J. Nitta[2], L.E. Golub[3], V.V. Bel'kov[3], K. Richter[1], D. Weiss[1], C. Schönhuber[1], I. Caspers[1], P. Olbrich[1], and S.D. Ganichev[1] — [1]University of Regensburg, Germany — [2]Tohoku University, Sendai, Japan — [3]Ioffe Institute, St. Petersburg, Russia

Here we report on the realization of the persistent spin helix in InAs quantum wells (QWs) hosting a two dimensional electron gas. The sample consists of a 4 nm wide $In_{0.53}Ga_{0.47}As$ QW with $In_{0.52}Al_{0.48}As$ barriers and was grown strain free on a (001)-oriented InP substrate. A persistent spin helix can emerge if the $\boldsymbol{k}$-linear Rashba and Dresselhaus spin orbit interactions are of equal strength ($\alpha = \beta$). The realization of

this condition has been proved by magneto-transport measurements, where the transition from weak anti-localization to weak localization and back to weak anti-localization was observed under a variation of the gate voltage. This result was confirmed by measurements of the anisotropy of THz radiation induced photocurrents, the circular photogalvanic and the spin-galvanic effect, applying the methods of [1]. Via these methods the relative strength of α and β was estimated in a wide temperature range from 5 K up to room temperature. We also analyzed the importance of the $\boldsymbol{k}$-cubic Dresselhaus terms.

[1] S. Giglberger et al., Phys. Rev. B **75**, 035327 (2007).

HL 33: Ge/Si II

Time: Tuesday 9:30–11:15 Location: EW 015

HL 33.1 Tue 9:30 EW 015

Ion-beam mixing in crystalline and amorphous germanium isotope multilayers — •M. Radek[1], H. Bracht[1], R. Kube[1], M. Posselt[2], and B. Schmidt[2] — [1]WWU Münster — [2]HZDR

Self-atom mixing induced by Gallium (Ga) implantation in crystalline and amorphous germanium (Ge) is investigated using an isotopic multilayer structure of alternating ^{73}Ge and ^{nat}Ge layers grown by molecular beam epitaxy. The distribution of the implanted Ga atoms and ion-beam induced depth-dependent mixing was determined by means of the secondary ion mass spectroscopy (SIMS). The position and form of the implanted Ga peak is very similar in the amorphous and crystalline Ge and can be reproduced accurately by computer simulations based on binary collision approximation (BCA), whereas the ion-beam induced self-atom mixing strongly depends on the state of the Ge structure. The data from SIMS-measurements reveal a stronger mixing in the crystalline than in the amorphous Ge. Atomistic simulation based on BCA can reproduce the experimental data only if unphysically low displacement energies are assumed. The low displacement energies deduced within the BCA approach are confirmed by experiments with mixing induced by silicon implantation. The disparity observed in the ion-beam mixing efficiency of crystalline and amophous Ge indicates different dominant mixing mechanisms. We propose that self-atom mixing in crystalline Ge is mainly controlled by radiation enhanced diffusion during the early stage of mixing before the crystalline structure turns into an amorpous state, whereas in an already amoprhous state self-atom mixing is mediated by cooperative diffusion events.

HL 33.2 Tue 9:45 EW 015

A hydrogen-related luminescence band in p- and n-type germanium — •Matthias Allardt, Vladimir Kolkovsky, and Jörg Weber — Technische Universität Dresden, 01062 Dresden, Germany

The present work focuses on the photoluminescence (PL) studies in hydrogen-plasma treated p- and n-type germanium. After DC hydrogen plasma treatments in the temperature range 80 - 150 °C a new hydrogen-related luminescence band at 723 meV was observed in p- and n-type germanium. The intensity of the band decreases rapidly with temperature and disappears at around 15 K. No shift of the band was detected in the samples with different shallow impurities. The origin of the luminescence band will be discussed.

HL 33.3 Tue 10:00 EW 015

Probing local strain and composition in Ge nanowires by means of tip-enhanced Raman scattering — •Juan S. Reparaz[1,2], Niculina Peica[1], Ronny Kirste[1], Alejandro R. Goñi[2,3], Gordon Callsen[1], Markus R. Wagner[1], Maria I. Alonso[2], Miquel Garriga[2], I. Carmen Marcus[2], Isabelle Berbezier[4], Jannina Maultzsch[1], Christian Thomsen[1], and Axel Hoffmann[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, u o a 10623 Berlin, Germany — [2]Institut de Ciència de Materials de Barcelona-CSIC, Esfera UAB, 08193, Bellaterra, Spain — [3]ICREA, Passeig Lluís Companys 23, 08010 Barcelona, Spain — [4]IM2NP, CNRS - Univ. Aix Marseille, Campus St. Jèrôme, Case 142, 13397 Marseille Cedex 20, France

In this work we investigate local strain and composition in Ge nanowires using tip-enhanced Raman scattering (TERS). We will mainly focus on the influence of the tip on the NW's Raman spectrum, showing that the electromagnetic field enhancement due to the TERS effect allows to probe the local composition and strain in these nanostructures. A close comparison with what can be achieved using micro-Raman will be discussed, showing the great advantages of TERS over conventional far-field optical techniques. As a striking result we will show the presence of local vibrational modes (LVMs) of the GeGe mode in the presence of a Au rich enviroment which acts as catalyst for the NWs growth, are only observed using TERS. Finally, the dependence of strain and composition with the position along the NWs will be presented.

HL 33.4 Tue 10:15 EW 015

Electrical characterization of Ge nanodomes via AFM based techniques — •Markus Kratzer[1], Christian Prehal[1], Maria Rubezhanska[2], Sergey Kondratenko[3], Yury Kozyrev[2], and Christian Teichert[1] — [1]Institute of Physics, Montanuniversität Leoben, Franz Josef Straße 18, 8700 Leoben, Austria — [2]O.O. Chuiko Institute of Surface Chemistry, National Academy of Sciences of Ukraine, Kiev, Ukraine — [3]National Taras Shevchenko University, Physics Department, Kiev, Ukraine

Low-dimensional nanostructures like nanodots, nanowires, and nanodomes (NDs) have attracted scientific interest due to their potential application in electronics, optoelectronics, and photovoltaics. In this work, we report on the electrical characterization of single Ge nanodomes utilizing conductive atomic force microscopy (C-AFM), photoconductive AFM (PC-AFM), and Kelvin Probe force microscopy (KPFM). The Ge NDs were grown on Si(001) by means of molecular beam epitaxy (MBE) under ultra-high vacuum (UHV) conditions. The AFM measurements were performed under ambient conditions in dark and under illumination. Two-dimensional current maps revealed a higher conductivity of the NDs compared to the surrounding. Conductivity variations within single NDs could be observed, which will be discussed with respect to ND facets and strain-induced changes in the local density of states. Current-to-voltage (IV) measurements on individual NDs revealed a dependence of the IV characteristics on the ND size. Support in the framework of the Ukrainian-Austrian Project M/139-2007 is acknowledged.

HL 33.5 Tue 10:30 EW 015

Focused ion beam induced damage in germanium and synthesis of free-standing germanium nano-webs — •Rupert Langegger, Alois Lugstein, and Emmerich Bertagnolli — Institute of Solid State Electronics, Floragasse 7, A-1040, Vienna, Austria

Efficient light emitters compatible with standard CMOS technology have been a subject of research for more than a decade. The influence of strain and doping concentration on the efficiency of the luminescence in germanium has been already studied. To further comprehend processes in nanoscale regime we intensively investigated germanium under various conditions.

Germanium was irradiated with focussed Ga+-ions with a kinetic energy of 30 keV. The surface modifications as a function of angle of ion beam incidence, fluence and surface temperature has been investigated by scanning electron microscopy and AFM imaging. The photoluminescence-properties were investigated with a WITec alpha300 and an excitation wavelength of 532nm.

At room temperature physical sputtering was observed leading to ripples on the Germanium surface. At a substrate temperature of T=600°C physical sputtering was observed leading to flat bottomed boxes independent of the ion fluencies.

Furthermore we present an approach for focused ion beam induced synthesis of free-standing germanium nano-webs with a thickness below 20 nm and luminescence in the near-infrared region.

HL 33.6 Tue 10:45 EW 015

Tuning the Electronic Properties of Germanium Nanowires by Room Temperature Focused Ion Beam Implantation — •Clemens Zeiner[1], Alois Lugstein[1], Thomas Burchhart[1], Peter Pongratz[2], Justin G. Connell[3], Lincoln J. Lauhon[3], and Emmerich Bertagnolli[1] — [1]Institute for Solid State Electronics, TU Wien, Vienna, Austria — [2]Institute for Solid State Physics, TU Wien, Vienna, Austria — [3]Department of Materials Science and Engineering, Northwestern University, Evanston, Illinois, United States

Germanium nanowires (Ge-NW) have moved in the focus of the

nanoscience community as promising candidates for novel quantum devices due to their favourable material properties. Our investigations show outstanding effects of FIB ion implantation into Ge-NW. The NWs are grown using a VLS process and contacted by electron beam lithography. Low resistivity contacts were formed by Cu diffusion forming Cu_3Ge/Ge-NW heterostructures with atomically sharp interfaces. By FIB implantation of 30 keV Ga and Bi ions at room temperature, the Ge-NW conductivity increases up to 3 orders of magnitude with increasing ion fluence without further annealing. Four point measurements prove that the conductivity enhancement emerges from the modification of the wires themselves. The Ga distribution in the implanted Ge-NWs was measured using atom probe tomography. Finally the feasibility of improving the device performance of top-gated Ge-NW MOSFETs by FIB implantation is shown.

HL 33.7 Tue 11:00 EW 015

Temperature induced phase separation and nanocrystal formation in bulk amorphous $Si_xGe_yO_z$ — •Alexander Nyrow[1], Christian Sternemann[1], Christoph Sahle[1], Achim Hohl[2], Kolja Mende[1], Marco Moretti Sala[3], Ralph Wagner[4], Alexander Schwamberger[1], Inge Brinkmann[1], and Metin Tolan[1] — [1]Fakultät Physik/DELTA, Technische Universität Dortmund, D-44221 Dortmund, Germany — [2]Institute for Materials Science, Darmstadt University of Technology, D-64287 Darmstadt, Germany — [3]European Synchrotron Radiation Facility, F-38043 Grenoble Cedex, France — [4]Fachbereich C -Physik, Bergische Universität Wuppertal, D-42119 Wuppertal, Germany

Since the discovery of the visible luminescence group IV semiconductor nanocrystals (NCs) obtained great attention during recent years. Due to the high efficiency of the luminescence, oxide matrix embedded Ge and Si NCs can be used as high efficient light emitting diodes or as fast and stable non-volatile memory devices. The band structure and thus the optical properties of the NCs depend very strongly on the NC size. Thus, bulk amorphous $Si_xGe_yO_z$ can serve as starting material for SiO_2 matrix embedded Ge NC production because (i) oxide embedded Ge NCs have a smaller band gap and a higher dielectric constant compared to Si NCs which results in higher charge retention times and (ii) Si is preferentially oxidized so that Ge NC formation can be tuned. In this study, temperature induced phase separation and NC formation have been investigated by x-ray diffraction, x-ray absorption near-edge spectroscopy and x-ray Raman scattering.

HL 34: Organic Electronics and Photovoltaics: Simulations and Optics I (jointly with DS, CPP, O)

Time: Tuesday 9:30–11:15 Location: H 2032

HL 34.1 Tue 9:30 H 2032

Excited states of terminally dicyanovinyl-substituted oligothiophenes and C_{60}: Frenkel vs. charge-transfer excitons — •Björn Baumeier[1], Denis Andrienko[1], and Michael Rohlfing[2] — [1]Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany — [2]Department of Physics, University of Osnabrück, Barbarastr. 7, 49076 Osnabrück, Germany

Excited states of terminally dicyanovinyl-substituted oligothiophenes (DCVnT) and C_{60}, a donor-acceptor combination used in state-of-the-art small-molecule-based organic photovoltaic devices, are studied using *ab initio* many-body Green's functions theory within the *GW* approximation and the Bethe-Salpeter equation. Calculations including resonant-antiresonant transition coupling and dynamical screening for DCVnT monomers yield excitation energies in excellent agreement with spectroscopic data. More importantly, it is possible with this approach to explicitly treat excited states in model dimers of DCVnT and C_{60}. This in particular allows to gain nanoscale insight into the relative energies of local (Frenkel) and charge-transfer excitations, which influence the charge generation in devices.

We will present results for model systems of DCV4T:C_{60} and DCV5T:C_{60} and will analyze the dependence of the relative excitations on, e.g., the arrangement of donor and acceptor molecules in the dimer and the length of the donor, as well as discuss the consequences for performance in organic photovoltaic devices.

HL 34.2 Tue 9:45 H 2032

Microscopic simulations of charge transport in disordered organic semiconductors — •Denis Andrienko, Bjoern Baumeier, Falk May, Manuel Schrader, and Victor Ruehle — Max Planck Institute for Polymer Research, Mainz, Germany

Charge carrier dynamics in an organic semiconductor can often be described in terms of charge hopping between localized states. The hopping rates depend on electronic coupling elements, reorganization energies, and driving forces, which vary as a function of position and orientation of the molecules. The exact evaluation of these contributions in a molecular assembly is computationally prohibitive. Various, often semi-empirical, approximations are employed instead. In this work, we review some of these approaches and introduce a software toolkit which implements them.[1] The purpose of the toolkit is to simplify the workflow for charge transport simulations, provide a uniform error-control for the methods, flexible platform for their development, and eventually allow in silico pre-screening of organic semiconductors for specific applications. All implemented methods are illustrated by studying charge transport in amorphous films of tris(8-hydroxyquine)aluminium, a common organic semiconductor.

[1] V. Rühle, A. Lukyanov, F. May, M. Schrader, T. Vehoff, J. Kirkpatrick, B. Baumeier, D. Andrienko, J. Chem. Theory Comput., 7, 3335 (2011)

HL 34.3 Tue 10:00 H 2032

Migration of singlet excitons in thin films of oligothiophene molecules — •Jens Ludwig, Susanne Hintschich, Hannah Ziehlke, Karl Leo, and Moritz Riede — Institut für Angewandte Photophysik, Technische Universität Dresden, 01069 Dresden, Germany

In organic materials, such as thin amorphous films of oligothiophenes, localized singlet excitons constitute the primary photoexcitations. Via Förster Resonant Energy Transfer (FRET) they migrate between different molecular sites, represented by an inhomogeneously broadened density of states (DOS).

Dispersive exciton migration in thin films of dicyano-substituted terthiophenes is probed by time resolved spectroscopy using a streak camera and simulated with a Monte-Carlo program based on thermally activated hopping of excitons. The time-resolved spectral relaxation and its temperature dependence, as well as the energy dependent decay curves are consistently described within this picture. Side chains appended to the backbone of the oligothiophenes impact the morphology and average intermolecular distance and hence significantly influence the efficiency of exciton migration. In this presentation, oligothiophene derivates with different side chains are compared regarding their exciton dynamics in thin films. We also consider energy transfer to C_{60} in blend layers with the terthiophene derivatives, leading to a very fast quenching of luminescence from the terthiophene molecules.

HL 34.4 Tue 10:15 H 2032

Vibrational Davydov-splittings in oriented organic semiconductor crystals: polarization-dependent measurements versus theoretical calculations — •Tobias Breuer[1], Mali Celik[2], Peter Jakob[3], Ralf Tonner[2], and Gregor Witte[1] — [1]AG Molekulare Festkörperphysik — [2]AG Theoretische Oberflächenchemie — [3]AG Oberflächenphysik, Philipps-Universität Marburg, D-35032 Marburg

Vibrational properties of highly ordered crystalline perfluoropentacene (PFP) films epitaxially grown on KCl(100) and NaF(100) substrates have been studied by means of transmission infrared spectroscopy and density functional theory. The different molecular orientations adopted by PFP on both substrates (standing vs. lying) and their epitaxial ordering [1] enable precise polarization-resolved measurements along individual crystallographic directions and thus allow an unambiguous experimental determination of the polarizations of the IR modes. Computations of the vibrational spectra beyond the single-molecule approximation were employed at the periodic dispersion-corrected density functional level (PBE-D2PBC) and compared to non-periodic calculations (PBE/def2-TZVPP). Thereby, a comparison between experiment

and different theoretical models was enabled. A microscopic explanation for the experimentally observed Davydov splitting of some modes and the IR-inactivity of others was derived, based on the mutual coupling of the dynamical dipole moments of the two molecules within the unit cell.

[1] T. Breuer et al., Phys. Rev. B 83, 155428 (2011).

HL 34.5 Tue 10:30 H 2032

XPS investigation of charge transfer complexes with strong donor / acceptor molecules: composites and interfaces — •Sebastian Stolz, Eric Mankel, Julia Maibach, Thomas Mayer, and Wolfram Jaegermann — Technische Universität Darmstadt, Materials Science Institute, Surface Science Division, Petersenstraße 32, 64287 Darmstadt, Germany

Organic charge transfer complexes like TTF-TCNQ have raised interest due to their electronic and optical properties being highly sensitive to small variations of the molecular constituents. In this manner, the electrical properties of TTF-TCNQ and its derivates vary significantly, and hence different applications for organic electronic devices are imaginable. Thin film layers of DBTTF-TCNQ were prepared in UHV and inert atmospheres respectively to avoid contamination. Preparation methods used were (1) evaporation of solution grown crystals, (2) drop casting under Ar atmosphere, and (3) co-evaporation of the individual molecules with varying donor / acceptor ratios. Additionally, DBTTF was deposited stepwise onto a clean TCNQ substrate in order to investigate the reaction mechanism. The resulting thin films were analyzed by in-situ photoemission spectroscopy, partially carried out at the U49/2 beamline at Bessy II. The stoichiometric ratio of donor and acceptor molecules was determined and the formation of the CT-complex was confirmed for all samples. In case of a stoichiometric ratio unequal to 1:1, the spectra show a mixture of the CT-complex and neutral excess molecules. Finally, the experimentally determined spectra were compared to DFT-calculations.

HL 34.6 Tue 10:45 H 2032

A new differential reflectance spectroscopy method with enhanced sensitivity — •Harald Zaglmayr, Lidong Sun, and Peter Zeppenfeld — Institute of Experimental Physics, Johannes Kepler Univeristät, Linz, Austria

Differential reflectance spectroscopy (DRS), measures the normalized difference of the reflectance of the bare and adsorbate covered surface, respectively. The technique possesses enhanced surface sensitivity and is thus widely used for the in-situ study of organic thin film growth [1,2]. The signal to noise ratio of the obtained spectra, which determines the sensitivity of the method, strongly depends on the stability of the light source. Here, we introduce a new method to overcome the influence of the instability of the light source by normalizing the spectrum of the reflected beam with that of the incident beam, which are measured simultaneously. Our approach shows a drastic improvement of the signal to noise ratio of the DR spectra. The new instrument has been successfully applied to monitor the in-situ growth of alpha-sexithiophene (α-6T) and cobalt-tetramethoxyphenylporphyrin (Co-TMPP) on the Cu(110)-(2x1)O reconstructed surface. The details of the technical realization and the scientific results concerning the organic thin film growth will be reported in this contribution.

[1] R.Forker, T.Fritz; Phys. Chem. Chem. Phys., 2009, 11, 2142-2155
[2] U.Heinemeyer *et al.*; Phys. Rev. Lett., 2001, 104, 257401

HL 34.7 Tue 11:00 H 2032

Interface Effects on the Glass Transition in Thin Polystyrene Films studied with High Temperature Single Molecule Fluorescence Microscopy — •Dominik Wöll[1], Bente Flier[2], Moritz Baier[2], Klaus Müllen[3], Stefan Mecking[2], and Andreas Zumbusch[2] — [1]Zukunftskolleg, Universität Konstanz, Germany — [2]Fachbereich Chemie, Universität Konstanz, Germany — [3]Max-Planck-Institut für Polymerforschung Mainz, Germany

The glass transition is a ubiquitous phenomenon in many materials. Despite its high importance and considerable research efforts, a full understanding of this property is still lacking. In thin polymer films, interfaces complicate things as they alter the glass transition in their vicinity. Experimental approaches to study the influence of interfaces on dynamics in polymers are thus very challenging. In our contribution, we present single molecule fluorescence spectroscopy as a new method to investigate such interfacial effects on the glass transition of polymers. We measured the translational diffusion coefficients of single perylene diimide molecules in thin polystyrene films up to temperatures of 150 °C and analyzed their distributions. These distributions and the number of mobile molecules depend strongly on film thickness. They can be modeled with Monte Carlo random walk simulations assuming a reduced glass transition temperature and an increased residence probability of dye molecules at the polymer surface.

HL 35: Transport: Quantum Coherence and Quantum Information Systems 3 (jointly with TT, MA)

Time: Tuesday 9:30–12:15 Location: BH 243

Invited Talk HL 35.1 Tue 9:30 BH 243

Making and manipulating Majorana fermions for topological quantum computation — •Felix von Oppen — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Unviersitaet Berlin, 14195 Berlin

Known theoretically for decades, Majorana fermions have never been observed as fundamental particles. But there is growing excitement among condensed matter physicists that Majorana fermions could be observed as quasiparticles in the solid state. This excitement is fueled by their remarkable properties: They are their own antiparticle and obey an exotic (and yet unobserved) form of quantum statistics called non-Abelian statistics. These properties make Majorana fermions the simplest candidate for realizing topological quantum information processing which could go a long way towards alleviating the problem of decoherence in conventional quantum computation.

Among the systems predicted to support Majorana fermions are exotic fractional quantum Hall states as well as hybrid structures of topological insulators, semimentals, or semiconductors with conventional superconductors. Realizations based on semiconductor quantum wires in proximity to conventional superconductors are perhaps particularly promising since they allow for relatively detailed scenarios of how to manipulate the Majorana fermions. In this talk, I will discuss this proposal to realize Majorana fermions.

HL 35.2 Tue 10:00 BH 243

Engineering and manipulating Majorana bound states in 1D quantum wires — •Panagiotis Kotetes[1], Alexander Shnirman[2], and Gerd Schön[1] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, D-76128 Karlsruhe, Germany

Recently, the interest in topological quantum computing has grown due to the appearance of promising platforms for realizing the long sought Majorana bound states. Among the proposals that appear suitable for engineering the Majorana bound states, the most prominent involves a 1D semiconducting quantum wire in proximity to a bulk s-wave superconductor, where in addition a Zeeman magnetic field is applied. In this work, we investigate the possibility of performing qubit operations via the adiabatic variation of certain internal parameters without using any external gates or network of wires. The crucial feature of our model is the combination and interplay of phases for the magnetic field and the superconducting order parameter. In an appropriate junction setup, we explore the possible phase configurations that could lead to a Majorana bound state exchange.

HL 35.3 Tue 10:15 BH 243

Coulomb-assisted braiding of Majorana fermions in a Josephson junction array — •Fabian Hassler[1], Bernard Van Heck[2], Anton Akhmerov[2], Michele Burrello[2], and Carlo Beenakker[2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Instituut-Lorentz, Universiteit Leiden, P.O. Box 9506, 2300 RA Leiden, The Netherlands

We show how to exchange (braid) Majorana fermions in a network of superconducting nanowires by control over Coulomb interactions

rather than tunneling. Even though Majorana fermions are charge-neutral quasiparticles (equal to their own antiparticle), they have an effective long-range interaction through the even-odd electron number dependence of the superconducting ground state. The flux through a split Josephson junction controls this interaction via the ratio of Josephson and charging energies, with exponential sensitivity. By switching the interaction on and off in neighboring segments of a Josephson junction array, the non-Abelian braiding statistics can be realized without the need to control tunnel couplings by gate electrodes. This is a solution to the problem how to operate on topological qubits when gate voltages are screened by the superconductor.

HL 35.4 Tue 10:30 BH 243

Quantum information transfer between topological and spin qubit systems — •Martin Leijnse and Karsten Flensberg — Nano-Science Center and Niels Bohr Institute, University of Copenhagen, Denmark

In this talk I will introduce a method to coherently transfer quantum information, and to create entanglement, between topological qubits and conventional spin qubits. The transfer method uses gated control to transfer an electron (spin qubit) between a quantum dot and edge Majorana modes in adjacent topological superconductors. Because of the spin polarization of the Majorana modes, the electron transfer translates spin superposition states into superposition states of the Majorana system, and vice versa. Furthermore, I will discuss how a topological superconductor can be used to facilitate long-distance quantum information transfer and entanglement between spatially separated spin qubits [1,2].

[1] M. Leijnse, K. Flensberg, PRB **84**, 140501(R) (2011)
[1] M. Leijnse, K. Flensberg, PRL **107**, 210502 (2011)

15 min. break.

Invited Talk HL 35.5 Tue 11:00 BH 243

Distinguishing quantum and classical transport through nanostructures — •Clive Emary[1], Neill Lambert[2], Franco Nori[2,3], and Yueh-Nan Chen[4] — [1]TU Berlin, Germany — [2]RIKEN, Japan — [3]University of Michigan, USA — [4]National Cheng-Kung University, Tainan, Taiwan

I will discuss the question of how to distinguish quantum from classical transport through nanostructures using fundamental quantum-mechanical inequalities. I will briefly discuss how Bell's inequalities can be employed to investigate entanglement in the solid-state, before focusing on a less well-known inequality, the Leggett-Garg inequality. This latter probes the 'macroscopic realism' of a system, i.e. whether or not the system has a well-defined state independent of the observer. I will describe how the Leggett-Garg inequality can be realised in transport context, and how it can be violated by quantum coherent transport.

HL 35.6 Tue 11:30 BH 243

Spin-orbit-induced strong coupling of a single spin to a nanomechanical resonator — •Andras Palyi[1,2], Philipp R. Struck[1], Mark Rudner[3], Karsten Flensberg[3,4], and Guido Burkard[1] — [1]University of Konstanz, Germany — [2]Eotvos University, Budapest, Hungary — [3]Harvard University, Cambridge, Massachusetts, United States — [4]Niels Bohr Institute, Copenhagen, Denmark

We theoretically investigate the coupling of electron spin to vibrational motion due to curvature-induced spin-orbit coupling in suspended carbon nanotube quantum dots. Our estimates indicate that, with current capabilities, a quantum dot with an odd number of electrons can serve as a realization of the Jaynes-Cummings model of quantum electrodynamics in the strong-coupling regime. A quantized flexural mode of the suspended tube plays the role of the optical mode and we identify two distinct two-level subspaces, at small and large magnetic field, which can be used as qubits in this setup. The strong intrinsic spin-mechanical coupling allows for detection, as well as manipulation of the spin qubit, and may yield enhanced performance of nanotubes in sensing applications [1].

[1] arXiv:1110.4893)

HL 35.7 Tue 11:45 BH 243

Emission spectrum of a driven nonlinear resonator — •Stephan André[1,2], Lingzhen Guo[1,3], Michael Marthaler[1,2], and Gerd Schön[1,2] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [3]Department of Physics, Beijing Normal University, Beijing 100875, China

Motivated by recent "circuit QED" experiments [1,2] we investigate the properties of coherently driven nonlinear resonators. By using Josephson junctions in superconducting circuits, strong nonlinearities can be engineered, which lead to the appearance of pronounced quantum effects with a low number of photons in the resonator.

Based on a master equation approach we determine the emission spectrum and observe for typical circuit QED parameters, in addition to the primary side-peaks, second-order peaks which are not predicted by a linearized theory. These peaks result from transitions between next-to-nearest levels in the rotating frame and from fluctuations of the oscillation amplitude. We show that an effective Planck constant provides a measure for the importance of the quantum effects.

[1] I. Siddiqi *et al.*, Phys. Rev. B **73**, 054510 (2006).
[2] F.R. Ong *et al.*, Phys. Rev. Lett. **106**, 167002 (2011).

HL 35.8 Tue 12:00 BH 243

Noise-induced transition in an electronic Mach-Zehnder interferometer — •Andreas Helzel[1], Leonid Litvin[1], Werner Wegscheider[2], and Christoph Strunk[1] — [1]Institute of exp. and applied physics, University of Regensburg, Germany — [2]Solid State Physics Laboratory, ETH Zurich, 8093 Zurich, Switzerland

The visibility of Aharonov-Bohm interference of an electronic Mach-Zehnder interferometer (MZI) shows a lobe structure when changing the applied DC bias. Multiple side lobes are present at filling factors from 1.5 to 2. By varying the transmission of a quantum point contact set in series at a distance D before the MZI (QPC0) we can suppress the multiple side lobes to a single side lobe. This occurs at a transmission probability of $T_{QPC0} = 0.5$. Above this transmission the lobe structure is robust and does not change qualitatively. For $T_{QPC0} < 0.5$ the multiple side lobes disappear and the central lobe width increases drastically with decreasing transmission. We see these properties both in the visibility and in the AB-phase. This behavior coincides with a recently proposed noise-induced phase transition [1].

[1] Ivan P. Levkivskyi, Eugene V. Sukhorukov, Phys. Rev. Lett. **103**, 036801 (2009)

HL 36: Magnetic Semiconductors (jointly with MA)

Time: Tuesday 9:30–12:45 Location: H 0112

HL 36.1 Tue 9:30 H 0112

Growth of high-quality EuO films by rf-sputtering — •Thomas Mairoser[1], Alexander Melville[2], Artur Glavic[3], Jürgen Schubert[3], Darrell G. Schlom[2], and Andreas Schmehl[1] — [1]Universität Augsburg — [2]Cornell University, USA — [3]Forschungszentrum Jülich

The ferromagnetic semiconductor europium oxide exhibits a multitude of giant physical properties, such as a metal-to-insulator transition, colossal magneto-resistance, and pronounced magneto-optic effects. Its spin-polarization of >90% in the ferromagnetic state [A. Schmehl *et al.* , Nature Materials **6**, 882 (2007)] and its excellent electronic compatibility with Si have spawned new interest in EuO in the rapidly growing field of spin-electronics.

Because of instability in air the growth of thin films of this highly versatile material is challenging. Up to now high-quality films were only accessible by UHV deposition techniques like molecular beam epitaxy or UHV pulsed laser deposition. Previous film growths using co-sputtering from multiple targets (Eu and Eu_2O_3) resulted in polycrystalline films with second phases.

Here we report the growth of high-quality epitaxial films on (110) oriented $YAlO_3$ substrates using rf-sputtering from a single Eu_2O_3 target. The structural and magnetic properties of the commensurately strained films match those of the best EuO films reported in literature.

HL 36.2 Tue 9:45 H 0112

Ultrafast Enhancement of Ferromagnetism via Photoexcited Carriers in EuO — •Masakazu Matsubara[1], Andreas Schmehl[2], Jochen Mannhart[3], Darrell G. Schlom[4], Mauricio Trujillo Martinez[5], Johann Kroha[5], and Manfred Fiebig[1] — [1]Department of Materials, ETH Zürich, Switzerland — [2]Institut für Physik, Universität Augsburg, Germany — [3]Max Planck Institute for Solid State Research, Germany — [4]Department of Materials Science and Engineering, Cornell University, USA — [5]Physikalisches Institut, Universität Bonn, Germany

EuO is a magnetic semiconductor, which undergoes a ferromagnetic transition at the Curie temperature (T_C) of 69 K. Electron doping to the stoichiometric compound greatly enhances the T_C and is accompanied by a nearly 100% spin polarization of the charge carriers in the ferromagnetic state, which makes electron-doped EuO a very attractive candidate for spintronics applications.

Here we have explored the possibility of the ultrafast control of magnetic properties of EuO via photoexcited carriers by a femtosecond pulse laser irradiation. Ultrafast spin dynamics was investigated in a variety of Gd-doped EuO ($Eu_{1-x}Gd_xO$) films with different carrier densities and T_C, exploiting the time-resolved magnetization-induced second-harmonic generation. The results show the ultrafast increase of magnetization, with a characteristic temperature dependence, in low/medium Gd-doped samples. This is attributed to the increase of the indirect exchange interaction mediated by the photoexcited carriers.

HL 36.3 Tue 10:00 H 0112

EuO on Silicon for spintronics investigated by HAXPES — •C. Caspers[1], M. Müller[1], A. Gloskovskii[2], M. Gorgoi[3], C.S. Fadley[4], and C.M. Schneider[1,5] — [1]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich — [2]Analytische und Anorganische Chemie, Johannes Gutenberg-Universität, Mainz — [3]Helmholtz-Zentrum für Materialien und Energie, BESSY II, Berlin — [4]Department of Physics, University of California Davis, USA — [5]Fakultät für Physik and Center for Nanointegration Duisburg-Essen

Magnetic oxides combine electrical insulation and spin selectivity, qualifying them as highly efficient spin-selective tunnel barriers on silicon. Our approach joins two beneficial aspects: EuO is predicted to be the only magnetic oxide thermodynamically stable on silicon, the mainstay of semiconductors; moreover we are holding full control over structural, chemical, and magnetic properties of the MBE-grown EuO.

EuO thin films were synthesized by Oxide-MBE. RHEED pattern confirm the epitaxial growth of EuO on clean Si(100). A bulk-sensitive HAXPES study revealed an integral Eu(2+) valency (ferromagnetic) of 4 nm thick EuO/Si heterostructures with less than 4% antiferromagnetic Eu(3+). A depth-dependent HAXPES investigation with optimized interface sensitivity provided the optimum chemical parameters for the EuO/Si transport interface: The formation of EuSix can be minimized to less then 10% coverage of the interface, and SiOx is found to be $< 20\%$. Concluding, we succeeded in preparing EuO/Si heterostructures with high-quality magnetic, structural and chemical properties, being promising as spin filter contacts to silicon.

HL 36.4 Tue 10:15 H 0112

Magnetization of Mn implanted Ge annealed by flash lamp — •Zenan Jiang, Danilo Bürger, Slawomir Prucnal, Kun Gao, Wolfgang Skorupa, Heidemarie Schmidt, Manfred Helm, and Shengqiang Zhou — Helmholtz Zentrum Dresden Rossendorf, Inst Ion Beam Phys & Mat Res, Dresden, Germany

Ge-based diluted magnetic semiconductors (DMS) have drawn extensive attentions over the past decades due to the potential to be applied in spintronic devices and to be integrated with the mainstream Si microelectronics. The hole-mediated effect in DMS provides the possibility to realize the control of magnetic properties by the electrical control of free carriers. In this contribution, Mn implanted Ge with the Mn concentrations between 2 and 10% and annealed subsequently with flash lamp was investigated and discussed. All samples show ferromagnetism with the Curie temperature in the range from 250 to 300 K which may be interpreted as the co-contribution of the Ge matrix diluted with Mn ions and of Mn-rich nanoclusters[1]. SQUID measurements show evidence that the Mn-rich nanoclusters may have multiple distinct magnetic phases or a bimodal size distribution. It is also inferred that more Mn atoms are possibly incorporated into the Ge lattice with higher annealing energy using flash lamp annealing at 3 ms time scale. The enhancement of magnetoresistance is consistent with the magnetization as well as the inhomogeneous nature of the implanted layer.

[1] Shengqiang Zhou et al., PHYSICAL REVIEW B 81, 165204 (2010)

HL 36.5 Tue 10:30 H 0112

Magnetic Mn-Doped Indium Tin Oxide Films Prepared by Vacuum Thermal Evaporation — •Scarlat Camelia[1], Xu Qingyu[2], Shalimov Artem[1], Voelskow Matthias[1], Fronk Michael[3], Salvan Georgeta[3], Zahn R.T. Dietrich[3], Helm Manfred[1], and Iacomi Felicia[4] — [1]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany — [2]Southeast University, China — [3]Semiconductor Physics, Chemnitz University of Technology, Germany — [4]Al. I. Cuza University, Iasi, Romania

The optical and electrical properties of indium tin oxide (ITO) thin films are highly dependent on the deposition parameters. Undoped and Mn doped ITO thin films were grown on SiO_2/Si substrates by vacuum thermal evaporation (VTE) using different atomic sources ratio. In order to have practically stress-free ITO films, all the samples were annealed at 450°C for 2 hours in air. The Mn-doped ITO films exhibit room temperature ferromagnetism after annealing. We analyzed the magnetization data from SQUID measurements using simulations based on the Preisach approach and derived the magnetic parameters of superparamagnetic nanoparticles in the Mn-doped ITO films, namely, the magnetization of individual particles and the distribution of coercive fields. The Mn-content in Mn-doped ITO films was investigated by Rutherford backscattering spectrometry and analysed using the RUMP data processing computer code. Results from magneto-optical and magneto-electrical measurements are presented. Magneto-transport measurements reveal negative magnetoresistance, while no anomalous Hall effect is observed.

HL 36.6 Tue 10:45 H 0112

Multiband V-J model for dilute magnetic semiconductors — •Stefan Barthel[1], Gerd Czycholl[1], and Georges Bouzerar[2,3] — [1]Institute for Theoretical Physics, University of Bremen, Otto-Hahn-Allee 1, D-28359 Bremen, Germany — [2]Institut Néel, 25 avenue des Martyrs, B.P. 166, 38042 Grenoble Cedex 09, France — [3]School of Engineering and Science, Jacobs University Bremen, Campus Ring 1, D-28759 Bremen, Germany

A multiband empirical tight-binding model for magnetically doped group-III-V-semiconductors with zincblende structure (e.g. $Ga_{1-x}Mn_xAs$,etc.) is applied to the calculation of effective Mn-Mn exchange couplings J_{ij}. The pd-coupling is treated non-perturbatively and nonmagnetic scattering is included. A polynomial expansion of the spectral density allows for the study of orbital-resolved exchange couplings for very large system sizes, which can be directly mapped on a disordered Heisenberg model. Finally a comparison of our findings using realistic input parameters (bandstructure, impurity concentration, pd-coupling, impurity potential) to available ab-initio data (LDA, LDA+U) is made. Our approach seems promising to bridge the gap between model and ab-initio methods.

15 min. break

HL 36.7 Tue 11:15 H 0112

Magnetism in Phase Change Materials Doped with Magnetic Impurities — •Wei Zhang[1], Yan Li[1,2], and Riccardo Mazzarello[1,2] — [1]Institute for Theoretical Solid State Physics, RWTH Aachen, Aachen, Germany — [2]JARA Fundamentals of Future Information Technology, Aachen, Germany

Chalcogenide phase-change materials undergo fast and reversible transitions between the amorphous and crystalline phase upon heating. This property is exploited in rewritable optical discs and nonvolatile phase-change memories, which are based on the strong optical and electronic contrast between the two phases respectively. Recently, phase change materials doped with magnetic impurities have drawn interest from both experimental and theoretical sides. In this work, we investigate the structural, electronic and magnetic properties of $Ge_2Sb_2Te_5$, a prototypical phase-change material, doped with several types of magnetic impurities, namely Cr, Mn, Co, Ni, by *ab initio* simulations. Both amorphous and crystalline (hexagonal and cubic rocksalt) phases of $Ge_2Sb_2Te_5$ were considered. We show that, when $Ge_2Sb_2Te_5$ is doped with Cr or Mn, the system displays a strong magnetic contrast between the crystalline phases and the amorphous phase. This behavior is similar to that of Fe-doped $Ge_2Sb_2Te_5$, which was recently investigated

experimentally and theoretically. On the contrary, $Ge_2Sb_2Te_5$ doped with Co or Ni turns out to be non-magnetic in the amorphous phase. Our results indicate that Cr and Mn impurities can be used to dope $Ge_2Sb_2Te_5$, with the goal of exploiting the phase-change behavior for magnetic switching applications.

HL 36.8 Tue 11:30 H 0112

Anomalous hysteretic Hall effect in a ferromagnetic, Mn-rich, amorphous Ge:Mn nano-network — •Danilo Bürger, Shengqiang Zhou, Marcel Höwler, Xin Ou, György Kovacs, Helfried Reuther, Arndt Mücklich, Wolfgang Skorupa, Manfred Helm, and Heidemarie Schmidt — Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, P.O. Box 510119, 01314 Dresden, Germany

The read out of the magnetization state in magnetic semiconductors by electrical Hall resistance measurements makes it possible to use ferromagnetic semiconductors in nonvolatile memories. In a previous work [1], we fabricated ferromagnetic Ge:Mn by Mn ion implantation and pulsed laser annealing (PLA) and observed hysteretic Hall resistance below 10 K. By applying different PLA conditions we fabricated a percolating, Mn-rich, amorphous Ge:Mn nano-network with hysteretic Hall resistance up to 30 K. This nano-network is embedded in crystalline Ge:Mn between 5 nm and 40 nm under the sample surface. We applied chemical and physical etching to confirm the contribution of the nano-network to the magnetic properties. The nanonet has a significant influence on the correlation between magnetism and anomalous Hall resistance. In the future such nano-networks may be used to spin-polarize free charge carriers in semiconductors at room temperature. [1] S. Zhou *et al.*, Phys. Rev. B **81**, 165204 (2010)

HL 36.9 Tue 11:45 H 0112

Transition metal doped ZnO: Studies from DFT with various types of exchange-correlation treatment — •Sanjeev K. Nayak, Markus E. Gruner, Heike C. Herper, and Peter Entel — Faculty of Physics, University of Duisburg-Essen

Transition metal (TM) doped ZnO has been a long-standing problem. Since the density functional theory (DFT) with local density approximation (LDA) as the exchange-correlation potential underestimates the optical band gap, the impurity state is more likely to overlap with the valence or conduction band and thus the identification of the type of magnetic interaction is hampered. We have used different correction schemes to the exchange-correlation potential to improve the optical band gap of ZnO, namely by adding a orbital specific Hubbard U correlation to the d-orbitals of Zn and TM and by treating the exchange-correlation by the Hartree-Fock exchange through the Heyd-Scuseria-Ernzerhof (HSE) screened hybrid-functional. We focus on the nearest neighbor (n.n.) interactions of TM (TM = Cr, Mn, Fe, Co and Ni) occupying the cationic Zn sites, because in absence of carriers and any lattice defects the n.n. magnetic interaction strength is expected to be the highest. Our preliminary results show that most of the TM in ZnO favor antiferromagnetic interaction. Thus, in the quest for ferromagnetism in ZnO based DMS, focus should be on the role of lattice defects and additional impurities.

HL 36.10 Tue 12:00 H 0112

Ferromagnetische Resonanz an Chromspinellen — •Dieter Ehlers, Hans-Albrecht Krug von Nidda, Vladimir Tsurkan und Alois Loidl — Lst. für Experimentalphysik V, Universität Augsburg, 87435 Augsburg

Am ferromagnetischen Spinell $CdCr_2S_4$, an dem Ferroelektrizität sowie eine goße magnetokapazitive Kopplung nachgewiesen worden ist [Hem], haben wir die magnetokristalline Anisotropie mithilfe der ferromagnetischen Resonanz vermessen und untersucht. Aufgrund der Probenpräparation konnte ausgeschlossen werden, dass die Anisotropie von Verunreinigungen wie Cr^{2+} auf Oktaederplätzen oder Fe^{2+} auf Tetraederplätzen [Hoe, Pin] ausgeht, d. h. sie ist eine intrinsiche Eigenschaft der Verbindung. Weiterhin konnte das Modell der kubischen Anisotropie für das System verfeinert werden, indem eine uniaxiale Anisotropie für Cr^{3+} zusammen mit der Austauschverschmälerung angenommen wurde. Damit lassen sich beobachtete Anomalien der Linienbreite in den $\langle 111 \rangle$-Richtungen temperaturabhängig beschreiben.

[Hem] J. Hemberger, P. Lunkenheimer, R. Fichtl, H.-A. Krug von Nidda, V. Tsurkan, A. Loidl, Nature **434**, 364 (2005)

[Pin] H. L. Pinch, S. B. Berger, J. Phys. Chem. Solids **29**, 2091 (1968)

[Hoe] B. Hoekstra, R. P. van Stapele, Phys. Stat. Sol. **55**, 607 (1973)

HL 36.11 Tue 12:15 H 0112

Electronic structure study of the ferrospinel NiFe2O4 — •Martina Müller[1], Christian Caspers[1], Stephan Kramer-Sinzinger[1], Sven Döring[2,4], Michaela Gorgoi[3], Carsten Westphal[2], and Claus M. Schneider[1,4] — [1]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich — [2]Experimentelle Physik 1 und DELTA, Technische Universität Dortmund — [3]Helmholtz-Zentrum für Materialien und Energie, BESSY II, Berlin — [4]Fakultät für Physik and Center for Nanointegration, Universität Duisburg-Essen

The ferrospinel NiFe2O4 is an insulating oxide with high magnetic ordering temperature. This rare combination makes it very attractive for application as magnetic building blocks in spintronics devices, i.e. as spin filter contacts to semiconductors or in artificial multiferroic heterostructures. We succeeded in growing NiFe2O4 (NFO) epitaxial thin films on SrTiO3 substrates. Since the electronic and magnetic properties of NFO thin films can strongly depend on substrate, film thickness and eventually differ from the bulk material, we clarified their electronic properties by means of photoemission spectroscopy in the soft and hard X-ray regime. This (HAX)PES study allows to element-specifically probe the chemical state of the Fe, Ni and O valence bands and core levels both in the bulk and surface-near regions. In particular, analyzing the Fe, Ni 2p and 3p states gives information on the depth-dependent cation stoichiometry and lattice site distribution, which we correlate with NFO/STO structural and magnetic properties.

HL 36.12 Tue 12:30 H 0112

Antiferromagnetism in CuMn-V compounds: from semimetal to semiconductor antiferromagnets — •Frantisek Maca, Jan Masek, and Tomas Jungwirth — Institute of Physics ASCR, Prague, Czech Republic

We report on a theoretical study of CuMn-V antiferromagnets. Previous works showed low-temperature antiferomagnetism and semimetal electronic structure of the semi-Heusler CuMnSb. We present theoretical predictions of high-temperature antiferromagnetism in the stable orthorhombic phases of CuMnAs and CuMnP. The electronic structure of CuMnAs is at the transition from a semimetal to a semiconductor and we predict that CuMnP is a semiconductor.

We show that the transition to a semiconductor-like band structure upon introducing the lighter group-V elements is present in both the metastable semi-Heusler and the stable orthorhombic crystal structures. On the other hand, the orthorhombic phase is crucial for the high Néel temperature. The first experimental results are consistent with the theory predictions.[1]

[1] F. Maca, J. Masek, O. Stelmakhovych, X. Marti, K. Uhlirova, P. Beran, H. Reichlova, P. Wadley, V. Novak, T. Jungwirth, J. Magn. Magn. Mater. (2011) in print.

HL 37: Quantum Dots and Wires: Optical Properties I (mainly InGaAs Dots)

Time: Tuesday 10:45–13:15 Location: ER 164

HL 37.1 Tue 10:45 ER 164

Time resolved Faraday rotation and ellipticity experiments with two pump excitation of electrons and holes in InGaAs QDs — •Dennis Barmscheid[1], Steffen Varwig[1], Irina A. Yugova[1,2], Alex Greilich[1], Alexander Schwan[1], Crispin Müller[1], Dmitri R. Yakovlev[1], Dirk Reuter[3], Andreas D. Wieck[3], and Manfred Bayer[1] — [1]Experimentelle Physik II, TU Dortmund, D-44221 Dortmund, Germany — [2]Institute of Physics, St. Petersburg State University, 198504 St. Petersburg, Russia — [3]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

The investigation of charge carrier spin dynamics in quantum dots plays an important role for the developement of spintronics. For this we perform pump-probe Faraday rotation and ellipticity experiments

on self-assembled (In,Ga)As/GaAs quantum dot ensembles.

Due to an excitation with a train of pump pulses, the phase of the spin precessions in the inhomogeneous QD-ensemble is synchronized to the laser repetition time T_R. By two pump excitation scheme, with pumps separated by delay T_D, the spins have to fulfill two phase synchronization conditions simultaneously and show rephasing within T_D and $T_R - T_D$. This leads to increases of the signal amplitude, called bunches, every multiple of T_D.

It can be shown, that these bunches are different phenomena than the spin echoes, which occur after spin rotations. We show how this method provides an additional opportunity to study the interaction of electrons and holes with the nuclei.

HL 37.2 Tue 11:00 ER 164

Phase synchronization of hole spin precessions in InGaAs quantum dots — •Steffen Varwig[1], Dennis Barmscheid[1], Irina A. Yugova[1,2], Alex Greilich[1], Alexander Schwan[1], Crispin Müller[1], Dmitri R. Yakovlev[1], Dirk Reuter[3], Andreas D. Wieck[3], and Manfred Bayer[1] — [1]Experimentelle Physik II, TU Dortmund, D-44221 Dortmund, Germany — [2]Institute of Physics, St. Petersburg State University, 198504 St. Petersburg, Russia — [3]Angewandte Festkörperphysik, Ruhr- Universität Bochum, D-44780 Bochum, Germany

The spin of charge carriers in semiconductor quantum dots is a promising candidate for implementing a quantum bit. We study the spin coherence of holes in an ensemble of self-assembled (In,Ga)As/GaAs QDs by optical faraday rotation and ellipticity measurements. With a periodic train of short pump pulses it is possible to overcome the obstacle of fast spin dephasing due to inhomogeneities. The phase of the spin precession in an external magnetic field is thereby synchronized and this leads to constructive interference of the single spin contributions to the measured signal. Thus one can observe the spin coherence on a long time scale, offering the ability to measure the coherence time T_2.

HL 37.3 Tue 11:15 ER 164

Spin Noise of Holes in Quantum Dots — •Ramin Dahbashi[1], Jens Hübner[1], Fabian Berski[1], Julia Wiegand[1], Xavier Marie[2], Klaus Pierz[3], Hans Werner Schumacher[3], and Michael Oestreich[1] — [1]Institute for Solid State Physics, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany — [2]Université de Toulouse; INSA, UPS, CNRS; LPCNO, 135 avenue de Rangueil, F-31077 Toulouse, France — [3]Physikalisch Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

We measure the spin dephasing of holes localized in self-assembled (InGa)As quantum dots by spin noise spectroscopy [1]. The localized holes show a distinct hyperfine interaction with the nuclear spin bath despite the p-type symmetry of the valence band states. The experiments reveal a short spin relaxation time of 27 ns and a second, long spin relaxation time which exceeds the first one by more than one order of magnitude. The two times are attributed to heavy hole spins aligned perpendicular and parallel to the stochastic nuclear magnetic field. Intensity dependent measurements and numerical simulations reveal despite low laser intensity and large detuning that the long relaxation time is still obscured by light absorption.

[1] Dahbashi *et al.*, Measurement of heavy-hole spin dephasing in (InGa)As quantum dots, arXiv:1109.0610v1 [cond-mat.mes-hall] (2011, Submitted to APL).
[2] Müller *et al.*,Semiconductor spin noise spectroscopy: Fundamentals, accomplishments, and challenges, Physica E 43, 569 (2010).

HL 37.4 Tue 11:30 ER 164

All optical preparation, storage and readout of a single spin in an individual quantum dot — Vase Jovanov, Florian Klotz, Alexander Bechtold, Stephan Kapfinger, Silvia Spiga, •Sebastian Koch, Daniel Rudolph, Max Bichler, Martin S. Brandt, and Jonathan J. Finley — Walter Schottky Institute and Center for Nanotechnology and Nanomaterials, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

We demonstrate all optical preparation and storage of a single electron in an individual self-assembled InGaAs quantum dot (QD) and high fidelity measurement of its spin projection by driving a luminescence recycling transition. Hereby, we optically induce spin-charge conversion to convert the spin information into charge occupancy (1e or 2e) and then repeatedly measure the charge occupancy by pumping an excited state of the negatively charged trion. By probing the temperature and magnetic field dependence of the spin dynamics we extract electron and hole Landé g-factors and map out the spectrum and spin structure of hot trion transitions. The devices investigated are QD spin memory structures that can be switched between two modes of operation; (i) charging, where optically generated holes are removed from the dot whilst electrons remain stored due to the presence of an AlGaAs barrier and (ii) readout, where excitons optically pumped into the dot recombine to produce luminescence. The spin lifetime of the stored electron was measured by monitoring the storage time dependence of the spin blockade as the temperature and magnetic field was varied.

HL 37.5 Tue 11:45 ER 164

Resonant photocurrent spectroscopy of excited states in a single quantum dot molecule — Florian Klotz[1], •Andreas Waeber[1], Kai Müller[1], Gerhard Abstreiter[1], Hubert Krenner[2], Martin Brandt[1], and Jonathan Finley[1] — [1]Walter Schottky Institut, Technische Universität München, Deutschland — [2]Lehrstuhl für Experimentalphysik I, Universität Augsburg, München

We present resonant photocurrent spectroscopy performed on a single quantum dot (QD) molecule consisting of a pair of vertically stacked self-assembled InGaAs quantum dots. The experiments are performed at low temperature by sweeping the electric field to tune the QD transitions in and out of resonance with an excitation laser kept at a fixed wavelength. Besides the expected anti-crossing of direct and indirect exciton states in the molecule, we observe a series of additional anti-crossings that we identify as arising from coupling of excited excitonic states in the lower dot of the molecule with the orbital ground state of the neutral exciton in the upper dot. Furthermore, the photocurrent spectra yield first indications of non-radiative Förster coupling within the molecule that manifest as weak anti-crossings. We investigate both effects for applied magnetic fields from 0 up to 10 T allowing us to distinguish them via their individual magnetic field dependence.

HL 37.6 Tue 12:00 ER 164

Symmetry adapted formalisms to calculate elastic and electronic properties of (111)-oriented zincblende quantum dots — •Oliver Marquardt[1], Miguel A. Caro[1,2], Stefan Schulz[1], and Eoin P. O'Reilly[1,2] — [1]Tyndall National Institute, Lee Maltings, Cork, Ireland — [2]University College Cork, Cork, Ireland

(111)-oriented, site-controlled InGaAs quantum dots (QDs) are highly promising candidates for the generation of entangled photons, required for novel quantum logical and quantum cryptographic applications. Whereas conventional zincblende QDs grown along the [001] direction exhibit a non-vanishing fine structure splitting (FSS) intrinsically, the C_{3v}-symmetry of (111)-oriented QDs is high enough to allow for a vanishing FSS, as was recently confirmed experimentally. Due to the extremely small aspect ratio together with the huge size of these structures, the simulation of the electronic structure of such systems is computationally highly expensive. We have therefore analytically rotated the eight-band $\mathbf{k} \cdot \mathbf{p}$ formalism, together with a continuum elasticity model, to allow for an efficient and accurate description of such QDs in a (111)-oriented cell that allows for different discretizations along in-plane and growth directions. Here we analyze realistic (111)-grown InGaAs QDs and provide a detailed picture of their elastic and electronic properties. Our formalisms for (111)-oriented zincblende systems also allows us to gain some more insight into the material parameters of wurtzite semiconductor materials.

[1]: O. Marquardt et al., to be submitted.
[2]: S. Schulz et al., Phys. Rev. B **84**, 125312 (2011).

HL 37.7 Tue 12:15 ER 164

Tight binding model of strain-reducing layers in semiconductor quantum dots — •Elias Goldmann and Frank Jahnke — Institute of theoretical physics, Universit of Bremen

In recent years, semiconductor quantum dots have been the subject of intense research. Especially the excitonic fine-structure splitting (FSS) has received much attention due to its influence on the photon pair entanglement of the quantum dot biexciton emission.
We present results of an atomistic empirical tight-binding model (ETB) for the calculation of electronic properties of semiconductor nanostructures. We choose a sp^3s^* basis localized at each atomic site and include next-neighbour-interaction as well as spin-orbit-coupling. The influence of lattice-mismatch induced strain is accounted for on an atomistic scale via the valence-force-field method using the Keating potential. An implementation of the Krylov-Schur algorithm with harmonic

extraction in SLEPc [1] is used to compute the interior eigenstates and eigenenergies of the resulting TB-Hamiltonian.
We use the calculated eigenstates as an input for a full configuration interaction treatment to compute the FSS. Within this ETB model we investigate the electronic properties of lens- and trapezoid-shaped self-assembled InGaAs quantum dots in a InGaAs strain-reducing layer [2], embedded in a GaAs matrix and located on top a wetting layer. The influences of dot shape and Indium-concentration on the confined electronic states and optical transitions are presented.
[1] V. Hernandez *et al.*, ACM. Trans. Math. Software: **31** 351 (2005)
[2] A. Amtout *et al.*, J. Appl. Phys. **96** 3782 (2004)

HL 37.8 Tue 12:30 ER 164

Sharp luminescence from a site-controlled single quantum dot — •Ole Hitzemann[1], Alexander Dreismann[1], Erik Stock[1], André Strittmatter[1], Andrei Schliwa[1], Jan-Hindrik Schulze[1], Tim D. Germann[1], Waldemar Unrau[1], Udo W. Pohl[1], Axel Hoffmann[1], Dieter Bimberg[1], and Vladimir Haisler[2] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institute of Semiconductor Physics, Russian Academy of Sciences, Novosibirsk, Russian Federation

Site-controlled growth of single quantum dots (QDs) is essential for applications such as single-photon sources. We investigate InGaAs QDs grown by metal organic vapor phase deposition using a buried stressor for lateral positioning. The buried stressor is formed by controlled partial oxidation of an AlGaAs layer to create an AlO_x aperture as it has been used previously for current-confinement in vertical-cavity surface emitting laser diodes. The oxidation reduces the volume of this layer thus inducing strain in adjacent GaAs layers. The QDs are grown on a GaAs surface 150 nm above the oxide layer but the nucleation sites are controlled by the inner boundaries of the oxide aperture.

Using a sub-micrometer oxide aperture we observe only luminescence from a single QD within a 60 meV spectral range. The observed luminescence consists of a doublet of two lines that are 80 μeV apart with a full width at half maximum of 80 μeV each, limited by the spectral resolution of the setup. In autocorrelation measurements using a Hanbury-Brown Twiss setup we demonstrate an antibunching thus proving emission from a single QD.

HL 37.9 Tue 12:45 ER 164

Scanning near-field infrared micro-spectroscopy on buried InAs quantum dots — •Markus Fehrenbacher[1], Rainer Jacob[1], Stephan Winnerl[1], Harald Schneider[1], Manfred Helm[1], Marc Tobias Wenzel[2], Anja Krysztofinski[2], Hans-Georg von Ribbeck[2], and Lukas M. Eng[2] — [1]Institut für Ionenstrahlphysik und Materialforschung, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Institut für Angewandte Photophysik, TU Dresden, Germany

Providing an optical resolution on the nanometer length scale, scanning near-field optical microscopy (SNOM) turned out to be a capable technique to investigate the optical properties of perovskites [1], buried semiconductors [2] and single quantum dots [3]. Thereby, the linewidth of the observed resonances (5 - 8 meV) is significantly smaller than the inhomogeneously broadened line-width of other spectroscopic measurements. Using a scattering-type-SNOM (s-SNOM) combined with a tunable free-electron laser (FEL) light source we investigated the electronic structure of single InAs quantum dots, capped under a 70 nm thick GaAs layer [3]. Spectroscopic near-field scans clearly identified two inter-sublevel transitions within the quantum dots at 85 meV and 120 meV, contrasting from the surrounding medium. Moreover, spatially scanning the s-SNOM tip at fixed excitation energies allowed mapping the 3D distribution of such buried quantum dots.

[1] S. Kehr et al. Nature Comm. 2, 249 (2011) [2] R. Jacob et al., Optics Ex. 18, 26206 (2010) [3] R. Jacob, PhD thesis, TU Dresden (2011)

HL 37.10 Tue 13:00 ER 164

Single site-controlled InGaAs quantum dots: narrow linewidth and electrical current injection — •Alexander Huggenberger[1], Christian Schneider[1], Tobias Heindel[1], Alexander Niederstrasser[1], Stephan Reitzenstein[1,2], Sven Höfling[1], Lukas Worschech[1], Alfred Forchel[1], and Martin Kamp[1] — [1]Wilhelm Conrad Röntgen-Center for Complex Material Systems und Technische Physik, Universität Würzburg — [2]Institut für Festkörperphysik, Technische Universität Berlin

Site-controlled quantum dots (SCQDs) offer a scalable way to integrate single quantum dots (QDs) into devices like single photon sources or sources of entangled photons. There are different ways to direct the QD nucleation to pre-defined positions. In our work we use ebeam lithography and wet etching of nano-holes into a GaAs (100) substrate to obtain both control over the QD position and high optical quality of the SCQDs. With our approach we can reduce the effect of spectral diffusion that broadens the single SCQD emission.

We present our results on the improved optical quality of site-controlled quantum dots that can be excited either optically or electrically. The linewidth of single SCQD photoluminescence could be reduced to only 38 μeV for above bandgap optical excitation. Furthermore, we show the integration of site-controlled QDs into optical cavities and achieve cavity enhanced emission as well as emission of non-classical light under electrical current injection.

HL 38: Photovoltaics: CIGS and related Materials

Time: Tuesday 11:15–13:15 Location: ER 270

HL 38.1 Tue 11:15 ER 270

Characterization of grain boundaries in Cu(In,Ga)Se_2 by atom probe tomography — •Torsten Schwarz[1], Oana Cojocaru-Miredin[1], Pyuck-Pa Choi[1], Roland Würz[2], and Dierk Raabe[1] — [1]Max-Planck Institute for Iron Research GmbH, Düsseldorf, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Stuttgart, Germany

Solar cells based on the compound semiconductor Cu(In,Ga)Se_2 (CIGS) as absorber material exhibit the highest efficiency among all thin-film solar cells. This is surprising high in view of the polycrystalline defect-rich structure of the CIGS absorber films. The high efficiency has been commonly ascribed to the diffusion of alkali metal atoms from the soda-lime glass substrate into the CIGS layer, which can render the grain boundaries (GB) electrally inactive.
However, the exact mechanisms of how these impurities enhance the cell efficiency are yet to be clarified.
As a step towards a better understanding of CIGS solar cells, we have analyzed the composition of solar-grade CIGS layers at the atomic-scale by using pulsed laser Atom Probe Tomography (APT). To perform APT analyses on selected GBs site-specific sample preparation was carried out using the Focused Ion Beam lift-out technique. In addition, Electron Back Scattered Diffraction was performed to characterize the structure and misorientation of selected GBs.
Using APT, segregation of impurities at the GBs was directly observed. APT data of various types of GBs will be presented and discussed with respect to the possible effects on the cell efficiency.

HL 38.2 Tue 11:30 ER 270

Correlation of surface contour, optoelectronic and spectroscopic properties of Cu(In,Ga)Se_2 by SNOM and AFM — •Oliver Neumann[1], Stephan J. Heise[1], Rudolf Brüggemann[1], Max Meessen[1], Wolfram Witte[2], Dimitrios Hariskos[2], and Gottfried H. Bauer[1] — [1]Institute of Physics, Carl von Ossietzky University Oldenburg, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Stuttgart, Germany

Chalcopyrite absorbers exhibit local fluctuations of structural, optical and optoelectronic properties. We study the correlation of the surface contour and the local properties such as the integrated photoluminescence (PL) yield and the splitting of the quasi-Fermi levels in a Cu(In,Ga)Se_2-based thin-film system at room temperature by AFM and spatially resolved PL measurements at the identical position with a scanning near-field optical microscope (SNOM). The Cu(In,Ga)Se_2 layer is deposited on glass, etched with bromine-methanol to smooth the surface for a more homogeneous incoupling of laser light, and passivated with cadmium sulfide. Our measurements reveal a high structural correlation between surface contour, integrated PL yield and quasi-Fermi level splitting. Additionally, we observe trenches in the

surface contour which correspond to a dip or to a peak in the splitting of the quasi-Fermi levels and integrated PL yield. Furhermore some trenches show spectral variation of the PL compared to their direct environment. We discuss these observations with respect to the optoelectronic property and the composition of the absorber.

HL 38.3 Tue 11:45 ER 270

Sub-band-gap absorption of Cu(In,Ga)Se_2 thin film semiconductors — •Max Meessen, Rudolf Brüggemann, and Gottfried H. Bauer — Carl von Ossietzky University Oldenburg, Germany

The sub-band-gap absorption of Cu(In,Ga)Se_2 thin films has been studied by photothermal deflection spectroscopy (PDS) in conjunction with optical transmittance spectroscopy. The resulting absorption coefficients are compared to those calculated from photoluminescence spectra using Planck's generalized law. Quantities related to the absorption like Urbach energy and defect densities are derived from the absorption curves.

This concept has been applied to a series of bromine-methanol etched Cu(In_{x-1},Ga_x)Se_2 (x=0.3) absorbers with varying thicknesses. A shift in the band gap is observed with both methods and can be related to the gallium gradient in the samples. In contrast, the Urbach energy and defect absorption values are not substantially affected by the etching process.

The influence of CdS buffer layers or highly thermally conductive metallic back contacts on PDS results is studied by measuring nominally identical samples with and without those layers.

HL 38.4 Tue 12:00 ER 270

Investigation of defects in Cu(In,Ga)S_2 and Cu(In,Ga)Se_2 solar cells by space charge spectroscopy — •Julia Riediger[1], Jörg Ohland[1], Martin Knipper[1], Jürgen Parisi[1], Ingo Riedel[1], and Alexander Meeder[2] — [1]Thin Film Photovoltaics, Energy- and Semiconductor Research Laboratory, University of Oldenburg, D-26111 Oldenburg — [2]Soltecture GmbH, 12487 Berlin

If deep defect states in the absorber of a solar cell act as recombination centers, they may limit the carrier lifetime and thus the open circuit voltage. This is related to the defect's activation energy and spatial position. In this study the defect landscape of chalcopyrite thin film solar cells with varied absorber composition was investigated by space charge spectroscopy. The absorber layer in Cu(In,Ga)S_2 samples arises from rapid thermal process (RTP) in sulfur vapor while Cu(In,Ga)Se_2 absorbers were processed via co-evaporation of the constituents. Several defect states were found by deep level spectroscopy (DLTS) and thermal admittance spectroscopy (TAS). With the knowledge of the defect activation energies we derived the spatial defect concentrations from (illuminated) capacitance-voltage (CV) measurements and discuss the results for both material systems. To identify the often discussed "N1" defect, the measurements were repeated after annealing and changes in the defect spectra were evaluated.

HL 38.5 Tue 12:15 ER 270

The influence of CdS buffer layer thickness on low-temperature deposited Cu(In,Ga)Se_2 solar cells — •Stefan Puttnins[1,2], Thomas Unold[3], Philipp Krüger[1], Felix Daume[1,2], Karsten Pelz[1], Andreas Rahm[1], and Marius Grundmann[2] — [1]Solarion AG, Ostende 5, 04288, Leipzig, Germany — [2]Institut für Experimentelle Physik II, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany — [3]Helmholtz Zentrum Berlin für Materialien und Energie, Hahn Meitner Platz 1, 14109 Berlin, Germany

An additional n-type layer between p-type Cu(In,Ga)Se_2 (CIGSe) absorber and n-type ZnO:Al transparent front contact is needed for highly efficient CIGSe solar cells. A CdS layer deposited in a wet chemical bath processes is commonly used for this so called buffer layer.

In this work we analyze the influence of the deposition time and therefore thickness of this CdS buffer in respect to solar cell performance via current-voltage, quantum efficiency (QE) and time resolved photoluminescence (TRPL) measurements.

Thicker buffer layers lead to higher open circuit voltages (V_{OC}), higher shunt resistances, current losses in the QE range of 400-600 nm wavelength and concurrently current gains in the range of 800-1100 nm. This current gain and the increase of V_{OC} can be correlated to an increase in carrier lifetime measured via TRPL.

HL 38.6 Tue 12:30 ER 270

Capacitance-spectroscopical investigations of the influence of buffer layers on defect generation in CIGS solar cells — •Robert Karsthof[1,2], Stefan Puttnins[1,2], Karsten Pelz[1], Matthias Schmidt[2], and Marius Grundmann[2] — [1]Solarion AG, Ostende 5, D-04288 Leipzig — [2]University of Leipzig, Institute for Experimental Physics II, Linnéstraße 5, D-04103 Leipzig

The beneficial effect of the presence of buffer layers in Cu(In, Ga)Se_2 (CIGS) thin film solar cells on the cell performance has already been confirmed in numerous investigations. Nevertheless, the influence of certain deposition parameters of these layers (implemented at the Solarion AG by a cadmium sufide and an intrinsic zinc oxide layer) on device properties like defect generation at the buffer/absorber or window/buffer interface as well as energetical and spatial distribution of buffer-induced defects is not fully understood yet. In this work ZnO:Al/i-ZnO/CdS/CIGS/Mo/polyimide(PI) solar cells were investigated and the influence of a variation of the sputtering power during the i-ZnO process was analysed. The used methods were thermal admittance spectroscopy (TAS), capacitance-voltage (CV) and photocapacitance (PCap) measurements as well as CV spectroscopy with additional optical excitation (OCV). From the latter doping profiles of single defect species can be obtained.

HL 38.7 Tue 12:45 ER 270

Investigations of lateral and vertical compositional gradients in Cu(In,Ga)Se_2 prepared through Rapid Thermal Processing by highly spatially and spectrally resolved cathodoluminescence spectroscopy — •Mathias Müller[1], Stefan Ribbe[1], Frank Bertram[1], Thomas Hempel[1], Humberto Rodriguez-Alvarez[2], Jakob Lauche[2], Hans-Werner Schock[2], and Jürgen Christen[1] — [1]Institute for Experimental Physics, Otto-vonGuericke-University Magdeburg, Germany — [2]Helmholtz Center Berlin for Materials and Energy, Germany

We analyze Cu(In,Ga)Se_2 thin films using highly spatially and spectrally resolved cathodoluminescence (CL) spectroscopy at low temperature (T = 5 K). The films were deposited by means of a rapid thermal selenization process with growth times varying from 70 to 150 seconds. We find that lateral integral spectra exhibit a broad dominant peak with energies from 0.95 eV to 0.99 eV and a shoulder on the low-energy side. By varying the excitation density, a shift to higher energies of the main peak by 12.8 meV/decade can be observed for the samples with growth times of 100 s and 120 s. Investigations of the cross-sections reveal two distinct regions in the layer sequence. A Ga-rich layer next to the back contact can be identified showing lower luminescence intensities. In contrast, the layer on top reveals an In-rich concentration.

HL 38.8 Tue 13:00 ER 270

Investigations of vertical chemical gradients in Cu(In,Ga)S_2-thin films prepared by sulfurization of sputtered precursor layers using highly spatially resolved cathodoluminescence microscopy — •Stefan Ribbe[1], Mathias Müller[1], Frank Bertram[1], Thomas Hempel[1], Humberto Rodriguez-Alvarez[2], Jakob Lauche[2], Hans Werner Schock[2], and Jürgen Christen[1] — [1]Institute for Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Helmholtz Center Berlin for Materials and Energy, Germany

The luminescence properties of Cu(In,Ga)S_2(CIGS)-absorber layers for thin film solar cells have been studied by highly spatially resolved cathodoluminescence (CL) at low temperature ($T = 5$ K). In/Cu-Ga-precursors were annealed with elementary sulfur pellets in a rapid thermal process at different annealing times to represent different growth steps of the CIGS absorber layer. Spatially integral CL spectra show a dominant peak at 825 nm accompanied by a low-energy shoulder at 890 nm. Only a slight blue shift of the main peak is observed by variation of the excitation density. Investigations of cross-sections show for all samples a similar luminescence distribution. Near the molybdenum back contact distinct areas show luminescence emitting at $680 - 750$ nm. In contrast, in upper regions of the layer a homogeneous low-energy luminescence at around 820 nm is observed which exhibits the most intensive spots on the cross-section. In local spectra we observe a change of the dominant recombination channel at the interface of these two regions.

HL 39: ZnO and Relatives II

Time: Tuesday 11:30–13:15 Location: EW 202

HL 39.1 Tue 11:30 EW 202

A DFT study of N impurities in ZnO nanoparticles — •Johann Gutjahr, Sung Sakong, and Peter Kratzer — Fakultät für Physik and Center for Nanointegration (CeNIDE), Universität Duisburg-Essen, Duisburg, Germany

Zinc oxide nanostructures have attracted increasing interest due to their promising applications in electronic devices. ZnO is possibly ideally suited for blue/UV light-emitting diodes or laser diodes, once n- and p-doped ZnO can be produced reliably and reproducably. Nevertheless, p-type ZnO was obtained experimentally by N doping (Nature Materials **4**,42(2005)). We study N doping of nanoparticles (NP) because their properties can be tuned and they offer a simple way to produce ZnO material by e.g. sintering. In bulk ZnO, DFT calculations show the deep character of the N impurity on the O site because of the too high position of the charge transfer level $(0/-)$ in the band gap (APL **95**,252105(2009)).

As expected, the NP HOMO-LUMO gap is increased with decreasing NP size, but the N defect formation energy is found to be similar to bulk ZnO. Moreover, from the change of electron affinity we conclude the deepness of the N acceptor level. We also study different kinds of passivation and find that with H-passivation the adsorbate-induced states lie between VBM and acceptor level. Based on this, we explore the N acceptor level in thin ZnO-films as a model for the surface of a bigger particle to learn more about the influence of H-induced states.

HL 39.2 Tue 11:45 EW 202

Passivation of tungsten trioxide gated MISFETs based on ZnO channel material — •Anna Reinhardt, Michael Lorenz, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Semiconductor Physics Group

Recently, tungsten trioxide was reported to be an advantageous high-k gate oxide for transparent MISFETs with large on/off current ratios and low gate-voltage sweeps due to a high dielectric constant ($\epsilon_r \approx 70$)[1]. However, a slight hysteresis limiting the device switching speed occurs in the transfer characteristic.

The passivation of TFTs with lithographically processed SU-8 resist is very promising, providing a non-vacuum and low temperature process (max. 90 °C) compared to other deposition methods for passivation layers such as sputtering. We present our results on passivated tungsten oxide gated MISFETs deposited at room temperature on ZnO channel using pulsed-laser deposition. The electrical properties including on/off ratio, field-effect mobility and transfer characteristic are investigated by current-voltage measurements. In order to investigate the origin of the hysteresis and to study the distribution and density of defects quasi-static capacitance-voltage measurements as well as capacitance-voltage spectroscopy using different probing voltage frequencies were performed. Furthermore, time and temperature stability is compared to unpassivated devices.

[1] M. Lorenz *et al.*, Adv. Mater., doi: 10.1002/adma.201103087

HL 39.3 Tue 12:00 EW 202

Temperature dependent properties of ZnO/(Mg,Zn)O quantum wells with and without a distinct QCSE — •Marko Stölzel, Johannes Kupper, Matthias Brandt, Alexander Müller, Gabriele Benndorf, Michael Lorenz, and Marius Grundmann — Institut für Experimentelle Physik II, Universität Leipzig, Linnéstr. 5, 04103 Leipzig, Germany

Confinement effects, the Stokes shift and the quantum-confined Stark effect (QCSE) determine the luminescence properties of polar ZnO/(Mg,Zn)O quantum wells (QWs). We present temperature dependent photoluminescence and optical transmission measurements to separate these effects and determine the origin of the luminescence.

Single QW structures have been prepared by pulsed laser deposition (PLD) on a-plane sapphire substrate exhibiting excitons with and without a distinct QCSE. The QCSE leads to a redshift of the QW luminescence maximum beneath the free exciton energy in ZnO as well as a change of the dynamics from a single exponential decay function to a non-exponential one, well described by a stretched exponential decay function. The internal electric field was evaluated to 0.66 MV/cm. Based on QWs without a distinct QCSE, the Stokes shift will be determined in dependence of well width and temperature.

The radiative decay time was found to increase linearly with temperature for both types of QWs indicating free exciton emission as the major recombination channel. With increasing temperature, the internal electric field is screened by free charge carriers, leading to a drop of the radiative decay time and reduction of the redshift above 50 K.

HL 39.4 Tue 12:15 EW 202

Electrical characterization of proton-irradiated MgZnO thin films — •Florian Schmidt[1], Matthias Schmidt[1], Holger von Wenckstern[1], Daniel Spemann[2], and Marius Grundmann[1] — [1]Universität Leipzig, Institut für Experimentelle Physik II, Abteilung Halbleiterphysik, Linnéstraße 5, 04103 Leipzig — [2]Universität Leipzig, Institut für Experimentelle Physik II, Abteilung Nukleare Festkörperphysik, Linnéstraße 5, 04103 Leipzig

Zinc oxide (ZnO) is a semiconductor which is known for its high radiation hardness making the material suitable for space applications. Ternary MgZnO is an excellent material system for the fabrication of quantum well heterostructures and thus for potential application in exciton-related photonic devices. Whereas the influence of proton bombardment on the incorporation of defects in pure ZnO has been reported [1], no data are yet available regarding the exposure of MgZnO to protons. To study the effect of radiation, $Mg_{1-x}Zn_xO$ thin films with Mg contents of $0 \leq x \leq 2\%$ were irradiated by 2.25 MeV protons with fluences ranging from $1 \times 10^{13}\,cm^{-2}$ to $2 \times 10^{14}\,cm^{-2}$. The samples grown by pulsed-laser deposition were characterized by means of C-V measurements, deep level transient spectroscopy (DLTS) and Laplace DLTS. The proton irradiation generates a deep-level, labelled E4 in the literature, which has been tentatively assigned to the oxygen vacancy [1,2]. The generation rate of the defect in the MgZnO thin films was determined.

[1] F. D. Auret *et al.*, Appl. Phys. Lett., **79**(19), 3074 (2001).
[2] T. Frank *et al.*, Appl. Phys. A **88**, 141 (2007).

HL 39.5 Tue 12:30 EW 202

Raman spectra of ZnO and nitrogen doped ZnO – Tensor elements and additional modes — •Thomas Sander, Christian Reindl, Sebastian Eisermann, Elisabeth A. Zolnowski, Stefan Lautenschläger, Bruno K. Meyer, and Peter J. Klar — I. Physikalisches Institut, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 16, 35392 Gießen

Raman spectra of wurtzite ZnO have been studied intensively in the past. However, some unanswered questions still remain, like the Raman tensor elements, which have not been determined yet and are of fundamental physical interest. Furthermore, ZnO is a promising candidate for potential applications in optics and optoelectronics in the near UV region, if one overcomes the lack of reliable p-type doping. Nitrogen is an acceptor in ZnO. Incorporating N into ZnO leads to several additional modes in Raman spectra whose origins are still controversial.

Wurtzite bulk ZnO substrates and nitrogen doped ZnO thin films grown by CVD were studied by Raman spectroscopy. The phonon spectra were recorded in backscattering geometry at room temperature. The samples were rotated around the axis defined by the 532 nm, polarized excitation laser in different scattering geometries. The results allow one to determine the four tensor elements of ZnO and proof the fundamental selection rules. Furthermore, they will shed light on the origin of the controversially discussed additional Raman modes in the spectra caused by the nitrogen incorporation.

HL 39.6 Tue 12:45 EW 202

Hyperfeinwechselwirkung in ZnO unter uniaxialem Druck — •Rita Przewodnik und Reiner Vianden — Helmholtz-Institut für Strahlen und Kernphysik, 53115 Bonn, Deutschland

Untersucht werden Zinkoxid Einkristalle unter uniaxialer Belastung im Druckbereich von 0-300 MPa. Aufgrund der Wurtzitstruktur bildet sich ein zur c-Achse axialsymmetrischer, elektrischer Feldgradient (EFG) aus, dessen Betrag vom c/a Verhältnis der Kristallachsen abhängt. Das Verhältnis der Kristallachsen ändert sich im Belastungsfall, womit der EFG beeinflusst wird.

Die Änderung des EFG in Abhängigkeit von der externen Druckspannung wird mit der Methode der gestörten γ-γ-Winkelkorrelation (Perturbed Angular Correlation, PAC) bestimmt. Als Sonden werden

dazu ^{111}In-Ionen implantiert, die substitutionell auf Zinkplätzen ins Kristallgitter eingebaut werden. Die entstehenden Implantationsschäden werden vor der Messung ausgeheilt. Die Experimente zeigen in dem betrachteten Druckbereich eine lineare Zunahme des EFG bei uniaxialer Druckerhöhung in Richtung der c-Achse. Eine Druckerhöhung entlang der m-Achse führt zu einer linearen Abnahme bei zunehmender Asymmetrie des EFG.

HL 39.7 Tue 13:00 EW 202

Hydrostatic pressure dependence of the refractive index in ZnO and GaN — •Felix Käss[1,2], Juan Sebastian Reparaz[1,2], Gordon Callsen[2], Markus Raphael Wagner[2], Alejandro Rodolfo Goñi[1,3], Maria Isabel Alonso[1], Miquel Garriga[1], and Axel Hoffmann[2] — [1]Institut de Ciència de Materials de Barcelona-CSIC, Esfera UAB, 08193, Bellaterra, Spain — [2]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, u o a 10623 Berlin, Germany — [3]ICREA, Passeig Lluís Companys 23, 08010 Barcelona, Spain

In this work we will present the hydrostatic pressure dependence of the real part of the refractive index in ZnO and GaN. By using a diamond anvil cell (DAC) combined with an optical transmission experiment we study the Fabry-Pérot interferences in the transparency region (approx. below 3.2 eV). A large series of interference peaks arising from the cavity-modes allow for the determination of the energy dependent refractive index. Many experimental complications which we found to be critical will be discussed in detail, leading to a detailed description of the optimum characteristics which are required for an ethalon to optically manifest in the DAC enviroment.

HL 40: Impurities / Amorphous Semiconductors

Time: Tuesday 11:30–13:15 Location: EW 015

HL 40.1 Tue 11:30 EW 015

The dangling-bond defect in crystalline and amorphous silicon: insights from ab initio calculations of EPR parameters — •Gernot Pfanner, Christoph Freysoldt, and Jörg Neugebauer — Max-Planck Institut für Eisenforschung, Max-Planck Strasse 1, D-40237 Düsseldorf

The efficiency of thin-film a-Si:H solar cells is severely limited by light-induced defects (Staebler-Wronski effect). In this context, electron-paramagnetic resonance (EPR) is a key technique to probe for the local atomic structure of defects with unpaired spins such as the silicon dangling-bond (db). However, the assignment of the EPR signal to a specific defect structure requires comparison to theoretical models.

Using density-functional theory, we address structure-property relationships by combining systematic studies for idealized db models in c-Si with a statistical analysis of a variety of dbs in a-Si:H supercells. Our studies reveal the influence of the local geometry on sp-hybridization and delocalization. Yet, the structural variability of a-Si:H cannot be captured by these idealized defect models alone. Rather, our calculations indicate that a relatively broad distribution of db-like structures gives rise to the experimental signal supporting a recent re-evaluation of EPR parameters from multi-frequency EPR [1]. Furthermore, to investigate how the stability of the dbs is affected by residual strain fields, we apply external strain to our crystalline and amorphous db models and monitor the evolution of structure and EPR properties.

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[1] M. Fehr (et al.), Phys. Rev. B (in press), http://arxiv.org/abs/1103.5641

HL 40.2 Tue 11:45 EW 015

Vibrational spectra of charged point defects in ionic oxides — Jianchuan Wang, •Christoph Freysoldt, and Jörg Neugebauer — Max-Planck-Institut für Eisenforschung, Düsseldorf

We report calculations of the vibrational spectra of point defects which include the complete coupling to the host matrix. Such couplings are expected for charged defects in oxides and other ionic materials due to the long-range nature of electrostatic interactions. The dynamical matrix is computed from an electro-elastic model which combines long-range electrostatic forces with a pairwise interatomic harmonic correction for a limited number of neighbors. The model parameters are obtained from a few accurate density-functional theory *ground-state* calculations, requiring only forces and potentials which are readily available. Available symmetries are fully exploited. The approach is demonstrated for the +2 O vacancy in MgO. We show that the presence of the defect breaks the symmetry of the Born effective charge tensor of nearby atoms, and discuss the relevant sum rules. We also analyse how the defect modifies the vibrational density of states.

HL 40.3 Tue 12:00 EW 015

Evidence for Fe2+ in Wurtzite Coordination: Iron Doping Stabilizes ZnO Nanoparticles — •Jianping Xiao[1,2], Agnieszka Kuc[2], Suman Pokhrel[3], Marco Schowalter[4], Satyam Parlapalli[4], Andreas Rosenauer[4], Thomas Frauenheim[1], Lutz Mädler[3], Lars Pettersson[5], and Thomas Heine[2] — [1]Bremen Centre for Computational Materials Science, Bremen, Germany — [2]School of Engineering and Science, Jacobs University Bremen, Germany — [3]IWT Foundation Institute of Materials Science, Bremen, Germany — [4]Institute for Solid State Physics, Bremen, Germany — [5]Stockholm University, Stockholm, Sweden

First-principles calculations are used to investigate the structural and electronic properties of Fe-doped ZnO nanoparticles. Based on extensive validation studies surveying various density functionals, the hybrid functional PBE0 is employed to calculate the structures, formation energies, and electronic properties of Fe in ZnO with Fe concentrations of 6.25, 12.5, and 18.75 at%. Substitution of Zn by Fe, zinc vacancies, and interstitial oxygen defects is studied. High-resolution inner-shell electron energy loss spectroscopy measurements and X-ray absorption near-edge structure calculations of Fe and O atoms are performed. The results show that Fe-doped ZnO nanoparticles are structurally and energetically more stable than the isolated FeO(rocksalt) and ZnO (wurtzite) phases. The Fe dopants do not significantly alter the host ZnO lattice parameters. Simulations of the absorption spectra demonstrate that Fe2+ dominates in the Fe-doped ZnO nanoparticles reported recently, whereas Fe3+ is present only as a trace.

HL 40.4 Tue 12:15 EW 015

Defects in amorphous silicon nitrides: Si_3N_4-Si_3N_x — •Leif Eric Hintzsche, Georg Kresse, Martijn Marsmann, Gerald Jordan, Changming Fang, and Thomas Watts — Computational Materials Physics, University of Vienna, Sensengasse 8/12, 1090 Vienna, Austria

Amorphous silicon nitride is widely used for memory and photovoltaic devices. In solar cells, it serves as a passivation and antireflection layer. In most cases, the silicon nitride layers are not stoichiometric and contain significant amounts of hydrogen. Currently, it is not well understood what distinguishes a good passivation layer that minimizes reflection losses from a bad passivation layer. To gain a more detailed atomic scale understanding, we present a careful study of the electronic properties of stoichiometric and non-stoichiometric silicon nitrides in the range of Si_3N_5-Si_3N_3. For each stoichiometry, several structural models are created containing typically 100 Si atoms. The evolution of the band gap, participation ratio, as well as the geometric and electronic defects states are analysed in detail. For the preparation of the structures, simulated annealing combined with standard density functional theory is applied, whereas the Heyd-Scuseria-Ernzerhof hybrid functional is used to analyse the electronic properties of the final structures.

HL 40.5 Tue 12:30 EW 015

Charge Carrier Density Control in In-based Multi Compound Solution Processed Oxide TFTs — •Marlis Ortel, Marko Marinkovic, Gesa Helms, and Veit Wagner — Jacobs University Bremen, School of Engineering and Science, Campus Ring 8, 28759 Bremen, Germany

Novel oxide semiconductors have recently caught much attention for TFTs in high-end 3D-TVs and smart-sensor applications. Materials like In-Ga-Zn-O (IGZO) show very high mobility, transparency and they are solution processable. When electrical stress is applied the TFT characteristics shifts. A reason for this instability are oxygen vacancies, which are attributed to weak indium-oxygen bonds. The vacancies result in traps and doping of the active layer.

In this work charge carrier control in TFTs by addition of Al and Si to indium oxide was investigated. These components were chosen with respect to the bonding properties to oxygen. Si and Al show almost the same ionic radius but differ in the bond dissociation energy to oxygen by a factor of 1.6. A systematic influnce on the charge carrier density caused by oxygen vacancies is expected. For the investigation TFTs were electrically and morphologically characterized. The analysis gave a high mobility of 12cm2/Vs for the In-Al-O material system. The density of deep trap states near the mid-gap was analyzed to be 6.8E12eV-1cm-2 in In-Al-O and as low as 2.2E12 eV-1cm-2 in the In-Si-O material system.

In conclusion addition of silicon is a proper method to control the bulk charge carrier density, i. e. doping level, in In-based oxide TFTs.

HL 40.6 Tue 12:45 EW 015

THz spectroscopy of the 29 cm^{-1} oxygen vibrational line in natural silicon and isotopically enriched ^{28}Si — •Kurt Lassmann[1], Boris Gorshunov[1,2,3], P.S. Korolev[2,4], E.S. Zhukova[1,2,3], V.P. Kalinsuhkin[2], N.V. Abrosimov[5], P.G. Sennikov[6], H.-J. Pohl[7], S. Zakel[8], and Martin Dressel[1] — [1]1. Phys. Inst., Univ. Stuttgart — [2]A.M. Prokhorov Gen. Phys. Inst., RAS, Moscow — [3]Moscow Inst. Physics and Technology — [4]Lomonosov Moscow State Univ. — [5]Leibniz Inst. Kristallzüchtung, Berlin — [6]Inst. Chem. High-Purity Substances, Nizhny Nowgorod — [7]PTB, Braunschweig — [8]VITCON-Projektconsult, Jena

Looking for a possible host-isotope effect on the low-energy two-dimensional motion of interstitial oxygen in silicon we have measured the resonance parameters of the lowest transition of the 30 cm^{-1} band of the Si-O-Si complex in natural Si and in isotopically enriched ^{28}Si at temperatures between 5 K and 22 K by means of coherent-source terahertz spectroscopy. At 5.5 K we obtain for the resonance maxima 29.24 ± 0.003 cm^{-1} and 29.22 ± 0.003 cm^{-1} and for the line widths 0.09 ± 0.01 cm^{-1} and 0.11 ± 0.01 cm^{-1} for ^{28}Si and ^{nat}Si, respectively. Both lines can be fitted by single Lorentzians, so, no obvious isotopic structure or asymmetry of the line in ^{nat}Si due to the Si neighbors in the Si-O-Si complex is detected. We therefore conclude that down-shift and broadening of the ^{nat}Si-resonance is not due to the Si isotopes in the isolated Si-O-Si complex but to an average effect of the isotopically inhomogeneous lattice.

HL 40.7 Tue 13:00 EW 015

Diffusion of Cu (I) in amorphous In_2S_3 thin films investigated by Rutherford backscattering spectroscopy — •Albert Juma[1], Paul Pistor[1], Thomas Dittrich[1], and Elke Wendler[2] — [1]Helmholtz-Centre Berlin for Material and Energy, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [2]Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Amorphous In_2S_3 thin films can be used in charge-selective layer systems for example in contact with chalcopyrite absorber or in contact with CuSCN hole conductor. Diffusion of Cu (I) plays a crucial role for the electronic properties of charge-selective contact systems with In_2S_3. In our experiments CuSCN was sprayed as a Cu (I) source on evaporated amorphous In_2S_3 thin films (layer thickness 100 nm) and the annealing temperature was varied and annealing time was fixed. After annealing CuSCN was etched away in pyridine solution. The Cu concentration profiles were obtained from Rutherford backscattering (He^+) measurements. Temperature dependent diffusion coefficients were deduced from the measurements. The value of the exponential prefactor was of the order of 10^8 cm^2s^{-1} and the activation energy amounted to about 0.9 eV. A suggestion on the diffusion mechanism will be drawn.

HL 41: Organic Electronics and Photovoltaics: Simulations and Optics II (jointly with DS, CPP, O)

Time: Tuesday 11:30–13:00 Location: H 2032

HL 41.1 Tue 11:30 H 2032

Fast, stable and high-brightness light-emitting electrochemical cells — •Sebastian B. Meier[1,2], Daniel Tordera[3], Henk J. Bolink[3], Wiebke Sarfert[2], and Albrecht Winnacker[1] — [1]University of Erlangen-Nuremberg, Department of Materials Science, Chair VI: Materials for Electronics and Energy Technology, Erlangen, Germany — [2]Siemens AG, Corporate Technology, GTF Organic Electronics, Erlangen, Germany — [3]Instituto de Ciencia Molecular, Universitat de València, Paterna, Spain

Light-emitting electrochemical cells (LECs) are among one of the simplest class of light-emitting devices based on organic semiconducting materials. In its most facile form they just comprise a single solution-processed layer of an ionic transition metal complex (iTMC) sandwiched between two air-stable electrodes, which supports all the three events of charge injection, charge transport and radiative recombination. The ordinary architecture and the possibility to use stable electrode materials is a direct consequence of the ionic nature of the active layer enabling efficient charge injection with concomitant in-situ electrochemical doping resulting in the formation of a light-emitting p-i-n junction. There has been a longstanding issue in iTMC device operation between fast response and high stability when standard constant DC voltage is used, which is due to the dynamic nature of the junction. We will show how to stabilize the dynamic junction to achieve long-living ($>$ 1000 h) high-brightness ($>$ 1200 cd/m^2) iridium(III) iTMC-based LECs possessing simultaneous fast turn-on times ($<$ 20s) at considerable light intensity ($>$ 200 cd/m^2).

HL 41.2 Tue 11:45 H 2032

Charge Carrier Storage on Emitter Molecules in Organic Light-Emitting Diodes — •Caroline Weichsel[1], Sebastian Reineke[1,2], Björn Lüssem[1], and Karl Leo[1] — [1]Institut für Angewandte Photophysik, Technische Universität Dresden, George-Bähr-Str. 1, D-01069 Dresden, Germany — [2]Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA

In this contribution, we study trapping of charge carriers in phosphorescent organic light-emitting diodes (OLED) using the red emitter iridium(III)bis(2-methyldibenzo[f,h]quinoxaline) (acetylacetonate) [Ir(MDQ)2(acac)] by transient electroluminescence. We observe a transient overshoot exceeding regular light emission after voltage turn-off, which can be explained by delayed charge carrier recombination of charges stored in the emission layer. We study this mechanism by variation of the off-voltage and by adding thin quenching layers, which allow to determine the position of the emission zone during regular light emission and after voltage turn-off. Additionally, we show that the signal intensity is linearly proportional to the doping concentration. Investigations on the applied current and the pulse length show a saturation of the overshoot intensity, which we ascribe to the limited ability of emitter molecules to store electrons. We propose that this storage process negatively affects the external quantum efficiency of the OLED. We assume that the effect can also take place in other OLED structures and suggest that the methods presented here can help identifying charge carrier storage on emitter molecules.

HL 41.3 Tue 12:00 H 2032

Surface Modification Effect on Optical Anisotropy and Molecular Orientation of CuPc Thin Films — •L. Ding, M. Friedrich, O. Gordan, and D. R. T. Zahn — Semiconductor Physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany

Copper phthalocyanine (CuPc), as an organic semiconductor, attracts much attention currently due to its potential application in organic electronic and photovoltaic devices. Molecular orientation plays a significant role to improve the device performance. In situ spectroscopic ellipsometry (SE) and reflection anisotropy spectroscopy (RAS) are employed simultaneously to investigate the out-of-plane and in-plane anisotropy as well as molecular orientation of CuPc thin films, respectively.

Chemically prepared octadecyltrichlorosilane (OTS) monolayer with upright standing molecules shows a significant influence on the out-of-plane anisotropy with an average out-of-plane tilt angle of 69.3° +/- 4.1° but little impact on the in-plane anisotropy. Nearly flat lying CuPc molecules are observed on thermally evaporated Perylene-3,4,9,10-tetracarboxylic-3,4,9,10-dianhydride (PTCDA) layers thicker than 3.4 nm, giving an average tilt angle of 19.7° +/- 8.0° due to the

flat lying PTCDA molecules on Si. Meanwhile, the in-plane anisotropy of CuPc is much lower than that without PTCDA. The influence of the PTCDA layer thickness on molecular orientation can be explained by the island growth mode of PTCDA.

HL 41.4 Tue 12:15 H 2032

Stability of perfluroro-pentacene thin films on coinage metals — •Christian Schmidt[1], Tobias Breuer[1], Stefan Wippermann[2], Wolf Gero Schmidt[2], and Gregor Witte[1] — [1]Molekulare Festkörperphysik, Philipps-Universität Marburg, Germany — [2]Theoretische Physik, Universität Paderborn, Germany

The development of organic electronics greatly benefits from the systematic improvement of molecular properties by chemical functionalization. One example constitutes pentacene that can be prevented from oxidization by perfluorination. Topical investigations of the interface properties of perfluoropentacene (PFP) are frequently conducted only from an electronic point of view, measuring either macroscopic device properties or valence band spectra. In these studies possible chemical interactions have not been addressed since PFP is especially designed to be more stable than PEN. It was therefore unexpected that PFP monolayers on Cu(111) undergo degradation upon heating and that decomposition also occurs on Ag(111). This means that PFP is less stable than PEN, which desorbs intact from Ag(111). This behaviour is especially remarkable when considering that PFP is farther above metal surfaces than PEN. This unclear situation is very problematic, as the PFP-metal interface itself serves as a model system for electronic effects and is of vital interest in this field. Therefore, we systematically studied the thermal behaviour of PFP on the coinage metals by means of temperature NEXAFS and XPS. In order to understand underlying mechanisms we accompany our experimental data with density functional theory (DFT) calculations including chemical reactions.

HL 41.5 Tue 12:30 H 2032

Two dimensional band structure mapping of organic single crystals using the new generation electron energy analyzer ARTOF — •A. Vollmer[1], R. Ovsyannikov[1], M. Gorgoi[1], S. Krause[1], M. Oehzelt[1], N. Martensson[2], S. Svensson[2], P. Karlsson[3], M. Lundquist[3], J. Pflaum[4], T. Schmeiler[4], and N. Koch[1,5] — [1]Helmholtz Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany — [2]Uppsala University, Uppsala, Sweden — [3]VG Scienta, Uppsala, Sweden — [4]Universität Würzburg, Würzburg, Germany — [5]Humboldt-Universität zu Berlin, Berlin, Germany

We report on a novel type of photoemission instrument, the Angle Resolved Time Of Flight analyzer (ARTOF 10k)electron energy analyser. The instrument facilitates the simultaneous recording of kinetic energy and angular pattern of photoelectrons in a cone of up to 30° opening angle with very high energy resolution (100 μeV). Its transmission (250 times higher than in hemispherical analysers)allows for very mild conditions during the experiment turning the ARTOF into the predestined instrument to investigate sensitive specimens such as organic single crystals, as extremely low photon fluxes can be used. Even though organic single crystals are of increasing fundamental and applied scientific interest, knowledge of their electronic properties is still mainly based on theoretical calculations due to major experimental challenges in measuring photoemission. Here we present the band structures of rubrene and tetracene single crystals obtained with unprecedented quality using the ARTOF instrument within only a few hours of measurement time.

HL 41.6 Tue 12:45 H 2032

Electronic structure of prototypical organic-organic heterojunctions for photovoltaic applications — •Andreas Wilke[1], Raphael Schlesinger[1], Ullrich Hörmann[2], Jens Niederhausen[1], Johannes Frisch[1], Antje Vollmer[3], Julia Wagner[2], Mark Gruber[2], Andreas Opitz[1], Wolfgang Brütting[2], and Norbert Koch[1,3] — [1]Humboldt-Universität zu Berlin — [2]Universität Augsburg — [3]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH

In organic photovoltaic cells (OPVCs) typically two organic materials with electron acceptor and donor character are sandwiched between anode and cathode, forming either layered planar (PHJ) or bulk heterojunctions, where charge separation occurs. We report ultraviolet photoelectron spectroscopy (UPS) measurements done for three different organic-organic PHJs, comprising the donors sexithiophene (6T) and poly(3-hexylthiophene) (P3HT), and the acceptors diindenoperylene (DIP) and C60. The respective heterojunctions were formed on poly(ethylenedioxythiophene) : poly(styrenessulfonate) (PEDT:PSS) electrodes. The energy level alignment found experimentally for these heterojunctions are discussed in relationship to the open circuit voltages achieved in corresponding PHJ OPVCs. The offset between the highest occupied molecular orbital of the donor and the lowest unoccupied molecular orbital of the acceptor, an estimate for the maximum achievable open circuit voltage, peaked at 1.75 eV for the 6T/DIP PHJ. In actual OPVCs based on 6T/DIP, an open circuit voltage of up to 1.38 V was observed.

HL 42: Invited Talk: Claudia Draxl

Time: Tuesday 14:45–15:15 Location: EW 201

Invited Talk HL 42.1 Tue 14:45 EW 201

Excitons in organic semiconductors and organic/inorganic hybrid systems: Insight from many-body perturbation theory — •Claudia Draxl — Institut für Physik, Humboldt-Universität zu Berlin, Germany

Excitons are central quantities in the photophysics of materials used in opto-electronic devices. Their binding strength is governed by the degree of localization of the involved charge carriers. If the Coulomb interaction is efficiently screened, electrons and holes are free, like in metals, or form weakly bound pairs like in inorganic semiconductors. In organic molecular crystals, we find tightly bound Frenkel-type excitons with binding energies of several tens of an eV. Also low-dimensional structures, like polymer chains or carbon nanotubes exhibit strong electron-hole interaction. New exciting phenomena can arise when two different types on materials meet in a nanostructure.

From the theoretical point of view, excitons can be studied by the solution of the Bethe-Salpeter equation within many-body perturbation theory, using density-functional theory as a starting point. I will give an introduction to this theoretical approach and demonstrate with several examples the above described effects. They will comprise polymers and organic materials as well as valence and core excitations in inorganic semiconductors. Finally, I will discuss the optical absorption of a new "peapod", a hybrid material formed by organic molecules encapsulated in semiconducting carbon nanotubes. I will demonstrate that the two constituents, though being, purely van-der-Waals bound, interact in the excited state by forming hybrid excitons.

HL 43: Poster Session: Quantum Dots and Wires - Preparation and Characterization / Devices (incl. Laser) / Ultrafast Phenomena

Time: Tuesday 9:30–12:30 Location: Poster D

HL 43.1 Tue 9:30 Poster D

Lattice parameters and strain-accommodation in mixed zincblende/ wurtzite GaAs nanowires on Si — •Ullrich Pietsch[1], Andreas Biermanns[1], Steffen Breuer[2], Anton Davydok[1], Achim Trampert[2], and Lutz Geelhaar[2] — [1]Universität Siegen, Festkörperphysik, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany

In this contribution we present a x-ray diffraction study of the interface structure of GaAs nanowires grown on Si(111)-substrates using the Ga-assisted growth mode in molecular beam epitaxy. Under the

used growth conditions, NW growth starts with a large abundance of wurtzite structural units, but the zinc-blende structure dominates for longer growth times. Using grazing incidence diffraction, the wurtzite type GaAs in the NWs is found to exhibit a smaller inplane-lattice parameter than the corresponding zinc-blende type material. Using the applied growth mechanism, no pseudomorphic growth is obtained for NW-diameters down to 10nm. Instead, thin NWs grow relaxed, whereas for thicker NWs the plastic relaxation is incomplete. Although NWs grow dislocated, complete relaxation is hindered by a rough interface structure. This rough interface structure is likely caused by the initial etching-reaction of the liquid Ga droplets with the Si surface. Using asymmetric x-ray diffraction on single NWs, we measure both the in- and out-of-plane components of the displacement field caused by the incomplete relaxation process. Here, large fluctuations between different NWs are found, indicating that the detailed displacement field crucially depends on the (random) interface structure.

HL 43.2 Tue 9:30 Poster D

Investigation of single GaAs nanowires through grazing incidence X-ray diffraction — •Genziana Bussone[1,2], Rüdiger Schott[3], Anton Davydok[1], Andreas Biermanns[1], Dirk Reuter[3], Andreas D. Wieck[3], and Ullrich Pietsch[1] — [1]Universität Siegen, Festkörperphysik, Germany — [2]European Synchrotron Radiation Facility, Grenoble, France — [3]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Semiconductor nanowires (NWs) are a promising route for the conception of advanced electronic and photonic devices. For these purposes, absence of defects and homogeneity of the crystal lattice are crucial along the entire NW. Here, we report on the characterization of freestanding GaAs NWs using X-ray diffraction with a nanometer-sized X-ray beam, allowing to probe the crystal structure along the wire. GaAs NWs have been grown on a (111)-oriented GaAs substrate by molecular beam epitaxy using the gold-assisted growth mode. The position of the NWs was controlled by a direct implantation of Au using a focused ion beam system followed by an annealing procedure, which allows to precisely locate single NWs. The controlled arrangement and the nano-focus setup of beamline ID01 at the ESRF allowed the investigation of single, freestanding NWs in a grazing incidence geometry in order to probe the inplane-lattice parameter of the NWs. For random grown NWs, this is not possible due to the large footprint of the X-ray beam. Radial scans were performed at different heights along the NW. The data show a relaxation of the crystal lattice along the wire, revealed by the increasing of the lattice spacing closer to its top.

HL 43.3 Tue 9:30 Poster D

Growth of GaAs nanowires on GaAs (111)B substrates induced by focused ion beam — •Rüdiger Schott, Dirk Reuter, and Andreas D. Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Semiconductor nanowires are a promising system for applications in the areas of electronics and photonics as well as for exploring phenomena at the nanoscale. There are several approaches to grow nanowires at predetermined sites on the wafer. We report about growing GaAs-nanowires on GaAs (111)B substrates via the vaporliquid-solid (VLS) mechanism in an ultra-high-vacuum (UHV)-cluster consisting of a molecular beam epitaxy (MBE) and a focused ion beam (FIB) system. Our idea is to implant metal seeds for the nanowire growth using FIB. Due to the UHV transfer between the FIB and the MBE chamber, no further cleaning step of the substrate surface is necessary. We were able to grow single nanowires in user defined patterns on the wafer. Nanowire diameters below than 20nm were observed. The structural and optical properties of the nanowires were investigated by SEM, TEM and photoluminescence spectroscopy.

HL 43.4 Tue 9:30 Poster D

Strain in GaAs / InAs core-shell nanowire heterostructures grown on GaAs — •Andreas Biermanns[1], Torsten Rieger[2,3], Anton Davydok[1], Mihail Ion Lepsa[2,3], and Ullrich Pietsch[1] — [1]Universität Siegen, Festkörperphysik, Germany — [2]Peter Grünberg Institut-9, Forschungszentrum Jülich, Germany — [3]JARA-Fundamentals of Future Information Technology

The growth of semiconductor nanowires (NWs) has attracted significant interest in recent years due to the possible fabrication of novel semiconductor devices for future electronic and opto-electronic applications. Compared to planar heterostructures, the nanowire approach offers an advantage regarding the possibility to form heterostructures between highly lattice mismatched systems, because the free surface of the nanowires allows to relieve the strain more efficiently. One particular way to form heterostructures in the NW geometry, is the fabrication of core-shell devices, in which a NW core is surrounded by a shell of different material. The understanding of the mutual strain between core and shell, as well as the relaxation behavior of the system are crucial for the fabrication of functional devices. In this contribution we report on first x-ray diffraction measurements of GaAs-core / InAs-shell nanowires grown on GaAs (111) by molecular beam epitaxy. Using symmetric - and grazing-incidence x-ray diffraction, the relaxation state of the InAs shell as well as the strain in the GaAs core are measured as function of the InAs shell thickness, showing a gradual relaxation behavior of the shell.

HL 43.5 Tue 9:30 Poster D

Vapor-solid growth of InAs nanowires on GaAs substrates by MBE — •Torsten Rieger[1,2], Mihail Ion Lepsa[1,2], Thomas Schäpers[1,2], and Detlev Grützmacher[1,2] — [1]Peter Grünberg Institute - 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology

There are two general regimes for the growth of self-catalyzed InAs nanowires (NWs) on GaAs (111)B substrates covered with SiO_x: (1) low V/III ratio and high substrate temperature and (2) high V/III ratio and low substrate temperature. In the first regime, the NW growth is due to an In droplet while in the second one, the NWs grow without a droplet in the vapor-solid mode. Here, we present a detailed study about the vapor-solid growth of InAs NWs. It is found that the appropriate SiO_x layer thickness is important to achieve a high density of vertical NWs. When the thickness is higher than 5 nm, the NW density is low and they tend to grow tilted. At SiO_x thicknesses around 4 nm, the density is between 10 and 20 NW/μm^2. The NW length is influenced by both In and As_4 beam fluxes. The length distribution is broad while the distribution of the NW diameters is narrow. Diameters down to 30 nm are achieved. Finally, the influence of the growth parameters on the crystal structure of the InAs NWs is described.

HL 43.6 Tue 9:30 Poster D

Correlating the Crystal Structure and Quantum Transport of Individual InAs Nanowires — •Martin Schuck[1,2], Christian Blömers[1,2], Robert Frielinghaus[2,3], Torsten Rieger[1,2], Stefan Trellenkamp[2,4], Carola Meyer[2,3], Mihail Ion Lepsa[1,2], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2,5] — [1]Peter Grünberg Institut -9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA - Fundamentals of Future Information Technology — [3]Peter Grünberg Institut -6, Forschungszentrum Jülich, 52425 Jülich, Germany — [4]Peter Grünberg Institut -8, Forschungszentrum Jülich, 52425 Jülich, Germany — [5]II. Physikalisches Institut, RWTH Aachen, 52074 Aachen, Germany

InAs nanowires often exhibit crystal phase mixing between zinc blende and wurtzite structure resulting in a high density of stacking faults and undulations of the band gap. Up to now, their influence on the quantum transport properties is not clear. To unravel possible correlations, a detailed investigation of the crystal structure combined with transport measurements of the same individual nanowire is required. Here we present a process technology suitable to address this problem. First windows are etched into Si_3N_4 transmission electron microscopy (TEM) membranes. Then InAs nanowires, grown by molecular beam epitaxy (MBE), are dispersed on the membranes. Some InAs nanowires will span across a window and will be contacted via standard electron beam lithography to perform transport measurements. Consequently, this setup fulfills the requirements and transport measurements as well as TEM are performed on an individual nanowire.

HL 43.7 Tue 9:30 Poster D

Elemental and Structural Analysis of Nanowires in Cross-Sectional Specimens — •Benedikt Bauer, Johannes Bill, Marcello Soda, Andreas Rudolph, Elisabeth Reiger, and Josef Zweck — Universität Regensburg, Regensburg, Germany

To use nanowires (NWs) as building blocks for future electronics, functionalization is needed. One way to achieve this is the growth of radial heterostructures, also known as core-shell approach.

To access core and shell(s) of core-shell NWs separately for structural and compositional analysis in transmission electron microscopy (TEM) the NWs must be cut perpendicular to their axis into $\lesssim 100$ nm thick slices to allow for an investigation in cross-section. For this we use ultramicrotomy as a fast and gentle method which has some advantages over other thin film preparation methods: In contrary to embedding and grinding it is possible to cut several tens of sample slices from one

specimen block which also allows to access different regions along the NW axis and therefore different stages of the growth process. Compared to focused ion beam cutting the preparation induced crystal damage and surface amorphization is rather low.

The technique was used on GaAs/(Ga:Mn)As core-shell NWs as well as on GaAs/AlGaAs mutli-core-shell NWs grown in molecular beam epitaxy (MBE). We present high resolution TEM images and energy dispersive X-ray (EDX) analysis results to illustrate the potential of this preparation method.

HL 43.8 Tue 9:30 Poster D

Alloy formation during InAs nanowire growth on GaAs(111) — •Anton Davydok[1], Torsten Rieger[2,3], Muhammad Saqib[1], Andreas Biermanns[1], Thomas Grap[2,3], Mihail Lepsa[2,3], and Ullrich Pietsch[1] — [1]Festkörperphysik, Universität Siegen, Walter-Flex-Str. 3,57072, Siegen, Germany — [2]Peter Grünberg Institut-9, Forschungszentrum Jülich, Germany — [3]JARA-Fundamentals of Future Information Technology

The growth of semiconductor nanowires has attracted significant interest in recent years due to the possible fabrication of novel semiconductor devices for future electronic and opto-electronic applications. A possible way to obtain nanowires is the growth in molecular beam epitaxy on the (111)B oriented surface of the desired substrate, covered by a thin oxide layer. A crucial parameter in this method is the initial thickness of the oxide layer, often determined by an etching procedure. In this contribution, we report on the structural investigation of InAs nanowires grown on GaAs substrates covered by different oxide-layers using x-ray diffraction. In this contribution, we report on the structural investigation of InAs nanowires grown via an In droplet on GaAs substrates covered by different oxide layers using x-ray diffraction.Using a combination of symmetric and asymmetric x-ray diffraction, we observe that for growth on a defective oxide layer, alloy formation takes place and a large amount of InGaAs is formed, whereas for growth on an initially smooth oxide layer, only pure InAs is formed.

HL 43.9 Tue 9:30 Poster D

Optical studies of InAs Quantum Dots on GaAs doped with rare earth ions by ion beam implantation — •Markus K. Greff, Dirk Reuter, and Andreas D. Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Single spins in semiconductors could offer the possibility to integrate information storage and processing in a single material basis and the development of quantum information processing based on solid state systems. We dope InAs Quantum Dots (QD) with Eu that possesses a nearly half filled, strongly localised f-shell in GaAs. This, in combination with the strong carrier confinement in the QDs, could lead to a stronger magnetic coupling between the magnetic ion and the confined carriers. The QDs and the surrounding GaAs matrix have been doped with Eu at 30 keV by ion beam implantation and subsequently annealed by rapid thermal annealing using proximity capping to avoid surface degradation from arsenic loss.

In this contribution we would like to present results of first photoluminescence measurements at 77 K which show that, due to the interaction of the QDs and the Eu ion, a new distinct peak, which origin is not yet fully understood, appears in the PL spectrum.

HL 43.10 Tue 9:30 Poster D

Capacitance-Voltage spectroscopy of InAs quantum dots under external applied strain — •Sascha René Valentin, Arne Ludwig, Dirk Reuter, and Andreas D. Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstrasse 150, D-44780 Bochum

Self-assembled InAs quantumdots (QDs) are integrated on a variety of interesting optical and electronic devices and are also highly interesting from a fundamental point of view. Electric fields are often used to tune the optical and electronic properties of QDs. Just recently it has been shown that external applied strain can reversibly shift the optical emission energy of QDs. Theoretical calculations indicate that the shift in the emission energy originates rather in the changed Coulomb interaction between the charge carriers than in the shift of the energy levels themselves. In this project we want to directly measure the interaction energies of the carriers using capacitance voltage (CV) spectroscopy. In the device we present, a thin electrically contacted CV-membrane is bonded to a PMNPT-piezoelectric actuator. This allows to apply strain to the QDs. The devices are equipped with ohmic contacts and Schottky gates and thus enable electrical measurements of a QD ensemble. CV results for a membrane sample are presented.

HL 43.11 Tue 9:30 Poster D

Structural characterization of InAs and $In_{0.25}Ga_{0.75}As$/GaAs nanostructures grown on GaP(001) — •Christopher Prohl, Yannick Rodriguez Sillke, Andrea Lenz, Josephine Schuppang, Murat Öztürk, Gernot Stracke, André Strittmatter, Dieter Bimberg, Holger Eisele, and Mario Dähne — Institut für Festkörperphysik, Technische Universität Berlin

Due to the low lattice mismatch, GaP is an interesting material for the implementation of III-V-semiconductor applications into silicon-based technology. Therefore, the development of epitaxially grown nanostructures on GaP substrates for opto-electronic devices, like quantum dots, is an interesting task. InAs/GaP quantum dots are also promising for new nanomemory cells due to higher expected localization energies of the charge carriers inside the QDs than in InAs/GaAs QDs, resulting in longer storage times. In this contribution, first results of molecular beam epitaxy (MBE) grown samples of InAs quantum dots on a GaP(001) substrate, characterized by reflection high energy diffraction (RHEED) and scanning tunneling microscopy (STM) will be presented. RHEED clearly shows a 2D→3D transition, while first STM images show 3D islands, which are similar in size and density to comparable InAs/GaAs QDs. Furthermore, capped $In_{0.25}Ga_{0.75}As$/GaAs/GaP and GaAs/GaP nanostructures grown by metal organic vapor phase epitaxy (MOVPE) were identified by cross-sectional STM (XSTM). XSTM images of $In_{0.25}Ga_{0.75}As$/GaAs/GaP and 2 ML GaAs on GaP(001) show that the GaAs is not assembled within the nominal 2 ML, but segregated along growth direction.

HL 43.12 Tue 9:30 Poster D

3D-Determination of InGaAs Quantum Dots in Cross-Section TEM Specimens — •Maren Schiersch[1], Tore Niermann[1], André Strittmatter[2], Tim David Germann[2], Gernot Stracke[2], Jan-Hindrik Schulze[2], Udo W. Pohl[2], and Michael Lehmann[1] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Because Quantum Dots (QDs) offer a variety of applications, they are a current hot research topic. TEM investigations of QDs structures are usually performed in cross-section. However, in cross-section the QD-layer is only imaged in projection. So it is not possible to access the number of QDs or density at all. To investigate the distribution of QDs we apply a method using tilt series [1]. At increased tilt angles, the planar QD distribution becomes visible using dark-field images in the light of the chemical sensitive reflection {200}. As result the QD size and density as well as the thickness of the specimen can be evaluated from the recorded tilt series. Furthermore, the angular distribution, the distribution of QDs and thus the distance of nearest neighbors are determined. This method is applied on specimens with InGaAs-QDs buried in GaAs with different In-concentrations. This work is supported by the DFG Collaborative Research Centre 787.

[1]: Beanland, R. et al.: Electron tomography of III-V quantum dots using dark field 002 imaging conditions. In: Journal of Microscopy. The Royal Microscopical Society, February 2010 (237), p. 148-154

HL 43.13 Tue 9:30 Poster D

TEM-Investigation of strain fields in In(Ga)As quantum dots — •Moritz Hartwig[1], Tore Niermann[1], André Strittmatter[2], Tim David Germann[2], Gernot Stracke[2], Jan-Hindrik Schulze[2], Udo W. Pohl[2], and Michael Lehmann[1] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

In Stranski-Krastanov growth-mode the strain of the wetting layer is relaxed by growth of 3D islands. This is exploited in the self-organized growth of In(Ga)As quantum dots (QD) on GaAs substrate. These QDs are buried under a further GaAs layer. The remaining strain fields have an effect on the optoelectronic properties of these nanostructures. TEM dark-field images in the light of strong reflections (like {400} in GaAs) are extremely sensitive to strain fields. In order to investigate only the strain fields of single QDs, dark field images of the chemically sensitive {200}-reflection are utilized under large specimen tilt angle preventing imaging of QDs, which are not isolated. The strain components in in-plane and in growth direction are investigated individually. A change in the symmetry of the strain fields in growth direction is observed in specimen with an additional strain-reducing layer. Furthermore, a slight asymmetry of the in-plane component is

found, possibly caused by a distorted shape of the QDs.
This work is supported by the DFG Collaborative Research Centre 787 "Semiconductor Nanophotonics".

HL 43.14 Tue 9:30 Poster D

Characterization of tensile-strained GaAs/GaSb nanostructures — •Jan Grosse[1], Andrea Lenz[1], Josephine Schuppang[1], Holger Eisele[1], Marie Duhamel[2], Alban Gassenq[3], Thierry Talierco[3], Eric Tournie[3], and Mario Dähne[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institut Supérieur de l'Electronique et du Numérique, 41 Boulevard Vauban, 59046 Lille cedex, France — [3]Université Montpellier 2, Institut d'Electronique du Sud, UMR CNRS 5214, 34095 Montpellier cedex 5, France

The Ga(In)As/GaSb material system may act as a model system for tensile-strained nanostructures, which are promising for near-to-mid infrared applications. However, compared to a compressively strained system such as In(Ga)As/GaAs the structural properties of tensile-strained layers are practically unexplored up to now. In order to investigate the size, shape, and stoichiometry of semiconductor nanostructures, cross-sectional scanning tunneling microscopy (XSTM) is a very powerful method. Here, we present an XSTM study of the characteristics of different GaAs layers with varying nominal layer thickness grown by molecular beam epitaxy (MBE). Atomically resolved XSTM-images will be presented, which show a non-coherent wetting layer as well as some agglomerations for one and two monolayer (ML) thick GaAs films and the formation of quantum dot-like structures in case of three and four ML thick GaAs films.

HL 43.15 Tue 9:30 Poster D

Measurement of electrostatic potential at group III-N semiconductors using electron holography — •Jae Bum Park, Tore Niermann, and Michael Lehmann — Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17. Juni 135, D-10623 Berlin, Germany

Off-axis electron holography (EH) allows acquiring the whole information of the electron wave, i.e. amplitude and phase, the latter is usually lost. The phase of the electron wave is sensitive to electrostatic potential variation due to doping profiles from pn-junctions and piezoelectric fields at quantum wells. We employ this interference technique on group III-N semiconductor heterostructures. Because the phase of the electron wave is also affected by the specimen thickness, thickness measurement approaches like dark field imaging (DF) and convergent beam electron diffraction (CBED) are applied. However, the determined potentials from measured phase information normally show a discrepancy from the expected one. Additionally the surface depletion effect must be taken into account for quantitative analysis of the electrostatic potential from the reconstructed phase. This research is performed to investigate the influence of these effects on the observed mismatch of the potential. This work is carried out within the DFG collaborative research center CRC 787 Nanophotonik.

HL 43.16 Tue 9:30 Poster D

Low density 1.55 μm Indium phosphide based quantum dots — •Matusala Yacob, Mohamed Benyoucef, and Johann Peter Reithmaier — Institute of Nanostructure Technologies and Analytics (INA), Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Germany

Due to their unique optical and mechanical properties, semiconductor quantum dots (QDs) can be used as a building block of quantum information processing. However, for this application circular and low density QDs operating in the telecom wavelength bands should be realized. In this work, we investigate the effect of growth parameters on shape, size and density of InAs QDs grown on lattice matched InAlGaAs/InP system using solid source molecular beam epitaxy. A red-shift of photoluminescence emission wavelength from 1.2 to 1.8 μm with increase in InAs coverage was observed. The QD density is reduced using two approaches. In the first approach, the substrate temperature was decreased after QD growth by introducing growth stop. This allows ripening of InAs structures creating large sized dots with relatively low density. In the second approach, the QD growth rate is decreased to increase the migration length of ad-atoms. Single dot emissions at 1.55 μm were observed confirming the formation of large sized dots with low QD density.

HL 43.17 Tue 9:30 Poster D

Electrical Contacting of Pyramidal Microcavities for Single-Photon Applications — •Daniel Rülke, Daniel M. Schaadt, Heinz Kalt, and Michael Hetterich — Institut für Angewandte Physik, Karlsruhe Institute of Technology (KIT), Wolfgang-Gaede-Str. 1, 76131 Karlsruhe, Germany

In order to fabricate electrically driven single-photon devices, we have established a manufacturing process for the contacting of single pyramidal microcavities. The cavities consist of reversed GaAs pyramids with InAs quantum dots (QDs) located close to their tip and have been fabricated by a combination of molecular-beam epitaxy, e-beam lithography and wet-chemical etching. These cavities reveal very good outcoupling efficiencies for the QD emission and guarantee low numbers of QDs in the cavity, due to their shape. Electrical contacts to individual cavities have been realized by free-standing GaAs and PMMA bridges.

HL 43.18 Tue 9:30 Poster D

All-oxide junction field-effect transistors — •Friedrich-Leonhard Schein, Holger von Wenckstern, Heiko Frenzel, and Marius Grundmann — Institut für Experimentelle Physik II, Fakultät für Physik und Geowissenschaften, Universität Leipzig, Germany

We report on the first ZnO-based junction field-effect transistors (JFETs) using an all-oxide p-n-junction as top-gate contact. The oxide materials were grown by pulsed-laser deposition on an a-plane sapphire substrate. A ZnO channel layer was deposited at 680 °C followed by room temperature deposited p-type $ZnCo_2O_4$. Sputtered Au contacts serve as Ohmic source and drain electrodes as well as current spreading layer for the gate electrode. Standard photolithography and lift-off was used for device processing. The p-type conductivity of $ZnCo_2O_4$ thin films [1, 2], which are X-ray amorphous if grown at room temperature, was confirmed by Seebeck effect measurements. An average transmittance of $T_{VIS} = 54\,\%$ was determined for a 40 nm thin film of this material.

The normally-on JFETs exhibit a channel mobility of $\mu_{ch} = 8.4\,cm^2/Vs$, a subthreshold slope $S = 91\,mV/decade$ and a current on/off-ratio larger than 10^7. These properties are similar to that of the best oxide-based FETs, typically having $\mu_{ch} = 5 - 15\,cm^2/Vs$, $S < 100\,mV/decade$ and $I_{on/off} > 10^7$ [3].

[1] M. Dekkers *et al.*, Appl. Phys. Lett. **90**, 021903 (2007).
[2] S. Kim *et al.*, J. Appl. Phys. **107**, 103538 (2010).
[3] M. Grundmann *et al.*, Phys. Status Solidi A **207**, 1437 (2010).

HL 43.19 Tue 9:30 Poster D

Passivation of ZnO-based MESFETs — •Fabian J. Klüpfel, Stefan Müller, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Abteilung Halbleiterphysik, Linnéstr. 5, 04103 Leipzig

Transparent semiconductors related to ZnO have recently drawn much atttention of the scientific community, e.g. for the application in liquid crystal displays. ZnO-based devices are known to be very sensitive to surface-related effects [1]. The surface termination can for instance lead to highly conductive surface conduction paths [2]. This can be exploited for applications such as gas or chemical sensors. However, to build stable electronic circuits it is neccessary to reach a stable interface, which keeps the electric properties of the device within the desired figures of merit. This can be done by passivating the devices with suitable materials. For thin film transistors based on (Ga,In,Zn)O channels, the usage of the epoxy based photo resist SU-has been proposed [3]. ZnO-based Schottky diodes have been successfully passivated with a $CaHfO_3$ layer [2]. We could show, that these materials are also suitable for the passivation of (Mg,Zn)O-based metal-semiconducor field-effect transistors. The static device properties could even be enhanced in some cases, while the dynamic properties up to 1 Mhz were not affected. Also the influence on the temperature stability and the avoidance of vacuum induced effects has been investigated.

[1] Allen *et al.*, Trans. Electr. Dev. 56, 2160 (2009)
[2] von Wenckstern *et al.*, J. Elec. Mat. 39, 559 (2009)
[3] Olziersky *et al.*, J. Appl. Phys. 108, 064505 (2010)

HL 43.20 Tue 9:30 Poster D

High Temperature Characteristics of Tungsten/Silicon Schottky Diodes — •Markus Arnold, Michael Pleul, Daniel Lehmann, and Dietrich R. T. Zahn — Semiconductor Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany

For Schottky diodes the diffusion of metal into the semiconductor at elevated temperature plays an important role for the properties as traps

are created at or close to the interface.

The electrical behaviour of three types of Schottky diodes is compared at high temperatures. Tungsten is the contact metal for all cases, but the silicon substrate is varied between p-doped, nominally undoped, and n-doped. In situ current-voltage (I-V) measurements and capacitance-voltage (C-V) measurements of Tungsten/Silicon Schottky diodes are presented.

The Schottky diodes are annealed up to 700 °C in vacuo to characterise the diode stability during annealing. The influence of the dopant species on the barrier height and the diffusion properties are discussed. Deep-level transient spectroscopy (DLTS) measurements are presented revealing the annealing dependent trap concentration at the Schottky interface.

HL 43.21 Tue 9:30 Poster D

High Temperature Induced Traps in Tungsten/GaN Schottky Diodes — •Michael Pleul, Markus Arnold, Daniel Lehmann, and Dietrich R. T. Zahn — Semiconductor Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany

The properties of metal/semiconductor interfaces like in Schottky diodes are highly dependent on traps near the interface created by the diffusion of metal into the semiconductor. The investigation comprises *in situ* I-V (current-voltage) and C-V (capacitance-voltage) measurements of Tungsten/GaN Schottky diodes at different annealing temperatures up to 700 °C. In addition DLTS (Deep Level Transient Spectroscopy) measurements are performed to reveal the annealing dependent trap concentration.

HL 43.22 Tue 9:30 Poster D

Low-threshold polymeric microgoblet lasers — •Tobias Grossmann[1,2,4], Torsten Beck[1,2], Klinkhammer Sönke[2,3,4], Christoph Vannahme[4], Uli Lemmer[2,3], Timo Mappes[4], and Heinz Kalt[1,2] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology KIT, 76128 Karlsruhe, Germany — [2]DFG Center for Functional Nanostructures CFN, KIT, 76128 Karlsruhe, Germany — [3]Light Technology Institute, KIT, 76128 Karlsruhe, Germany — [4]Institute of Microstructure Technology, KIT, 76128 Karlsruhe, Germany

Optical whispering-gallery-mode (WGM) resonators like microspheres or microtoroids have evolved in recent years to versatile photonic devices with applications like lasers, filters or sensors. In particular, polymeric microcavities are of high potential since they combine a multitude of outstanding properties: exceedingly high quality factors (Q-factors), easy doping and thus realization also of active resonators and low material costs.

We have recently introduced a novel type of polymeric resonator with surface-tension induced cavity geometry: microgoblets of PMMA on silicon. These resonators are produced by subsequent planar lithography of the PMMA, isotropic etching of the silicon and a thermal reflow step. The latter not only leads to the goblet-like shape but also to a smooth cavity surface with reduced lithographic blemishes and thus to Q-factors of passive resonators exceeding 10^6. When doped with rhodamine 6G these resonators are efficient lasers at 600nm with a laser threshold as low as 3nJ/pulse.

HL 43.23 Tue 9:30 Poster D

Development of monolithic dual frequency quantum dots based semiconductor laser suitable for tunable continuous wave terahertz generation — •Vitalii Sichkovskyi, Kamen Kozhuharov, and Johann Peter Reithmaier — Technische Physik, Institute of Nanostructure Technologies and Analytics, University of Kassel, Heinrich-Plett Str. 40, D-34132 Kassel, Germany

Presently there is a considerable research activity in the development of new terahertz (THz) sources. The most promising candidate as a compact, tunable and low-cost THz emitter is the combination of a photomixer and an optical beat source. Here we report on developing of monolithic difference frequency generation source. It is designed as two coupled distributed-feedback (DFB) lasers tuned by controlling the temperature of the individual DFB laser. MBE grown laser structure consists of a GRINSCH design including single In0.60Ga0.40As QDs active layer embedded in 800 nm core waveguide surrounded by 1600 nm AlGaAs claddings layers. The broad area lasers processed from the laser structure revealed high internal quantum efficiency of 95%, low transparency current density of 139 Acm-2, high slope efficiencies > 0.45 W/A per facet, and low temperature sensitivity of the emission wavelength as low as 0.096 nm/K. Deep structure plasma etch processes for the GaAs and InP gratings of the dual-wavelength DFB lasers were developed and optimized, providing excellent anisotropy and uniformity of the structures. Platinum micro-heaters for the tuning of the lasers were fabricated and tested on RWG lasers, providing temperature increase at the ridge of 65°, at heater current of 140 mA.

HL 43.24 Tue 9:30 Poster D

Intersubband dynamics in two-photon quantum well infrared photodetectors — •Carsten Franke[1], Harald Schneider[1], Jérôme Faist[2], and H. C. Liu[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany — [2]ETH Zürich, 8093 Zürich, Switzerland — [3]Shanghai Jiao Tong University, 200240 Shanghai, China

Two-photon quantum well infrared photodetectors (QWIPs) are interesting nonlinear devices for autocorrelation measurements in the mid-infrared and THz-regime. Here we investigate two-photon QWIPs in the mid-infrared with absorption wavelengths at around six microns, based on the material systems InGaAs/AlGaAs on GaAs and GaInAs/AlInAs on InP. We study the intersubband relaxation dynamics by interferometric autocorrelation. To create the necessary mid infrared sub-picosecond pulses, we use a regenerative amplifier system with subsequent wavelength conversion by optical parametric amplification and difference frequency generation. With this we can create mid-infrared laser pulses shorter than 200 fs tunable from 3 to 10 μm. For the intersubband relaxation time we determined values between 590 and 730 fs.

HL 43.25 Tue 9:30 Poster D

From bistability to break-down of normal-mode splitting in microcavity systems — •Regina Kruse, Stefan Declair, Jens Förstner, and Stefan Schumacher — Physics Department and Center for Optoelectronics and Photonics Paderborn (CeOPP), Universität Paderborn, Paderborn, Germany

We study the nonlinear excitation dynamics of a microcavity system with normal mode splitting. Our model includes a single optical cavity mode coupled to an electronic two-level system. The results from the corresponding Maxwell-Bloch equations are compared to a full 3D FDTD calculation [1]. In agreement with earlier studies [2] we observe bistable behaviour for continuous wave excitation while scanning the frequency range around the resonances with the pump. Additionally to this steady-state behaviour we explicitly study the nonlinear system dynamics in time. With this method we are able to analyze the transition from nomal-mode splitting to bistable behaviour until the strong coupling regime breaks down for high excitation densities.

[1] S. Declair, X. Song, T. Meier and J. Förstner: Simulation of Mutual Coupling of Photonic Crystal Cavity Modes and Semiconductor Quantum Dots *AIP Conf. Proc. 1398, 123 (2011). [2] J. Gripp, S. Mielke and L. Orozco: Evolution of the vacuum Rabi peaks in a detuned atom-cavity system *Phys. Rev. A56, 3262 (1997).

HL 43.26 Tue 9:30 Poster D

Optical excitation conditions for generating squeezed phonon states in a quantum dot — •Daniel Wigger[1], Doris E. Reiter[1], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Theoretische Physik III, Universität Bayreuth, 95440 Bayreuth

We study theoretically squeezing properties of phonons generated after optical excitation of a semiconductor quantum dot (QD). We model the QD in the strong confinement limit as a two level system coupled by the Fröhlich interaction to longitudinal optical (LO) phonons. An ultrashort laser pulse creates an exciton in the QD, which leads to a shift of the equilibrium position of the lattice ions. Thus lattice vibrations, i.e. phonons, are created. For an excitation with two pulses we find that Schrödinger cat states, i.e. superpositions of coherent states, build up. Depending on the time delay and relative phase between the pulses and on the coupling strength the fluctuation properties of theses states can fall below their vacuum limit, i.e. squeezing occurs [1]. By using the Wigner function we can illustratively analyze the influence of the material and excitation parameters on the fluctuation properties.

[1] Sauer et el., PRL 105, 157401 (2010)

HL 43.27 Tue 9:30 Poster D

Optical excitation of squeezed LO phonons in a quantum well — •Thomas Papenkort[1], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]Institut für Theoretische Physik III, Universität Bayreuth, 95440 Bayreuth,

Germany

Squeezed states combine questions of fundamental quantum mechanics with the promise of a precision of measurements that was previously deemed impossible to achieve. With squeezed light fields this promise has already been achieved, and it is only natural to try to carry over these huge successes to the field of solid state physics: that is, to learn how to generate squeezed phonon states in crystals.

In this contribution we present quantum-kinetic simulations showing how to generate squeezed phonon states in a quantum well by optical driving. In such states the uncertainty of the lattice displacement or momentum is reduced below its zero-temperature value. We demonstrate how to calculate the coupled electron-phonon dynamics within a realistic microscopic model of a quantum well, achieving quantitative results for, e.g., the squeezing factor. We fully take into account spatial averaging, which is both unavoidable experimentally and crucial for the lattice uncertainty variables. Our simulations then reveal which ultrashort laser excitations are capable of generating squeezed states and predict the strength and time-dependence of the squeezing factor.

HL 43.28 Tue 9:30 Poster D

Laser-induced nonthermal melting in Si — •Tobias Zier, Eeuwe S. Zijlstra, and Martin E. Garcia — Theoretical Physics, University of Kassel, Germany

When a solid is excited by an intense ultrashort laser pulse a nonequilibrium state is created, where the electrons are very hot (several 10,000 K) and the ions remain cold. In silicon bond softening occurs after such an excitation. If the intensitiy of the laser pulse is high enough, some phonon modes become unstable. This causes ionic motion and a disordering within the first picosecond. This phenomenon is known as nonthermal (ultrafast) melting and has been studied intensively for different materials since the invention of ultrashort laser pulses. Recently, a new effect in this context was observed: the concerted decay of several x-ray diffraction peak intensities. To understand this new phenomenon we did some MD-simulations and calculated the structure-factors for every timestep after the excitation. With this information we were able to calculate the time-evolution of the x-ray diffraction peak intensities.

HL 44: Poster Session: Quantum Dots and Wires - Transport & Optical Properties

Time: Tuesday 9:30–12:30 Location: Poster D

HL 44.1 Tue 9:30 Poster D

Two-path Transport Measurements on a Triple Quantum Dot — •Monika Kotzian, Maximilian C. Rogge, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover, Germany

We present transport measurements on a lateral triple quantum dot with a star-like geometry and one lead attached to each dot.[1] Technical and scientific improvement allow the fabrication of triple quantum dots and their analysis.[2] Research on them is motivated by fundamental physics and by the fact that they can work as a single qubit.[3] It also is the smallest system with quantum dots being part of a qubit chain needed for quantum computers. Our sample design allows to simultaneously measure the conductance along two different paths with two quantum dots in each path. The structure is made with local anodic oxidation by AFM on a GaAs/AlGaAs heterostructure. By controlling the potentials via the four gates triple points with two dots and quadruple points with all three dots in resonance can be established.[4,5] Using two of the leads as source contacts and one lead as a drain contact, signatures of three dots can be detected in both transport paths. The setup provides the possibility of applying different bias voltages to the two sources and detecting excited states of the dots.

[1] M. C. Rogge, R. J. Haug, Phys. Rev. B 77, 193306 (2008). [2] D. Schröer, et al., Phys. Rev. B 76, 075306 (2007). [3] P. Hawrylak, M. Korkusinski, Solid State Comm. 136 (2005), pp. 508-512. [4] L. Gaudreau, et al., PRL 97, 036807 (2008). [5] M. C. Rogge, R. J. Haug, NJP 11, 113037 (2009).

HL 44.2 Tue 9:30 Poster D

Real-time charge sensing analysis of metastable states in double quantum dots — •Martin Andreas Brühlmann[1], Daniel Biesinger[1], Dominik Zumbühl[1], Jeramy Zimmerman[2], and Art C. Gossard[2] — [1]Department of Physics, University of Basel, Switzerland — [2]Materials Department, University of California, Santa Barbara, California, USA

We investigate metastable charge states in lateral GaAs few-electron double quantum dots using real-time charge sensing. We use adjacent quantum dots as highly-sensitive charge sensors with a rise time of a few ms and a very good signal-to-noise ratio. Observing the charge stability diagram at very low dot-reservoir tunneling rates of a few Hz, a well defined diamond-shaped area between the (0,0) and the (1,1) triple points appears, showing charge-switching between the (1,0) and (0,1) states as a function of time resulting in a telegraph-like signal.

To further study this telegraph diamond, we gather statistics of the tunneling events and extract tunnel rates as a function of gate voltage using an adaptive algorithm. It measures repeatedly the times the system remains in one state before switching to the other and extracts the tunneling rate from the histogram of those times. Detailed testing with computer generated data shows that the algorithm works properly within statistical accuracy and is only limited by the bandwidth of the setup.

HL 44.3 Tue 9:30 Poster D

Characterization of an electron-accounting circuit — •Michael Wulf, Lukas Fricke, Frank Hohls, Bernd Kaestner, Ralf Dolata, Philipp Mirovsky, Klaus Pierz, Thomas Weimann, and Hans W. Schumacher — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

Operating single-electron pumps, based on dynamic quantum dots [1,2], in series while monitoring each of their outputs with single-electron resolution allows the characterization of the individual components by counting. This is complementary to previous measurements of these devices, where the time-averaged pumped current is measured [1,2] or its noise spectrum [3].

It is shown that pump operation is consistent with the required single electron resolution of metallic single-electron transistors (SET) and the rates of pump errors are measured in a low-frequency electron-counting experiment.

Time-domain correlations of the transistor signals allow identification and subsequent accounting for pump errors. This constitutes a first proof-of-principle of our electron accounting scheme [4], which aims to meet the requirements of quantum-current metrology even for a circuit built of imperfect components.

[1] M. D. Blumenthal et al., Nat. Phys. 3, 343 (2007)
[2] B. Kaestner et al., Phys. Rev. B 77, 153301 (2008)
[3] N. Maire et al., Appl. Phys. Lett. 92, 082112 (2008)
[4] M. Wulf and A. B. Zorin, e-print arXiv:0811.3927

HL 44.4 Tue 9:30 Poster D

Thermal white noise measurements of 2D and 1D electron gases — •Philipp Miechowski[1], Sven S. Buchholz[1], Dirk Reuter[2], Andreas D. Wieck[2], and Saskia F. Fischer[1] — [1]Neue Materialien, Humboldt-Universität zu Berlin, D-10099 Berlin — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum

Electron-phonon interactions in semiconductors depend strongly on the lattice temperature, as thoroughly investigated in high-mobility 2D electron gases (2DEG) at temperatures below some 10 K. Open questions with respect to electron-phonon interactions remain for systems at the transition from 2D to 1D and suitable thermometry methods need to be established.

We apply thermal voltage noise measurements in the cross-correlation technique (0-20 kHz) [1]. For the setup calibration, we use discrete resistors. We make use of heating currents to create a temperature gradient over quasi-1D quantum structures. An improved measurement setup allows to eliminate noise contributions of the serial resistances caused by ohmic contacts and leads.

We investigate the influence of the lateral electronic confinement from 2D to 1D on the electron-phonon interaction and observe different temperature dependences for wide and narrow etched structures.

Noise thermometry proves to be an adequate instrument for the investigation of electron-phonon interactions in nano-structured semiconductors.

[1] S.S. Buchholz et.al., arxiv: 1111.1591 (2011).

HL 44.5 Tue 9:30 Poster D

Untersuchung von Leitwertfluktuationen in Quantenpunktkontakten aus GaAs/AlGaAs-Heterostrukturen — •Danilo Kühn[1], Sven Buchholz[1], Olivio Chiatti[1], Dirk Reuter[2], Andreas Wieck[2] und Saskia Fischer[1] — [1]Neue Materialien, Inst. f. Physik, Humboldt-Universität zu Berlin, D-10099 Berlin — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum

Eindimensionale, ballistische elektrische Leiter wie Quantenpunktkontakte (QPCs) in zweidimensionalen Elektronengasen zeigen bei tiefen Temperaturen eine Quantisierung des Leitwerts in Einheiten von $n \cdot e^2/h$. Unterhalb des ersten Leitwertplateaus können Vorplateaus beobachtet werden, deren Ursache noch nicht vollständig geklärt ist. Möglich sind die "0,7"-Leitwertanomalie und resonantes Tunneln über Störpotentiale. Letzteres resultiert aus Ionisationsstörstellen und kann gezielt beeinflusst werden, z.B. durch eine Gate-Abkühlspannung (Potentialmodulation) [1]. In dieser Arbeit wird bei bestimmten Gate-Abkühlspannungen ein Telegrafierauschen zwischen zwei Energiezuständen beobachtet [2]. Dieses Rauschen wird in Abhängigkeit von Temperatur und Gate-Abkühlspannung systematisch untersucht. Die Messungen werden zeitaufgelöst an QPCs basierend auf GaAs/AlGaAs-Heterostrukturen vorgenommen.

[1] S.F. Fischer et al., Appl. Phys. Lett. 81, 2779 (2002).
[2] S.S. Buchholz, Dissertation (2011).

HL 44.6 Tue 9:30 Poster D

Illumination induced charging peaks observed by capacitance-voltage spectroscopy — •Patrick Alexander Labud, Dirk Reuter, Arne Ludwig, and Andreas Dirk Wieck — Angewandte Festkörperphysik, Ruhr-Universität Bochum

Since 1994 electron-electron and hole-hole interaction has been studied intensively in self-assembled InAs quantum dot (QD) samples using capacitance-voltage spectroscopy (C-V). The energetic positions of the charging peaks are considerably affected by the Coulomb interaction energies and in standard C-V spectra only the Coulomb repulsion is seen. In this contribution we present C-V data obtained under illumination. Under these conditions additional charging peaks appear due to attractive Coulomb interaction between illumination induced holes and electrons tunneling into the QD. We could resolve up to five additional charging peaks belonging to an X^0, X^{1+}, X^{2+}, X^{3+}, X^{4+}-complex formed upon electron charging. The individual Coulomb energies are calculated from the charging gate voltage and the charging dynamics is discussed.

HL 44.7 Tue 9:30 Poster D

Electronic characterization of single GaN nanowires — •Markus Schäfer[1], Christian Länger[1], Pascal Hille[1], Florian Furtmayr[1,2], and Martin Eickoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, D-35392 Gießen, Germany — [2]Walter Schottky Institut, Technische Universität München, D-85748 Garching, Germany

Semiconductor nanowires (NWs), and in particular wide-bandgap GaN NWs are promising candidates for nanoscale (opto)-electronic devices with a high integration density such as NW transistor structures. In this context it is important to systematically study the electronic properties of single GaN NWs with different doping levels. For this purpose NWs doped with different concentrations of silicon were grwon by plasma assisted molecular beam epitaxy on silicon (111) substrates and electrically contacted by electron beam lithography. We report on the preparation of samples with contacted single n-type GaN NWs and their electronic properties. We present results of conductivity, photocurrent and thermoelectric measurements.

HL 44.8 Tue 9:30 Poster D

Persistent conductivity in ZnO nanowires in different gas atmospheres — •Davide Cammi, Irma Slowik, Raphael Niepelt, Andreas Johannes, and Carsten Ronning — Institute of Solid State Physics, Friedrich-Schiller-Universität, Max-Wien-Platz 1, 07743 Jena, Germany

Nanostructures of ZnO, due to the high surface to volume ratio, show a strong persistent photoconductivity (PPC). The current induced by above gap illumination persists for a long time after switching off of the excitation, compared to the typical lifetime of photogenerated carriers in the bulk. This effect is based on the up-ward band bending induced by the adsorption of oxidizing molecules at the surface, like oxygen, present in the ambient. The built-in potential tends to separate free electrons and holes generated by the optical irradiation, increasing their lifetime. PPC considerably influences the properties of nanostructure based devices for optoelectronic applications or chemical and biochemical sensors. We compare the PPC observed in untreated and treated ZnO nanowires with different coating layers, which should passivate the surface, reducing the band bending and correspondingly the persistence of the photoconductivity. Furthermore, the influence of hydrogen plasma treatment is presented. We exposed nanowires to different atmospheres, performing measurements in synthetic air (oxygen-rich), nitrogen, carbon dioxide and air, studying the effect of different pressures. A model is proposed to explain the different observed decay rates of the current depending on the chemical species present in the ambient and on the treatment of the surface.

HL 44.9 Tue 9:30 Poster D

Many-particle electron dynamics in InAs self-assembled quantum dots — •A. Kurzmann[1], A. Beckel[1], B. Marquardt[1], M. Geller[1], B. Baxevanis[2], D. Pfannkuche[2], A. D. Wieck[3], D. Reuter[3], and A. Lorke[1] — [1]Faculty of Physics and CeNIDE, University of Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany — [2]Institute for Theoretical Physics, University of Hamburg, Jungiusstrasse 9, 20355 Hamburg, Germany — [3]Chair for Applied Solid State Physics, Ruhr-Universität Bochum, Universitätsstraße 150, 44780 Bochum, Germany

Visionary quantum information processing (QIP) requires the access to excited, i. e. non-equilibrium, charge or spin states to serve as one building block for the needed qubits. With their strong confinement, self-assembled quantum dots (QDs) are ideal candidates for qubits operating at above liquid helium temperatures. We have demonstrated an all-electrical preparation and read out technique of excited many-particle states using a nearby two-dimensional electron gas [1] as charge sensing detector [2]. This new technique is used here to investigate the dynamics of excited electron states in InAs/GaAs QDs evolving from non-equilibrium towards equilibrium configuration. These time-resolved measurements enables separating the many-particle spectrum into the contributions from different equilibrium and excited states and serve as a starting point for further investigations on the spin dynamics in an all-electrical measurement scheme.

[1] B. Marquardt et al., Nat. Commun. **2**, 209 (2011).
[2] B. Marquardt et al., Appl. Phys. Lett. **95**, 022113 (2009).

HL 44.10 Tue 9:30 Poster D

Numerical analysis of few-electron transport in multi-gate nanowire field-effect transistors — •Jose Maria Castelo[1], Klaus Michael Indlekofer[1], and Joerg Malindretos[2] — [1]RheinMain University of Applied Sciences, FB ING / IMtech, D-65428 Rüsselsheim, Germany — [2]Georg-August-Universität Göttingen, IV. Physikalisches Institut, D-37077 Göttingen, Germany

We consider a nanowire-based field-effect transistor (NWFET) with a coaxial gate geometry, which provides ideal electrostatic control and gives rise to a screened Coulomb interaction. For the theoretical description of one-dimensional (1D) non-equilibrium transport, we employ a Green's function formalism (NEGF). Few-electron Coulomb charging effects due to resonantly trapped electrons are taken into account by use of a multi-configurational approach (MCSCG) [1] for application-relevant temperatures. The electrostatics within the channel are described by a Coulomb Green's function. These concepts provide the framework for the open source simulation tool "NWFET-Lab" [2] which is used in the following numerical studies.

Specifically, we consider a multi-gate NWFET. Using multiple bias and control gate electrodes, the channel's axial potential profile can be defined, being equivalent to a position dependent doping. Employing a 1D FET model, we analyze the influence of the position and length of the control gate segment on the electronic transport characteristics.

[1] K.M. Indlekofer et al., Phys. Rev. B **72**, 125308 (2005).
[2] J.M. Castelo and K.M. Indlekofer, http://sourceforge.net/projects/nwfetlab (2011).

HL 44.11 Tue 9:30 Poster D

Phonon-assisted relaxation and linewidth enhancement of exciton states in double quantum dots — •Jonas Daniels[1], Tilmann Kuhn[1], and Pawel Machnikowski[2] — [1]Institut für Fes-

tkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Institute of Physics, Wrocław University of Technology, 50-370 Wrocław, Poland

Here we consider theoretically excitons in a pair of lens-shaped vertically aligned InAs/GaAs QDs in the presence of an external electric field. Single-particle wave functions of the confined carriers are calculated using a variational multicomponent envelope function scheme, while Coulomb interaction is included within the standard configuration-interaction to determine the exciton states. In dependence of the applied field, we study the optical spectrum for different geometries. Changing the applied field leads to a transition of various exciton states from a direct type, where the carriers are mainly localized in the same dot, to an indirect type, where they are mainly localized in different dots. These changes are accompanied by different hole and electron related anticrossings, visible in absorption spectra. The lines of the exciton transitions are broadened due to phonon-related processes such as phonon-assisted relaxations and tunneling. We calculate the linewidths due to deformation potential and piezoelectric coupling of the excitons to acoustic phonons. We show that the linewidths strongly depend on the spatial overlap and the energy separation of the involved electron and hole states and thus both the interdot distance and the applied field.

HL 44.12 Tue 9:30 Poster D

Coherent coupling of quantum dots in a micropillar cavity — •Ferdinand Albert[1], Kanchana Sivalertporn[2], Jacek Kasprzak[3], Micha Strauss[1], Christian Schneider[1], Sven Höfling[1], Martin Kamp[1], Alfred Forchel[1], Stephan Reitzenstein[1,4], Egor Muljarov[2], and Wolfgang Langbein[2] — [1]Technische Physik, Universität Würzburg, D-97074 Würzburg, Germany — [2]School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA, UK — [3]Institut Néel, CNRS et Université Joseph Fourier, F-38042 Grenoble, France — [4]Present address: Institute of Solid State Physics, TU Berlin, D-10623 Berlin, Germany

Coherent coupling between distant quantum systems is a crucial topic in quantum information science and cavity quantum electrodynamics since it constitutes the basis for future quantum logic gates and networks. Within this context high quality optical microresonators containing quantum dots with individual exciton states have proven to be suitable candidates to study the strong light-matter coupling. In this work we report on the coherent coupling between three individually localized quantum dot excitons via the photonic mode of a micropillar resonator. This is demonstrated by means of two-dimensional spectroscopy of the sample's coherent four-wave mixing response, where the coherent interaction can be controlled by tuning the cavity and exciton energies. Moreover, the experimental results are well reproduced in a quantitative theoretical model of the cavity mediated coupling of the excitons. Our results present a crucial step forward towards a quantum bus technology based on semiconductor photonic structures.

HL 44.13 Tue 9:30 Poster D

Rabi oscillations in single InGaAs/GaAs quantum dots embedded in modified H2 photonic crystal microcavities — •Mohannad Al-Hmoud[1], Wadim Quiring[1], Simon Gordon[1], Stefan Declair[1], Jens Förstner[1], Dirk Reuter[2], Andreas Wieck[2], and Artur Zrenner[1] — [1]Center for Optoelectronics and Photonics Paderborn, Universität Paderborn, Paderborn, Germany — [2]Department of Physics, Ruhr-Universität Bochum, Bochum, Germany

Modification of the inner holes has a great influence on the quality factor of photonic crystal microcavities. So far, only experiments on modified H1 and L3 geometries were performed. Here we report on fabrication and spectroscopic characterization of H2 microcavities with modification of the position of the inner holes. We found that the quality factor can be significantly increased in comparison to non-modified structures. We chose to investigate the H2 cavity, because it has the potential to offer high Q-factors for larger defect regions. This is expected to offer more degrees of freedom for future designs of functionalized defect regions, for example with electric contact pads to the center of the defect region. Using this kind of cavities, we have investigated the p-shell Rabi oscillations of an exciton in a single InGaAs/GaAs quantum dot. We performed pulsed resonant excitation in the p-shell and detected the emission from the s-shell. To study the effect of the cavity on the p-shell Rabi oscillations, we have done experiments where a cavity mode is on- and off-resonance with the s-shell.

HL 44.14 Tue 9:30 Poster D

Effects of longitudinal acoustic phonons to the long-time dynamics in optically driven GaAs quantum dots — •Sebastian Lüker[1], Doris Reiter[1], Vollrath Martin Axt[2], and Tilmann Kuhn[1] — [1]Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Theoretische Physik III, Universität Bayreuth, 95440 Bayreuth

Semiconductor quantum dots are of great importance both for the investigation of fundamental quantum effects and for future optoelectronic applications. We discuss the laser-induced long-time dynamics in a GaAs quantum dot coupled to longitudinal acoustic phonons. In the strong confinement limit we model the quantum dot as a two level system. To study the dynamics of this system we use the density matrix formalism. The many particle nature of the system due to carrier-phonon interaction leads to an infinite hierarchie of equations of motion which we truncate by a fourth order correlation expansion. In the limit of long times the two level system reaches a stationary state close to a thermal distribution of the dressed states as a result of the interaction with phonons. We discuss the influence of external parameters, in particular temperature and intensity of the laser-field, on the state in the long-time limit. Furthermore we analyze the energy flow between the subsystems during the dynamics, revealing details about the role of the phonons. When comparing our results to a numerically exact real-time path integral method, which may act as a benchmark, we find a good agreement in a surprisingly wide range of parameters [M. Glässl, S. Lüker et al., Phys. Rev. B **84**, 195311 (2011)].

HL 44.15 Tue 9:30 Poster D

Optical Phonons in InAs/AlAs Structures with InAs and AlAs Nanocrystals — •Evgeniya Sheremet[1], Alexander Milekhin[2], Alexander Kalagin[2], Alexander Toropov[2], and Dietrich R.T. Zahn[1] — [1]Semiconductor Physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany — [2]Institute of Semiconductor Physics, 630090 Novosibirsk, Russia

Layered InAs/AlAs structures with InAs and AlAs nanocrystals (NCs) formed by Stranski-Krastanov growth on (001)-oriented GaAs substrates were investigated by Raman spectroscopy. Selection rules for the optical phonons in the structures were studied in a backscattering geometry from planar (001) and cleaved (110) surfaces using a micro-Raman setup. Transverse and longitudinal optical (TO and LO) phonons as well as interface (IF) phonons were observed for InAs (AlAs) NCs in AlAs (InAs) matrices. Optical phonon frequencies of InAs (AlAs) NCs are upshifted (downshifted) compared to the ones of the corresponding bulk materials. These shifts result from compressive (tensile) built-in strain in the NCs. The frequencies of optical phonons were used to determine deformationtensor components. It was found that optical phonons of InAs NCs obey Raman scattering selection rules for a superlattice consisting of materias with zinc-blende structure. However the selection rules are weakened since all the optical phonon peaks were detected in forbidden geometries ($z(x,x)\bar{z}$ and $y'(z,z)\bar{y}$', where x, z and y' stand for [100], [001] and [110], respectively). Meanwhile, the selection rules for optical phonons of AlAs NCs are lifted. This effect can be caused by built-in strain and defects.

HL 44.16 Tue 9:30 Poster D

Carrier Trapping and Optical Properties of InAs/InP Quantum Dashes — •Piotr Kaczmarkiewicz[1,2], Paweł Machnikowski[1], and Tilmann Kuhn[2] — [1]Institute of Physics. Wrocław University of Technology, 50-370 Wrocław, Poland — [2]Institut für Festkörpertheorie, Westfälische Wilhelms-Universität, Münster, Germany

We model the optical properties of semiconductor InAs/InP quantum dashes (QDashes), that is, highly elongated quantum dot structures. These structures are often characterized by a non-uniform shape and the presence of width fluctuations. We show that such shape irregularities can act as additional trapping centers within the confinement volume of a QDash and strongly influence its optical properties.

We show how the optical transition rates depend on various QDash shape parameters (e.g., amplitude and position of the widening of the structure) and study the polarization properties of radiation emitted by the system. We confirm that the presence of a QDash width fluctuation leads to a strong localization of the exciton ground state, which results in a reduction of its anisotropy, in spite of the strong elongation of the whole structure. Such a character of the confining potential not only manifests itself by a reduced value of the degree of linear polarization of the exciton ground state, but also strongly affects the properties of higher energy excitonic states.

HL 44.17 Tue 9:30 Poster D

Energy dispersion and 3D magnetic anisotropy of electron- and hole g-factors in (In,Ga)As/GaAs self-assembled quantum dots — •Alexander Schwan[1], Britt-Marie Meiners[1], Alex Greilich[1], Anré B. Henriques[2], Álvaro D. B. Maia[2], Alain A. Quivy[2], Steffen Varwig[1], Stefan Spatzek[1], Dmitri R. Yakovlev[1], and Manfred Bayer[1] — [1]Experimentelle Physik 2, Technische UniversitätDortmund, 44221 Dortmund, Germany — [2]Instituto de Física, Universidade de SãoPaulo, C.P. 66318, São Paulo, Brazil

The electron and hole Larmor spin precession was studied by time-resolved pump-probe Faraday rotation on an inhomogeneous ensemble of singly-charged self-assembled quantum dots. Dependence of electron g-factor on optical transition energy was measured. It is shown that the electron g-factors are similar for quantum dots with very different geometrical parameters, and their change with optical transition energy is almost identical[1].

The g-factor anisotropy was derived from the data measured in a vector rotate magnet system, which allows full 360 degrees spherical rotation of a magnetic field up to 3T. We determine all g-factor tensor components, and found nearly isotropic electron g-factor and a strong anisotropic hole g-factor.

[1] A. Schwan, B.-M. Meiners, A. B. Henriques, A. D. B. Maia, A. A. Quivy, S. Spatzek, S. Varwig, D. R. Yakovlev, and M. Bayer. APL 98, 233102 (2011)

HL 44.18 Tue 9:30 Poster D

Optical properties of ultra-low density GaAs Quantum Dots — •Vera Paulava, David Sonnenberg, Andreas Graf, Christian Heyn, and Wolfgang Hansen — Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

We study a novel type of GaAs quantum dots (QDs), which are formed by filling of self-assembled nanoholes in semiconductor surfaces. The holes were drilled using local droplet etching (LDE) during molecular beam epitaxy [1]. In our case, nanoholes are drilled into AlGaAs barrier material with Al droplets and subsequently filled with GaAs to form the quantum dots. The QD size can be precicesly controlled by the filling level. Here we present a study of the optical properties of such GaAs QDs with ultra-low densities of $6 \cdot 10^6$ cm^{-2}. The low density of these dots is achieved without any lithographic or other ex-situ preparation steps, and allows clear single-dot photoluminesence studies of the excitonic states up to high excitation power by using a focused laser for excitation. Especially the exciton energies and the exciton-biexciton splittings are studied in dependence of the QD size.

[1] Heyn et al., Appl. Phys. Let. 94, 183113 (2009)

HL 44.19 Tue 9:30 Poster D

Optical properties of coupled GaAs Quantum Dots fabricated by double-filling of ultra-low density nanoholes — •Achim Küster, David Sonnenberg, Andreas Graf, Vera Paulava, Christian Heyn, and Wolfgang Hansen — Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

The recent fabrication of self-organized ultra-low density nanoholes in AlGaAs surfaces with depths of approximately 25 nm enables the fabrication of a new type of coupled quantum dots (QD). For this, the nanoholes are filled with two layers of GaAs and an AlGaAs barrier layer of a few nm in between. The sizes of each resulting QD as well as of the barrier layer can be controlled seperately by the thickness of the respective filling layer. The ultra-low nanohole density of $6 \cdot 10^6$ cm^{-2} allows for the optical study of a single coupled QD structure without interference from other QDs by using a focused laser for excitation. We study the optical properties of single coupled QD structures using micro-photoluminesence measurements in dependence of the QD size and separation.

HL 44.20 Tue 9:30 Poster D

Micro-magneto-optics and photocurrent-spectroscopy of large $In_{0.3}Ga_{0.7}As$ quantum dots — •Peter Gold[1], Manuel Gschrey[1], Andreas Löffler[1], Sven Höfling[1], Alfred Forchel[1], Martin Kamp[1], and Stephan Reitzenstein[1,2] — [1]Universität Würzburg, Technische Physik, Am Hubland, D 97074 Würzburg — [2]Present address: Institute of Solid State Physics, Hardenbergstrasse 36, Technische Universität Berlin, D-10623 Berlin

Quantum dot (QD) microcavities are of high interest for the observation of cavity quantum electrodynamics (cQED) effects in the weak or strong coupling regime and their application in quantum light sources. An important parameter that influences the strength of the coupling between light and matter is the oscillator strength f of the involved QD exciton. In this context, laterally elongated $In_{0.3}Ga_{0.7}As$ QDs are of particular interest due to their large oscillator strength in the range of $f \approx 40 - 50$. Here we present a comprehensive spectroscopic study on the optical properties of $In_{0.3}Ga_{0.7}As$ QDs by applying high resolution micro-magneto-optical and micro-photocurrent (μPC) spectroscopy. These experimental results are compared to those obtained from standard $In_xGa_{1-x}As$ QDs with an indium content of $x = 0.6$ and $x = 1.0$, respectively, and oscillator strengths of $f \approx 10$. We observe particular large diamagnetic coefficients for the $In_{0.3}Ga_{0.7}As$ QDs and a clear correlation between the diamagnetic coefficient and the Landé g-factor of the QDs. In addition, a strong fano-like asymmetry of the X lineshape is observed in μPC. The experimental results are in good agreement with numerical simulations.

HL 44.21 Tue 9:30 Poster D

Optical Transitions in Si-Ge-Heterostructures — •Petru Tighineanu[1], Inga Anita Fischer[2], Jörg Schulze[2], and Kurt Busch[3] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institut für Technologie, Karlsruhe, Germany — [2]Institut für Halbleitertechnik, Universität Stuttgart, Stuttgart, Germany — [3]Institut für Physik, Humboldt-Universität zu Berlin, Berlin, Germany

We investigate optical transitions in low-dimensional Si-Ge-heterostructures such as Ge dots embedded in a Si matrix. The MBE growth of Ge dots on prepatterned Si substrates affords a high degree of control over dot geometry, size homogeneity, and dot positions. Si-Ge intermixing during dot growth can be influenced by the choice of growth temperature. We present results on theoretical predictions for optical transition energies and charge distribution as a function of dot geometry and material composition using a multiband k.p envelope function formalism by taking into account the strain field and spin-orbit coupling. In particular, we show that spatial inhomogeneities in the Ge content of the dot can lead to increased quantum confinement and, therefore, to an effective reduction in dot size. We compare our model predictions with measurements with a view towards functionalizing the structures for Si-Ge optoelectronic applications.

HL 44.22 Tue 9:30 Poster D

Carrier confinement in GaN/AlGaN nanowire heterostructures — •Jörg Teubert[1], Florian Furtmayr[1], Pascal Becker[1], Jan Müssener[1], Alexey Chernikov[3], Sören Schäfer[3], Sangam Chatterjee[3], Jordi Arbiol[2], and Martin Eickhoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Germany — [2]ICREA and Institut de Ciencia de Materials de Barcelona, Spain — [3]Faculty of Physics and Materials Science Center, Philipps Universität Marburg, Germany

GaN nanowires (NWs) can be grown by molecular beam epitaxy using a catalyst free growth process. Due to their low density of defects group III-nitride NWs present a promising approach for the realization of improved nano- or optoelectronic devices. With this respect, the realization of heterostructures embedded in NWs is of major importance. We analyzed the three dimensional carrier confinement in GaN nanodiscs (NDs) embedded in $Al_xGa_{1-x}N$/GaN NWs and its effect on their photoluminescence (PL) properties for Al concentrations in the barriers (x_{Al}) between $x_{Al} = 0.04$ and 1 and for different ND heights. Structural analysis by high resolution transmission electron microscopy reveals the presence of a lateral AlGaN shell. In order to obtain a deeper understanding of the relevant effects we performed three dimensional numerical simulations of the confinement which show that the effects of the AlGaN shell have to be considered to explain the observed dependence of the emission energy on x_{Al}. Effects of axial and radial internal electric fields have been investigated using NW samples with different ND thickness.

HL 45: Photovoltaics: Silicon-based Systems I

Time: Wednesday 9:30–11:00 Location: ER 270

HL 45.1 Wed 9:30 ER 270

Selektive Ablation dünner dielektrischer Schichten von Silizium mittels ultrakurzer Laserimpulse — •Tino Rublack[1], Martin Schade[2] und Gerhard Seifert[3] — [1]Zentrum für Innovationskompetenz (ZIK) * SiLi-nano, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany — [3]Naturwissenschaftliche Fakultät II, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany

Eine Strukturierung von Silizium-Solarzellen durch selektives Entfernen der dünnen dielektrischen Passivierungs- bzw. Antireflexschichten wird derzeit bei hocheffizienten Solarzellen im Labor meist fotolithographisch durchgeführt. Eine kosteneffiziente und industrietaugliche Alternative hierzu stellt die selektive Ablation dieser Schichten mit ultrakurzen Laserimpulsen dar. In unserer Arbeit haben wir mit verschiedenen Lasersystemen, deren Pulsdauern zwischen 50 fs und 2000 fs variierten, den Mechanismus der selektiven Ablation untersucht. Hierbei wurden zusätzlich zum Einfluss der Pulsdauer auch die Einflüsse der Wellenlänge im Bereich von 266 nm bis 10 μm und des Fokalradius untersucht. Es konnte mittels Licht- und Rasterkraftmikroskopie, Raman-Spektroskopie sowie Rasterelektronen- und Transmissionselektronenmikroskopie gezeigt werden, dass eine selektive Ablation von SiO_2, Si_xN_y und Al_2O_3 auf Silizium unter Erhalt der Kristallstruktur im geöffneten Bereich möglich ist.

HL 45.2 Wed 9:45 ER 270

Microstructuring of silicon with femtosecond laser pulses — •Waldemar Freund[1], Jan P. Richters[2], Jürgen Gutowski[1], and Tobias Voss[1] — [1]Institute of Solid State Physics, Semiconductor Optics Group, Universitiy of Bremen — [2]Department of Physics, University of Grenoble

"Black silicon" has been a field of intense studies in recent years. To fabricate this material, a crystalline p-doped silicon wafer is structured with ultrashort laser pulses in a sulfurhexafluoride (SF_6) atmosphere. The physics on the ultrashort time scale results in two processes: the formation of laser-induced periodic surface structures (LIPPS) and the simultaneous doping of the silicon with sulfur far above the solubility limit creating a p-n^+-junction which acts as a solar cell under illumination. The periodic surface structures considerably enhance light absorption in "black silicon" at energies below the silicon bandgap. The extremely high doping with sulfur results in the formation of a distinct defect band which is the origin of high absorptance in the near-infrared spectral region. Silicon treated with this process therefore constitutes a promising material for applications in thin film solar cells. We show experimental results on optimization of black-silicon solar cell efficiency through passivation of surface defects after treatment with HF. A significant increase in short circuit current of black silicon solar cells is observed when using thinner p-silicon substrates. Our studies represent important steps towards the fabrication of efficient thin-film solar cells with increased infrared sensitivity on base of easy-to-produce black silicon.

HL 45.3 Wed 10:00 ER 270

Formation of Black Silicon by differently polarized femtosecond laser pulses — •Stefan Kontermann[1], Anna Lena Baumann[1], Thomas Gimpel[2], Kay Michael Guenther[2], Augustinas Ruibys[1], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich Hertz Institute, EnergieCampus, Am Stollen 19, 38640 Goslar, Germany — [2]Clausthal University of Technology, Institute of Energy Research and Physical Technologies and EFZN, EnergieCampus, Am Stollen 19A, 38640 Goslar, Germany

Irradiating a silicon surface with femtosecond laser pulses results in a low reflecting surface structure consisting of cone like features. Adding sulfur to the atmosphere, where the light material interaction takes place, yields an enhanced infrared absorption of this Black Silicon substrate. Due to the sub band gap absorption, Black Silicon allows a better exploitation of the light energy contained in the sun spectrum. Therefore Black Silicon is one of the materials that are about to enter the photovoltaic research and development stage. In earlier studies the influence of different parameters on the Black Silicon structure like laser pulse number per spot, laser fluence, pressure in the processing chamber, or the crystal orientation were investigated. In this work we present results from a study of the Black Silicon structures when laser pulses of different polarization are applied. We examine the correlation between surface properties and polarization and compare these results to the structure formed by linearly polarized fs-laser pulses using scanning electron microscopy and absorption measurements.

HL 45.4 Wed 10:15 ER 270

Crystal structure at the surface of femtosecond-laser microstructured silicon for photovoltaics — •Thomas Gimpel[1], Ingmar Höger[2], Fritz Falk[2], Stefan Kontermann[3], and Wolfgang Schade[1,3] — [1]Clausthal University of Technology, EFZN, 38640 Goslar — [2]Institute of Photonic Technology, 07745 Jena — [3]Fraunhofer Heinrich Hertz Institute, 38640 Goslar

Black Silicon structured by means of femtosecond (fs) laser pulses in a sulfur containing atmosphere is an attractive candidate for intermediate band photovoltaics. A single fs-laser step yields a light trapping structure and the implementation of sulfur far above equilibrium concentration. Incorporated sulfur states within the silicon band gap realize n-doping and form an intermediate band which allows photons with energies below the silicon band gap to be absorbed.

Nevertheless, structuring silicon by means of fs-laser pulses partially destroys the crystal structure of the monocrystalline substrates. Former transmission electron microscope (TEM) investigations point out only a small sample area and could barely take any annealing processes into account. Therefore we perform electron backscatter diffraction (EBSD) measurements on differently structured samples. We show how light trapping structures are partially monocrystalline after fs-laser irradiation and how annealing influences the crystal structure. The results are promising to improve the crystal quality of fs-laser structured Black Silicon.

HL 45.5 Wed 10:30 ER 270

Surface recombination in black silicon — •Michael Algasinger, Julie Paye, Svetoslav Koynov, Martin S. Brandt, and Martin Stutzmann — Walter Schottky Institut, Technische Universität München, 85748 Garching, Germany

Nanotextured silicon, also referred to as black silicon (b-Si), shows a reflectivity of around 2-5% in the whole range of Si absorption [1]. The needle-like structure is in a scale of the wavelength of the incident light. According to the model of Stephens and Cody [2] such a surface is an effective medium with a graded optical density, which provides no interface where a reflection could appear. Furthermore, this nanostructure shows light trapping effects, increasing the optical path by a factor of up to 15 [3]. Both effects make b-Si interesting for application in thin film solar cells. The nanostructure is produced by a wet etching process which increases the surface area. This leads to an elevated recombination of photo-induced carriers. In order to benefit from the good optical properties of b-Si in solar cells, the loss in efficiency due to the additional surface recombination needs to be minimized. Effects of different surface treatments on the surface recombination velocity will be compared. First results of diffusion length measurements and electrical detected magnetic resonance (EDMR) will be presented.

[1] S. Koynov, M. S. Brandt, and M. Stutzmann, Appl. Phys. Lett. 88, 203107 (2006).

[2] R. B. Stephens and G. D. Cody, Thin Solid Films 45, 19 (1977).

[3] S. Koynov, M. S. Brandt, and M. Stutzmann, J. Appl. Phys. 110, 043537 (2011).

HL 45.6 Wed 10:45 ER 270

Black silicon passivation by conformal thermal ALD deposited Al_2O_3 coatings — •Martin Otto[1], Matthias Kroll[2], Thomas Käsebier[2], Roland Salzer[3], and Ralf B. Wehrspohn[1,3] — [1]Martin-Luther-University Halle-Wittenberg, μMD Group - Institute of Physics, Halle, Germany — [2]Friedrich Schiller University Jena, Institute of Applied Physics, Jena, Germany — [3]Fraunhofer Institute for Mechanics of Materials Halle, Halle, Germany

Upon inductive coupled plasma reactive ion etching (ICP-RIE) of Si surfaces needle-like nanostructures with aspect ratios up to 10 emerge showing excellent anti-reflection and light-trapping properties with absorption over 97% throughout the UV and VIS spectral range. In addition, the absorption at the band edge of silicon is enormously en-

hanced due to scattering. In this work we report on the feasibility to deposit conformal Al_2O_3 dielectric layers on these very rough silicon surfaces which enable adequate surface passivation. Lifetimes over 170 μs have been measured on deep structured b-Si substrates. The optical properties of black silicon (b-Si) and the possible influence of applied alumina passivation layers as well as their passivation performance are discussed.

HL 46: Focus Session: AlGaN Materials for UV Emitters

Group III-nitride based ultraviolet light emitting diodes are gaining more and more attention, e.g. as replacement for bulky and inflexible mercury vapor lamps. However, their efficiencies are still far below that of blue and green LEDs. The key challenges are related to the AlGaN materials that are required to realize UV emitters. They can be attributed to fundamental material properties (i.e. band structure), the high defect densities caused by heteroepitaxy, and the difficulty in mixing very dissimilar materials like InN and AlN. It is the aim of this focus session to provide an overview of novel approaches to tackle these problems, ranging from bulk crystal growth of AlN to epitaxy of AlGa(In)N alloys, investigations of basic properties of AlGaN materials as well as performance characteristics of UV emitting (and detecting) devices. (Organizers: Markus Weyers, Ferdinand-Braun-Institut Berlin, Mathias Bickermann and Michael Kneissl, TU Berlin)

Time: Wednesday 9:30–12:45 Location: ER 164

Invited Talk HL 46.1 Wed 9:30 ER 164
AlN-based technology for electronics and optoelectronics — •Zlatko Sitar[1], Ramon Collazo[1], Raoul Schlesser[2], Spalding Craft[2], Baxter Moody[2], Seiji Mita[2], Jinqiao Xie[2], Anthony Rice[1], and James Tweedy[1] — [1]MSE, North Carolina State University, Raleigh, NC, USA. — [2]HexaTech, Inc., Morrisville, North Carolina, USA.

For the first time in history of III-nitrides, the availability of low defect density (<10E3 cm-2) native AlN substrates offers an opportunity for growth of AlGaN alloys and device layers that exhibit million-fold lower defect densities than the incumbent technologies and enable one to assess and control optical end electrical properties in absence of extended defects. Epi-ready AlN wafers are fabricated from AlN boules grown by physical vapor transport at temperatures between 2200 and 2300°C. Gradual crystal expansion is achieved through a scalable, iterative re-growth process in which the high crystal quality is maintained over many generations of boules. Low defect density AlN and AlGaN epitaxial films are grown upon these wafers that exhibit superior optical properties in terms of emission efficiency and line width and can be doped with an efficiency that is several orders of magnitude higher than possible in technologies using non-native substrates. UV LED structures and Schottky diodes were fabricated on these materials that exhibit low turn-on voltages and breakdown fields greater than 10 MV/cm. This presentation will review state-of-the-art of AlN-based technology and give examples of potential applications in future devices and contrast these with other wide bandgap technologies.

Topical Talk HL 46.2 Wed 10:00 ER 164
Towards Sub-300 nm AlGaN Laser Diodes on Bulk AlN Substrates — •Thomas Wunderer[1], Christopher Chua[1], John Northrup[1], Zhihong Yang[1], Noble Johnson[1], Michael Kneissl[1,4], Gregory Garrett[2], Hongen Shen[2], Michael Wraback[2], Baxter Moody[3], Spalding Craft[3], Raoul Schlesser[3], Rafael Dalmau[3], and Zlatko Sitar[3] — [1]Palo Alto Research Center Inc., Palo Alto, CA, USA — [2]US Army Research Laboratory, Adelphi, MD, USA — [3]HexaTech Inc., Morrisville, NC, USA — [4]Inst. of Solid State Physics, TU Berlin, Berlin, Germany

We report recent progress on the development towards sub-300 nm laser diodes. By using high-quality bulk AlN substrates we are able to achieve excellent crystalline quality of the epitaxially grown MOCVD laser hetero-structures. We successfully realized optically pumped AlGaN-based lasers in the wavelength regime between 237 and 291nm with threshold pump power densities below 130 kW/cm2. Results of structural and optical investigation methods will confirm the high material quality, which led to the high lasing performance. We will discuss the polarization properties of the lasers with different emission wavelengths and present concepts of how to address the electrical challenge of high bandgap laser diodes.

Topical Talk HL 46.3 Wed 10:30 ER 164
High-efficiency AlGaN-based light-emitting diodes for the UV-A wavelength range — •Richard Gutt[1], Thorsten Passow[1], Michael Kunzer[1], Wilfried Pletschen[1], Lutz Kirste[1], Kamran Forghani[2], Ferdinand Scholz[2], Klaus Köhler[1], and Joachim Wagner[1] — [1]Fraunhofer-Institut für Angewandte Festkörperphysik (IAF), Freiburg — [2]Institut für Optoelektronik, Universität Ulm

To date, AlGaN-based light emitting diodes (LEDs) emitting in the ultraviolet (UV) wavelength range exhibit much lower external quantum efficiencies (EQE) compared to their highly-developed GaN-based counterparts covering the visible spectral range. This can be ascribed to two major reasons. On the one hand, epitaxial growth of AlGaN on sapphire typically leads to a large density of threading dislocations, which are known to act as non-radiative recombination centers. On the other hand, the demand for shorter emission wavelengths inhibits the use of GaInN quantum wells (QWs), which show efficient light emission despite the quite high dislocation density in GaN-based LEDs.

In this talk, we present different approaches towards the reduction of threading dislocations in AlGaN with an Al content of $\sim$ 20 %. Moreover, a significant enhancement in light emission by using GaN QWs with very low In content is demonstrated. We also address the challenges in achieving a high carrier injection and light extraction efficiency. Combining all these measures, we demonstrated LEDs emitting at wavelengths around 350 nm with an EQE exceeding 7 %, which is among the highest values reported for AlGaN-based LEDs.

Coffee Break (15 min)

Topical Talk HL 46.4 Wed 11:15 ER 164
Growth and properties of bulk AlN crystals — •Boris Epelbaum — CrystAl-N GmbH, Dr.-Mack-Straße 77, D - 90762 Fürth

Single-crystalline aluminum nitride is a very promising substrate material for nitride-based optoelectronic devices performing in deep UV spectral range. The feasibility of bulk AlN growth using high-temperature Physical Vapor Transport (PVT) method has been convincingly confirmed during last years, but important crystal quality issues still remain. In this presentation we will show our most recent achievements in growth of bulk AlN crystals and discuss some quality issues:

(i) Specific defects in bulk AlN such as macropipes and localized misoriented domains and their evolution during growth process, (ii) Crystal faceting and boule enlargement within a single growth process. The influence of temperature gradient on growth interface and faceting effects on enlargement and structural quality of crystal rim. (iii) Variations of UV transmission in different crystal areas

Finally high structural quality crack-free bulk AlN crystals up to 40 mm in diameter grown using various polar and semi-polar orientations will be demonstrated.

Topical Talk HL 46.5 Wed 11:45 ER 164
Studies about defect reduction in AlGaN hetero structures — •Ferdinand Scholz[1], Kamran Forghani[1], Haoyuan Qi[1], Mohammadreza Gharavipour[1], Martin Klein[1], Oliver Klein[2], Ute Kaiser[2], Benjamin Neuschl[3], Klaus Thonke[3], Richard Gutt[4],

and Thorsten Passow[4] — [1]Institut für Optoelektronik, Universität Ulm, 89081 Ulm — [2]Zentrale Einrichtung Elektronenmikroskopie, Universität Ulm, 89081 Ulm — [3]Institut für Quantenmaterie, Universität Ulm, 89081 Ulm — [4]Fraunhofer-Institut für Angewandte Festkörperphysik, 79108 Freiburg

Owing to its large and tunable band gap, $Al_xGa_{1-x}N$ is the key semiconductor for the development of UV light emitting devices. Currently, many groups study the realization of such LEDs emitting at wavelengths below 350nm. Obviously, the radiative efficiency decreases with decreasing wave length, which is most probably caused by the increasing defect density in such materials with increasing Al content x. We have investigated how the defect density in AlGaN structures with x 20 - 50% can be reduced by optimizing the respective MOVPE process. One possibility is the integration of in-situ deposited SiN interlayers which should act as dislocation blocking layers. This concept works excellently in GaN, but with only limited success in AlGaN. By transmission electron microscopy studies, we analyzed the functionality of SiN in AlGaN in more detail. UV LEDs grown on optimized AlGaN layers showed very high light output powers proving the success of our defect density reducing methods.

Topical Talk HL 46.6 Wed 12:15 ER 164

Dielectric properties and band structure evolution in AlGaN alloys — •Christoph Cobet — Center of Surface and Nanoanalytics, Johannes Kepler University , Linz, Austria

During the past 10 years the optoelectronic properties of group-III-nitrides have been investigated in a wide spectral range. These efforts were driven on one hand by the demand on reference data for novel optoelectronic devices and for proving band structure calculations and on the other hand by the continuous improvement of the crystal quality of epitaxial films. Step by step it was possible to elucidate many fundamental electronic properties and to increase the general understanding of the constituting electronic background. Recently remaining uncertainties concerned for example the fundamental question whether cubic AlN has an indirect band gap and the identification of related band structure peculiarities. Moreover, the impact of the exciton formation and the exact band ordering at the Γ- and other high symmetry points in the Brillouin-zone are discussed under consideration of strain effects. It will be shown on the basis of complete AlGaN series, how these kinds of questions were addressed by measuring the entire dielectric function from the visible to the far UV.

HL 47: Invited Talk: Dieter Weiss

Time: Wednesday 9:30–10:00 Location: EW 201

Topical Talk HL 47.1 Wed 9:30 EW 201

Spin transistor action via tunable adiabaticity — Christian Betthausen[1], Tobias Dollinger[2], Henri Saarikoski[2], Valery Kolkovsky[3], Grzegorz Karczewski[3], Tomasz Wojtowicz[3], Klaus Richter[2], and •Dieter Weiss[1] — [1]Experimentelle und Angewandte Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [3]Institute of Physics, Polish Academy of Sciences, 02668 Warsaw, Poland

Spin-transistor prototypes, employing spin-orbit interaction, principally suffer from low signal levels due to limitations in spin injection efficiency, fast spin relaxation and dephasing processes. Here we present an alternative concept to implement spin transistor action where efficiency is improved by keeping spin transport adiabatic. To this end a helical stray field B, generated by ferromagnetic dysprosium stripes, is superimposed upon a two-dimensional electron system in CdMnTe. Due to the giant spin splitting, occurring at low temperatures and small B in CdMnTe quantum wells, the B-helix translates into a spin-helix and the electron spins follow adiabatically the imposed spin texture. Within this approach the transmission of spin-polarized electrons between two contacts is regulated by changing the degree of adiabaticity, i.e. an electron's ability to follow the spin helix. This is done by means of a small applied homogeneous magnetic field while the degree of adiabaticity is monitored by the channel resistance. Our scheme allows spin information to propagate efficiently over typical device distances and provides an alternative route to realize spintronics applications.

HL 48: Focus Session: Spintronics (jointly with MA)

Time: Wednesday 10:00–13:15 Location: EW 201

HL 48.1 Wed 10:00 EW 201

Electron spin decoherence in SiC nuclear spin bath — •Nan Zhao, Christian Burk, and Joerg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart , Germany

The coherent control of electron spin of defect centers in SiC was reported very recently [1]. Here, we calculate the decoherence of defect center electron spin in SiC nuclear spin bath. In SiC, the nuclear spin bath consists of two types of spin-1/2 isotopes, Si-29 and C-13. The natural abundance of Si-29 is 4.7%, about four times larger than that of C-13. Intuitively, the spin decoherence in SiC nuclear spin bath would be faster than NV in diamond. However, our calculations demonstrate that, when nuclear spin bath dominates decoherence process, the averaged coherence time of electron spin in SiC will be comparable or even longer than that of NV in diamond. We show that the reason for this counter-intuitive result is the suppression of the hetero-nuclear spin flip-flop process in magnetic fields. Our research provides the possibility of further exploring the quantum coherent spin dynamics in SiC.

Reference:

[1] Koehl, W. F., Buckley, B. B., Heremans, F. J., Calusine, G., & Awschalom, D. D. Room temperature coherent control of defect spin qubits in silicon carbide. Nature, 479, 84 (2011).

HL 48.2 Wed 10:15 EW 201

Coherent spin states of vacancy defects in silicon carbide — •Sang-Yun Lee[1], Yuki Doi[2], Shuta Mori[2], Takaaki Shimooka[2], Torsten Rendler[1], Nan Zhao[1], Helmut Fedder[1], Singi Miwa[2], Yoshishige Suzuki[2], Norikazu Mizuochi[2], and Jörg Wrachtrup[1] — [1]University of Stuttgart, Stuttgart, Germany — [2]Osaka University, Osaka, Japan

Since the first demonstration of the single spin detection of vacancy defects in diamond, the electron spins in the carbon vacancy defects have been considered as a good candidate for the semiconductor qubit especially due to their long coherence time at room temperature. It has been believed that this outstanding property originates from its highly localized bound state deep in the bandgap which prevent spin states from being affected by various decoherence sources [1]. Similarly isolated states can be found in various wide bandgap semiconductors. Among them, the long coherence time ($T_2 \simeq 40\ \mu s$ at R.T.) of electron spin ensemble of divacancy defect states in the silicon carbide (SiC) has been reported recently [2]. We hereby report our recent results on coherent spin states of various silicon vacancy defects including divacancy defects and other vacancy-related defects in SiC. The optical transitions are used to observe the electron spin resonance from them at room temperature. The coherence times of those defect states at room and low temperatures will be presented, and discussion about the decoherence processes will be given.

[1] J. R. Weber, *et al.*, P. NATL. ACAD. SCI. USA 107, 8513 (2010)
[2] W. F. Koehl, *et al.*, Nature 479, 84 (2011)

HL 48.3 Wed 10:30 EW 201

Nuclear spin quantum registers with NV centers in diamond — •Helmut Fedder[1], Jan Honert[1], Nan Zhao[1], Junichi Isoya[2], and Jörg Wrachtrup[1] — [1]3. Physikalische Institut, Uni Stuttgart — [2]University of Tsukuba, Japan

Nitrogen-Vacancy centers in diamond are promising solid state sys-

tems for quantum information processing with long (several ms) spin coherence time at room temperature. The defect has a strong optical transition that can be used for preparation and readout of the electron spin [1]. Nearby nuclear spins can be used to realize quantum registers with few qubits [2]. Single shot nuclear spin readout has been demonstrated in high magnetic fields [3]. Here we present recent results towards multi nuclear spin qubit registers. Exploiting the long coherence time in isotopically clean diamond, we enable addressing of weakly coupled nuclear spins. A detailed account will be given on the decoherence mechanisms, dynamical decoupling techniques and robust manipulation using double quantum transitions.

[1] Jelezko et al. PRL 93, 130501 (2004)
[2] Neumann et al. Science 320, 1326 (2008), Multipartite Entanglement Among Single Spins in Diamond
[3] Neumann et al. Science 329, 542 (2010), Single-Shot Readout of a Single Nuclear Spin

HL 48.4 Wed 10:45 EW 201

Spin Hall Effect on Triangular Lattice — •Paul Wenk[1], Georges Bouzerar[1,2], and Stefan Kettemann[1,3] — [1]School of Engineering and Science, Jacobs University Bremen, Campus Ring 1, Bremen 28759, Germany — [2]Institut Néel, 25 avenue des Martyrs, B.P. 166, 38042 Grenoble Cedex 09, France — [3]Asia Pacific Center for Theoretical Physics and Division of Advanced Materials Science Pohang University of Science and Technology (POSTECH) San31, Hyoja-dong, Nam-gu, Pohang 790-784, South Korea

We investigate the intrinsic Spin Hall Effect on a two-dimensional triangular lattice in the presence of both Rashba and Dresselhaus spin-orbit coupling. This type of lattice is especially interesting due to the build-in geometrical frustration and absence of particle-hole symmetry. We analyze the Spin Hall Effect by applying Chebyshev expansion and Kernel Polynomial Method, which allows for the variation of spin-Hall conductivity as a function of disorder strength on large system sizes.

HL 48.5 Wed 11:00 EW 201

Extended spin dephasing times in a 110-grown high-mobility GaAs/AlGaAs quantum well under conditions of optical gating measured by resonant spin amplification technique — •M. Griesbeck[1], M. Glazov[2], E. Sherman[3], T. Korn[1], D. Schuh[1], W. Wegscheider[4], and C. Schüller[1] — [1]Institute for Experimental and Applied Physics, Regensburg University, Germany — [2]Ioffe Physical-Technical Institute, St. Petersburg, Russia — [3]Department of Physical Chemistry, The University of the Basque Country, Bilbao, Spain — [4]Solid State Physics Laboratory, ETH Zürich, Switzerland

Recently, very long spin dephasing times were discovered in a high-mobility two-dimensional electron system (2DES) embedded in a 30 nm wide symmetric (110)-grown GaAs/AlGaAs quantum well [1,2]. We have found that resonant spin amplification (RSA) [3] measurements are a convenient tool to determine all relevant parameters of anisotropic spin dynamics in our sample. Here, we show that a decrease of the carrier density by low-intensity above-barrier illumination (often referred to as optical gating) leads to a drastic increase of both the in-plane and the out-of-plane spin dephasing times. The observed spin dephasing time along the growth direction exceeds by far the previously reported values, what is most likely related to the high sample quality and the precise control of the band profile of the quantum well.

[1] R. Völkl et al., Phys. Rev. B 83, 241306 (2011)
[2] M. Griesbeck et al., preprint: http://arxiv.org/abs/1111.5438
[3] J. M. Kikkawa et al., Phys. Rev. Lett. 80, 4313 (1998)

Coffee Break (15 min)

HL 48.6 Wed 11:30 EW 201

Electric field-driven coherent spin reorientation and spin rephasing of optically generated electron spin packets in InGaAs — •Sebastian Kuhlen[1,3], Klaus Schmalbuch[1,3], Markus Hagedorn[1,3], Paul Schlammes[1,3], Marten Patt[1,3], Mihail Lepsa[2,3], Gernot Güntherodt[1,3], and Bernd Beschoten[1,3] — [1]II. Physikalisches Institut A, RWTH Aachen University, 52074 Aachen — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich — [3]JARA: Fundamentals of Future Information Technology, 52074 Aachen

Full electric-field control of spin orientations is one of the key tasks in semiconductor spintronics. We demonstrate that electric field pulses can be utilized for phase-coherent 2π spin rotation of optically generated electron spin packets in InGaAs epilayers using time-resolved Faraday rotation. Through spin-orbit interaction, the electric-field pulses act as local magnetic field pulses (LMFP). By the temporal control of the LMFP, we can turn on and off electron spin precession and thereby rotate the spin direction into arbitrary orientations in a 2-dimensional plane [1]. Moreover, using two subsequent pulses of opposite polarity allows us to perform spin echo measurements by reversing the spin precession direction. Although our spin transport experiment is in the diffusive regime, we unexpectedly observe that electric field-induced spin dephasing is reversible to a large extent.

[1] S. Kuhlen *et al.* arXiv 1107.4307

This work has been supported by DFG through FOR912.

HL 48.7 Wed 11:45 EW 201

Time-resolved electrical detection of optically triggered spin coherence in InGaAs — •Ivan Stepanov[1], Stefan Göbbels[1], Tobias Wenz[1], Gernot Güntherodt[1], Mihail Lepsa[2], and Bernd Beschoten[1] — [1]II. Physikalisches Institut, RWTH Aachen University, Germany — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich GmbH, Germany

Direct conversion of electron spin precession into a detectable electrical voltage plays an important role in many spintronic concepts. In previous experiments spin-dependent photocurrents were observed in DC measurements on 2DEGs and QWs and could be explained by the spin-galvanic effect (SGE) [1].

Here we report on the first time-resolved electrical measurement of the spin-dependent photo-voltage in n-InGaAs. Phase triggering of electron spin coherence is achieved by circularly polarized picosecond laser pulses. Electron spin precession in a transverse external magnetic field can be directly monitored as photo-voltage oscillations using a phase-triggered sampling oscilloscope as a probe. The magnetic field dependence of phase and amplitude of the photo-voltage along $[1\bar{1}0]$ agree well with the predictions of the SGE. Time-resolved Faraday rotation (TRFR) measurements on the same sample under identical experimental conditions show good agreement between the measured spin dephasing times and the g-factor in the photo-voltage probes and the TRFR.

This Work has been supported by DFG through FOR 912

[1] S.D. Ganichev *et al.*, Nature **417**, p. 153 (2002)

HL 48.8 Wed 12:00 EW 201

Anisotropic spin-orbit coupling probed by time-resolved photovoltage measurements in InGaAs/GaAs heterostructures — •Stefan Göbbels[1], Ivan Stepanov[1], Christopher Franzen[1], Gernot Güntherodt[1], Mihail Lepsa[2], and Bernd Beschoten[1] — [1]II. Physikalisches Institut, RWTH Aachen University, Germany — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich GmbH, Germany

Electrical detection of spin polarization is a central issue in developing spintronic devices. The spin-orbit coupling (SOC) in III-V semiconductors opens a pathway for electrical spin detection with non-magnetic electrodes via the spin-galvanic effect (SGE), which directly converts spin polarization into an electrical voltage [1].

Here, we report on the first observation of spin precession by time-resolved photovoltage measurements, which unveils more information about spin dynamics than obtained by previous static measurements. Our results on n-InGaAs/GaAs heterostructures reveal a strong crystal anisotropy of the photovoltages. While in the $[1\bar{1}0]$-direction the SGE is observed, arising from the in-plane spin polarization, we find in the [110]-direction that the photovoltage signal originates from an out-of-plane spin polarization and increases linearly with an in-plane magnetic field. Thus, two different SOC effects are observed along different crystal axes, which cannot be distinguished by phase-insensitive static measurements.

This work has been supported by DFG through FOR 912.

[1] S. D. Ganichev *et al.*, Nature **417**, 153 (2002)

HL 48.9 Wed 12:15 EW 201

Dark-bright mixing of interband transitions in [111] grown semiconductor quantum dots — •Bernhard Urbaszek[1], Gregory Sallen[1], Misha Glazov[2], Eougeniious Ivchenko[2], Takashi Kuroda[3], Takaaki Mano[3], Sergej Kunz[1], Kazuaki Sakoda[3], Xavier Marie[1], and Thierry Amand[1] — [1]Toulouse University, LPCNO-CNRS, France — [2]Ioffe Institute, St.-Petersburg, Russia — [3]NIMS, Tsukuba, Japan

Due to their inherently high symmetry, quantum dots grown along the [111] crystal axis have been indentified as suitable sources of entan-

gled photon pairs via the exciton-biexction cascade [1]. We show that the underlying crystal symmetry does also result in highly unusual carrier spin physics probed in polarization resolved single dot photoluminescence spectroscopy. We observe for symmetric [111] grown GaAs/AlGaAs quantum dots in longitudinal magnetic fields applied along the growth axis in addition to the expected bright states also nominally dark transitions for both charged and neutral excitons. We uncover a strongly non-monotonous, sign changing field dependence of the bright neutral exciton splitting resulting from the interplay between exchange and Zeeman effects [2]. Our theory shows quantitatively that these surprising experimental results are due to magnetic-field-induced $\pm 3/2$ heavy-hole mixing, an inherent property of systems with C_{3v} point-group symmetry.

[1] Schliwa et al., PRB 80, 161307 (2009) & Singh and Bester, PRL 103, 063601 (2009) & Mohan et al., Nat. Photon. 4, 302 (2010)

[2] G. Sallen et al, Phys. Rev. Lett. 107, 166604 (2011)

HL 48.10 Wed 12:30 EW 201

Spin relaxation dynamics in spin-LEDs — •Henning Höpfner[1], Carola Fritsche[1], Arne Ludwig[2], Astrid Ebbing[2], Frank Stromberg[3], Heiko Wende[3], Werner Keune[3], Dirk Reuter[2], Andreas D. Wieck[2], Nils C. Gerhardt[1], and Martin R. Hofmann[1] — [1]Photonics and Terahertz Technology, Ruhr-University Bochum, Germany — [2]Applied Solid State Physics, Ruhr-University Bochum, Germany — [3]Faculty of Physics and Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, Germany

In recent years, spin-optoelectronics has been a field of both extensive and intensive research. In particular, the fabrication of spin light-emitting diodes (LEDs) has been intensively investigated.

Here we present a detailed investigation of spin injection into spin quantum dot LEDs. Our samples are GaAs based pin-type diodes and consist of a MgO tunnel barrier capped with a Fe/Tb multilayer injector operating in magnetic remanence and InAs quantum dots in the active region. The Fe/Tb multilayer allows us to operate our devices in magnetic remanence, which enables the separation of spin injection and relaxation effects from parasitic effects due to external magnetic fields (Appl. Phys. Lett. 99 (5), 051102 (2011)).

In this study we focus on spin relaxation during transport to the active region and spin relaxation in the active region prior to carrier recombination. Using a series of samples with varying injection path length we analyze relaxation during transport, while the ratio of carrier lifetime to spin lifetime determines the degree of polarization of the emission from the device.

HL 48.11 Wed 12:45 EW 201

Hot carrier effects on lateral electron spin diffusion in n-type GaAs — •Tobias Henn, Jan-Henrik Quast, Tobias Kiessling, and Wolfgang Ossau — Physikalisches Institut (EP3) der Universität Würzburg, 97074 Würzburg, Germany

We report on spatially resolved two-color Hanle-MOKE studies of low temperature electron spin diffusion in bulk n-type GaAs. We investigate the influence of lattice temperature and external magnetic fields on the lateral electron spin diffusion for a broad range of donor concentrations covering the insulating and metallic regime.

Our results demonstrate that the commonly used standard drift-diffusion model **[1,2]** is not capable of describing the lateral spin diffusion profiles observed under non-resonant optical spin injection. We find that the non-resonant optical excitation results in a local heating of the electron system with respect to the lattice which persists over length scales comparable to the spin diffusion length. Consideration of this hot carrier effect is demonstrated to be crucial for reliable extraction of spin propagation parameters from optical experiments.

[1] S. A. Crooker and D. L. Smith, PRL, **94** (2005), 236601

[2] M. Furis et al., NJP, **9** (2007), 347

HL 48.12 Wed 13:00 EW 201

Orts- und polarisationsaufgelöste PL-Messungen an Mn-dotiertem GaAs — •Franz Münzhuber[1], Georgy Astakhov[1], Tobias Kiessling[1], Vladimir Korenev[2] und Wolfgang Ossau[1] — [1]Physikalisches Institut (EP3) der Universität Würzburg, 97074 Würzburg, Germany — [2]A. F. Ioffe Physico-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

Bei der Beobachtung von Spin-Diffusion in Halbleitern hat man oftmals damit zu kämpfen, dass intrinsische Effekte durch die elektrisch oder optisch induzierten, extrinsischen Ladungsträger überlagert oder verfälscht werden. Eine p-Dotierung führt zu einem rein extrinsischen Elektronensystem, welches aber aufgrund des starken BAP-Mechanismus sehr schnell depolarisiert. Dotiert man GaAs jedoch mit Mangan, können die Löcher mit den Mn-Rümpfen koppeln, so dass die die Relaxationszeit τ_S um bis zu zwei Größenordnungen ($\tau_S > 150$ ns) steigt [1]. In PL-Messungen konnten wir feststellen, dass die an den beiden das Spektrum dominierenden (X und $e - A_{Mn}$) Übergängen beteiligten Elektronen erheblich voneinander abweichende Polarisationsgrade sowie unterschiedliche τ_S besitzen. Diese überraschende Erkenntnis widerspricht der Argumentation von Paget [2], nach der der Spinaustausch zwischen angeregten Elektronen sehr viel schneller als die Rekombination vonstattengeht. Weiterhin lässt sich eine erhebliche Verbreiterung des räumlichen Profils des $e - A_{Mn}$-Übergangs gegenüber dem Profil der Anregung und der Exzitonen erkennen.

[1] G. V. Astakhov et al., PRL **101**, 076602 (2008)

[2] D. Paget, PRB **24**, 3776 (1981)

HL 49: Ultrafast Phenomena

Time: Wednesday 9:30–11:45 Location: EW 202

HL 49.1 Wed 9:30 EW 202

Intra-excitonic extreme nonlinear optics — •Martin Teich[1], Martin Wagner[1], Dominik Stehr[1], Harald Schneider[1], Manfred Helm[1], Sangam Chatterjee[2], Hyatt Gibbs[3], and Galina Khitrova[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden — [2]Faculty of Physics and Material Sciences Center, Philipps University, Renthof 5, 35032 Marburg — [3]University of Arizona, 1630 East University Boulevard, Tucson, Arizona 85721 USA

A fundamental problem in light-matter interaction is the coupling of an intense, monochromatic electromagnetic wave with a quantum mechanical two-level system. One effect related to this is the Autler-Townes or AC Stark effect. Originally observed and described in molecular spectroscopy the effect refers to a splitting of an energy level that is resonantly coupled via intense radiation to an adjacent level, i.e. the states get "dressed" by the light-matter interaction. We investigate this effect using a free-electron laser (FEL) driven intra-excitonic transition between the 1s and 2p states in a semiconductor multiple quantum well [1]. We have observed distinct intensity- and wavelength-dependent Rabi sidebands of the heavy-hole hh(1s) exciton line when the FEL was tuned around the 1s-2p transition. We also present measurements at higher electric fields exploring the regime beyond the rotating-wave approximation.

[1] M. Wagner, H. Schneider, D. Stehr, S. Winnerl, A. M. Andrews, S. Schartner, G. Strasser, and M. Helm, Phys. Rev. Lett. 105, 167401 (2010).

HL 49.2 Wed 9:45 EW 202

Two dimensional photon echo spectroscopy applied to quantum well intersubband dynamics — •Thi Uyen-Khanh Dang, Carsten Weber, Sebastian Eiser, Andreas Knorr, and Marten Richter — Institut für Theoretische Physik, Technische Universität Berlin, Deutschland

A thorough understanding of correlation effects and many-body interactions is an important issue for the investigations of intersubband dynamics in semiconductor quantum wells. The two dimensional photon echo spectroscopy is capable of tracking relaxation processes inside the material since it gives a mapping of excitation and response frequency [1]. Here, we calculate the two-dimensional photon echo signal, applied on the dynamics of a single n-doped GaAs/AlGaAs quantum well. Our model calculations are carried out within a density matrix approach using correlation expansion until second order Born including a non-Markovian treatment of electron-phonon interaction [2]. Our results reveal the temporal dynamics of the system for the regime of low carrier densities.

[1] Abramavicius et al., Chem. Rev. 109, (2009)

[2] S. Butscher et al., Phys. Rev. B. 72, (2005)

HL 49.3 Wed 10:00 EW 202

THz control of matter states: Coherent excitons beyond the Rabi-splitting — •Benjamin Ewers[1], Niko S. Köster[1], Ronja Woscholski[1], Martin Koch[1], Sangam Chatterjee[1], Galina Khitrova[2], Hyatt M. Gibbs[2], Andrea C. Klettke[3], Mackillo Kira[3], and Stephan W. Koch[3] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany — [2]College of Optical Sciences, The University of Arizona, 1630 E. University Blvd., Tucson, Az, 85719-0094, USA — [3]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Mainzer Gasse 33, D-35032 Marburg, Germany

Strong external electromagnetic fields can be used to induce highly nonlinear modifications of the electronic matter states. We show experimentally and theoretically how optically induced excitonic polarization in semiconductors is modified and controlled by intense, single-cycle terahertz (THz) pulses. A resonant low-intensity excitation of GaAs-type direct-gap semiconductors induces coherent excitons with s-like orbital symmetry. The additional application of an electromagnetic field in the range of THz frequencies allows for a direct coupling of the coherent excitons to polarization states with p-type symmetry. By monitoring the low-intensity optical pulse we find a pronounced bleaching of the 1s-exciton resonance, a THz-induced Rabi-splitting, and a pronounced modulation on the high-energy side of the 1s-exciton resonance. All these features are fully explained by our quantum-mechanical many-body theory.

HL 49.4 Wed 10:15 EW 202

Localization of light-modes in disordered ZnO nanoneedle-arrays — •David Leipold and Erich Runge — Technische Universität Ilmenau, 98693 Ilmenau, Germany

Whereas Anderson localization of electrons and excitons in solids is well established for about half a century, the localization of light is notoriously hard to observe in experiments due to weak variations of the dielectric properties and/or the presence of absorption.

We present calculations of localized light-modes in dense random arrays of vertically aligned ZnO nanoneedles. This material provides strong scattering accompanied by low absorption and enables experiments to map the localized wavefunction. We present results of full 3D solutions of Maxwell's equations for our model system. We observe light modes whose intensity is concentrated in small spatial areas and, correspondingly, non-Gaussian intensity histograms. Positive correlation between long lifetimes and the degree of localization is observed. The correlation is strongest for the most localized modes.

We thank M. Maschek, S. Schmidt, M. Silies, and C. Lienau from the Carl von Ossietzky Universität Oldenburg as well as T. Yatsui, K. Kitamura and M. Ohtsu from the University of Tokyo, who did the experiments which inspired this theoretical work.

HL 49.5 Wed 10:30 EW 202

Control of transverse polariton patterns in semiconductor microcavities — •Przemyslaw Lewandowski, Andreas Lücke, and Stefan Schumacher — Physics Department and Center for Optoelectronics and Photonics Paderborn (CeOPP), Universität Paderborn, Paderborn, Germany

Transverse optical patterns are suitable for realising very efficient all-optical switches in atomic vapour systems [1], e.g. Rubidium. Here, we theoretically analyse to which extent the underlying concept of wave-mixing induced coherent transverse patterns and their control can be transferred to a semiconductor-based system. We study quantum-well based planar semiconductor microcavities as promising candidates.

Our theoretical investigation of the coherently-driven nonlinear polariton dynamics is based on a direct time-domain solution of the Maxwell and semiconductor Bloch-equations in the coherent limit and mean-field approximation for the excitonic component (resembling an extended two-component Gross-Pitaevskii-type equation). We (i) analyse in detail the stability and bistability of the spatially homogenous stationary solutions of these nonlinear equations and (ii) present fully two-dimensional numerical calculations showing transverse pattern formation in spatially anisotropic systems. We also demonstrate the all-optical control of these patterns in analogy to what was achieved in atomic vapour systems before [1].

[1] A.M.C. Dawes, D.J. Gauthier, S. Schumacher, N.H. Kwong, R. Binder, and A.L. Smirl, Transverse optical patterns for ultra-low-light-level all-optical switching, Laser & Photonics Reviews 4, 221 (2010).

HL 49.6 Wed 10:45 EW 202

Femtosecond thermomodulation in Cu — •Johanna Flock[1], Markus Beyer[1], Manuel Obergfell[1], Christian Monachon[2], Thomas Dekorsy[1], and Jure Demsar[1,2,3] — [1]Dept. of Physics and CAP, Univ. of Konstanz, D-78457 — [2]Laboratory for Mechanical Metallurgy, EPFL CH-1015 — [3]Complex Matter Dept., Jozef Stefan Institute, SI-1000

Since discrepancies between the two temperature model[1] in the thermomodulation (TM) scenario[2] and experimental data exist[3], we have performed systematic measurements of the time-evolution of the dielectric function in Cu thin films over broad spectral range (1.5-2.5eV) as a function of photoexcitation energy (1.55eV and 3.1eV) and density. Here excitation with 1.55eV results in intraband transitions within the sp-band while in the case of 3.1eV interband processes from the narrow d-band 2eV below the Fermi level to the sp-band dominate. For both excitation energies the spectral changes are consistent with the fs-TM scenario. Only for the case of the intraband excitation the predicted excitation density dependence of the e-ph thermalization rate[1] is observed. For 3.1eV excitation energy the relaxation dynamics is excitation density independent. These results imply that the relaxation strongly depend on the initial electron distribution function, and point out that numerous recent studies on high-Tc superconductors[4] need to be revisited. [1]Kaganov, Sov.Phys.JETP4,(1957); Allen, PRL59,(1987). [2]Brorson, PRL64,(1990). [3]Kabanov, PRB78,(2008); Gadermaier, PRL105,(2010). [4]Brorson, Sol.Stat.Comm.74,(1990); Perfetti, PRL99,(2007);Mansart, PRB82,(2010).

HL 49.7 Wed 11:00 EW 202

Time-resolved vibrational dynamics in a single Si_3N_4 Nanostructure — •Oliver Ristow, Martin Grossmann, Mike Hettich, Elaine Barretto, Martin Schubert, Axel Bruchhausen, Elke Scheer, and Thomas Dekorsy — Departement of Physics and Center of Applied Photonics, University of Constance, D-78457 Konstanz, Germany

In this work we present time domain all-optical investigations of single Si_3N_4 nanostructures using high-speed asynchronous optical sampling (ASOPS). In order to achieve a high spatial resolution a microscope objective is used with the ASOPS system, which allows for resolving and addressing single nanostructures as well as to scan over large sample areas. We demonstrate the capabilities to investigate two dimensional confined nanostructures, such as nanomechanical systems (NEMS). As one example we show the results of pump-probe experiments analyzing the time-resolved vibrational properties of the nanomechanical resonators' beam based on Si_3N_4 and gold. The typical dimensions of such a nanostructure are 100 nm by 100 nm in cross section and 2-3 micron in length. These systems constitute an ideal model system for the investigation of phonon dissipation in NEMS. With this all optical method especially the high frequency range (GHz) is accessible. Due to the high spatial resolution of our system we are able to accurately address different parts of the structures and investigate in the spatial distribution of the different vibrational modes. By combining the measurements with finite element simulations we obtain a good insight on the acoustical dynamics of these structures.

HL 49.8 Wed 11:15 EW 202

Squeezed thermal phonons precurse nonthermal melting of silicon — •Tobias Zier, Eeuwe S. Zijlstra, and Martin E. Garcia — Theoretical Physics, University of Kassel, Germany

Femtosecond laser pulses can be used to practically instantaneously manipulate bonds in solids through the creation of a hot electron plasma. At sufficiently high fluences, some phonon modes may even become unstable, causing acceleration of the atoms, followed by a disordering within several 100's of femtoseconds. This ultrafast solid-to-liquid phase transition is called nonthermal melting and has been observed in silicon, germanium, gallium arsenide, indium antimonide, and bismuth. It is, however, not known which physical process leads up to nonthermal melting at fluences below the melting threshold. Here we show for silicon that in this regime the room temperature phonons become thermally squeezed. We found that the origin of this effect is the sudden femtosecond-laser induced softening of interatomic bonds, which can also be described in terms of a modification of the potential energy surface. We further found in ab initio molecular dynamics simulations on laser-excited potential energy surfaces that the atoms move in the same directions during the first stages of nonthermal melting at high fluences and thermal phonon squeezing at lesser fluences. Our results demonstrate that thermal phonon squeezing is the precursor to nonthermal melting in silicon. Based on the general nature of the underlying bond softening mechanism we believe that this relation

between thermal squeezing and nonthermal melting is not material specific, but should occur in all materials exhibiting the latter process.

HL 49.9 Wed 11:30 EW 202

Spectrally resolved photon echo measurements in CdTe QWs — •L. Langer[1], S. Poltavtsev[2], I. A. Yugova[1,2], G. Karczewski[3], T. Wojtowicz[3], J. Kossut[3], D. R. Yakovlev[1,4], I. A. Akimov[1,4], and M. Bayer[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]Physical Faculty of St. Petersburg State university, 198504 St. Petersburg, Russia — [3]Institute of Physics, Polish Academy of Sciences, 02668 Warsaw, Poland — [4]A.F. Ioffe Physical-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

We report on trion and exciton decoherence in epitaxially grown, 20 nm thick CdTe/CdMgTe quantum wells using degenerate transient four wave mixing (TFWM) technique with heterodyne detection.Use of spectrally narrow picosecond pulses allows measuring the FWM signal for exciton and trion resonances separately. Time-resolving the FWM signal provides direct information on reversible and irreversible dephasing in the system under study. The measured photon-echo behavior for both inhomogeneously broadened exciton- and trion resonances reveals decoherence times of $\tau_X = 5\,\mathrm{ps}$ and $\tau_T = 24\,\mathrm{ps}$ at temperature $T = 2\,\mathrm{K}$. Depending on the polarization configuration of two beams, different light induced gratings can be generated. For colinearly polarized beams, a population grating is induced while for crossed-linearly polarized beams a spin grating is formed. While a magnetic field of up to 0.7 T applied in Voigt geometry does not alter the population grating, the spin grating's FWM signal is modulated at the Larmor frequency.

HL 50: III-V Semiconductors II (mainly Arsenides)

Time: Wednesday 9:30–10:45 Location: EW 203

HL 50.1 Wed 9:30 EW 203

Free-standing rolled-up metal oxide field-effect-transistor — •Daniel Grimm[1], Carlos C. B. Bufon[1], Dominic J. Thurmer[1], Christoph Deneke[1,2], Franziska Schäffel[1], Paola Atkinson[1,3], and Oliver G. Schmidt[1] — [1]IFW Dresden, Germany — [2]LNLS, Campinas, Brazil — [3]Institut des nanosciences de Paris, France

In this work we demonstrate for the first time a three-dimensional free-standing metal oxide field-effect-transistor based on strained hybrid nanomembranes. The fabrication process combines conventional device patterning with selective etching to form the three-dimensional rolled-up transistor (RUFET).

Firstly, Ohmic contacts, gate electrodes and Al_2O_3 dielectrics are defined on the surface of single-crystalline semiconducting multilayers grown on top of a sacrificial layer. Upon selective etching of the sacrificial layer, the complete planar transistor curls up so that the nanomembrane based channel bonds back onto the gate electrode resulting in a rolled-up double-gate device. This rolled-up technique yields a substantial reduction of the free-standing device footprint, decreasing further the body effect.

The employed GaAs layers show a variety of surface states, which pin the Fermi-level forming rather deep depletion regions. By Poisson's equation calculations we engineer the thickness and doping level close to the complete depletion regime. The RUFET is then driven in the depletion mode regime and showed typical transfer characteristics as well as gate-voltage swings around 200 mV/decade with on-off ratios of several orders of magnitudes.

HL 50.2 Wed 9:45 EW 203

Generation and detection of picosecond transverse phonon pulses in high-index GaAs — •Jasmin Jäger[1], Michael Bombeck[1], Alexey Salasyuk[1,2], Alexey Scherbakov[2], Andrey Akimov[3], Dmitri Yakovlev[1,2], and Manfred Bayer[1] — [1]Experimentelle Physik II, TU Dortmund, Germany — [2]Ioffe Physical Technical Institute of the Russian Academy of Sciences, St. Petersburg, Russia — [3]School of Physics and Astronomy, University Nottingham, United Kingdom

The aim of this work is the first direct observation of a picosecond coherent pulse of transverse phonons travelling a macroscopic distance through high-index GaAs. In the experiment the pump pulse of an amplified Ti:Sa-laser (800nm, 150fs duration, pulse energy up to 150μJ) excites a 100nm Al-film deposited on the back side of the GaAs slab grown along (311)-direction. The film serves as an optoelastic transducer, which expands due to the ultrafast optical heating and injects a picosecond strain pulse into the sample. The pulse travels through the 100μm tick slab and is detected at the front surface by the modulation of the linearly polarized probe pulse. The difference in the sound velocities for LA and TA acoustic phonons allows separating them in the time-resolved signal. Together with the modulation of the probe pulse intensity due to the well-known elasto-optical effect, we also detect the rotation of the probe polarization plane. The latter is due to the strain-induced linear dichroism and depends on the phonon polarization and relative orientation of the probe beam polarization plane and crystallographic directions of the slab.

HL 50.3 Wed 10:00 EW 203

Millisecond flash lamp annealed GaAs: a promising light emitter material at 1.3 μm — •Kun Gao[1], Slawomir Prucnal[1], Zenan Jiang[1], Wolfgang Skorupa[1], Manfred Helm[1], Oksana Yastrubchak[2], Lukasz Gluba[2], and Shengqiang Zhou[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), P.O. Box 510119, 01314 Dresden, Germany — [2]Maria Curie-Sklodowska University, Pl. M. Curie-Sklodowskiej 1, 20-035 Lublin, Poland

Gallium arsenide based materials have outstanding performances in light-emitting devices and are being widely used in optical communication devices in virtue of their remarkable efficiency and thermal stability.

We present a novel method to achieve the 1.3 μm light emitting by defect-induced luminescent centers. Mn-implanted and N-implanted GaAs as well as un-doped GaAs wafers were treated by millisecond flash lamp annealing techniques. The optical properties of the samples were investigated. Results have shown the successful incorporation of Mn and N into GaAs lattice. For the intrinsic and the N-incorporated GaAs, a strong luminescence peak occurs at 1.3 μm. On the other hand, Mn-doping has suppressed this luminescence. It is still noticeable that the 1.3 μm light emitting only have a slight redshift (about 20 nm) and 58% intensity decline as the temperature rises from 20 K to room temperature. Our investigation suggests that after flash lamp annealing GaAs based materials exhibit a promising prospect on applications of light emitters and detectors for optical communication devices.

HL 50.4 Wed 10:15 EW 203

Zeeman splitting and diamagnetic shift of spatially confined quantum-well exciton polaritons in an external magnetic field — •Arash Rahimi-Iman[1], Christian Schneider[1], Julian Fischer[1], Steffen Holzinger[1], Matthias Amthor[1], Lukas Worschech[1], Alfred Forchel[1], Stephan Reitzenstein[1,2], Sven Höfling[1], and Martin Kamp[1] — [1]Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Present address: Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany

We report on pronounced magneto-optical effects of spatially confined polariton modes in an InGaAs quantum well microcavity. The polaritons were trapped by a lithographically modulated cavity length. In contrast to etched structures suffering from nonradiative recombination, this approach allows for a gentle modification of the dielectric properties and results in a confinement potential of 7.5 meV. In the presence of an external magnetic field, a diamagnetic shift and Zeeman splitting of the quantized modes were observed for different trap diameters, ranging from 1 to 10 μm. This confirms that the polaritonic properties of the emission modes are preserved even for small traps. Moreover, a clear correlation between the magnetic response and the excitonic fraction of the polaritons was identified by magnetic field-dependent measurements which could be confirmed by a simple Hopfield coefficient model. For 10-μm trap modes, such magneto-optical effects were obtained over a broad range of k-vectors and angular mode numbers, providing evidence of strong coupling for all detected modes.

HL 50.5 Wed 10:30 EW 203

Detection of THz Signals with a GaAs Field Effect Transistor — •Sascha Preu[1], Sangwoo Kim[2], Peter G. Burke[3], Hong Lu[3], Mark S. Sherwin[4], and Arthur C. Gossard[3] — [1]Lehrstuhl für angewandte Physik, Univ. Erlangen, Germany — [2]Tanner Research, Monrovia, CA, USA — [3]Materials Department, University of California, Santa Barbara, CA, USA — [4]Physics. Dept, Institute for THz Science and Technology, University of California, Santa Barbara, CA, USA

We report on direct detection and homodyne mixing operation of a field effect transistor (FET) far above frequencies where the transistor has gain. The FET consists of a remotely doped AlGaAs-GaAs channel with a two dimensional electron gas. For direct detection, the THz power is coupled to the device via a broadband logarithmic-periodic antenna with a frequency range of about one order of magnitude (50 GHz-500 GHz). The FET rectifies the THz signal along the gated region, providing a DC signal proportional to the total incident THz power. Despite a large impedance mismatch, we achieved a direct detection noise equivalent power (NEP) of 20 nW/$\sqrt{Hz}$ at room temperature at 230 GHz. Further optimization and impedance matching suggests a theoretical detection limit below 1 pW/$\sqrt{Hz}$. We also investigated a FET under mixing operation with narrowband antennas, resulting in an NEP of 960 pW/Hz at 370 GHz.

HL 51: Topological Insulators II (jointly with MA, DS, O, TT)

Time: Wednesday 9:30–13:00 Location: EB 301

HL 51.1 Wed 9:30 EB 301

Topologically-related properties in presence of disorder. First-principle study — •Stanislav Chadov — Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden

The presence of disorder is often seen as a destructive mechanism which must be reduced by any means. In present study we attempt to make it constructive due to the robustness of the spin current in topological insulators with respect to the time-reversal symmetric perturbations. Based on the first-principle calculations involving the Coherent Potential Approximation (CPA), we inspect the disorder-affected transport properties of the random alloys between topologically non-trivial and trivial materials. The subsequent analysis encounters few interesting aspects: the way how to increase the Hall angle by using random disorder and an indication for the topological Anderson insulator. In addition CPA provides an alternative recipe to validate the non-trivial topological state of the material based on a purely bulk information.

HL 51.2 Wed 9:45 EB 301

Probing the topological states of Sb_2Te_3 by spin polarized photoemission spectroscopy — •Christian Pauly[1], Gustav Bihlmayer[2], Marcus Liebmann[1], Dinesh Subramaniam[1], Martin Grob[1], Alexander Georgi[1], Markus Scholz[3], Jaime Sanchez Barriga[3], Stefan Blügel[2], Oliver Rader[3], and Markus Morgenstern[1] — [1]II. Physikalisches Institut B, RWTH Aachen University and JARA-FIT, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA-FIT, Germany — [3]Helmholtz-Zentrum für Materialien und Energie, Berlin, Germany

Using high resolution spin- and angle-resolved photoemission spectroscopy, we map the electronic structure and spin texture of the surface states of the topological insulator Sb_2Te_3. Similar to the well explored Bi_2Te_3 and Bi_2Se_3 which possess TI properties with the most simple electronic structure [1], we directly show that Sb_2Te_3 exhibits Z_2 topological properties with a single spin-Dirac cone at the Γ-point. In addition, a strongly spin-orbit split surface state is observed at lower energy. In Γ-K direction, the band is located within a spin-orbit gap, governing the energy position of the state. In combination with DFT calculation, we provide direct evidence for an argument given by Pendry [2], that there must be at least one surface state inside a SO gap, if the gap is located in the zone. Thus, similar to the topological state, this state is protected by symmetry. [1] H. Zhang et al., Nature Phys. 5, 438 (2009) [2] J. B. Pendry et al., Surf. Sci. 49, 87 (1975)

HL 51.3 Wed 10:00 EB 301

Electronic properties and magnetic anisotropy of individual Co adatoms adsorbed on topological insulator surfaces — •T. Eelbo[1], M. Sikora[2], M. Waśniowska[1], M. Dobrzański[2], M. Gyamfi[1], G. Bihlmayer[3], I. Miotkowski[4], A. Kozlowski[2], and R. Wiesendanger[1] — [1]Institute of Applied Physics, University of Hamburg, Jungiusstr. 11, Hamburg, Germany — [2]Department of Solid State Physics, AGH University of Science and Technology, Aleja Mickiewicza 30, Kraków, Poland — [3]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [4]Department of Physics, Purdue University, West Lafayette, USA

The interaction of magnetic impurities adsorbed on topological insulator surfaces causes changes of the electronic properties of the surfaces or the adatoms themselves. In addition the adatoms can present different magnetic properties due to interaction with the host. For this reason we studied the electronic properties and magnetic anisotropy of individual Co atoms adsorbed on Bi_2Se_3 by means of scanning tunneling microscopy/spectroscopy (STM/STS) and x-ray magnetic circular dichroism (XMCD) at low temperatures. After the deposition onto the cold surface STM measurements reveal two different adsorption sites for Co adatoms. Two resonances in the occupied states for both species of adatoms are found using STS. Moreover, XMCD measurements reveal a magnetic anisotropy with the easy axis being aligned out-of-plane. The experimental findings are compared to results of ab-initio calculations.

HL 51.4 Wed 10:15 EB 301

Theoretical study on the reactive chemical doping of the Bi_2Se_3 surface — •Janos Kiss[1,2], Stanislav Chadov[1,2], and Claudia Felser[1,2] — [1]Institute of Inorganic Chemistry and Analytical Chemistry, Johannes Gutenberg University, Mainz — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

Recent experimental results have shown that the surface of Bi_2Se_3 exposed to air will become *n*-type doped. Furthermore, the surface gradually undergoes an oxidation reaction leading to a degradation of the surface transport properties, where the contribution of the topological surface states are consequently decreasing. This is expected to be caused by Se vacancies. However, the formation mechanism of this vacancies and the interaction of moisture -i.e. water- with Bi_2Se_3 is still not clarified. Therefore, we will present the results of our large scale ab-initio calculations and molecular dynamics simulations in order to investigate the effect of Se vacancies and the reactivity of water upon the electronic and atomic structure of the surface.

HL 51.5 Wed 10:30 EB 301

Heusler topological insulators: Electronic structure and transport properties — •C. Shekhar[1], S. Ouardi[2], G. H. Fecher[1,2], A. K. Nayak[1], A. Gloskovskii[2], E. Ikenaga[3], S. Ueda[4], K. Kobayashi[4], and C. Felser[1,2] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden — [2]Institute of Inorganic Chemistry and Analytical Chemistry, Johannes Gutenberg - University, Mainz — [3]Japan Synchrotron Radiation Research Institute, SPring-8, Hyogo, Japan — [4]National Institute for Materials Science, SPring-8, Hyogo, Japan

Topological insulators have a high potential for spintronics devices and quantum computation. Various Heusler compounds crystallize in a fcc structure of the $C1_b$ type and consist of 2 transition metals and a main group element. If the compounds contain heavy metals and a lanthanide element then they exhibit extraordinary physical properties including superconductivity, half-metallic, semiconducting-like behavior, giant magnetoresistivity, heavy fermion state and zero band gap. The density of states of XMZ Heusler compounds (M = Gd, Lu, X= Au, Pt, Pd and Z= Pb, Sb, Bi) were investigated by hard X-ray photoelectron spectroscopy. The comparison of the experimental results to calculations gives evidence for the zero band gap state of the compounds. Further, the temperature dependence of electrical conductivity, magneto resistance, Hall mobility, Seebeck coefficient and thermal conductivity were investigated. The compounds exhibit a high Hall mobility and a linear magnetoresistance (MR). The observed linear MR is a quantum MR and due to the topological insulator state.

HL 51.6 Wed 10:45 EB 301

Topological phase transitions in Bi(111) bilayer by breaking

time-reversal symmetry — •Hongbin Zhang, Frank Freimuth, Gustav Bihlmayer, Stefan Blügel, and Yuriy Mokrousov — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Time-reversal breaking brings forth many novel phenomena in topological insulators [1]. In this work, using the first principles FLAPW method combined with the Wannier functions technique [2], we investigated topological phase transitions with respect to exchange fields of a two-dimensional topological insulator – Bi(111) bilayer [3]. Numerical evaluation of the spin Chern number [4] for different magnitudes of exchange fields reveals that when the time reversal symmetry is broken by a small exchange field, the system keeps the properties of a topological insulator. After a metallic phase in the intermediate region, the quantum anomalous Hall phase with the non-zero Chern number occurs at sufficiently large enough exchange fields. We analyzed the relation between the spin Chern number, the Z_2 number and the Chern number, and also the phase diagram from the viewpoint of the evolution of the electronic structure, edge states and transport properties in this system. We acknowledge funding under HGF-YIG Programme VH-NG-513.

[1] X. Qi, *et al.*, Phys. Rev. B. **78**, 195424 (2008).
[2] www.flapw.de; F. Freimuth, *et al.*, Phys. Rev. B. **78**, 035120 (2008).
[3] M. Wada, *et al.*, Phys. Rev. B **83**, 121310(R) (2011).
[4] E. Prodan, *et al.*, Phys. Rev. B **80**, 125327 (2009).

HL 51.7 Wed 11:00 EB 301

Predicting surface states from the bulk embedding self-energy — •Daniel Wortmann, Gustav Bihlmayer, and Stefan Blügel — Institute for Advanced Simulation & Peter Grünberg Institut, Forschungszentrum Jülich und JARA, 52425 Jülich, Germany

The protected states localized at surfaces and interfaces of topological insulators are a consequence of the electronic structure of the bulk. Their peculiar features like the typical spin-structure makes them an interesting field of basic research with possible applications in spintronics.

We demonstrate how these states can be efficiently simulated by means of the embedding self-energy as obtained in the Green function embedding technique[1]. The embedding self-energy, which can be understood as a generalized logarithmic derivative, is a property of the bulk crystal only and contains all information required to analyze the consequences of the bulk topology on the surface bandstructure. Using the FLAPW implementation of the embedding method as provided in the FLEUR-code[2], we show how the surface states of prototypical topological insulators like Bi_2Se_3 can be studied efficiently with an easy and direct access to effects for example due to electric fields applied to the surface.

[1] D. Wortmann, H. Ishida, S. Blügel. Phys. Rev. B **66**, 075113(02)
[2] http://www.flapw.de

15 min. break

HL 51.8 Wed 11:30 EB 301

Influence of magnetic impurities on doping and scattering properties of topological surface states: Fe on Bi_2X_3 (X=Te, Se) — •Markus R. Scholz[1], J. Sánchez-Barriga[1], D. Marchenko[1], A. Varykhalov[1], E. Rienks[1], A. Volykhov[2], L. V. Yashina[2], and O. Rader[1] — [1]Helmholtz-Zentrum Berlin — [2]Moscow State University

We study the effect of Fe impurities deposited on the surface of the topological insulators Bi_2Se_3 and Bi_2Te_3 by means of photoelectron spectroscopy. The topological surface state reveals surface electron doping when the Fe is deposited at room temperature and hole doping when deposited at low temperture ($\sim$ 10 K). We show that in both cases the topological surface state remains intact and gapless. We analyze the line broadening for pure Bi_2X_3 (X=Se, Te) and after deposition of Fe. We observe that the constant broadening in the bulk band gap range increases by a factor of 2 upon deposition of Fe. Because we deposit the Fe without electron doping, this result is not due to a gain in warping as was recently suggested. We discuss the results based on different types of scattering mechanisms.

HL 51.9 Wed 11:45 EB 301

Origin of the strong circular dichroism of the topological surface state of Bi_2Te_3 — •Jaime Sánchez-Barriga[1], M. R. Scholz[1], D. Marchenko[1], A. Varykhalov[1], O. Rader[1], A. Volykhov[2], L. V. Yashina[2], J. Braun[3], J. Minár[3], and H. Ebert[3] — [1]Helmholtz-Zentrum Berlin — [2]Moscow State University — [3]Ludwig-Maximilians-Universität München

We have recently reported a strong circular dichroism effect in angle-resolved photoemission of the spin polarized topological surface state of Bi_2Te_3 [1]. The effect has been observed recently also for Bi_2Se_3 and the origin is controversial [2-4]. An initial-state model has been employed to determine the spin orientation directly [3]. We present a series of photoemission measurements and density functional calculations coupled to one-step photoemission theory. Both experiment and theory reveal that the dichroism effect changes sign as a function of photon energy which excludes the initial-state model.

[1] M. R. Scholz, J. Sánchez-Barriga, D. Marchenko, A. Varykhalov, A. Volykhov, L. V. Yashina, O. Rader, submitted to Phys. Rev. Lett. (2010), arXiv:1108.1053
[2] S. R. Park et al., arXiv:1103.0805
[3] Y. H. Wang, D. Hsieh, D. Pilon, L. Fu, D. R. Gardner,Y. S. Lee, N. Gedik, arXiv:1101.5636
[4] Y. Ishida et al., Phys. Rev. Lett. 107, 077601 (2011)

HL 51.10 Wed 12:00 EB 301

Prediction of topological insulators in TlBiSe2 family of chalcogenides — •binghai yan — BCCMS, University of Bremen, Bremen

In this work, we predicted several new topological insulator materials in thallium (Tl) based ternary chalcogenides from first-principles calculations, including TlBiQ2 and TlSbQ2 (Q=Te, Se and S). TlBiSe2 and TlSbSe2 are found to be strong TIs with a large energy gap (~ 0.2 eV), while TlBiTe2 is a topological semimetal. A simple Dirac-type dispersion of topological surface states is observed, similar to the Bi2Se3 type of materials. On the other hand, TlBiS2, TlSbTe2 and TlSbS2 are small gap insulators near the topological trivial-nontrivial transition boundary. Particularly TlBiTe2 can be a good candidate in the seeking of Majorana fermions for its co-existing superconductivity property. The topological feature of TlBiSe2 and TlBiTe2 has already been confirmed by recent experiments. References: 1. B.H. Yan, C.X. Liu, H.J. Zhang, C.Y. Yam, X.L. Qi, Th. Frauenheim and S.C. Zhang, Europhys. Lett. 90, 37002 (2010). 2. Y. L. Chen, Z. K. Liu, J. G. Analytis, J.-H. Chu, H. J. Zhang, B. H. Yan, S.-K. Mo, R. G. Moore, D. H. Lu, I. R. Fisher, S. C. Zhang, Z. Hussain, and Z.-X. Shen, Phys. Rev. Lett. 105, 266401(2011).

HL 51.11 Wed 12:15 EB 301

A recipe for new Topological Insulators based on bonds, bands, symmetry andheavy atoms — •L. Müchler[1], B. Yan[2,3], S. Chadov[1,4], F. Casper[1], S-C. Zhang[2], and C. Felser[1,4] — [1]Institute of Inorganic Chemistry and Analytical Chemistry, Johannes Gutenberg - University, Mainz — [2]Department of Physics, McCullough Building,Stanford University,Stanford, CA 94305-4045, USA — [3]Bremen Center for Computational Materials Science, Universität Bremen, Am Fallturm 1, 28359 Bremen, Germany — [4]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany.

In this work we will present a recipe to find new Topological Insulators (TIs) based on bonds, bands, symmetry and heavy atoms. A big issue concerning the compounds known up to now is the control of the bulk carrier density to produce truly insulating samples in the bulk. Using concepts from chemistry and supported by density-functional calculations, we want to motivate an extended search for new compounds with tunable bulk properties.

HL 51.12 Wed 12:30 EB 301

Graphene nanoribbons with Au induced spin-orbit effects: a DFT study — •Gustav Bihlmayer and Stefan Blügel — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Historically, the prediction of a topological protection of the edge state of a zig-zag graphene nanoribbon (ZGNR) was at the beginning of the field of topological insulators. Unfortunately, a realization of this system is prevented by (i) the extremely small spin-orbit coupling (SOC) in graphene and (ii) the tendency towards formation of antiferromagnetically coupled edge states in ZGNRs.

New experimental and theoretical results show that SOC effects can be enhanced by substrates and/or adatoms with a large atomic number, so that up to 100 meV spin-splitting can be realized in the graphene. Additionally, hybridization with the substrate changes also the localization of the edge state and its tendency towards antiferro-

magnetic ordering. Density functional theory calculations of Au supported graphene (with and without adatoms) and ZGNRs will illustrate these effects and point the way towards a realization of a ZNGR with a topologically protected edge state.

HL 51.13 Wed 12:45 EB 301

Collision dominated scattering in 3D topological insulators — •Peter Lemmens[1], Vladimir Gnezdilov[2], Dirk Wulferding[1], Yurii Pashkevich[3], Ekaterina Pomjakushina[4], Kazimierz Conder[4], and Helmuth Berger[5] — [1]IPKM, TU-BS, Braunschweig, Germany — [2]ILTPE NAS, Ukraine — [3]DonFTI, Donetsk, Ukraine — [4]PSI, Villigen, Switzerland — [5]EPFL, Lausanne, Switzerland

Despite topological protection in 3D topological insulators there exist scattering processes induced by a resonant excitation from a bulk valence band to Dirac states. This signal in Raman scattering has a Lorentzian lineshape and spin-helical symmetry with a scattering rate of 40 cm^{-1}. A comparison of different compounds (Bi_2Se_3, Bi_2Te_3), substitution experiments as well as first results on BiTeI with giant Rashba spin splitting are presented. Work supported by DFG and NTH.

HL 52: Organic Electronics and Photovoltaics: Electronic Properties I (jointly with DS, CPP, O)

Time: Wednesday 9:30–11:15 Location: H 2032

HL 52.1 Wed 9:30 H 2032

Design of novel dielectric surface modifications for perylene thin-film transistors — •Christian Effertz[1], Ingolf Segger[1], Philip Schulz[1], Arno Classen[2], Carsten Bolm[2], and Matthias Wuttig[1,3] — [1]I. Physikalisches Institut (IA), RWTH Aachen, 52056 Aachen — [2]Institut für Organische Chemie (IOC), RWTH Aachen, 52056 Aachen — [3]JARA FIT, Forschungszentrum Jülich, 52425 Jülich

Dielectric surface modifications (DSMs) can improve the performance of organic thin-film transistors (OTFTs) significantly. To gain a deeper understanding of this performance enhancement and to facilitate high mobility transistors, perylene based OTFTs utilizing novel dielectric surface modifications have been produced. Novel DSMs, which are based on derivates of tridecyltrichlorosilane (TTS) with different functional end-groups have been applied to tailor the adhesion energy of perylene. The resulting samples were characterized by electronic transport measurements, scanning probe microscopy and x-ray diffraction (XRD). Measurements of the surface free energy of the modified dielectric enabled the calculation of the adhesion energy of perylene upon these novel DSMs by the equation-of-state approach. These calculations demonstrate the successful tailoring of the adhesion energy. The insight gained in this study was used to carefully choose further novel DSMs based on polymers. Utilizing these novel DSMs, perylene thin-films and TFTs with a superior film quality, in terms of crystallinity and morphology, as well as performance, in terms of mobility, have been produced[1]. [1]: Effertz, C., et. al. (2011), Adv. Func. Mater. doi: 10.1002/adfm.201101299

HL 52.2 Wed 9:45 H 2032

Intermolecular hybridization governs molecular electrical doping — •Ingo Salzmann[1], Georg Heimel[1], Steffen Duhm[2], Martin Oehzelt[3], Patrick Pingel[4], Benjamin George[3], Alexander Schnegg[3], Klaus Lips[3], Ralf-Peter Blum[1], Antje Vollmer[3], and Norbert Koch[1,3] — [1]Humboldt Universität zu Berlin, Germany — [2]Chiba University, Japan — [3]Helmholtz Zentrum Berlin, Germany — [4]Universität Potsdam, Germany

Strong molecular acceptors in organic semiconductor (OSC) films are typically used for molecular electrical p-type doping assuming electron transfer from OSC to dopant. Positive polarons in the fundamental OSC gap are thus expected and could be observable in ultraviolet photoelectron spectroscopy (UPS) as emission feature at, or close to the Fermi Energy (E_F) with *reduced* ionization energy (IE), which, however, has not been observed to date. We present a study on the prototypical OSC/p-dopant pair pentacene (PEN) and tetrafluorotetracyano-quinodimethane (F4-TCNQ) up to 1:1 ratio [1]. The IE of 1:1 mixed (amorphous) films is *increased* and larger than possible for pure PEN, while all states occur well below E_F in UPS. We suggest OSC/dopant frontier molecular orbital hybridization forming a doubly occupied bonding and an empty anti-bonding supramolecular hybrid orbital with reduced fundamental gap, which is in fact found by optical absorption measurements and corroborated by density-functional theory (DFT) calculations. Based on similar results for various OSCs, common doping-related observations are discussed within this framework. [1] I. Salzmann, G. Heimel et al., *Phys. Rev. Lett.*, in press.

HL 52.3 Wed 10:00 H 2032

Effect of molecular p-doping on hole density and mobility in P3HT and MEH-PPV — •Patrick Pingel and Dieter Neher — Institute of Physics and Astronomy, University of Potsdam, D-14476 Potsdam

Molecularly doped semiconducting polymers can exhibit exceptionally high electrical conductivity, making them suitable for use in solution-processed organic circuitry. Recently, p-doping of conjugated polymers with the strong molecular acceptor tetrafluorotetracyanoquinodimethane, F_4TCNQ, has been introduced.

Here, we present a detailed study of the doping efficiency and carrier mobility in thin layers of poly(3-hexylthiophene), P3HT, and poly(2-methoxy-5-(2'-ethylhexyloxy)-p-phenylene vinylene), MEH-PPV, doped with F_4TCNQ over a wide range of concentrations. Investigation of these layers with impedance spectroscopy in a metal-insulator-semiconductor (MIS) geometry allowed us to determine both charge carrier density and mobility as a function of doping ratio.

We show that the density of mobile holes increases strictly linearly with increasing F_4TCNQ concentration, but the mobilities in P3HT and MEH-PPV exhibit non-monotonic dependencies on doping concentration. This behavior can be fully explained by a model originally developed by Arkhipov et al. [Phys. Rev. B **72**, 235202 (2005)], which predicts that the Coulomb potential of a doping-induced negative counterion acts as a trapping center for holes. Thus, energetical disorder in the polymer layer is effectively increased upon chemical doping.

HL 52.4 Wed 10:15 H 2032

Investigation of the degradation processes in small molecule solar cells using impedance spectroscopy — •André Döring, Lorenzo Burtone, Martin Hermenau, Karl Leo, and Moritz Riede — Institut für Angewandte Photophysik, Technische Universität Dresden, 01062 Dresden, Germany

The purpose of this work is to correlate the impedance spectra (IS) of different solar cell structures - composed of small molecules - with the degradation processes that take place under different aging conditions.

The materials chosen for the optically active bulk-heterojunction layer are ZnPc as donor and C_{60} as acceptor, often used in small-molecule solar cells. In addition to the bulk-heterojunction, doped electron and hole transport layers forming a p-i-n structure are used. Concomitant with the measurement of the IS, the characteristic parameters of the device (i.e. j_{SC}, V_{OC}, FF, PCE, EQE) are monitored during the degradation and correlated to the changes in the IS.

Analyzing the IS gives the possibility to identify different electrical processes that take place in the device. At the beginning of the aging process, we observe an initial improvement of the solar cell parameters, in conjunction with a decreasing trap response in the IS spectra. To investigate in more details the role of trap states for the solar cell performance, simplified structures are prepared. We identify in this way the trap location, type and density inside the solar cell structure. The devices are also exposed to controlled atmospheric conditions to investigate whether oxygen or water vapor is more responsible for the observed change in the electrical properties of the solar cell.

HL 52.5 Wed 10:30 H 2032

IR spectroscopic investigation of the MoO_3 doping efficiency in CBP — •Tobias Glaser[1,4], Sven Tengeler[1,4], Sebastian Beck[1,4], Daniela Donhauser[2,4], Bernd Lunkenheimer[3,4], Andreas Köhn[3,4], and Annemarie Pucci[1,4] — [1]Universität Heidel-

berg, Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg — [2]Technische Universität Braunschweig, Institut für Hochfrequenztechnik, Schleinitzstraße 22, 38106 Braunschweig — [3]Universität Mainz, Institut für Physikalische Chemie, Jakob-Welder-Weg 11, 55128 Mainz — [4]InnovationLab GmbH, Speyerer Str. 4, 69115 Heidelberg

A major challenge towards high-efficiency and low-voltage organic electronic devices such as OLEDs is to overcome the low bulk conductivity of the organic films. P-type doping with transition-metal oxides like tungsten oxide and molybdenum oxide has proven to increase the charge carrier concentration in hole transporting materials. But the doping efficiency of only a few percent is rather low and the reason for the low efficiency is not fully understood yet. We investigated doping of the ambipolar charge transport material 4,4'-Bis(N-carbazolyl)-1,1'-biphenyl (CBP) with MoO_3 using FTIR-spectroscopy in ultrahigh-vacuum. Comparison of the measured spectra of films with different MoO_3-concentration to DFT-calculations reveals the amount of charge transfer from CBP to MoO_3 but also shows that most of the CBP molecules are still in the neutral state. Also the impact of substrate temperature during the evaporation process is investigated.

Financial support by BMBF (project MESOMERIE) is gratefully acknowledged.

HL 52.6 Wed 10:45 H 2032

Agglomeration of MoO_3 doped into organic thin films studied by TEM-spectroscopy and Tomography — •Daniela Donhauser[1,2], Katrin Schultheiss[1,2], Levin Dieterle[1,2], Martin Pfannmöller[3], Rasmus R. Schröder[3], Tobias Glaser[4,2], Bernd Lunkenheimer[5,2], Michael Kröger[1,2], and Wolfgang Kowalsky[1,2] — [1]Institut für Hochfrequenztechnik, Technische Universität Braunschweig — [2]InnovationLab GmbH, Heidelberg — [3]CellNetworks, Universität Heidelberg — [4]Kirchhoff-Institut für Physik, Universität Heidelberg — [5]Institut für Physikalische Chemie, Johannes Gutenberg-Universität Mainz

Electrochemical doping is essential to overcome limitations in organic devices imposed by low intrinsic conductivity and high injection barriers at the contacts. Materials with very deep lying HOMO-levels like CBP (4,4'-Bis(N-carbazolyl)-1,1'-biphenyl) can be doped with transition metal oxides, e.g. MoO_3. In such systems a very low doping efficiency has been found for which the physical origin is not understood. With TEM spectroscopy we could show that agglomeration of MoO_3 in the CBP-matrix is most likely the reason for the low doping efficiency. Using TEM tomography we observed that MoO_3 forms filament-like structures perpendicular to the substrate. Combining our results with FTIR-measurements, which indicate a charge carrier localization at single molecules, we can model the charge transport to occur at the interface of the MoO_3 filaments and the organic matrix.

HL 52.7 Wed 11:00 H 2032

Depth Profiling of Organic Electronic Materials by Gas Cluster Ion Beam — •Andrey Lyapin — Physical Electronics GmbH, Fraunhoferstr. 4, D-85737, Ismaning, Germany

The development of new electronic devices incorporating organic materials, such as Organic Light Diodes (OLED) and Organic Photovoltaics (OPV) is rapidly increasing. To control quality, performance and lifetime of these devices, it is necessary to characterize the layered structures and the dopant distributions in the thin organic materials. Conventional surface analysis techniques such as XPS and ToF-SIMS, combined with mono-atomic ion beam sputtering, have been widely used for chemical depth profiling of inorganic thin films. However, this approach has not been successful for the depth profiling of organic materials due to the loss of chemical information during the sputtering process. Recent cluster ion beam developments utilizing C_{60}^+ ions have also had limited success for the depth profiling of OLED and OPV structures due to similar modification of chemical and molecular information as a function of sputter depth. The use of surface-sensitive techniques will be discussed for chemical and molecular characterization of OLED and OPV materials in combination with newly developed Gas Cluster Ion Beam (GCIB) source to achieve non-destructive chemical/molecular characterization beyond the surface and through the device. The GCIB source with an average of 2500 Ar atoms per single charged ion has shown dramatic results that both simplify and improve upon the analysis of OLED and OPV materials with a C_{60}^+ cluster ion beam.

HL 53: Transport: Topological Insulators 3 (jointly with TT, MA)

Time: Wednesday 9:30–13:00 Location: BH 334

HL 53.1 Wed 9:30 BH 334

Spin-dependent thermoelectric transport in topological insulators — •Dietrich G. Rothe, Marine Guigou, Björn Trauzettel, and Ewelina M. Hankiewicz — Institut für Theoretische Phys. und Astrophys. Würzburg

We analyze spin-dependent thermoelectric transport of topological insulators based on (Hg,Cd)Te quantum wells using the non-equilibrium Green's function technique within the Bernevig-Hughes-Zhang model. The motivation for our work is to generate spin currents in a medium with strong spin orbit coupling by a gradient of temperature in the absence of magnetic fields. Furthermore, we would like to better understand to what extend the thermoelectric coefficients probe spectral properties of such devices.

We investigate specifically the spin Nernst effect, a transverse spin current induced by a longitudinal temperature gradient, in a four-terminal setup. Interestingly, we predict a peak in the spin Nernst signal when the device is operated in the topologically non-trivial regime. This peak is directly related to the minigap formed by overlapping edge states from opposite boundaries of our device. Hence, the spin Nernst effect is a powerful experimental tool to analyze the size and the structure of the minigap. Additionally, we see that the spin Nernst effect is rather sensitive to details of the band structure. We discuss how this effect can be used to distinguish the topologically trivial from the non-trivial regime and why the energy dependence of transport is markedly resolved in the experimental signatures of the spin Nernst signal.

HL 53.2 Wed 9:45 BH 334

Topological insulators in magnetic fields: Quantum Hall effect and edge channels with non-quantized θ-term — •Matthias Sitte[1], Achim Rosch[1], Ehud Altman[2], and Lars Fritz[1] — [1]Institute for Theoretical Physics, University of Cologne, Cologne, Germany — [2]Department of Condensed Matter Physics, The Weizmann Institute of Science, 76100 Rehovot, Israel

We investigate how a magnetic field induces one-dimensional edge channels when the two-dimensional surface states of three-dimensional topological insulators become gapped. The Hall effect, measured by contacting those channels, remains quantized even in situations, where the θ-term in the bulk and the associated surface Hall conductivities, σ_{xy}, are not quantized due to the breaking of time-reversal symmetry. The quantization arises as the θ-term changes by $\pm 2\pi n$ along a loop around n edge channels. Model calculations show how an interplay of orbital and Zeeman effects leads to quantum Hall transitions, where channels get redistributed along the edges of the crystal. The network of edges opens new possibilities to investigate the coupling of edge channels.

[1] M. Sitte, A. Rosch, E. Altman, and L. Fritz, arXiv:1110.1363

HL 53.3 Wed 10:00 BH 334

Fractional quantum Hall states in lattice models and their potential realization due to multiple orbitals — •Stefanos Kourtis, Jörn Venderbos, Jeroen van den Brink, and Maria Daghofer — Institute for Theoretical Solid State Physics, IFW Dresden, 01171 Dresden, Germany

It has been recently demonstrated that topologically non-trivial lattice models of interacting particles can lead to a fractional quantum Hall effect without a magnetic field as long as the band width is very narrow. This has triggered a search for possible realizations of such models in optical lattices or materials. One promising observation is that electronic orbital degrees of freedom can lead to the nearly flat bands needed for a fractional-quantum Hall ground state [1]. We map the topologically non-trivial band of such a multi-orbital system onto an effective lattice model [2]. We use exact diagonalization to obtain the ground state of the effective model taking into account Coulomb interactions and investigate its topological properties. In particular, we calculate the eigenvalue spectra, ground states and Chern numbers for a variety of filling fractions and obtain clear indications of a hier-

archy of fractionally charged excitations.
[1] J. W. F. Venderbos, M. Daghofer and J. van den Brink, Phys. Rev. Lett. 107, 116401 (2011).
[2] Jörn W.F. Venderbos, Stefanos Kourtis, Jeroen van den Brink and Maria Daghofer, arXiv:1109.5955 (2011).

HL 53.4 Wed 10:15 BH 334

Quantum transport in nanostructures of Bi_2Se_3-topological insulator — •Joseph Dufouleur[1], Romain Giraud[1], Andreas Teichgräber[1], Silke Hample[1], Stephan Neuhaus[1], Barbara Eichler[2], Oliver G. Schmidt[2], and Bernd Büchner[1] — [1]Institute for Solid State Research - IFW Leibniz Institute, Helmholtzstr. 20, D-01069 Dresden, Germany — [2]Institute for Integrative Nanosciences - IFW Leibniz Institute, Helmholtzstr. 20, D-01069 Dresden, Germany

Three-dimensional topological insulators belong to a new class of semiconductors with a large spin-orbit coupling which have spin-polarized Dirac fermions at their surface. In theory, these materials are insulating in the bulk, so that charge transport is only due to electronic surface states. In pratice, the Fermi energy often stands above or below the bulk band gap, due to uncontrolled defects formed during the growth of single crystals, or of epitaxial thin films or nanostructures. This makes the electrical properties of topologically-protected surface states difficult to measure, unless ultra-thin flakes of these materials are prepared.

To overcome this difficulty, we performed quantum transport measurement in ultra-thin Bi_2Se_3 flakes grown by CVD. We used e-beam litography technics to pattern Hall bars in the topological insulator. The measurements were done at low temperature and in an in-plane and perpendicular magnetic field up to 15 T.

HL 53.5 Wed 10:30 BH 334

Interaction and disorder effects in 3D topological insulator thin films — •Elio Koenig[1], Pavel Ostrovsky[2], Ivan Protopopov[2], Igor Gornyi[2], and Alexander Mirlin[1,2] — [1]Institut für Theorie der Kondensierten Materie Karlsruher Institut für Technologie Wolfgang-Gaede-Str. 1 D-76131 Karlsruhe — [2]Institut für Nanotechnologie Hermann-von-Helmholtz-Platz 1 76344 Eggenstein-Leopoldshafen

It has been recently predicted that Coulomb interaction drives a surface of a 3D topological insulator into a critical state. We employ the sigma-model formalism to investigate the effect of electron-electron interaction on the transport by surface states in topological insulator thin films. We take into account the interaction of electrons on different surfaces and also the top-bottom asymmetry of the film (different densities of states and strength of disorder on top/bottom surface). This asymmetry is naturally present in experiments where the electronic densities on the surfaces are controlled independently by means of electrostatic gates. The lack of symmetry between top and bottom surfaces is shown to have strong effect on the film conductivity. The interplay of weak antilocalization, Coulomb interaction within and between surfaces and topological protection leads to a rich flow diagram representing the low temperature behavior of the system. The connection with recent experiments on Bi_2Se_3 films is discussed.

HL 53.6 Wed 10:45 BH 334

Rashba spin-orbit interaction in the superconducting proximity effect in helical Luttinger liquid — •Pauli Virtanen and Patrik Recher — Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany

We consider the superconducting proximity effect in a helical Luttinger liquid at the edge of a 2D topological insulator. In addition to correlations between the left and right moving modes, coupling to a s-wave superconductor can also induce correlations inside a single mode, as the spin axis of the edge modes is not necessarily constant. This can be induced controllably in HgTe/CdTe quantum wells via the Rashba spin-orbit coupling. We discuss the consequent transport signatures, and point out a long-ranged feature in a dc conductance measurement that can be used to distinguish the two types of correlations present.

HL 53.7 Wed 11:00 BH 334

Bloch–Zener Oscillations in Graphene and Topological Insulators — •Viktor Krueckl and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

Conventional free electrons in a superlattice subject to an accelerating drift potential feature a periodic motion known as Bloch oscillations. This physical phenomenon is enriched for topological insulators and graphene, since the electronic structure of those materials close to the Fermi energy is governed by a linear dispersion with a vanishing bandgap between electron and hole states. As a consequence superlattices based on zero-gap semiconductors exhibit characteristic Bloch–Zener oscillations that emerge from the coherent superposition of Bloch oscillations and multiple Zener tunneling between the electron and hole branch [1]. We demonstrate this mechanism by means of wave packet dynamics in various spatially periodically modulated nanoribbons subject to an external bias field. The associated Bloch frequencies exhibit a peculiar periodic bias dependence which we explain within a two-band model. Supported by extensive numerical transport calculations, we show that this effect gives rise to distinct current oscillations observable in the I-V characteristics of graphene and mercury telluride superlattices.
[1] Viktor Krueckl and Klaus Richter, arXiv:1109.5541v1 (2011)

15 min. break.

HL 53.8 Wed 11:30 BH 334

Generalized string order in 1D symmetry protected topological phases — •Frank Pollmann[1], Ari Turner[2], and Erez Berg[3] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [2]University of Amsterdam, 1090 GL Amsterdam, The Netherlands — [3]Department of Physics, Harvard University, Cambridge, MA 02138, USA

A topological phase is a phase of matter which cannot be characterized by a local order parameter. It has been shown that gapped phases in 1D systems can be completely characterized using tools related to projective representations of the symmetry groups. An example of a symmetry protected topological phase is the Haldane phase of S = 1 chains. Here the phase is protected by any of the following symmetries: dihedral group of π-rotations about two orthogonal axes, time-reversal symmetry, or bond centered inversion symmetry. We introduce non-local order parameters as generalization of string order for each case which can be simply calculated using numerical methods such as Density-Matrix Renormalization Group (DMRG). These non-local order parameters provide a practical tool for numerically detecting different phases.

HL 53.9 Wed 11:45 BH 334

Tunable quantum spin Hall effect in double quantum wells — •Paolo Michetti[1], Jan C. Budich[1], Elena G. Novik[2], and Patrik Recher[1,3] — [1]Institute of Theoretical Physics and Astrophysics, University of Würzburg, D-97074 Würzburg, Germany — [2]Physical Institute, University of Würzburg, D-97074 Würzburg, Germany — [3]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany

The field of topological insulators (TIs) is rapidly growing. The quantum spin Hall effect, characterized by a single pair of helical edge modes protected by time-reversal symmetry, has been demonstrated in HgTe-based quantum wells (QWs) with an inverted bandgap. Concerning possible applications, the quest for materials with an easily controllable TI phase is a key issue.

We analyze, employing an extended version of the Bernevig-Hughes-Zhang model, the topological properties of a generically coupled HgTe-based double QW (DQW). In particular we show how in such a system a TI phase can be driven by an inter-layer bias voltage, even when the individual layers are non-inverted. We also provide a numerical estimate of the system parameters, based on k.p calculations, suggesting the experimental feasibility of the present proposal.

Consequently, a DQW composed of non-inverted QWs, which could be in principle made of suitable narrow gap semiconductors different from HgTe, can be driven into a topologically non-trivial phase with the application of a gate bias.

HL 53.10 Wed 12:00 BH 334

Strong Correlations in a Generic Topological Insulator: The Transition-Metal Oxide Na_2IrO_3 — •Manuel Laubach[1], Ronny Thomale[2], Stephan Rachel[3], and Werner Hanke[1] — [1]Theoretical Physics, University of Würzburg, D-97074 Würzburg — [2]Department of Physics, McCullough Building, Stanford University, Stanford, California 94305-4045 — [3]Department of Physics, Yale University, New Haven, CT 06520, USA

A key recent advancement in condensed-matter physics is to study the interplay between nontrivial topology and electronic correlations. In 5d transition-metal oxides, both the spin-orbit interaction and the elec-

tron correlation emerge at comparable orders of magnitude. In these systems, a variety of specifically tailored crystal structures are available, enabling the design of robust topological insulators. In this work, we study theoretically a monolayer of the 5d-compound Na_2IrO_3, modeled by a Hubbard-type of Hamiltonian on a honeycomb lattice where the spin symmetry is not conserved. Based on a variational cluster approach (VCA), the zero temperature phase diagram is obtained. We can identify, through an increase of the Hubbard U, the transition from a quantum spin Hall insulator to either a spin liquid phase or an antiferromagnetic insulating phase, depending on the strength of the spin-orbit coupling. We illustrate the evolution of the quasiparticle spectral function for bulk and edge-states upon variation of system parameters.

HL 53.11 Wed 12:15 BH 334

A quantum dot in a quantum spin Hall edge: Interaction effects — •Carsten Timm — Technische Universität Dresden, Germany

The edge states of a quantum spin Hall system are topologically protected but can be gapped by a magnetic field. A quantum dot realized by two magnetic tunneling barriers in a quantum spin Hall edge is proposed and transport through this device is analyzed. The analysis goes beyond linear response and incorporates electron-electron interaction in a combination of Green-function and master-equation approaches. A partial recurrence of non-interacting behavior is found for strong interactions. The possibility of controlling the magnetization of the edge by a locally applied gate voltage is proposed.

HL 53.12 Wed 12:30 BH 334

Inelastic electron backscattering in a generic helical edge channel — •Thomas L. Schmidt[1,2], Stephan Rachel[1], Felix von Oppen[3], and Leonid I. Glazman[1] — [1]Department of Physics, Yale University, 217 Prospect Street, New Haven, CT 06520, USA — [2]Department of Physics, University of Basel, 4056 Basel, Switzerland — [3]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universitaet Berlin, 14195 Berlin, Germany

We calculate the low-temperature conductance of a generic one-dimensional helical liquid which exists at the edge of a two-dimensional topological insulator (quantum spin Hall insulator). In a generic case, the S_z spin-symmetry is absent, which opens a possibility of single-particle inelastic electron backscattering. We show that although time-reversal invariance is preserved, inelastic backscattering gives rise to a temperature-dependent deviation from the quantized conductance, $\delta G \propto T^4$. In addition, δG is sensitive to the position of the Fermi level in the gap of the insulator. We present an effective model for this type of helical liquid and determine its parameters explicitly from numerical solutions of microscopic models for two-dimensional topological insulators in the presence of Rashba spin-orbit coupling.

HL 53.13 Wed 12:45 BH 334

Magnetoconductance of disordered HgTe strips — •Sven Essert and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

Quantum wells of HgTe show the fascinating phenomenon of edge state transport which leads to a finite conductance in an energy window where the bulk material is insulating. This edge conductance exhibits special properties. One is, that it is expected to be stable against non-magnetic disorder because of a topological protection by time-inversion symmetry.

Inspired by this, we numerically investigate how the conductance of disordered HgTe strips of finite width changes under the application of a time-reversal symmetry breaking external magnetic field. We compare our results for different disorder models to experimental data.

Additionally, we study how the so-called "topological Anderson insulator" phase of HgTe strips, i.e. the phenomenon that finite disorder drives the metallic system into a quantum spin hall state with quantized edge conductance, is affected by the application of an external magnetic field.

HL 54: Optical Properties

Time: Wednesday 11:00–12:45 Location: EW 203

HL 54.1 Wed 11:00 EW 203

Exciton-polariton condensates in a ZnO-based microcavity — Helena Franke[1], Chris Sturm[1], •Rüdiger Schmidt-Grund[1], Tom Michalsky[1], Gerald Wagner[2], and Marius Grundmann[1] — [1]Universität Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig — [2]Universität Leipzig, Institut für Mineralogie, Kristallographie und Materialwissenschaft, Josephinenstr. 7, 04317 Leipzig

We report on the observation of macroscopically coherent states of exciton-polaritons in a ZnO-based bulk planar microcavity (MC) up to 250 K. The threshold behaviour of the photoluminescence intensity as a function of the laser excitation power together with the corresponding spectral narrowing of the emission reveals clear signatures of a Bose-Einstein condensate for negative detunings. For positive detunings however, no condensation occurred but the emission from an electron-hole plasma was detected. At low temperatures and very negative detuning, we find ballistic propagation of the condensate polaritons in the pump-induced potential landscape, which makes these ZnO-based MC promising candidates for application based on polariton transport. The determined propagation length amounts to several μm, similar to values which can be estimated from data on GaAs-based wire-MC [1]. Our effect is caused by strong repulsive interactions of excitons in our system, leading to an immense blueshift of the condensate emission up to 30 meV and hence to pronounced dynamic effects. Due to photonic disorder in our samples the condensate reveals signatures of Bose-glass like states at certain detuning/temperature values.
[1] E. Wertz *et al.*, Nature Phys. **6**, 860 (2010).

HL 54.2 Wed 11:15 EW 203

Zero-dimensional periodic array of polariton condensates — •Edgar Cerda-Mendez[1], Dmitry Krizhanovski[2], Klaus Biermann[1], Maurice Skolnick[2], and Paulo Santos[1] — [1]Paul Drude Institut for Solid State Physics, Berlin, Germany — [2]Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom

Polaritons are quasiparticles arising from the strong coupling between excitons and photons in a semiconductor microcavity. Being dilute bosons, they show a transition to a non-equilibrium macroscopical single quantum state (condensate), at a critical density N_c. Polaritons inherit a long de Broglie wavelength from their photonic component, so N_c is low and condensation occurs at temperatures in the kelvin range. The condensate has extended length (L) and time coherence. In this work, we demonstrate the controlled fragmentation of an extended exciton-polariton condensate (L$\sim$30 μm) in an (Al,Ga)As-based microcavity into a periodical array of zero-dimensional condensates of size <4 μm. Fragmentation is induced by the periodic potential created by the spatial interference of two surface acoustic waves (SAWs) of wavelength λ_{SAW} =8 μm. The SAWs modulates the exciton and microcavity energies forming potential minima, where polaritons can condense. The threshold of condensation is reduced by modification of the scattering process and spatial confinement of the polaritons, which reduces the local losses. Condensation in high orbital states produced by the periodic potential is also observed allowing to observe the screening of the acoustic potential by nonlinear polariton-polariton interactions.

HL 54.3 Wed 11:30 EW 203

Microscopic optical investigation of a GaN based semi microcavity for fabricating a full resonant hybrid structure — •A. Franke, B. Bastek, O. August, S. Petzold, S. Sterling, T. Hempel, P. Veit, J. Christen, P. Moser, C. Berger, J. Bläsing, A. Dadgar, and A. Krost — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

For the investigation of strong coupling between an excitonic and a cavity mode we fabricated a hybrid GaN based microcavity (MC). The sample consists of an epitaxially grown bottom DBR of 40.5 lattice matched AlInN/GaN $\lambda/4$ layer pairs and a $3\lambda/2$ cavity containing a fivefold InGaN/GaN multi quantum well. First the microscopic reflectivity and emission properties of the MC structure without top DBR

were investigated across the full 2" wafer size at identical positions on the sample. The center wavelength of the bottom DBR stop band exhibits a red shift of 8 nm from the center to the middle part of the wafer. A similar behavior is observed for the MQW emission wavelength. Resonance, i.e., a match of both wavelengths, is found at a circular region near the center part of the wafer. Full resonance of the sample was achieved by dry etching of the cavity layer to the optimal optical cavity thickness of $3\lambda/2$. No influence of the etching process on the emission properties of the active layer was observed. The microcavity was completed by depositing an eightfold dielectric Ta_2O_5/SiO_2 top DBR. Local photoluminescence spectra show a strong narrowing of emission peaks compared to the half MC.

HL 54.4 Wed 11:45 EW 203

Second harmonic generation from strained silicon grating structures — •Clemens Schriever[1], Christian Bohley[1], Johannes de Boor[2], Christian Eisenschmidt[1], Jens Lange[1], and Jörg Schilling[1] — [1]Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany — [2]Max-Planck Institut für Mikrostrukturphysik, Halle (Saale), Germany

The second harmonic signal of structured and unstructured, strained and unstrained silicon is investigated. Strain is applied by a thermally grown oxide layer and a surface grating is created by means of laser interference lithography and a dry etching process. The strain distribution inside the grating ridges is investigated by means of high resolution x-ray diffraction (HRXRD) and compared with finite element simulations. The azimuthal distribution of the second harmonic signal is measured in a reflection geometry and the signals of unstructured planar and structured grating samples are compared. The reduced rotational symmetry due to the nanostructuring has a profound effect on the second harmonic signal of the (111)-surface and leads to an increased directionality of the SHG-signal. A first simple model, approximating this effect as a convolution of the SHG-signal of the original (111)-surface and the characteristic reflection properties of the silicon grating structure shows good agreement with the experimental data.

HL 54.5 Wed 12:00 EW 203

Optical Rolled-Up Microtube Resonators Operating in the Visible Spectral Range — •Christian Strelow[1], Andreas Schramm[2], Stefanie Kietzmann[1], Alf Mews[1], and Tobias Kipp[1] — [1]Institute of Physical Chemistry, University of Hamburg, Germany — [2]Optoelectronics Research Centre, Tampere University of Technology, Tampere, Finland

We report on rolled-up optical microtube resonators that operate in the visible spectral range. The microtubes are formed by the self-rolling mechanism of strained semiconductor bilayers grown by molecular beam epitaxy. Recently, we reported on hybrid systems in which microtubes, that act as passive optical resonators, are coupled to chemically synthesized nanocrystals, that act as active light emitters.[1] A solution of nanocrystals was filled into the hollow core of the microtubes. Their coupling to optical modes of the microtubes is made possible by the microtubes' thin walls (typically 40 to 100 nm) that lead to long-ranging evanescent fields into the microtube core. The use of AlInGaAs-based microtubes restricted the choice of possible nanocrystals to systems emitting below 1.65 eV, i.e., the band gap of the layer system. In this work we report on the successful fabrication of AlInP-based microtubes with larger band gap allowing to operate the resonators in the visible spectral range. We demonstrate optical modes in these microtube resonators by coupling them to highly luminescent CdSe-based core-shell colloidal nanocrystals.

We acknowledge financial support by the DFG via KI1257/1.

[1] K. Dietrich *et al.*, Nano Letters **10**, 627 (2010).

HL 54.6 Wed 12:15 EW 203

Near-infrared Photoluminescence of Nanostructured Graphite — •Markus Glaser, Rupert Langegger, Alois Lugstein, and Emmerich Bertagnolli — Vienna University of Technology, Institute of Solid State Electronics, Vienna, Austria

The recent research on graphene and its unique physical properties led to the emergence of a new field of technology, called graphene electronics, with possible applications in transistors or optoelectronic devices. As graphene is a single layer of a graphite crystal, the research on graphene also brought the complex physical properties of graphite back into the center of attention. Recently we presented a method for extracting graphite sheets of varying thickness on bulk HOPG by focused ion beam processing at elevated sample temperatures. These graphite sheets were found to exhibit a distinct near-infrared photoluminescence (PL) signal at 532 nm laser excitation. Further investigation of this unexpected PL was done on several synthetic and natural graphite samples that were mechanically exfoliated with a scotch tape and deposited on silicon substrates with an isolating sacrificial layer. The PL signal is found to be stable at cw laser excitation with power densities of about 400 kW/cm^2 to tens of MW/cm^2 where no destruction of the sample flakes was observed. A possible dependence of PL on the flake thickness and its lateral dimensions is proposed. Furthermore we assume that crystalline graphite is essential for the PL, which was verified by Raman spectroscopy. Electrical characterization and photocurrent measurements where done to determine a possible application in optoelectronic devices.

HL 54.7 Wed 12:30 EW 203

Bethe-Salpeter Equation in the Tamm-Dancoff Approximation and beyond — •Tobias Sander, Ronald Starke, and Georg Kresse — Computational Materials Physics, University of Vienna, Sensengasse 8/12, 1090, Austria

Within the framework of many body perturbation theory, optical absorption spectra are usually calculated using the GW method followed by a subsequent solution of a Bethe-Salpeter like equation. The second step usually involves several approximations. First, the Green function is represented by a one-particle Green function. Second, in solid state calculations, the coupling between resonant (positive frequency branch) and anti-resonant (negative frequency branch) excitations is usually neglected. This approximation is referred to as Tamm-Dancoff approximation. In this work we (i) discuss an efficient method to remove the Tamm-Dancoff approximation for solids, (ii) apply the new approach to three prototypical systems, Si, LiF and Ar. To this end, the recently suggested quasi-particle GW (QPGW) of Shilfgaarde et al. is used to perform the GW calculations [1], followed by a solution of the BSE [2]. We find that the Tamm-Dancoff approximation underestimates the excitonic binding energy by about 300 meV in LiF and Ar, whereas only negligible changes are observed for Si.

[1] M. van Schilfgaarde, T. Kotani, and S. Faleev, Phys. Rev. Lett. 96, 226402 (2006).
[2] S. Albrecht, L. Reining, R. Del Sole, and G. Onida, Phys. Rev. Lett. 80, 4510 (1998).

HL 55: Photovoltaics: Silicon-based Systems II

Time: Wednesday 11:15–12:45 Location: ER 270

HL 55.1 Wed 11:15 ER 270

Photo-induced tunneling current microscopy on amorphous silicon films covered by metal islands — •Andreas Englisch, Uwe Schmitt, and Uwe Hartmann — Institute of Experimental Physics, Universität des Saarlandes, P.O. Box 15 11 50, D-66041 Saarbrücken

The efficiency of thin film solar cells consisting of amorphous silicon is strongly reduced in the wavelength regime beyond 800 nm. In order to overcome this disadvantage, silver nano-particles were placed at close vicinity to the intrinsic photoactive layer. The regime of the optical resonances overlaps with the regime of low intrinsic absorbance of the amorphous silicon. The subsequent increase of the efficiency cannot be explained by optical field enhancement effects only. To understand the mechanism of charge carrier generation in the vicinity of the silver islands STM und STS-measurements were performed across an illuminated scanning area. The samples were composed of 20 nm amorphous silicon films on a 1000 nm thick ITO layer deposited onto a glass substrate. A 4 nm thick silver layer below the percolation threshold was located either between silicon and ITO or on top of the silicon film. First measurements with the silver island film at the silicon-ITO- interface show local variations of the change of the tunneling current on top of the silicon layer if the intensity of the light (820 nm wavelength) is varied. The contrast is influenced by the topography but not con-

sistently, which is a hint to the influence of the hidden metal island film. Intensity-dependent U-I-characteristics were analyzed in order to deconvalve the serial tunneling and photo resistances of the sample.

HL 55.2 Wed 11:30 ER 270

Plasmonic enhanced NIR response in thin film a-Si:H solar cells — •Florian Lükermann[1], Ulrich Heinzmann[1], and Helmut Stiebig[2,1] — [1]Molecular and Surface Physics, Bielefeld University, 33615 Bielefeld, Germany — [2]Malibu GmbH & Co. KG, 33609 Bielefeld, Germany

Metal nanoparticles (NPs) exhibit Localized Surface Plasmon (LSP) resonances upon interaction with electromagnetic radiation. These LSP resonances accompany strong field enhancements in the close surroundings of the NPs.

In previous work [1] it has been shown that incorporating silver NPs in hydrogenated amorphous silicon (a-Si:H) photosensitive devices in the n-layer/i-layer configuration can yield a photocurrent for photons with energies below the a-Si:H bandgap. This photocurrent is attributed to excitation of charge carriers originating from states inside the a-Si:H bandgap which are mediated by the LSP resonances.

A distinct design of solar cell structures or photosensitive devices is necessary in order to observe this sub bandgap absorption in external quantum efficiency measurements. The talk will deal with recent results on this topic.

[1] F. Lükermann, F. Hamelmann, U. Heinzmann, H. Stiebig, 2011. Silver nanoparticles for enhanced light absorption in thin film amorphous silicon solar cells. Science Direct, Energy Procedia (in press)

HL 55.3 Wed 11:45 ER 270

Paramagnetic defects at the interface of silicon heterojunction solar cells detected by Electrically Detected Magnetic Resonance — •Benjamin Muguluvila George[1], Jan Behrends[2], Tim Ferdinand Schulze[1], Matthias Fehr[1], Lars Korte[1], Manfred Schmidt[1], Alexander Schnegg[1], Klaus Lips[1], and Bernd Rech[1] — [1]Helmholtz Zentrum Berlin für Materialien und Energie — [2]Freie Universität Berlin

Amorphous silicon (a-Si:H)/crystalline silicon (c-Si) heterojunction solar cells reach the highest efficiency of mass produced silicon solar cells. Due to the high quality of the silicon wafer material and low thickness of a-Si:H used, the passivation quality of interface defects ultimately determines device efficiency. Additionally this heterojunction is an instructive model system for state-of-the-art microcrystalline silicon (mu-cSi:H) solar cells as they intrinsically possess a high number of a-Si:H/c-Si interfaces at grain boundaries. In this study the spectroscopic properties of paramagnetic defects at the a-Si:H/c-Si interface are investigated by low temperature electrically detected magnetic resonance (EDMR) due to its high sensitivity and the ability to study fully processed solar cells. Spin-dependent recombination between conduction band tail states in the a-Si:H bulk and a-Si:H/c-Si interface dangling bonds is detected. By taking a rotation pattern this signal has been assigned to the a-Si:H/c-Si interface. The g-tensor of this site on the [111] oriented silicon wafer resembles the values of the well-known Pb center at the SiO2/Si interface. By way of sample preparation it can be excluded that natural SiO2 is present at the interface.

HL 55.4 Wed 12:00 ER 270

Photovoltaic potential of femtosecond laser hyperdoped silicon — •Augustinas Ruibys[1], Kay-Michael Günther[2], Stefan Kontermann[1], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich Hertz Institute, EnergieCampus, Am Stollen 19B, 38640 Goslar — [2]Clausthal University of Technology, EFZN, EnergieCampus, Am Stollen 19B, 38640 Goslar

Hyperdoping silicon with a femtosecond laser in a sulfur rich environment extends its absorption capacity far into the infrared. It is believed that high concentrations of sulfur create sub-bands rather than recombination centers within silicon. We present first deep-level transient spectroscopy (DLTS) measurement results that display the existence of a sub-band gap energy structure, although energy level degeneration could not yet be concluded. We then calculate the detailed balance limit of conversion efficiency for the hyperdoped silicon with an arbitrary positioned sub-band. Strategies to exploit the photovoltaic potential of this new material are discussed.

HL 55.5 Wed 12:15 ER 270

Classification of different types of precipitates grown in block-cast multicrystalline solar silicon — •Susanne Richter[1], Martina Werner[1], Sina Swatek[1], Benjamin März[2], and Christian Hagendorf[1] — [1]Fraunhofer-Center für Silizium-Photovoltaik CSP, Walter-Hülse-Str. 1, 06120 Halle (Saale) — [2]Fraunhofer-Intstitut für Werkstoffmechanik IWM, Walter-Hülse-Str. 1, 06120 Halle (Saale)

Precipitates in multicrystalline silicon (mc-Si) for wafer-based solar cell production are of great importance for the efficiency and production yield in the photovoltaic industry. In particular, it has been shown that during the crystallization of mc-Si ingots the accumulation of C and N in the Si melt results in the development of precipitates like SiC and Si3N4 in various morphologies. We present here a study on the morphological structure and the elemental composition of different types of precipitates. In particular, intermixture types occasionally occurring during the growth of mc-Si ingots in VGF crystallizers were investigated. Results from different methods for microstructural, morphologic and chemical analyses including IR microscopy, ToF-SIMS, FIB target preparation for TEM combined with nanospot-EDS and SAED are shown. A more detailed classification with the help of the investigated material properties is proposed.

HL 55.6 Wed 12:30 ER 270

Determination of quasi-Fermi level separations and characteristic tail-state energies of microcrystalline silicon by photoluminescence — •Sven Burdorf, Rudolf Brüggemann, and Gottfried Heinrich Bauer — Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany

Hydrogenated microcrystalline silicon (μc-Si:H) is used as the bottom cell of amorphous silicon/microcrystalline silicon tandem cells. The density of band-tail states is one of the factors limiting the performance of the microcrystalline absorber layer; in particular tails limit the splitting of the quasi-Fermi levels and thus the open-circuit voltage. The band-tail profile can be measured by electronic methods like modulated photocurrent (MPC), thermally stimulated currents (TSC) etc; the straightforward interpretation of the results however, requires samples on insulating substrates with coplanar contacts, which are in contradiction to solar cell architectures. Thus, a contactless method, like photoluminescence, for the analysis of the absorber properties in diode structures is much more appropriate. In this contribution, we present a luminescence approach based on Kirchhoff's generalized law to evaluate photoluminescence (PL) spectra of μc-Si:H in terms of the separation of quasi-Fermi levels and the characteristic tail state energies by assuming an exponential band-tail distribution and PL originating from tail-tail transitions. We extract from the PL-spectra of HWCVD-prepared μc-Si:H layers characteristic tail-state energies of about 50 meV and an energetic splitting of quasi-Fermi level at 20 K of about 1 eV.

HL 56: Organic Electronics and Photovoltaics: Electronic Properties II (jointly with DS, CPP, O)

Time: Wednesday 11:30–13:00 Location: H 2032

HL 56.1 Wed 11:30 H 2032

Point of inflection in IV curves due to degradation of cathode-organic interface — •Sidhant Bom, Nivedita Yumnam, and Veit Wagner — Jacobs University Bremen, School of Engineering and Science, Campus Ring 1, 28759 Bremen, Germany

The formation of point of inflection in IV curves is very well known in the field of organic photovoltaics. However, the opinion on this matter is diverse and conflicting. In an attempt to understand this phenomenon, we carried out series of experiments in which we were able to emulate the s-shape in the IV curve. In this study P3HT:PCBM bulk heterojunction solar cells were fabricated in between ITO/PEDOT:PSS and aluminum electrodes. Storing a completely fabricated cell in different environments resulted in a remarkable difference in the degradation of device parameters. Storing in

vacuum completely stopped the degradation process while storing in an air tight container with nitrogen ambient showed extreme degradation within 24 hours with a severe s-shape in the IV curve. Interface modification at the cathode by inserting an additional thin C_{60} layer resulted in a similar s-shaped curve in contrast to the standard device. The data are explained by a model introducing a variable potential barrier at the aluminum cathode.

HL 56.2 Wed 11:45 H 2032

Dye Sensitised Solar Cells with Carotenoid Molecules — •Gino Günzburger[1], Res Jöhr[1], Biljana Bozic Weber[2], Catherine Housecroft[2], Edwin Constable[2], Hubert Hug[3], Petra Buchwald Hunziker[3], Ernst Meyer[1], and Thilo Glatzel[1] — [1]University of Basel, Department of Physics, Switzerland — [2]University of Basel, Department of Chemistry, Switzerland — [3]DSM Nutritional Products Ltd., NRD CH, Kaiseraugst, Switzerland

We report the analysis of long time stable dye sensitized solar cells using organic carotenoid-based dyes (crocetin, torularhodin and bixin). The particular properties of natural dyes require sensitisation in anhydrous solvents as well as cell assembly under inert gas atmosphere. Furthermore, the exposure to UV light, and the heat-transfer to the sensitised layers was minimized. However, a standard KI based electrolyte was still employed.

The cells were prepared and characterised by IV- and QE-measurements without any anti-reflective or light incoupling foils, or additional light-scattering titania layers. In contrast to the expectations the present cells yield relatively high efficiencies and stability (colour and efficiency was unchanged over a period of days or even weeks). The measured efficiencies under 100 mW/cm^2 AM1.5 simulated sun light at 25°C were 1.23%, 0.40% and 0.75% for the crocetin, torularhodin and bixin cells, respectively. Comparable literature values for crocetin dyes are 0.56% and thus lower by a factor of more than 2. [1].

[1]Yamakazi et al. Solar Energy 81 (2007)

HL 56.3 Wed 12:00 H 2032

High Performance Organic Transistors and Circuits with Patterned Polypyrrole Electrodes — •Liqiang Li, Harald Fuchs, and Lifeng Chi — Physikalisches Institut, Universität Münster, Münster, Germany

Electronic circuits based on organic transistors have sparkled considerable research interests due to their unique applications. One of the key prerequisites to convert the high potential to real applications is the preparation and patterning of appropriate electrode materials. Until now, a variety of electrode materials have been utilized for organic devices, among which conducting polymer electrodes have been proposed to be a promising alternative to replace metal electrodes, as they are endowed with unique features which may embody some advantages of organic circuits. However, high performance and stable devices with pure polypyrrole electrodes, especially n-type transistors and complementary circuits, are not reported.

Here we demonstrate the high performance p-/n-type organic transistors and complementary inverter circuits by using patterned PPY as pure electrode. Remarkably, both transistors and inverters with PPY electrodes show good stability under continuous operation and long-term storage conditions. Furthermore, PPY electrodes also exhibit good applicability in solution-processed and flexible devices. All these results indicate the great potential of PPY electrodes in solution-processed, all-organic, flexible, transparent, and low-power electronics.

HL 56.4 Wed 12:15 H 2032

Design rules for charge-transport efficient host materials for OLEDs — •Falk May[1], Björn Baumeier[1], Denis Andrienko[1], and Christian Lennartz[2] — [1]Max Planck Institute for Polymer Research, Mainz, Germany — [2]BASF SE, GVC/E - B009, Ludwigshafen, Germany

The use of blue phosphorescent emitters in organic light emitting diodes (OLEDs) imposes demanding requirements on a host material. Among these are large triplet energies, the alignment of levels with respect to the emitter, the ability to form and sustain amorphous order, material processability, and an adequate charge carrier mobility. A possible design strategy is to choose a pi-conjugated core with a high triplet level and to fulfill the other requirements by using suitable substituents. Bulky substituents, however, induce large spatial separations between conjugated cores, can substantially reduce intermolecular electronic couplings, and decrease the charge mobility of the host. In this work we analyze charge transport in amorphous bis(triphenylsilyl)dibenzofuran, a typical deep-blue OLED host material, and show that mesomeric effects delocalize the frontier orbitals over the substituents recovering strong electronic couplings without inducing significant variations of local dipole moments, which otherwise would lead to additional energetic disorder, site energy correlations, and undesirable current filaments. By linking electronic structure, molecular packing, and mobility we provide a pathway to the rational design of hosts with high charge mobilities.

HL 56.5 Wed 12:30 H 2032

Octithiophene on Au(111): Coverage dependent adsorption geometry and exciton dynamics — •Lea Bogner[1], Erwan Varene[1], Yan Pennec[2], and Petra Tegeder[1] — [1]Freie Universität Berlin, Fachbereich Physik, Arnimallee 14, 14195 Berlin, Germany — [2]University of British Columbia, department of Chemistry and Physics, Vancouver, B.C. V6T 1Z4, Canada

Semiconducting organic molecules exhibit promising properties for applications in optoelectronic devices such as organic photovoltaic cells or organic light emitting diodes. In order to fully understand and improve the functionalities of organic semiconductors the investigation of adsorption properties, electronic structure and charge carrier dynamics at their interfaces with inorganic substrates plays a crucial role.

Octithiophene (8T) is the longest unsubstituted oligothiophene synthesized up to now and possesses the highest carrier mobility. Whereas several surface science studies on sexithiophene interfaces may be found in literature, little is known so far about 8T.

The adsorption geometry, electronic structure and exciton dynamics as function of 8T coverage have been investigated by means of scanning tunnelling microscopy (STM), high-resolution electron energy loss spectroscopy (HREELS) and time-resolved two-photon photoemission (2PPE). We found that 8T undergoes a change in the adsorption geometry from flat-lying in the sub-monolayer regime to a tilted configuration for the mono- and bilayer coverage. The photoemission intensities of the HOMO and HOMO-1 features as well as the exciton decay dynamics exhibit a strongly coverage dependent behavior.

HL 56.6 Wed 12:45 H 2032

Local Investigations on Air-stable n-Channel Perylene Diimide Based OFETs on Surface Modified SiO_x Dielectric — •Franziska Lüttich[1], Daniel Lehmann[1], Harald Graaf[1,2], Christian von Borczyskowski[1], and Dietrich R. T. Zahn[1] — [1]Chemnitz University of Technology, Institute of Physics, Germany — [2]Now at University Kassel, Institute of Chemistry, Germany

Organic semiconducting materials are interesting for low-cost and flexible applications like organic light-emitting diodes, organic solar cells, and organic field-effect transistors (OFETs). Stability and low mobilities are the most limiting properties for these applications. Surface modifications changing the surface energy of the dielectric in OFETs influences the orientation of the organic molecules and therefore the mobilities. The surface energy can be determined by water contact angle measurements.

In order to investigate the influence of the surface energy we used OFET substrates from Fraunhofer IPMS and varied the water contact angle of the 100 nm thick dielectric of thermal silicon dioxide in the range from 20° to 55°. Thereafter the air-stable Polyera ActivInk™ N1200 (PDI8-CN_2) was deposited by spin coating. The topography was determined using an Atomic Force Microscope (AFM). The electrical characterization was performed by DC measurements and additionally locally resolved by Kelvin Probe Force Microscopy (KPFM) to obtain an insight in the local surface potential and the contact resistances. The determined electron mobility were found to change with varying water contact angle.

HL 57: Photonic Crystals II

Time: Wednesday 12:00–13:15 Location: EW 202

HL 57.1 Wed 12:00 EW 202

Near-Field Coupling in Metamaterials — •Felix von Cube[1,2], Stephan Irsen[2], and Stefan Linden[1,3] — [1]Physikalisches Institut, Universität Bonn, 53113 Bonn, Germany — [2]Research center caesar, 53175 Bonn, Germany — [3]Institut für Nanotechnologie, Karlsruher Institut für Technologie (KIT), 76021 Karlsruhe, Germany

Metamaterials give rise to a variety of intriguing optical phenomena, e.g., a negative index of refraction, strong chirality and perfect lensing. The optical properties of a metamaterial can often be attributed to the excitation of localized plasmonic modes on the metallic substructures of the metamaterial. Electron energy-loss spectroscopy (EELS) in combination with scanning transmission electron microscopy (STEM) is a powerful tool to map the plasmon distributions on a nanometer scale with an energy resolution down to 0.15 eV.

Here, we investigate the near-field distributions of the interacting building blocks of a metamaterial. For these experiments, we have prepared a series of arrays in which we have successively increased the number of split-ring resonators. With STEM-EELS, we are able not only to map the optical bright modes, but also the optical dark modes. From the energy splitting of these modes, we get an indicator for the coupling strength of the metallic substructures in the metamaterial.

HL 57.2 Wed 12:15 EW 202

Analytically generated adaptive meshes for the Fourier Modal Method — •Jens Küchenmeister[1], Thomas Zebrowski[1], Sabine Essig[1], and Kurt Busch[2] — [1]Institut für Theoretische Festkörperphysik and DFG-Center for Functional Nanostructures, Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik, Newtonstr. 15, 12489 Berlin, and Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

The Fourier Modal Method is a versatile solver for Maxwell's equations for periodic systems which calculates transmittance and reflectance spectra by an expansion of the fields into eigenmodes. Problems appear for small structure features or large jumps in the permittivity distribution. These problems can be tackled using a mesh adapted to the structure: Firstly, coordinate lines are bent to match the structure's surface. Secondly, the density of coordinate lines along the surface is increased. In this contribution, we present how to build different types of analytical meshes and investigate their influence on the convergence behavior of the method. Especially, we address the influence of differentiability in adaptive meshing.

HL 57.3 Wed 12:30 EW 202

Advances of Modal Methods in the Simulation of Photonic Structures and Devices — •Thomas Zebrowski[1], Jens Küchenmeister[1], Michael Walz[1], and Kurt Busch[2] — [1]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik, Newtonstr. 15, 12489 Berlin, and Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

Modal methods feature an elegant and efficient way for solving photonic scattering problems with the help of the s-matrix algorithm. In this contribution, we will first give an overview over our current developments in the traditionally used Fourier modal method and present recent results for periodic as well as aperiodic structures like woodpile photonic crystals and liquid crystal based fiber gratings. However, for some applications it seems reasonable to replace the plane wave basis with a localized polynomial basis. This leads us to the B-spline modal method whose basic principles and particularities will be introduced in the second part.

HL 57.4 Wed 12:45 EW 202

Light-Mediated Coupling of a Single QD Coupled to Strongly Interacting Planar Photonic Crystal Cavities — •Stefan Declair, Torsten Meier, and Jens Förstner — University of Paderborn, Department of Physics and CeOPP, Warburger Str. 100, D-33098 Paderborn, Germany

We numerically investigate the light-mediated coupling between a semiconductor heterostructure, a quantum dot (QD), and strongly interacting planar photonic crystal cavities (PhCCs) using a Finite-Difference Time-Domain method. The light-matter Hamiltonian is used to calculate the macroscopic polarization via dynamic equations of motion for the interband coherence and density of the QD [1].
The photonic system consists of two strongly interacting L3 cavities with an optimized Q-factor [2], exhibiting an asymmetric line splitting of >600 GHz [3]. Resonant coupling of a QD (phenomenological dephasing rate in the GHz regime) to one photonic eigenmode of the coupled PhCC system leads to emission of the QD on the other photonic eigenmode with a strong coupling signature (normal mode splitting).
[1] C. Dineen et al., Electromagnetic field structure and normal mode splitting in photonic crystal nanocavities, Optics Express 13, 4980 (2005).
[2] Y. Akahane et al., High-Q photonic nanocavity in a two-dimensional photonic crystal, Nature 425, 944 (2003).
[3] S. Declair et al., Numerical Analysis of Coupled Photonic Crystal Cavities, Photonics and Nanostructures: Fundamentals and Applications 9, 345-350 (2011).

HL 57.5 Wed 13:00 EW 202

High and Subharmonic Generation with a Semiconductor Quantum dot in a Photonic Crystal Cavity — •Matthias Reichelt[1], Andrea Walther[2], and Torsten Meier[1] — [1]Department of Physics and CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany — [2]Institut für Mathematik, Universität Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany

A semiconductor quantum dot modeled as two-level system can emit radiation at specific high harmonic frequencies if it is excited with an intense properly shaped laser pulse [1,2]. Here, we show that it is also possible to downconvert the emission below the fundamental frequency. This proves useful when a dot which is placed into a photonic crystal is capable of emitting into an off-resonant cavity mode in the photonic band gap. Numerical calculations are performed with an optimization algorithm [3] plus a FDTD-simulation.

[1] M. Reichelt, A. Walther, and T. Meier, J. Opt. Soc. Am. B, *accepted for publication.*
[2] D. Golde, T. Meier, and S.W. Koch, J. Opt. Soc. Am. B, **23**, 2559 (2006).
[3] M. Reichelt, A. Walther, and T. Meier, Photonics and Nanostructures - Fundamentals and Applications **9**, 328 (2011).

HL 58: Focus Session: Structure and Transport in Organic Photovoltaics III (jointly with CPP)

Time: Wednesday 15:00–17:00 Location: ER 270

HL 58.1 Wed 15:00 ER 270

Many-body perturbation theory calculations for organic photovoltaics — •Carina Faber, Claudio Attaccalite, and Xavier Blase — Institut Néel, CNRS, Grenoble, France

We evaluate the performance of ab initio GW calculations for ionization energies (IEs) and for HOMO-LUMO gaps of thirteen gas phase molecules of interest for organic electronic and photovoltaics, including e.g. pentacene and free-base porphyrins. Our calculations are based on an efficient Gaussian-basis implementation of GW with explicit treatment of the dynamical screening through contour deformation techniques. We show that we significantly improve the IEs and gaps as compared to DFT Kohn-Sham results. Moreover, we study within the GW and Bethe-Salpeter approach the low lying singlet charge-transfer excitations in molecular donor/ acceptor complexes associating benzene, naphtalene and anthracene derivatives with the TCNE acceptor. Our calculations demonstrate that such techniques can reproduce

the experimental data with a mean absolute error of 0.1-0.15 eV for the present set of dimers, which is in excellent agreement with the best time-dependent density functional studies with optimized range-separated functionals. The present results pave the way for the study of photoinduced charge-transfer processes in photovoltaic devices with a parameter-free ab initio approach showing equivalent accuracy for finite and extended systems. Finally, we show in the case of C60 that the magnitude of the electron-phonon coupling, an important quantity that governs the mobility of carriers in organic systems, is much better described within GW as compared to standard DFT calculations.

HL 58.2 Wed 15:15 ER 270

Transport and Electric Fields in Amorphous Silicon Organic Hybrid Solar Cells — •Sebastian Schaefer[1], Tim Schulze[2], Lars Korte[2], Aad Gordijn[3], Jan Wördenweber[3], and Dieter Neher[1] — [1]Universität Potsdam, Germany — [2]Helmholtz Zentrum Berlin, Germany — [3]Forschungszentrum Jülich GmbH, Germany

We investigated hybrid structures based on nip a-Si:H cells where the p-type layer is replaced by the low band gap polymer PCPDTBT. In these devices the polymer acts as an extraction layer for holes generated in the intrinsic a-Si:H layer and additionally generates charge carriers in the red part of the spectrum, where a-Si:H does not absorb. IV- and quantum efficiency measurements of the hybrid cell show that both materials contribute to the photocurrent generation, indicating that exciton splitting at the hybrid interface as well as hole transfer from a-Si:H to the polymer are provided by the structure. However, low short circuit currents and fill factors lead to poor efficiencies. Simulations of the hybrid device band structure with AFORS-HET (Automat for Simulation of Heterostructures, Helmholtz Zentrum Berlin) indicate that low electric fields in the amorphous silicon layer may lead to the limited performance. This turns out to be a general problem of hybrid inorganic-organic devices since the dielectric constants differ remarkably between these materials. We investigated the electric fields in the hybrid cell with electroabsorption measurements which support our theoretical assumptions. Further studies show that by using doped organic layers the electric field is reconditioned in the amorphous silicon, leading to much better device performance.

HL 58.3 Wed 15:30 ER 270

Field-dependent Charge Carrier Generation, Recombination and Extraction in Polymer Based Solar Cells — •Juliane Kniepert, Ilja Lange, James Blakesley, and Dieter Neher — Universität Potsdam, Institut für Physik und Astronomie

Recently we used the time-delayed collection field (TDCF) method to show that charge generation in solvent annealed P3HT:PCBM solar cells is independent of the electric field[1]. In these blends solvent or thermal annealing leads to a phase-separated morphology and the corresponding solar cells exhibit high values for the external quantum efficiency and fill factor. By contrast, non-treated devices show significantly lower currents and fill factors.

A fundamental understanding of the processes leading to high fill factors and currents is of great importance for the development of a new generation of high efficiency polymer solar cells.

Here, we apply bias-dependent TDCF measurements to probe the generation and recombination of charge carriers in pristine and thermally annealed devices spincast from chloroform. In conjunction with numerical modelling, we show that the differences in the I-V characteristics are not caused by field-dependent dissociation or by the enhanced recombination in non-treated blends, but rather by more efficient extraction of holes in the annealed blend.

[1] J. Kniepert et al., J. Phys. Chem. Lett. 2, 700 (2011)

HL 58.4 Wed 15:45 ER 270

Phase separation in ternary charge-transfer-complexes — •Diana Nanova[1,2], Sebastian Beck[2], Milan Alt[2], Tobias Glaser[2], Annemarie Pucci[2], Katrin Schultheiss[1], Rasmus R. Schröder[5], Jens Pflaum[4], Wolfgang Kowalsky[1,3], and Michael Kröger[1,3] — [1]Institute for High-Frequency Technology ,TU Braunschweig, Germany — [2]Kirchhoff-Institute for Physics, U Heidelberg, Germany — [3]Innovation Lab GmbH, Heidelberg, Germany — [4]Institute for Experimental Physics VI, U Würzburg, Germany — [5]BioQuant, U Heidelberg, Germany

We studied, how mixing of two organic charge-transfer-complexes, which are deposited via thermal co-evaporation at different concentrations by substituting only the acceptor molecules, allows tuning of the optical and structural properties in analogy to inorganic III-V semiconductor compounds. The electron diffraction patterns we collected on samples of a so called ternary CT-system DB-TTF/F4-TCNQx/TCNQ1-x do not show any indication of a mixed crystalline phase or novel crystalline order. However, upon mixing of the complexes the crystallinity of the individual phases degrades. This effect is correlating with mixing ratio. We performed x-ray-diffraction measurements, which confirm the phase separation in the ternary system. Further, we do not observe a shift or the appearance of new peaks in the infrared spectra. Hence, there is no electronic interaction in the presented ternary system between the CT-complexes. In summary this means, that in the ternary system, a phase-separated growth mode dominates and mixing of the phases is not achieved.

HL 58.5 Wed 16:00 ER 270

Charge Carrier Dynamics in Blends of PCPDTBT/$PC_{70}BM$: Influence of Solvent Additives — •Steve Albrecht[1], Wolfram Schindler[2], Jona Kurpiers[1], Sybille Allard[3], Ullrich Scherf[3], and Dieter Neher[1] — [1]Universität Potsdam, Institute of Physics and Astronomy, Soft Matter Physics, D-14476 Potsdam, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, D-14109 Berlin, Germany — [3]Bergische Universität Wuppertal, Macromolecular Chemistry and Institute for Polymer Technology, Gauss-Strasse 20, D-42097 Wuppertal, Germany

We have applied time delayed collection field (TDCF) and photo-CELIV to investigate the photogeneration, recombination dynamics and transport of charge carriers in blends composed of PCPDTBT:$PC_{70}BM$ processed with and without the solvent additive diiodooctane. We show that the solvent additive affects several elementary processes involved in the photon to electron conversion in these blends. First, there is a pronounced field dependence of the generation of free carriers for both blends, with the field dependence being more pronounced without the additive. Second and most important, addition of diiodooctane leads to a three-fold increase of the carrier mobility, enabling rapid extraction of the charge in competition with bimolecular recombination. On the other hand, both blends show rather high but similar bimolecular recombination coefficients. All together, the improvement in generation and extraction of the free carriers explains well the twofold increase in device efficiency upon addition of the processing agent.

HL 58.6 Wed 16:15 ER 270

Equivalent circuit analysis for understanding s-shaped IV-characteristics in organic solar cells — •Bernhard Ecker[1], Hans-Joachim Egelhaaf[2], Roland Steim[2], Jürgen Parisi[1], and Elizabeth von Hauff[3,4] — [1]Energy and Semiconductor Research Laboratory, Institute of Physics, Carl von Ossietzky University, 26111 Oldenburg, Germany — [2]Konarka Technology GmbH, Landgrabenstr. 94, Nürnberg, Germany — [3]Institute of Physics, Albert-Ludwigs University of Freiburg, 79104 Freiburg, Germany — [4]Fraunhofer Institute for Solar Energy Systems, Heidenhofstr. 2, 79110 Freiburg, Germany

In this contribution we investigate the origin of s-shaped current voltage (IV) characteristics in inverted solar cells with a TiOx interlayer between the cathode and the P3HT:PCBM active layer. Initially, the solar cells demonstrate s-shaped IV characteristics, resulting in a low fill factor (FF). Upon light soaking with UV radiation the resistivity of the TiOx interlayer decreases, the s-shape disappears and the FF increases. Impedance spectroscopy (IS) is used to investigate the influence of the resistivity of the TiOx layer on the shape of the IV characteristics. A simple equivalent circuit is proposed to model the experimental data in both conditions, i.e. with s-shaped and regular shaped IV characteristics, respectively. The equivalent circuit elements can be attributed to the distinct layers in the solar cell, therefore giving insight into the origin of the s-shape. We show that IS in conjunction with equivalent circuit analysis can provide detailed information and we identify the resistivity of the TiOx interlayer ultimately influencing the shape of the IV characteristics.

HL 58.7 Wed 16:30 ER 270

Effect of AnE-PV copolymer blending on photophysical and photovoltaic properties — •Christian Kästner[1], Stefan Türk[2], Daniel Ayuk Mbi Egbe[3], Christoph Ulbricht[3], Öslem Usluer[3,4], Silke Rathgeber[5], and Harald Hoppe[1] — [1]Institute of Physics and Institute of Micro- and Nanotechnologies, Ilmenau University of Technology, Ilmenau, Germany — [2]Institute for Print and Media Technology, Chemnitz University of Technology, Chemnitz, Germany — [3]Linz Institute for Organic Solar Cells, Johannes Kepler University Linz, Austria — [4]Department of Chemistry, Mugla University, Mugla, Turkey — [5]Institute of Integrated Natural Science, University

Koblenz-Landau, Koblenz, Germany

Abstract: Investigations on the effect of side-chain variation of anthracene-containing poly(p-phenylene-ethynylene)-alt-poly(p-phenylene-vinylene) (PPE-PPV) copolymers (AnE-PVs) showed promising results for the design of bulk heterojunction solar cells. Furthermore, statistical side-chain substitution of these AnE-PVs resulted in an increased solar cell performance. Thus, the question arose whether these results are similarly achievable by blending of different copolymers bearing different side-chain substitutions, instead of side-chain blending of only one polymer backbone. This concept has been applied to fabricate bulk heterojunction solar cells by blending mixtures of copolymers with PCBM within a common solution. It is shown that this concept is beneficial for the solar cell performance compared to single polymer based donor-acceptor blends.

HL 58.8 Wed 16:45 ER 270

Anisotropy of charge and exciton transport in organic semiconductors — •Vera Stehr[1], Reinhold Fink[2], Johannes Pfister[2], Bernd Engels[3], and Carsten Deibel[1] — [1]Physikalisches Institut, Universität Würzburg, 97074 Würzburg — [2]Institut für Physikalische und Theoretische Chemie, Universität Tübingen, 72076 Tübingen — [3]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, 97074 Würzburg

Organic solar cells become more and more interesting for applications due to their low production costs and easy processability. In order to increase their efficiency it is very important to understand the basic principles of charge and exciton transport in these materials. The charge carrier mobility and the exciton diffusion length are the crucial material parameters which decide on the applicability for solar cells. The transport properties and their orientational dependency have been studied theoretically by means of quantum chemical methods and a hopping approach using Marcus theory along with the master equation. This approach is straightforward and is shown to provide qualitatively good results concerning the directional and morphological dependency of the transport parameters.

HL 59: Invited Talk: Jonathan Eroms

Time: Wednesday 15:00–15:30 Location: ER 164

Topical Talk HL 59.1 Wed 15:00 ER 164

Magnetotransport in Graphene Nanoribbons — •Jonathan Eroms — Institute of Experimental and Applied Physics, University of Regensburg, Germany

In this talk I will present our magnetotransport studies on graphene nanoribbons. To separate the different scattering mechanisms at work, we performed magnetotransport experiments in pulsed magnetic fields up to 60 Tesla. Close to the charge neutrality point, our samples show a high resistance which drops by about an order of magnitude at fields up to 20 Tesla, and then approaches a high field induced insulating state. At higher carrier densities we observe clear quantum Hall features. We can explain our data by assuming at least two different scattering mechanisms located at the sample edge and in the bulk. This is confirmed by corresponding transport simulations based on a tight binding model. Looking at phase-coherent effects in nanoribbons at millikelvin temperatures, in single nanoribbons we observe strong universal conductance fluctuations, while in arrays of nanoribbons, ensemble averaging suppresses the UCFs and allows us to study weak localization. Both effects show that at the lowest temperatures the phase coherence length approaches 1 micrometer, clearly exceeding the ribbon width.

HL 60: Graphene: Raman Spectroscopy

Time: Wednesday 15:30–16:45 Location: ER 164

HL 60.1 Wed 15:30 ER 164

Substrate dependence of the Raman 2D line of graphene — Alejandro Molina-Sanchez[1] and •Ludger Wirtz[1,2] — [1]Institute for Electronics, Microelectronics, and Nanotechnology (IEMN), CNRS, Lille, France — [2]Laboratory for the Physics of Advanced Materials, University of Luxembourg, Luxembourg

We present ab-initio calculations of phonons of graphene on hexagonal boron-nitride which is an example for an ideal flat insulating substrate. The measured double-resonant Raman spectra display shifts of the G and 2D lines comparing, e.g., the spectrum of graphene on silicon dioxide with the spectra of suspended graphene [1] and of graphene on hexagonal boron nitride [2]. In this work, we investigate the influence of the dielectric screening by the substrate on the electron-phonon coupling between the highest-optical phonon branch and the pi-bands of graphene [3]. This enables us to give an explanation for the substrate dependence of the Raman 2D peak position.

References:
[1] S. Berciaud, S. Ryu, L.E. Brus, T.F. Heinz, arXiv:0901.0729v1 [cond-mat.mtrl-sci]
[2] collaboration with F. Forster, A. Meier, K. Watanabe, T. Taniguchi, and C. Stampfer
[3] M. Lazzeri, C. Attaccalite, L. Wirtz, and F. Mauri, Phys. Rev. B 78, 081406(R) (2008).

HL 60.2 Wed 15:45 ER 164

Spatially resolved Raman spectroscopy of graphene on hexagonal boron nitride — Florian Forster[1], Anton Maier[1,2], Kenji Watanabe[3], Takashi Taniguchi[3], and •Christoph Stampfer[1,2] — [1]JARA-FIT and II. Institute of Physics B, RWTH Aachen, 52074 Aachen, Germany — [2]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [3]Advanced Materials Laboratory, National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

Graphene, an one-atom thick hexagonal carbon membrane with unique electronic properties is a promising candidate for high frequency devices and spintronics. However, graphene's ultimate surface to volume ratio makes also the substrate material highly crucial for accessing its full potential. Extensive research on graphene on SiO_2 has shown that the substrate introduces significant disorder, limits carrier mobilities and influences the operation of graphene nanodevices. More recently hexagonal boron nitride has been identified as a promising candidate to overcome some of these limitations. Here we present spatially resolved Raman spectroscopy measurements of single-layer graphene on hexagonal boron nitride substrates, which are compared with measurements of graphene on SiO_2. We show that at micrometer length scales fluctuations of local doping domains are significantly suppressed in graphene on hBN and that the average doping level of as-prepared graphene is reduced on hBN as compared to graphene on SiO_2. Finally we show that graphene flakes on hBN exhibit a significantly increased thermal coupling to the substrate as compared to SiO_2.

HL 60.3 Wed 16:00 ER 164

Resonant Raman scattering profiles and microphotoluminescence of single- and bilayer molybdenum disulfide — •Nils Scheuschner[1], Oliver Ochedowski[2], Marika Schleberger[2], and Janina Maultzsch[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin — [2]Universität Duisburg-Essen, Fachbereich Physik, Lotharstrasse 1-21, 47057 Duisburg

Due to their intrinsic band gap of approximately 1.9 eV and the lack of dangling bonds, atomically thin layers of molybdenum disulfide appear to be a good complement to graphene. For instance molybdenum disulfide could be used in graphene/molybdenum disulfide heterostructures for energy harvesting to create novel extremely thin photovoltaic devices. For this purpose it is a key requirement to understand the electronic structure and possible excitonic effects of single- and bilayer molybdenum disulfide. We present Raman resonance profiles of

first-order Raman modes in the energy range of the first optical transition. Furthermore we present micro-photoluminescence of molybdenum disulfide samples covering a wide range of layer numbers. We will discuss the influence of different substrates on the properties of molybdenum disulfide.

HL 60.4 Wed 16:15 ER 164

Symmetry of phonon modes in functionalized carbon nanotubes — •Christoph Tyborski, Matthias Müller, Janina Maultzsch, and Christian Thomsen — Institut für Festkörperphysik, TU Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Polarization dependent Raman spectroscopy is used to analyse the symmetry of phonon modes participating in the scattering process of functionalized CNTs on unoriented samples.

In pristine CNTs the Raman signal mainly originates from the (z,z)-matrix element of the A_{1_g} mode. Contrary to unfunctionalized tubes, we found that the contribution of modes with E-symmetry in the Raman signal is slightly higher in functionalized tubes. We attribute this to a break in the high symmetry of CNTs due to functionalization.

HL 60.5 Wed 16:30 ER 164

Interlayer coupling in graphene — •Felix Herziger, Patrick May, and Janina Maultzsch — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Raman spectroscopy has reveiled itself as a very versatile tool to investigate the properties of graphene. It is often used to distinguish a monolayer region from regions with more layers by the shape of the 2D band. Without optical contrast or topography measurements, this method is only reliable for layer number identification up to three layers.

Here we report Raman measurements of interlayer vibrational modes in graphene layers with varying thickness. These modes show a clear dependence on the number of graphene layers due to interlayer coupling. Therefore, Raman measurements can be used to identify the number of graphene layers and additionally investigate the interlayer interactions. For more than two layers, the distinction between the number of layers using interlayer modes can be more precise than the usual approach of analyzing the 2D mode.

HL 61: GaN: Preparation and Characterization II (mainly structural)

Time: Wednesday 15:00–16:15 Location: EW 202

HL 61.1 Wed 15:00 EW 202

Effect of the growth conditions on the early stages of pyramidal semipolar template growth — •Jan Wagner, Clemens Waechter, Julian Mack, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Center SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

The nitride material system is in the focus of many research studies for several years now because of the large tunability of the emission energy over the visible range. A challenge that occurs is the huge influence of the Quantum Confined Stark Effect (QCSE) which reduces the emission efficiency dramatically. One approach to manage this problem is the use of native non- or semi-polar substrates which are still quite expensive. A promising alternative for those substrates is the use of semipolar surfaces grown by epitaxial lateral overgrowth (ELO). The growth of active layers on the facets of GaN pyramids re- duces the QCSE and therefore enhances the emission efficiency. Since the pyramid facets serve as growth template for the active region, their crystalline quality directly affects the emission efficiency. This contribution therefore deals with the early growth stages of the GaN pyramids grown at different growth times and growth conditions. The structural investigation reveal the internal defects and gives an insight on the material quality in the pyramids and their facets.

HL 61.2 Wed 15:15 EW 202

Epitaxy and characterization of $Al_{1-x}In_xN$ grown by low pressure MOVPE on various substrates — •Ernst Ronald Buss, Uwe Rossow, Heiko Bremers, and Andreas Hangleiter — Institut für Angewandte Physik, TU Braunschweig

Due to the advantages of $Al_{1-x}In_xN$ compared to $Al_xGa_{1-x}N$ regarding lattice mismatch and contrast in refractive index to GaN it is a very promising material for claddings in GaN based laser structures. To minimize optical losses the $Al_{1-x}In_xN$ layers have to be quite thick, of high crystalline quality and very smooth.

Lattice matched $Al_{1-x}In_xN$ grown by low pressure MOVPE exhibits a typical surface morphology for small layer thicknesses consisting of small features of about 100 nm in diameter, some of which are decorated with a pit inside. To investigate the influence of parameters like the strain state of the $Al_{1-x}In_xN$, the defect density of the substrate, the material of the underlying layer, or the presence of $(1\bar{1}01)$ facets on surface morphology we performed growth experiments of single layer samples and multi layer structures on various substrates and templates. It turned out that the surface of $Al_{1-x}In_xN$ gets more fine-grained with increasing layer thickness. Varying the material of the underlying layer we were able to initiate the fine-grained morphology for thinner layers. For very large layer thicknesses, as well as for stacked sample structures of $Al_{1-x}In_xN$ and GaN with a large total film thickness of $Al_{1-x}In_xN$ we can observe a splitting in the composition independent of the properties of the underlying material. Hence, the origin of this splitting must be an instability during growth.

HL 61.3 Wed 15:30 EW 202

InGaN(0001) surface reconstructions — •C. Friedrich[1], A. Biermann[1], N. Esser[1,2], M. Kneissl[1], and P. Vogt[1] — [1]TU Berlin, Inst. f. Festkörperphysik EW6-1, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Leibniz-Inst. für Analytische Wissenschaften - ISAS e.V., Albert-Einstein Str. 9, 12489 Berlin, Germany

Surfaces of the InGaN alloy system are hardly understood in terms of their atomic structure. In order to reveal the principal mechanisms for the formation of surface reconstructions the preparation of such surfaces for measurements in ultra high vacuum (UHV) is crucial. The preparation and surface structure of high quality group-III-polar (0001) InGaN layers grown by metal-organic vapor phase epitaxy have been investigated. We show that different InGaN surface reconstructions such as (1×1), (1+1/6), (2×2) and $(\sqrt{3}\times\sqrt{3})R30°$ can be obtained by annealing at various temperatures under ultra high vacuum and nitrogen-rich conditions as observed by low energy electron diffraction. Depending on the annealing temperature and nitrogen supply these surfaces exhibit significant differences in stoichiometry and morphology as determined by Auger electron spectroscopy and atomic force microscopy measurements. We show that the (2×2) and $(\sqrt{3}\times\sqrt{3})R30°$ are explained by indium-adatoms and a related In depletion in the first group-III layer underneath whereas the (1+1/6) exhibits a discommensurate overlayer of group-III-atoms. Strain-relaxation is suggested to explain this structure formation.

HL 61.4 Wed 15:45 EW 202

Determination of piezoelectric fields in GaN/InGaN/GaN quantum wells by DPC — •Josef Zweck[1], Matthias Lohr[1], Michael Jetter[2], Clemens Wächter[2], Thomas Wunderer[3], and Ferdinand Scholz[3] — [1]Physics Faculty, University of Regensburg, FRG — [2]Institute for semiconductor optics and functional interfaces, Stuttgart University, FRG — [3]Institute for optoelectronics, Ulm University, FRG

Differential phase contrast microscopy senses the local electric field by measuring the deflection of the probe beam after passing through a specimen area carrying an electric field.

An application of the technique to measure piezoelectric polarization fields inside multi-layered structures such as quantum wells is demonstrated. For this purpose, piezoelectric fields within non-centrosymmetric crystal structures, based on GaN/InGaN/GaN quantum wells, are investigated. It can be shown that the technique is sensitive to these fields and yields detailed and quantitative information about the field distribution. The specific information and experimental limitations will be discussed in detail and first measurements are shown.

The main advantages turn out to be high sensitivity for electric fields, combined with a very high resolution in the nanometer regime, which is only limited by the STEM probe size. Another advantage is the large achievable field of view.

HL 61.5 Wed 16:00 EW 202

Investigation of the influence of InGaN underlying layers on the optical properties of InGaN quantum well structures — •Mathias Müller[1], Anja Dempewolf[1], Frank Bertram[1], Thomas Hempel[1], Antje Rohrbeck[1], Jürgen Christen[1], Alois Krost[1], Wang Lai[2], Wang Jiaxing[2], Wang Lei[2], and Luo Yi[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Department of Electronic Engineering,Tsinghua University, Beijing, China

The optical properties of InGaN/InGaN multiple quantum wells (MQWs) with InGaN underlying layers (UL) on sapphire substrates have been comprehensively investigated by highly spatially and spectrally resolved cathodoluminescence microscopy (CL) at He temperature and by temperature dependent photoluminescence spectroscopy (PL). The Indium content of the UL was systematically varied from 1% to 4% between the samples. SEM and AFM measurements were used to examine the sample morphology. The evaluation of the temerature dependent PL measurements shows a rising activation energy of nonradiative centers with increasing In content. CL investigations of the sample surface show elongated structures in the integral intensity images and peak wavelength images, which becomes more spot-like with rising In content. The peak energy of the MQW luminescence shows a blueshift with rising In content which may be caused by a possible reduction of the quantum confined Stark effect (QCSE). At the same time the FWHM of the MQW emission is reduced from 27 meV to about 18 meV when introducing ULs.

HL 62: Quantum Dots and Wires: Transport Properties I (mainly Quantum Wires)

Time: Wednesday 15:00–17:00 Location: EW 203

HL 62.1 Wed 15:00 EW 203

Low Temperature Conductance Quantization in GaAs Quantum Wires — •Christian Scheller[1], Gilad Barak[2], Loren N. Pfeiffer[3], Ken W. West[3], Amir Yacoby[2], and Dominik M. Zumbühl[1] — [1]Dep. of Physics, University of Basel, Switzerland — [2]Dep. of Physics, Harvard University, Cambridge, Massachusetts, USA — [3]Bell Labs, Lucent Technologies, Murray Hill, New Jersey, USA

We present low temperature quantum transport measurements of cleaved edge overgrowth quantum wires fabricated in GaAs-AlGaAs. When the electron density in the wire is varied using a gate voltage, pronounced conductance plateaus are observed. However, the conductance values of the plateaus are strongly suppressed below the universally expected multiples of $2e^2/h$ [1]. For the lowest mode, the plateau conductance saturates at $\approx 1e^2/h$ at low temperatures $T < 80$ mK and zero external magnetic field. This seems to suggest that the spin degeneracy is lifted, consistent with recent theory [2] predicting helical nuclear magnetism in the Luttinger liquid regime. Using the same setup and a similar chip carrier, we demonstrate electron temperatures down to 11 mK in metallic Coulomb blockade thermometers, suggesting that the sample cools far below 80 mK. We employ transport spectroscopy to investigate the system and further use resistively detected NMR in an attempt to elucidate the role of the nuclear spins. [1] "Nonuniversal Conductance Quantization in Quantum Wires", A.Yacoby et al., Phys. Rev. Lett. 77, 4612 (1996). [2] "Nuclear magnetism and electron order in interacting one-dimensional conductors", Bernd Braunecker, Pascal Simon, and Daniel Loss, Phys. Rev. B80, 165119 (2009).

HL 62.2 Wed 15:15 EW 203

Observation of Electron Interference in GaAs/InAs Core/Shell Nanowires — •Önder Gül[1,2], Christian Blömers[1,2], Torsten Rieger[1,2], Mihail I. Lepsa[1,2], Hans Lüth[1,2], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2,3] — [1]Peter Grünberg Institute -9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]II. Physikalisches Institut, RWTH Aachen, 52056 Aachen, Germany

Electron and spin interference in mesoscopic semiconductor systems is of fundamental interest for future spin- and quantum-based information technology. In this context, bottom-up device approaches such as templated self-assembled nanowires are particularly interesting.

Here we report on electron wave interference in GaAs/InAs core/shell nanowires grown by molecular beam epitaxy. Magnetotransport measurements were performed at 1.8 K and at magnetic fields up to 10 T. Additionally, gate voltage dependence of magnetotransport characteristics is investigated. Conductance oscillations are observed as a function of the magnetic field as well as the gate voltage. Fourier analysis of data suggests periodicity both in magnetic field and gate voltage. Further, phase-coherent transport properties of these nanowires are unravelled by applying the magnetic field in different orientations as well as by temperature dependent measurements.

HL 62.3 Wed 15:30 EW 203

Structural influences on quantum transport in InAs nanowires — •Robert Frielinghaus[1,4], Kilian Flöhr[2,4], Kamil Sladek[1,4], Stefan Trellenkamp[1,4], Thomas E. Weirich[3,4], Hilde Hardtdegen[1,4], Thomas Schäpers[1,2,4], Claus M. Schneider[1,4], and Carola Meyer[1,4] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]II. Physikalisches Institut, RWTH Aachen University, 52074 Aachen, Germany — [3]Central Facility for Electron Microscopy GFE, RWTH Aachen University, 52074 Aachen, Germany — [4]JARA Fundamentals of Future Information Technology

Self-assembled nanostructures such as InAs nanowires are candidates for future semiconductor nanoscale devices. However their atomic arrangement usually differs from device to device leading to fluctuations in the electrical properties as e.g. the electron phase coherence length. Using a special sample design we present quantum transport measurements together with transmission electron micrographs (TEM) taken from the same individual InAs nanowires. The as-grown nanowires are selectively placed on holes patterned in a TEM membrane. Low-temperature magnetotransport measurements of these suspended nanowires reveal universal conductance fluctuations that allow for the determination of the phase coherence length without any influence of the substrate. Variations in the transport behavior are correlated to the atomically resolved structure observed in TEM.

HL 62.4 Wed 15:45 EW 203

Electrical properties of catalyst-free MBE grown InAs nanowires — •Philipp Geselbracht[1], Stefanie Bolte[1], Dance Spirkoska[1], Simon Hertenberger[1], Verena Hintermayr[1], Markus Döblinger[2], Max Bichler[1], Gerhard Abstreiter[1,3], and Gregor Koblmüller[1] — [1]Walter Schottky Institut and Physik Department, TU München, Garching, Germany — [2]Department of Chemistry, Ludwig-Maxilians-Universität, Munich, Germany — [3]TUM Institute for Advanced Study, Garching, Germany

In this work we report on the electrical properties of catalyst-free, nominally undoped InAs nanowires grown on Si substrates using ultrapure, solid source molecular beam epitaxy (MBE). By applying a wide range of growth parameters we have obtained nanowires with different amount of zinc-blende and wurtzite segments in their crystal structure as investigated by Transmission Electron Microscopy (TEM). We have fabricated planar field effect transistor devices both in global back gate and top gate geometry. From transmission line method, as well as four point I-V measurements we have determined the contact resistance to be <1 kOhm . Our devices are characterized with large ON/OFF ratio and mobility in the range of 2000 cm2/Vs at room temperature confirming the worthiness of the catalyst-free growth mode. Additionally, we will discuss the effect of the gate geometry on the characteristics of the field effect devices and give first insight into wrapped gate devices

HL 62.5 Wed 16:00 EW 203

Growth and electrical characterization of modulation doped core-shell GaAs/AlGaAs nanowires — •Stefanie Bolte[1], Dance Spirkoska[1], Daniel Rudolph[1], Markus Döblinger[2], Max Bichler[1], Gregor Koblmüller[1], and Gerhard Abstreiter[1,3] — [1]Walter Schottky Institut and Physik Department, TU München, Garching, Germany — [2]Department of Chemistry, Ludwig-Maxilians-Universität, Munich, Germany — [3]TUM Institute for Advanced Study, Garching, Germany

In this work we will present the electrical properties of self-catalyzed, modulation (remotely) doped GaAs/AlGaAs core-shell nanowires grown by molecular beam epitaxy. The remote doping with Si delta-

layer in the AlGaAs shell, which is deposited on the {110} side facets of the GaAs core, results in the formation of complex one (1d) and two (2d) dimensional electron channels at the interface between the GaAs and the AlGaAs, as shown by nextnano3 simulation of the electron density. The n-type behavior of the doping was confirmed with back gate dependent measurements on the fabricated field effect transistor devices and the occurrence of the persistent photoconductivity effect at low temperatures. Magnetic field studies at low temperatures revealed a complex oscillatory behavior of the magnetoresistance, which is due to the superposition of the 2d and 1d channels of electrons on the side facets and the edges, respectively. Furthermore, we will discuss the dependence of the electrical properties on the crystal structure of the GaAs core, and the feasibility of obtaining high electron mobilities in these systems.

HL 62.6 Wed 16:15 EW 203

Hall Measurements on InAs Nanowires — •Christian Blömers[1,3], Thomas Grap[1,3], Stefan Trellenkamp[2,3], Mihail I. Lepsa[1,3], Detlev Grützmacher[1,3], Hans Lüth[1,3] und Thomas Schäpers[1,3,4] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Peter Grünberg Institut (PGI-8), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [3]JARA - Fundamentals of Future Information Technology — [4]II. Physikalisches Institut, RWTH Aachen, 52074 Aachen, Germany

In search of novel concepts for the realization of nanoelectronic devices, semiconductor nanowires grown by "bottom-up" techniques have shown great promise. Without any doubt, the knowledge about the free carrier concentration n_{el} is crucial for the fabrication of such devices on the nanometer scale. The most common method to determine n_{el} in nanowires is to utilize the field effect in a gate measurement setup. However, within this method, uncertainties such as the density of surface states between the nanowire and the dielectric material or the resulting nanowire capacitance influence results. Additionally, source and drain electrodes tend to screen the gate potential in devices of small size. Here we report on Hall measurements on InAs nanowires as an alternative method to determine n_{el}. By electron beam lithography we are able to fabricate side contacts to single nanowires to realize a Hall-measurement geometry. The side contacts allow us to measure a Hall-voltage, from which we deduce the carrier concentration in the wires.

HL 62.7 Wed 16:30 EW 203

Four-point electrical characterization and gas sensing properties of CuO nanowire devices — •Stephan Steinhauer, Elise Brunet, Giorgio Cataldo Mutinati, and Anton Köck — Health & Environment Department, Molecular Diagnostics, AIT Austrian Institute of Technology GmbH, 1220 Vienna, Austria

Metal oxide nanowires have recently attracted much attention as they may be used in numerous potential applications, especially in highly sensitive gas detecting devices. Unlike other metal oxides, cupric oxide (CuO) is known as a p-type semiconductor with a narrow band gap around 1.2eV. In order to gain a better understanding of CuO nanowire transport properties, we characterize them in a four-point configuration and investigate the influence of the surrounding gas atmosphere.

CuO nanowires are synthesized by thermal oxidation of resistively heated Cu wires at ambient conditions. By this method, CuO nanowires with lengths up to 100 micrometer and typical diameters between 30 and 150 nanometer can be fabricated. After the transfer to silicon substrates, single CuO nanowires are contacted in a four-point configuration by optical and electron beam lithography using a metal lift-off process. The temperature dependence of nanowire transport properties is investigated in four-point and two-point measurements in order to evaluate specific conductance and contact resistance. When operated as conductometric gas sensors, CuO nanowires show a strong interaction with the surrounding gas due to the high surface to volume ratio and are able to detect very small concentrations of the toxic gases CO and H2S in the low ppm range.

HL 62.8 Wed 16:45 EW 203

Optimal finite volume discretization of Schrödinger equations for cylindrical symmetric nanowires — •Paul Nicolae Racec — Weierstrass Institute Berlin, Mohrenstr. 39, 10117 Berlin, Germany — National Institute of Materials Physics, PO Box MG-7, 077125 Bucharest Magurele, Romania

We present a finite volume scheme for the one-particle effective mass Schrödinger equation with mixed boundary conditions, more precisely the Wigner-Eisenbud problem, on a bounded domain with cylindrical symmetry. Hence, we reduce the 3D problem to one in the (r, z) plane. We use linear triangular finite elements, structured meshing and the lumping approximation in the variational formulation of the discretized 2D problem. In order to remove the r^{-1} singularity, we approximate within every element the metric $r\,dr\,dz \simeq r_U^{(e)}\,dr\,dz$ and $1/r \simeq 1/r_U^{(e)}$, where $r_U^{(e)}$ is the r-coordinate of the circumcenter of the triangular element. We analyze the influence of the size and shape of the finite elements on the accuracy of the eigenvalues and eigenfunctions. We study a free-particle case and a nanowire resonant tunneling diode. In case of equilateral finite elements, we obtain a second order convergence for the eigenvalues, which is independent of the ratio m_r^*/m_z^*, where m_r^* and m_z^* are the r and z components of the effective mass tensor of the nanowire. In case of anisotropic masses, the optimal finite element shape is obtained with a grid, which is finer in the direction of the smaller effective mass.

This is a joint work with Stanley Schade and Hans-Christoph Kaiser.

HL 63: Devices I

Time: Wednesday 15:00–17:00 Location: EW 015

HL 63.1 Wed 15:00 EW 015

Mapping of reflectivity and excited carriers' transport in metal–insulator–metal heterosystems — Dominik Differt[1], Walter Pfeiffer[1], and •Detlef Diesing[2] — [1]Universität Bielefeld, Universitätsstr. 25, 33615 Bielefeld, Germany — [2]Fakultät für Chemie, Universität Duisburg-Essen, D-45117 Essen, Germany

The quality of large area thin film metal heterojunctions with interstitial oxide layers depends on the lateral homogeneity of the metal thicknesses and the interstitial oxide's barrier height. Lateral inhomogeneities on the microscopic scale may lead to changed properties of the macroscopic device. We present a new setup which enables the mapping of surface reflectivity and of photo excited carriers transport as well. For the lateral mapping of the **i**nternal **p**hoto **e**mission (**IPE**) in a Ag-TaO-Ta heterosystem the sample is raster scanned across the focus of a Schwarzschild objective (NA=0.4). The illumination with 400 nm laser radiation results in a focus diameter of 5 μm limiting the spatial resolution of the IPE microscope. Mapping across the 40 μm wide edge of the top metal film shows transport effects in the top silver electrode as well as the increasing excitation of carriers in the tantalum backelectrode with decrasing top electrode thickness. The spatial variation of the top electrode thickness at the edge of the electrode gives information about the relaxation dynamics of the photo excited carriers.

HL 63.2 Wed 15:15 EW 015

A new method for obtaining accurate capacitance-voltage curves in the presence of additional space charges — •Kay-Michael Günther[1], Hartmut Witte[2], Alois Krost[2], Stefan Kontermann[3], and Wolfgang Schade[1,3] — [1]Clausthal University of Technology, EFZN, Am Stollen 19B, 38640 Goslar, Germany — [2]Otto-von-Guericke University Magdeburg, Institute for Experimental Physics,Universitätsplatz 2, 39106 Magdeburg, Germany — [3]Fraunhofer Heinrich Hertz Institute, Am Stollen 19B, 38640 Goslar, Germany

Evaluating capacitance-voltage (C-V) curves is a powerful tool for obtaining doping concentration profiles. If the sample contains additional space charges like pn-junctions, defects, or Schottky barriers, the commonly used methods often deliver false results. The reason is that the capacitance of the investigated junction cannot be measured directly, but the impedance is interpreted in terms of an equivalent circuit (EC). We show that these commonly used ECs are only valid under special considerations and can easily produce false results. We present a new method which uses a more general approach based on whole impedance spectra instead of single impedances to acquire accurate C-V curves even in the presence of additional space charges. We compare our method with the conventional techniques and discuss its advantages and disadvantages.

HL 63.3 Wed 15:30 EW 015

Solution-processed *p*-channel tin monoxide thin-film transistors — •Koshi Okamura[1], Babak Nasr[1,2], Richard A. Brand[1], and Horst Hahn[1,2] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), 76021 Karlsruhe, Germany — [2]Joint Research Laboratory Nanomaterials, Technische Universität Darmstadt and KIT, Petersenstr. 32, 64287 Darmstadt, Germany

Oxide semiconductor thin-film transistors (TFTs) have been fabricated both in the conventional vacuum processes and in the solution-processes intensively for *n*-channel type zinc oxide (ZnO) and amorphous oxide semiconductors. The material search for the *p*-channel type is, however, still challenging. Tin monoxide (SnO) is so far the most promising *p*-type oxide semiconductor that has been demonstrated for epitaxially grown and sputtered TFTs. In this study, *p*-channel enhancement mode SnO TFTs are fabricated in a solution-process by spin-coating a methanol solution of the precursor tin(II) chloride dihydrate ($SnCl_2.2H_2O$), followed by an exposure to ammonium hydroxide and a postannealing in purified forming gas at a temperature of 450-500 °C. Systematic investigations reveal that the transistor performance is strongly dependent on the crystallinity and thin-film morphology, showing a highest field-effect mobility of 0.13 cm^2 V^{-1} s^{-1}, threshold voltage of -1.9 V, and on/off drain current ratio of 85.

HL 63.4 Wed 15:45 EW 015

Chemical surface modifications for altering electrical characteristics of silicon nanowire Schottky-barrier FETs — •Sebastian Pregl[1,2], Walter Weber[2], Joerg Opitz[3], and Gianaurelio Cuniberti[1] — [1]Institute for Materials Science and Max Bergmann Center of Biomaterials, TU Dresden, 01062 Dresden, Germany — [2]NaMLab GmbH, 01187 Dresden, Germany — [3]Fraunhofer Institute IZFP Dresden, 01109 Dresden, Germany

The interface of semiconductors to metals with a different work function introduces a Schottky barrier. For axially Ni-silicidized silicon nanowires a very sharp interface and thus a very defined and reproducible energetical barrier is created. We use $NiSi_2$-Si-$NiSi_2$ heterostructures as Schottky-barrier field effect transistors (SB-FETs) for sensor applications and nanoelectronic devices. Silicon nanowires can be grown as thin as 5nm with VLS (vapor liquid solid) technique in a CVD furnace. The high surface to volume ratio of such nanostructures makes their electronic properties very sensitive to surface adsorbates and covalently bound molecules. The effect of surface functionalization is investigated in respect of a potential use for biosensor applications and new ways to alter device characteristics of silicon nanowire FETs.

HL 63.5 Wed 16:00 EW 015

Two-color pump-probe experiments with balanced heterodyne detection on InAs/GaAs quantum dot semiconductor optical amplifiers — •Yücel I. Kaptan, Nina Owschimikow, and Ulrike Woggon — Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany

Degenerate one-color pump-probe measurements combined with a balanced heterodyne detection scheme prevailed in the last decade as a leading experimental tool for the measurement of gain and phase dynamics in QD SOAs. In this talk, we present an improved two-color pump-probe setup in which a mode-locked Ti:Sa laser and an infrared super continuum emitting fiber laser provide independently tunable ultrafast pump and probe pulses. Both laser sources have been synchronized via a phase-locked loop using a proportional-integral-derivative controller driving a piezo crystal. With a synchronization jitter of about 400fs we were able to investigate the carrier transition times between the QD ground and excited state, the 2D carrier reservoir and the waveguide. Separating the recovery within the QD states from the carrier recovery in the reservoir, we identify the carrier dynamics in the reservoir as the main contribution to overall phase dynamics and thus change in refractive index. We additionally show that the presented results of the intradot gain dynamics indicate a novel way for ultrafast switching of amplification and wavelength conversion.

HL 63.6 Wed 16:15 EW 015

AlInN/GaN FETs auf Si(001) — •Armin Dadgar, Hartmut Witte, Jürgen Bläsing, Annette Diez und Alois Krost — Institut für Experimentelle Physik, Otto-von Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg

Das Wachstum von FET Strukturen auf Si(001) eröffnet die Möglichkeit der Integration von GaN-basierter Hochleistungselektronik mit der gängigen Si CMOS Technologie. Wir untersuchen das Wachstum von AlInN/GaN-basierten FET Strukturen auf Si Substraten. Dabei ist AlInN ein interessantes Halbleitersystem, das das gitterangepasste Wachstum auf GaN bei gleichzeitig hohen pyroelektrischen Feldern ermöglicht. Dies erlaubt 2-dimensionale Elektronengaskonzentrationen, die deutlich über denen im System AlGaN/GaN mit ca. 1xE13 cm-3 liegen. Hier untersuchen wir die Eigenschaften von solchen Strukturen im Vergleich zu Strukturen auf dem ebenfalls in der CMOS Technologie eingesetzten Si(110) und dem für das GaN Wachstum üblichen Si(111). Hauptunterschied ist dabei die kristalline Qualität der Pufferschichten. Die Auswirkungen dieser Qualitätsunterschiede werden mittels Röntgendiffraktometrie, Hall-Effekt, Atomkraft- und Oberflächenpotentialmikroskopie und Photolumineszenzmessungen untersucht.

HL 63.7 Wed 16:30 EW 015

Effect of temperature and strain on the optical polarization of ultraviolet light emitting diodes — •T. Kolbe[1], A. Knauer[2], V. Kueller[2], J. Stellmach[1], C. Chua[3], Z. Yang[3], S. Einfeldt[2], P. Vogt[1], N.M. Johnson[3], M. Weyers[2], and M. Kneissl[1,2] — [1]Institute of Solid State Physics, TU Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany — [3]Palo Alto Research Center, 3333 Coyote Hill Road, Palo Alto, CA 94304, USA

The temperature and strain dependence of the optical polarization of the in-plane electroluminescence (EL) of (0001) oriented (In)(Al)GaN multiple quantum well (MQW) LEDs has been investigated. The EL measurements show a decrease of the emission intensity for transverse-electric (TE) polarized light relative to the transverse-magnetic (TM) polarization with decreasing emission wavelength. This can be explained by a change of the order of the heavy, light and split-off hole band in the (In)(Al)GaN active region with a changing Al-content. With increasing sample temperature it was found that the TM polarized part of the emission increases for LEDs with a dominant TE polarized emission (and inverted) because the occupation probability of high-energetic bands increases with increasing temperature. We further investigate the influence of the strain in the MQWs on the optical polarization of near UV LEDs. It was observed that the TM polarized part of the emission clearly increases if strain of the MQWs is reduced by a change of the barrier material between the quantum wells.

HL 63.8 Wed 16:45 EW 015

Efficiency droop in nonpolar InGaN quantum wells — •Lukas Schade[1,2], Ulrich Schwarz[1,2], Tim Wernicke[3], Jens Rass[3], Simon Ploch[3], Markus Weyers[4], and Michael Kneissl[3,4] — [1]Fraunhofer Institut für Angewandte Festkörperphysik (IAF), Freiburg — [2]Institut für Mikrosystemtechnik (IMTEK), Universität Freiburg — [3]Institut für Festkörperphysik, Technische Universität Berlin — [4]Ferdinand-Braun-Institut (FBH), Berlin

InGaN quantum wells (QWs) exhibit a decline of the internal efficiency at high charge carrier excitation. This has been observed for polar as well as for semipolar and nonpolar oriented QWs. Polar stands for the (0001) growth direction with strong piezoelectric fields. Due to the vanishing fields, the orthogonal growth directions (a or m) are called nonpolar, while all directions between are merged as semipolar orientations. In contrast to the polar and many semipolar QWs, nonpolar InGaN QWs provide a special property: optical polarization of the radiative transitions, which is a result of the anisotropic strain within pseudomorphic grown nonpolar QWs. Using this property, the broadened effective emission can be resolved into two fundamental transitions. They are spectrally separated by a defined energy which corresponds to the energy distance of the valence subbands. We studied nonpolar InGaN/InGaN Multi-QWs grown on low defect density GaN substrates with a setup for confocal microscopy. To reach high excitation densities of charge carriers, we use either a combination of an UV laser and highly focusing objectives or an electric pulse generator. The emission is spectrally analysed and compared to established models.

HL 64: GaN: Preparation and Characterization III

Time: Wednesday 16:30–18:30 Location: EW 202

HL 64.1 Wed 16:30 EW 202

Overcoming the limiting factors to achieve green lasing — •Andreas Kruse, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, TU Braunschweig

Group-III nitrides based materials have attracted great interest for optoelectronic devices such as light emitting diodes (LEDs) and laser diodes (LDs). However, for long wavelength emitting LEDs and LDs many challenges need to be overcome to improve their device performance. We focus our study on investigations of limiting factors of optical gain in InGaN-based laser structures by extending the emission wavelength to the green spectral range. For this purpose we carry out optical gain measurements using the variable stripe length method (VSLM) on laser structures grown on c-plane substrates (sapphire and GaN) with various parameters in the active zone (e.g. QW thickness, numbers of QWs, indium content). After optimization of structural parameters and growth conditions we have been able to achieve positive optical gain above 510 nm with low waveguide losses for our double quantum well (DQW) laser structures. The detailed study of optical gain behaviour reveals a small variation of inhomogeneous broadening of gain spectra with decreasing growth temperature. Additionally, we observe an influence of piezoelectric field on the modal gain amplitude with increasing indium content. Moreover, we discuss the impact of the nonradiative recombination processes on the optical gain. We observe a correlation between defect recombination and the inhomogeneous broadening, associated with the increased strain at high In content.

HL 64.2 Wed 16:45 EW 202

Impact of silane on heteroepitaxial growth and properties of a-plane GaN — •Matthias Wieneke, Thomas Hempel, Hartmut Witte, Antje Rohrbeck, Peter Veit, Jürgen Bläsing, Armin Dadgar, Jürgen Christen, and Alois Krost — Otto-von-Guericke-Universität Magdeburg, FNW/IEP, Universitätsplatz 2, 39106 Magdeburg

Silane is a well-established Si precursor to achieve n-type doped GaN layers. In the case of a-plane GaN layers we have demonstrated earlier a significant reduction of basal plane stacking faults to less than 10^4 cm^{-1} by using a silane flow rate to get a nominal Si doping level in the range of 10^{20} cm^{-3} [1]. By varying the silane flow rate as well as other growth parameters, e. g., growth temperature, V/III ratio, reactor pressure, their influences on the morphological and micro structural properties of Si doped a-plane GaN were investigated. Furthermore, we also found an evident dependency on the buffer layer thickness. Here heavily Si doped GaN grown on an about 1.5 μm thick coalesced GaN buffer layer exhibits no defect reduction. Based on these results some possible causes of the successful BSF reduction, e.g., selective etching or SiN nanomasking, will be discussed. [1] Wieneke et al., Physica Status Solidi B 248, 578 (2011)

HL 64.3 Wed 17:00 EW 202

In-situ Measurements and X-ray Diffraction of AlInN/AlGaN Distributed Bragg Reflectors — •Christoph Berger, Jürgen Bläsing, Armin Dadgar, Alexander Franke, Thomas Hempel, Jürgen Christen, and Alois Krost — Otto-von-Guericke-Universität Magdeburg

We report on the MOVPE-growth of lattice-matched $Al_{0.85}In_{0.15}N$/ $Al_{0.2}Ga_{0.8}N$ distributed Bragg reflectors (DBRs) with up to 45 layer pairs. These DBRs are suited as bottom mirrors in GaN-based microcavities for the realization of vertical cavity surface emitting lasers or even polariton lasers, which are working in the strong coupling regime. For the latter high Q-factors of the microcavities are prerequisite, thus the mirrors need to exhibit reflectivities above 99 %. To achieve such values, a high number of mirror pairs is required. Thus, the structures become vulnerable to relaxation processes or crack formation. Furthermore, the mirrors have to be laterally and vertically homogeneous with smooth interfaces. To evaluate the strain-state and the smoothness already during growth, the process was monitored by in-situ curvature and reflectance measurements. Subsequently, the Bragg reflectors were investigated by different methods of X-ray diffraction (XRD). This included high resolution XRD, asymmetrical reciprocal space mapping, as well as experiments under grazing incidence and in transmission geometry. From these various measurements, it could be ascertained that the crack-free structures are grown fully strained and possess a high structural and optical quality, enabling reflectivities of 99 % in the near UV region.

HL 64.4 Wed 17:15 EW 202

Pulsed growth of InN and $Ga_{1-x}In_xN$ with large x by MBE — •Andreas Kraus, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Technische UniversitätBraunschweig, Institut für Angewandte Physik, Mendelssohnstraße 2, 38106 Braunschweig

High In content GaInN is still a material which gains much attention due to its outstanding optical and electrical properties. Because of the large lattice mismatch and differences in bond strength to nitrogen high quality material is very hard to achieve.
To get a deeper understanding of the growth kinetics of this material system, InN and GaInN layers were grown on GaN templates by radio frequency molecular beam epitaxy using a pulsed growth mode. The approximately 100 nm thick InN layers were sequentially grown in 352 periods of $c_0/2$ In and N followed by a few seconds where only nitrogen reaches the surface. Hereby the time of nitridation was varied. The growth was monitored in-situ by reflection high energy electron diffraction and by optical reflectometry as well as ex-situ by atomic force microscopy and high resolution X-ray diffraction. Comparing the samples grown with different nitridation times during every In pulse, the samples with the longest nitridation time exhibit best structural quality in terms of XRD rocking widths and surface roughness measured by atomic force microscopy.
The results of these experiments were used to realize $Ga_{1-x}In_xN$ layers with x≈0.9. Also superlattice structures, where nominally 2 nm GaN are followed by $c_0/2$ InN, were grown. However, XRD analysis reveals that instead of pure InN, $Ga_{1-x}In_xN$ with x ≈ 0.3 is obtained.

HL 64.5 Wed 17:30 EW 202

Determination of indium content in semipolar GaInN multiple quantum well samples using XRD — •Heiko Bremers[1], Holger Jönen[1], Uwe Rossow[1], Stefan Schwaiger[2], Ferdinand Scholz[2], and Andreas Hangleiter[1] — [1]TU Braunschweig, Institute of Applied Physics, Braunschweig — [2]Universität Ulm, Institute of Optoelectronics, Ulm

X-ray diffraction is one of the most important tools to determine the structural properties of solids. In the III-nitrides it has been used very successfully to determine compositions of ternary layers in polar as well as in non-polar samples. In semipolar samples additional shear stresses result in a change of the angles between base vectors. In order to quantify these changes we have to rotate the tensors describing Hookes law to a new coordinate system S'. By using the fact that in growth direction the normal stress equals zero, one in principle is able to determine the composition.

For the example of $(11\bar{2}2)$ semipolar samples we will discuss the difficulties in really determining the composition. The properties of this particular orientation can be achieved by a rotation around the m-axis by an angle of approximately 58.4°. The rotation changes the base system S (x, y, z) from $[2\bar{1}\bar{1}0]$, $[01\bar{1}0]$, [0002] direction towards the new system S' (x', y', z') $[\bar{1}\bar{1}23]$, $[01\bar{1}0]$, $[2\bar{1}\bar{1}2]$ direction. Unfortunately there are no lattice planes available to directly measure the strain component in the new x-direction. We will discuss a way out of this dilemma by using relations between the old and new base system.

HL 64.6 Wed 17:45 EW 202

STEM and XRD investigations of ultra thin GaInN/GaN quantum wells with high indium content — •Lars Hoffmann[1], Heiko Bremers[1], Holger Jönen[1], Uwe Rossow[1], Thorsten Mehrtens[2], Marco Schowalter[2], Andreas Rosenauer[2], and Andreas Hangleiter[1] — [1]TU Braunschweig, Institute of Applied Physics, Braunschweig, Germany — [2]Universität Bremen, Institute of Solid State Physics, Bremen, Germany

While GaN-based blue light emitting devices exhibit exceptionally large internal quantum efficiencies (up to 90% at room temperature) their green counterparts quickly become less efficient at longer wavelength ("green gap"). Using Transmission Electron Microscopy (TEM) and X-ray diffraction (XRD) we have studied ultrathin (< 2nm) quantum well (QW) structures with high indium content suitable for blue-green laser and light emitting diodes. We investigate the homogeneity

of indium incorporation into the quantum well and its interface roughness. In order to obtain high indium content quantum wells we need to decrease the growth temperature, leading to poorer optical and structural quality of the GaN barriers. In our XRD and TEM measurements we observe in some cases that indium is also incorporated into the barriers. Depending on growth conditions, we observe an indium tail or even step-like structures in the barriers, caused by excess indium supplied during quantum well growth. Therefore the temperature profile and the gallium/indium ratio during growth need to be optimized to avoid indium segregation and unwanted incorporation into the barriers.

HL 64.7 Wed 18:00 EW 202

Optimierung der Präparation von GaN-basierten Proben mittels Niedrigenergie-Ionendünnung für (S)TEM — •Stephanie Bley[1], Thorsten Mehrtens[1], Andreas Rosenauer[1] und Satyam Parlapalli[2] — [1]AG Elektronenmikroskopie, Institut für Festkörperphysik, Universität Bremen, Otto-Hahn-Allee 1, 28359 Bremen, Deutschland — [2]Institute of Physics, Bhubaneswar 751005, India

Die Präparation von TEM-Proben mittels hochenergetischer Ionenstrahlen (Energie $>$ 5keV) bewirkt die Bildung von Punktdefekten bzw. die Amorphisierung der Probenoberfläche. Die amorphe Oberflächenschicht führt im TEM zu einem fleckigen, inhomogenen Bildkontrast, wodurch eine quantitative Analyse der Probe erschwert wird. Anhand von (S)TEM-Untersuchungen an GaN-basierten Proben wird gezeigt, dass durch die Präparation mittels Niedrigenergie-Ionendünnung (Energie $<$ 1keV) die amorphe Oberflächenschicht deutlich reduziert und der Bildkontrast verbessert wird. Dazu werden die experimentell ermittelten Daten für verschiedene Ionendünnungsverfahren mit simulierten Daten (Monte Carlo Simulation, SRIM) verglichen. Außerdem werden Dickenprofile der Probe durch den Vergleich der normierten Intensität aus STEM-Bildern mit einer durch die Frozen Lattice-Methode simulierten Referenzintensität erzeugt. Anhand der Änderung der Probendicke vor und nach der Behandlung mit niederenergetischen Ionen wird die Ätzrate bestimmt.

HL 64.8 Wed 18:15 EW 202

Bestimmung der Gitterparameter in orthorombisch verzerten semipolaren und unpolaren Wurtzitstrukturen — •Martin Frentrup, Tim Wernicke, Markus Pristovsek und Michael Kneissl — TU Berlin, EW 6-1, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany

Heteroepitaktisch gewachsene Nitridhalbleiterschichten mit semi- oder nichtpolarer Orientierung werden durch anisotrope Gitterfehlanpassungen rhomboedisch verzerrt. Dies macht die exakte Bestimmung der Gitterparameter und somit der Stöchiometrie in solchen Schichten mit hochauflösender Röntgenbeugung schwierig.

Wir haben ein Model entwickelt, das diese orthorombische Verzerrung berücksichtigt und mit dessen Hilfe es möglich ist die Gitterparameter und die Verzerrung an Hand nur weniger Röntgenreflexe zu bestimmen. Durch günstige Wahl der Koordinatenachsen und Ausnutzung von Symmetrien konnten wir die Zahl der unabhängigen Parameter von sechs auf vier reduzieren. Unter der Annahme, dass die Verzerrung nur zu einer kleinen Abweichung von der idealen Wurtzitstruktur führt, lässt sich die verallgemeinerte Gleichung für den Netzebenabstand d_{hkl} linearisieren. Dadurch reichen bereits vier voneinander unabhängige XRD-Reflexe aus, um das Gleichungssystem zu lösen und die vier Parameter eindeutig zu bestimmen. Hieraus können mit Hilfe unseres Models weitere Informationen zur Kristallschicht, wie die Gitterfehlanpassug, der Verspannungszustand und die stöchiometrische Zusammensetzung berechnet werden.

HL 65: Transport Properties II (Theory)

Time: Wednesday 17:00–18:15 Location: ER 164

HL 65.1 Wed 17:00 ER 164

Boltzmann equation approach to rectification at a potential step — •Stephan Rojek, Daniel Urban, Fred Hucht, and Jürgen König — Theoretische Physik, Universität Duisburg-Essen and CeNIDE, 47048 Duisburg, Germany

We study theoretically a two-dimensional electron gas with two regions separated by a potential step. A bias voltage parallel to the potential step leads to a transverse voltage proportional to the square of the applied bias voltage. This effect can be exploited for rectification, since the transverse voltage does not depend on the bias polarity. Our analysis is motivated by recent experiments [1, 2].

We model the system by means of the Boltzmann equation in the relaxation time approximation. We consider different relaxation times for scattering processes with energy transfer larger and lower than k_BT based on inelastic and elastic scattering processes, respectively. In order to study the rectification effects, the distribution function has to be calculated to second order in the applied electric field. The contributions from the bulk to the transverse voltage promise to be relevant for the measured data. Direct effects of the potential step depend on the energy dependence of the relaxation times. The potential step leads to a finite charge accumulation on the length scale of the energy diffusion length. The transverse electric field of this non-uniform charge distribution can be the leading contribution to the transverse voltage. We discuss the relevance of our results for the measurements in Ref. [1, 2].

[1] A. Ganczarczyk *et al.*, arXiv:0804.0689v3 (2009).
[2] A. Ganczarczyk *et al.*, AIP Conf. Proc. **1199**, 143 (2009).

HL 65.2 Wed 17:15 ER 164

Multiscale modeling of silicon nanowire FETs for sensor applications — Daijiro Nozaki, •Jens Kunstmann, Felix Zörgiebel, and Gianaurelio Cuniberti — Institute for Materials Science and Max Bergmann Center of Biomaterials, Dresden University of Technology, Germany

We present a theoretical framework for the calculation of charge transport through nanowire-based Schottky-barrier field-effect transistors (FETs) that is conceptually simple but still captures the relevant mechanisms of the transport process [1]. Our approach combines two approaches on different length scales: (1) the finite element method is used to model realistic device geometries and to calculate the electrostatic potential across the Schottky barrier by solving the Poisson equation, and (2) the Landauer-Büttiker approach combined with the method of non-equilibrium Green's functions is employed to calculate the charge transport through the device. Our model correctly reproduces typical I-V characteristics of FETs, and the dependence of the saturated drain current on the gate field and the device geometry are in good agreement with experiments. Our approach is suitable for 1D Schottky-barrier FETs of arbitrary device geometry and it is intended to be a simulation platform for the development of nanowire-based sensors.

[1] D. Nozaki, J. Kunstmann, F. Zörgiebel, and G. Cuniberti, Nanotechnology 22, 325703 (2010).

HL 65.3 Wed 17:30 ER 164

Effect of pH value and ionic strength on transport characterics of nanowire FETs — •Daijiro Nozaki, Jens Kunstmann, Felix Zörgiebel, and Gianaurelio Cuniberti — Institute for Materials Science and Max Bergmann Center of Biomaterials, TU Dresden, 01062 Dresden, Germany

For the development of ultra sensitive electrical bio/chemical sensors based on nanowires, the influence of the liquid environment such as the pH value, ionic strength of the solution, and the surface charge on the electron transport has to be understood. For this purpose, we implemented a modified Poisson-Boltzmann theory into a previously-developed multiscale model [1], which combines two models on different scales: (1) the finite element method for the calculation of electrostatic potential and (2) a Landauer transport approach based on non-equilibrium Green's functions formalism to calculate the charge transport through the device. We investigated the changes of the electric potential and transport characteristics due to the ionic concentration, the pH value, and surface charge densities, systematically. Using this model, we could reproduce the reduction of sensitivity of the sensors due to the screening effect from the electrolyte. [1] D. Nozaki, J. Kunstmann, F. Zörgiebel, and G. Cuniberti Nanotechnology 22, 325703 (2010).

HL 65.4 Wed 17:45 ER 164

Towards a Unifying Framework of AC Quantum Transport for Nanodevices including Scattering — •Diego Kienle — Theoretische Physik I, Universit\"at Bayreuth, 95440 Bayreuth

At present there is a significant need to model and understand dynamic quantum transport in realistic nanoscale devices including non-idealities e.g. due to scattering to ultimately guide the development of novel quantum devices operating at terahertz (THz) frequencies, even exploiting plasmon waves for THz sensing and emission. To step towards this goal, we discuss in this talk a general approach for linear AC quantum transport formulated by means of Non-Equilibrium Green Functions (NEGF) that is able to simultaneously handle the open nature of transport incorporated through self-energies, the complex dielectric environment typical for realistic devices, and most importantly the self-consistent dynamic coupling of the space-dependent AC charge and potential, the latter being essential to capture the plasmonic response of the system. Employing this approach, it is then discussed how scattering due to charged impurity atoms placed along the channel impacts the high-frequency response of nanodevices, specifically their plasmonic THz spectrum by example of a p-type carbon nanotube transistor. It is shown that particularly positively charged impurities cause a severe degradation of the THz plasmon modes, which vanish when the impurity concentration is sufficiently high. In this case, the AC response is solely determined by the single-particle excitation spectrum. [1] D. Kienle and F. Leonard, PRL 103, 026601 (2009). [2] D. Kienle, M. Vaidyanathan, and F. Leonard, PRB 81, 115455 (2010).

HL 65.5 Wed 18:00 ER 164

The effect of edge reconstruction in the electronic transport through transition metal dichalcogenide nanoribbons — •Mahdi Ghorbani Asl[1,2], Agnieszka Kuc[1], Gerd Schön[2], and Thomas Heine[1] — [1]Research Center for Functional Materials and Nanomolecular Science, Jacobs University Bremen, Bremen, Germany — [2]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie (KIT), Karlsruhe, Germany

Transition metal dichalcogenides, TX2 (T = Mo and W; X = S, Se, and Te), have become a focus of the substantial recent research, especially in their 2D crystalline forms in the wake of comprehensive research on graphene. Recent experiments have demonstrated that TX2 exhibit promising potentials for the next generation electronics [1]. However, a nanoflake or a nanoribbon can show different physical properties because of quantum confinement effects. In particular, edge atoms may influence the electronic transport properties of such low-dimensional materials. Using density functional based tight-binding (DFTB) method [2] combined with the Green's function technique [3], we have developed a code for coherent quantum transport calculations. We investigate the electron transport properties with a focus on the nature of the edge states in different type of nanoribbons.

[1] B. Radisavljevic, A. Radenovic, J. Brivio, V. Giacometti1 and A. Kis, Nature Nanotech 6, 147 (2011). [2] G. Seifert, D. Porezag, and T. Frauenheim, Int. J. Quantum Chemistry 58, 185 (1996) [3] S. Datta, Quantum transport: Atom to transistor, Cambridge University Press (2005).

HL 66: Transport Properties III (Experiments)

Time: Wednesday 18:15–19:30 Location: ER 164

HL 66.1 Wed 18:15 ER 164

Picosecond time-resolved photocurrents in GaAs nanowires — •Nadine Erhard[1], Leonhard Prechtel[1], Milan Padilla[1], Helmut Karl[2], Gerhard Abstreiter[1], Anna Fontcuberta[3], and Alexander Holleitner[1] — [1]Walter Schottky Institut and Physik-Department, TU München, Am Coulombwall 4a, D-85748 Garching, Germany — [2]Institute of Physics, University of Augsburg, D-86135 Augsburg, Germany — [3]Laboratoire des Materiaux Semiconducteurs, Ecole Polytechnique Federale de Lausanne, 1015 Lausanne, Switzerland

Conventional scanning photocurrent microscopy (SPCM) experiments on semiconductor nanowires are typically limited to timescales exceeding 10 ps. Yet, it is known from optical experiments that carrier relaxation and transport processes can occur on much faster timescales in semiconducting nanowires. We therefore apply a recently developed pump-probe photocurrent spectroscopy to investigate the photocurrent dynamics of p-doped GaAs nanowires with a picosecond time-resolution. Hereby, the ultrafast photocurrent response of the nanowire is sampled at a field probe in a stripline circuit. We discuss ultrafast thermoelectric, displacement, and carrier lifetime limited currents as well as the time-resolved transport of photogenerated holes.

HL 66.2 Wed 18:30 ER 164

Transporteigenschaften von (BGa)((As)P)-Kontaktschichten für monolithisch integrierte Ga(NAsP)-Laser auf Si-(001)-Substraten — •Christian Lück[1], Martin Zimprich[1], Sven Liebich[1], Andreas Arndt[1], Andreas Beyer[1], Bernardette Kunert[2], Kerstin Volz[1] und Wolfgang Stolz[1] — [1]Struktur- und Technologieforschungslabor (STRL) und Fachbereich Physik, Philipps-Universität Marburg, Hans-Meerwein-Straße, 35032 Marburg — [2]NAsP III/V GmbH, Am Knechtacker 19, 35041 Marburg

Die monolithische Integration von aktiven optischen Komponenten in die Silizium-Nanoelektronik führt zu neuartigen integrierten Schaltkreisen. Der hier vorgestellte Lösungsansatz für die Laserkomponente ist das verdünnt-stickstoffhaltige Materialsystem Ga(NAsP), das eine direkte Energielücke aufweist und gitterangepaßt auf Si-(001)-Substrat mittels der metall-organischer Gasphasenepitaxie abgeschieden werden kann. Erste Breitstreifenlaserstrukturen zeigen Laseremission bis 165 K mit einem Schwellstrom von 1,5 kA/cm^2 [1]. In diesen gitterangepassten Laserstrukturen werden (BGa)P-Kontaktschichten sowie (BGa)(AsP)-Wellenleiterschichten eingesetzt. Die elektrischen Transporteigenschaften dieser Schichtstrukturen wurden eingehend mittels temperatur-abhängiger Magnetotransportmessungen als Funktion der Dotierung und der Zusammensetzung aufgeklärt und im Hinblick auf den möglichen Einsatz in effizienten elektrischen Injektionslaserstrukturen auf Si (001)-Substrat optimiert.

[1] Liebich et al., Appl. Phys. Lett. 99, 071109 (2011).

HL 66.3 Wed 18:45 ER 164

Ballistic and thermoelectric contributions to transverse rectification in density-modulated 2D-systems — •Arkadius Ganczarczyk[1], Andy Quindeau[1], Martin Geller[1], Axel Lorke[1], Dirk Reuter[2], and Andreas D. Wieck[2] — [1]Experimental Physics and CeNIDE, Universität Duisburg-Essen — [2]Chair of Applied Solid State Physics, Ruhr-Universität Bochum

We investigate tunable transverse rectification in a density-modulated two-dimensinal electron gas (2DEG) from $T = 1.8$ K to 300 K. The 2DEG is patterned into a hall bar geometry. Using gate electrodes we induce two stripes of different charge carrier densities along the channel. The resulting density gradient perpendicular to the channel induces a transverse voltage, which - due to the symmetry of the device - does not change polarity when the current direction is reversed [1, 2].

To acquire a deeper insight into the physics behind this rectification effect, we investigate its dependence on modulation strength, temperature and the width of the stripes. The results are discussed using a billiard model, which describes the propagation of ballistic electrons in density-modulated 2D-systems. Also possible thermoelectric effects in the structure are considered. In order to calculate the expected thermoelectric voltage in such a system, the electron temperatures in the heated electron gas are determined experimentally. Both models are compared in order to obtain a deeper insight into this novel rectification effect.

[1] A. Ganczarczyk *et al.*, preprint:arXiv:0804.0689v3 (2009).
[2] A. Ganczarczyk *et al.*, AIP Conf. Proc. 1199, 143 (2009).

HL 66.4 Wed 19:00 ER 164

GaAs/AlGaAs resonant tunneling diodes with a GaInNAs absorption layer for telecommunication light sensing — •Fabian Hartmann, Fabian Langer, Dirk Bisping, Sven Höfling, Martin Kamp, Alfred Forchel, and Lukas Worschech — Technische Physik, Physikalisches Institut, Universität Würzburg and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Am Hubland, D-97074 Würzburg, Germany

GaAs based double AlGaAs barrier resonant tunneling diodes (RTD) were grown by molecular beam epitaxy with a nearby, lattice-matched GaInNAs absorption layer. The electrical and optical properties of the RTDs were investigated for different thicknesses of a thin GaAs buffer layer incorporated between the AlGaAs barrier and the GaInNAs absorption layer. RTD mesas with ring contacts and an aperture for optical excitation of charge carriers were fabricated with diameters from 12 down to 1 micrometer. A resonant current peak was observed for all samples at room temperature with a maximum peak-to-valley ratio of 3.9. Under illumination with laser light of 1300 nm wavelength, a pronounced photo-effect is found with sensitivities of about 1000 A/W.

HL 66.5 Wed 19:15 ER 164

Bistable swichting in double electron layer Y branch switches — •Stefan Kremling, Sven Höfling, Lukas Worschech, Martin Kamp, and Alfred Forchel — Technische Physik, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Physikalisches Institut, Universität Würzburg, Am Hubland, Bavaria, D-97074 Würzburg, Germany

Nanoelectronics with III-V compound semiconductors have attracted considerable attention due to their outstanding electron transport properties. Y-branch switches (YBSs) which consist of a drain split along a branching section into two branches have been proposed as efficient switching devices. Recently, selfgating of YBSs has been observed in the nonlinear regime at bias voltages of a few Volts, where one branch serves as gate to control the conductance of the other branch. In order to enhance the selfgating for small bias voltages, the couplings between the branches have to be maximized, e.g. by closely spaced electron layers. By means of electron beam lithography, YBSs were defined in double electron layers based on GaAs quantum wells embedded in AlGaAs barriers. The transfer characteristics of the YBSs were tested and maximum transconductances values of e/kT were observed at the transition to bistable switching. A model for a dynamic gate operation is proposed and compared with the measurements.

HL 67: Invited Talk: Dörthe Eisele

Time: Wednesday 17:15–17:45 Location: ER 270

Invited Talk HL 67.1 Wed 17:15 ER 270

Excitons in Artificial Light-Harvesting Antenna Systems — •Dorthe M. Eisele[1], Dylan H. Arias[1], Colby P. Steiner[1], Robert J. Silbey[1], Xiaofeng Fu[2], Daniela Nicastro[2], Keith A. Nelson[1], and Moungi G. Bawendi[1] — [1]Massachusetts Institute of Technology, Cambridge, USA — [2]Brandeis University, Waltham, USA

Molecular dye aggregates are close analogs of biological light-harvesting systems (LHS), and their hybrids with colloidal semiconductor quantum dots (QDs) extend the analogy to include reaction centers (RC). By means of Cryo-TEM, linear spectroscopy, and nonlinear 2D electronic spectroscopy, we show that nanotubular dye aggregates consist of two separate, weakly coupled exciton systems. In contrast, packages of these nanotubes, formed through supplementary synthetic methods, no longer content of separate excitonic systems but rather of one strongly coupled system. These results elucidate that excitonic interactions in such nanoscale systems are not only highly sensitive to changes within the supramolecular structure, but also to changes in their higher ordering. For inorganic/organic hybrid systems we show that light absorption by dye aggregates (to mimic a LHS) followed by emission from electrostatically conjugated QDs (to mimic a RC) provides a platform to address fundamental questions of what properties control the energy transport processes in excitonic nanoscale systems.

HL 68: Photovoltaics: Organic Semiconductors

Time: Wednesday 17:45–19:30 Location: ER 270

HL 68.1 Wed 17:45 ER 270

Quantum coherence controls the charge separation in a prototypical artificial light harvesting system — •Sarah Maria Falke[1], Carlo Andrea Rozzi[2], Nicola Spallanzani[2], Angel Rubio[3], Elisa Molinari[2], Daniele Brida[4], Margherita Maiuri[4], Giulio Cerullo[4], Heiko Schramm[1], Jens Christoffers[1], and Christoph Lienau[1] — [1]Carl von Ossietzky Universität, Oldenburg, Germany — [2]CNR, Centro S3, Modena, Italy — [3]Fritz-Haber-Institut, Berlin, Germany — [4]IFN-CNR, Politecnico di Milano, Italy

In artificial light harvesting systems the conversion of light into electrical or chemical energy happens on the femtosecond time scale and is thought to involve the incoherent jump of an electron from the optical absorber to an electron acceptor. Here we investigate the primary process of electronic charge transfer dynamics in a supramolecular triad, a prototypical elementary component for an artificial photosynthetic/photovoltaic system. Combining coherent femtosecond spectroscopy and first-principles quantum dynamics simulations, we provide compelling evidence that the driving mechanism of the photoinduced current generation cycle is a quantum correlated wavelike motion of electrons and nuclei on a timescale of few tens of femtoseconds. Our work highlights the fundamental role played by the chemical interface between the light-absorbing chromophore and the charge acceptor in triggering the coherent wavelike electron-hole splitting.

HL 68.2 Wed 18:00 ER 270

Doping induced performance enhancement in low bandgap polymer:fullerene solar cells — •Antonietta De Sio[1], Ali Veysel Tunc[1], Daniel Riedel[2], Enrico Da Como[2], Jürgen Parisi[1], and Elizabeth von Hauff[3] — [1]Energy and Semiconductor Research Laboratory, Institute of Physics, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany — [2]Photonics and Optoelectronics Group, Department of Physics and CeNS, Ludwig-Maximilians-Universität München, 80799 Munich, Germany — [3]Institute of Physics, Albert-Ludwigs University of Freiburg, 79104 Freiburg, Germany

We investigate the effect of molecular doping in poly[2,6(4,4-bis-(2-ethylhexyl)-4H-cyclopenta[2,1-b:3,4-b0]-dithiophene)-alt-4,7-(2,1,3-benzothiadiazole)] (PCPDTBT) and its blend with [6,6]-phenyl-C61-butyric acid methyl ester (PCBM). Tetrafluorotetracyanoquinodimethane (F4-TCNQ) is used to dope PCPDTBT via co-solution at different concentrations. The effect of doping on the transport properties of the neat polymer as well as of the blends is investigated with field effect measurements while photoinduced absorption spectroscopy is employed to get information on the charge separation efficiency. Bulk heterojunction solar cells with molecularly doped active layers were also prepared and characterized. We demonstrate that molecular doping is a simple and effective method to improve the performance in polymer:fullerene solar cells by reducing the recombination and increasing the hole mobility.

HL 68.3 Wed 18:15 ER 270

Field dependence of charge carrier generation in MDMO-PPV based organic solar cells — •Julia Kern[1], Clemens Grünewald[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, D-97074 Würzburg

One of the key issues of organic photovoltaics is the fundamental understanding of charge photogeneration and recombination. The dissociation of the singlet excitons created in the polymer is likely to occur via one of two distinct routes, the first one being direct dissociation to free charge carriers and the second one involving an intermediate step comprising the formation of an interfacial charge transfer exciton (CTE). In order to shed light onto the relevance of the respective dissociation patterns, we investigated the field dependence of CTE photoluminescence as a means of probing geminate recombination as well as of the photocurrent, being a direct indicator for free charge

carriers. Starting with MDMO-PPV blended with PCBM as a reference system, we employed various fullerene derivatives, systematically changing the lowest unoccupied molecular orbital (LUMO) and thus the open circuit voltage, correspondingly. This approach allows us to study the influence of the different parameters on the CTE binding energy, which can be derived from the dissociation probability predicted by the Onsager Braun model. In view of our results, we discuss the correlation between this binding energy and the field dependent charge generation.

HL 68.4 Wed 18:30 ER 270

Field- and Temperature Dependence of charge Photogeneration in organic bulk heterojunction solar cells — •Stefan Walter[1], Markus Mingebach[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, D-97074 Würzburg

A topic of high interest is to understand the principles of charge carrier generation and recombination in organic bulk heterojunction solar cells. Generation of free charge carriers with high yield is a crucial step to ensure high power conversion efficiencies. The dissociation of singlet excitons into free charge carriers may occur either directly or via the intermediate step involving Coulomb bound charge transfer states. The field dependence of charge carrier generation can help to distinguish between these two channels. In the case of the poly(3-hexylthiophene-2,5-diyl):[6,6]-phenyl-C61 butyric acid methyl ester (P3HT:PC60BM) blends almost no field dependence of extracted charge carrier density under positive bias between 0V and open circuit voltage was observed at room temperature [1], thus indicating a direct generation. In contrast we show a strong field dependence for poly[2-methoxy-5-(3′,7′-dimethyloctyloxy)-1,4-phenylenevinylene] :[6,6]-phenyl-C61 butyric acid methyl ester (MDMO-PPV:PC60BM) blends by applying field- and temperature dependent time delayed collection field measurements.

[1] J. Kniepert, M. Schubert, J.C. Blakesley and D. Neher, J. Phys. Chem. Lett., 2, 700-705 (2011).

HL 68.5 Wed 18:45 ER 270

Recombination Processes in Disordered Organic Bulk-Heterojunction Solar Cells — •Alexander Wagenpfahl[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius-Maximilians-University of Würzburg, 97074 Würzburg, Germany — [2]Bavarian Centre for Applied Energy Research (ZAE Bayern), 97074 Würzburg, Germany

In recent years the charge carrier recombination mechanisms in organic bulk-heterojunction solar cells have been controversially discussed. For blended organic semiconductors recombination orders between one, two or even higher have been reported. The origin of these observations, the recombination pathways as well as their impact on the device performance, still need further investigations to be understood in detail. In an organic bulk-heterojunction solar cell two blended but spatially separated semiconductor phases are used to gain current from the incident light. Due to their spatial disorder organic semiconductors generally show a Gaussian distribution of the molecular orbitals. Introducing this disorder into our macroscopic numerical device simulation, we show the possible interaction pathways of conducting and trapped electrical charges within the multiple trapping and release model. Based on these results we illustrate the impact of various recombination pathways for charge carriers on the observed current-voltage characteristics under consideration of phase separation aspects. Our results clearly show that it is crucial for the performance which recombination pathway is dominant in organic bulk-heterojunction solar cells and which role the energetic disorder plays in these processes.

HL 68.6 Wed 19:00 ER 270

Time and Spatially Resolved 1D-MonteCarlo Simulations on Charge Transport — •Manuel Ruf[1], Jens Lorrmann[1], Vladimir Dyakonov[1,2], and Carsten Deibel[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, D-97074 Würzburg

Charge transport in organic materials is one of the limiting steps for highly efficient solar cells. Further insight into the microscopic processes promise a better unterstanding of the underlying charge transport.

In this study we describe charge transport by a one dimensional Monte Carlo (1D-MC) simulation, which is based on multiple trapping and release events of charge carriers into a density of trap states while moving through the sample due to thermal and electric field energy. As long as a charge carrier is trapped, its contribution to current is zero. The actual form of the density of trap states determines the charge carrier release time therefore affecting the shape of the transient. The time dependence of the model allows simulation of transient measurement techniques, such as Time-Of-Flight (TOF) or charge extraction by linear increasing voltage (CELIV).

Hence we can probe the individual behaviour of single charge carriers, which allows studies of propagation of the spatial charge carrier distribution and energetic relaxation for different model parameters. The simplicity of this model provides low computing times, yet allows to reproduce physical behaviour as observed in measurements on regio regular poly(3-hexyl thiophene-2,5-diyl) (P3HT 4002E).

HL 68.7 Wed 19:15 ER 270

Thermodynamic efficiency limit of molecular donor-acceptor solar cells and its application to diindenoperylene (DIP)-based devices — •Mark Gruber[1], Julia Wagner[1], Ulrich Hörmann[1], Andreas Opitz[2], and Wolfgang Brütting[1] — [1]Institute of Physics, University of Augsburg, Germany — [2]Institute of Physics, Humboldt University, Berlin, Germany

Based on the principle of detailed balance we have developed a modified Shockley-Queisser theory including the effects of interfacial charge transfer (CT) states that allows for a quantitative assessment of the thermodynamic efficiency limits of molecular donor(D)/acceptor(A) solar cells. Key parameters entering the model, apart from the optical gap of the absorber material, are the energy (E_{CT}) and relative absorption strength (α_{CT}) of the CT state. We demonstrate how the open-circuit voltage and thus the power conversion efficiency are affected by different parameter values. Furthermore, we show that temperature dependent device characteristics can serve to determine the CT energy, and thus the upper limit of V_{OC} for a given D/A combination, as well as to quantify non-radiative recombination losses. The model is applied to DIP based photovoltaic devices, where open-circuit voltages between 0.9 and 1.4 V, depending on the partner, have recently been reported [1,2].

[1] J. Wagner et al., *Adv. Func. Mater.* 2010, 20, 4295.
[2] U. Hörmann et al., *Phys. Stat. Sol. RRL* 2011, 5, 241.

HL 69: Quantum Dots and Wires: Transport Properties II (mainly Quantum Dots)

Time: Wednesday 17:15–19:15 Location: EW 203

HL 69.1 Wed 17:15 EW 203

Influence of spin relaxation and Coulomb correlations on the dynamics of an open quantum dot — •Benjamin Baxevanis[1], Andreas Beckel[2], Bastian Marquardt[2], Martin Geller[2], Axel Lorke[2], and Daniela Pfannkuche[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [2]Fakultät für Physik and CeNIDE, Universität Duisburg-Essen, Duisburg, Germany

The significance of Coulomb interaction and spin relaxation on the time-dependent dynamics of a quantum dot that is weakly coupled to an electronic reservoir is investigated. The two systems are assumed to be initially separated and we calculate the time evolution as the tunneling between the reservoir and the quantum dot is instantly switched on. The charging of a single quantum dot in the sequential tunneling regime is determined by using a master equation for the occupation probabilities. To incorporate many-body effects the eigenstates of a finite number of correlated electrons in the quantum dot obtained by the exact diagonalization method are taken into account.

The electrons in the quantum dot can interact with phonons and the electron spin can couple to their orbital motion or to nuclear spin which leads to relaxation. We consider two types of relaxation processes: 1. an orbital relaxation in the dot, which is instantaneous compared to the tunneling dynamics and 2. a spin relaxation with a time scale, which can be in the order of the tunneling times. We compare how

different spin-relaxation times and the Coulomb correlations impact the charging dynamics of the quantum dot.

HL 69.2 Wed 17:30 EW 203

A self-referenced single-electron current source — •Lukas Fricke, Michael Wulf, Frank Hohls, Bernd Kaestner, Ralf Dolata, Philipp Mirovsky, Klaus Pierz, Thomas Weimann, and Hans W. Schumacher — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

A promising candidate for a quantum-based current source is the non-adiabatic electron pump [1], based on a dynamic quantum dot in a semiconducting nanostructure. High current outputs [2] and parallelization [3] for further increased currents have been demonstrated. However, to employ this device as a new current standard or as an on-demand electron source, a high pumping reliability and therefore a measure of single-electron pump accuracy is needed.

We demonstrate a mesoscopic circuit employing a series of semiconducting dynamic quantum dots in combination with metallic single electron transistors (SET) able to monitor the electrostatic potential between the pumps on the single-electron level and thereby individual pump errors. We operate the pumps in a single-shot mode, pumping one electron from node to node with a fidelity verified by the SETs. The rare pump errors can be identified and attributed to each pump so that the compound device acts as a highly accurate self-referenced quantum current source [4].

[1] B. Kaestner et al., Phys. Rev. B 77, 153301 (2008)
[2] M. D. Blumenthal et al., Nat. Phys. 3, 343 (2007)
[3] P. Mirovsky et al., Appl. Phys. Lett. 97, 252104 (2010)
[4] M. Wulf and A. B. Zorin, e-print arXiv:0811.3927

HL 69.3 Wed 17:45 EW 203

Transient capacitance measurements on GaAs quantum dots — •Jochen Kerbst, Pascal Schoof, Christian Heyn, and Wolfgang Hansen — Institut für Angewandte Physik, Jungiusstr 11, 20355 Hamburg

We investigate the basic physical properties of GaAs quantum dots (QDs) like activation energy for charge carrier emission and capture cross section. For this we embed a layer with QDs in the depletion zone of a Si-doped AlGaAs Schottky barrier and apply Deep Level Transient Spectroscopy (DLTS) [1]. The self assembled GaAs QDs are fabricated in a molecular beam epitaxy (MBE) system by first generating nanoholes in Si-doped AlGaAs utilizing Local Droplet Etching (LDE) [2]. Subsequent filling of the nanoholes with GaAs provides GaAs quantum dots with highly controlled structural properties. This is followed by a further n:AlGaAs layer and a metal gate electrode. For the DLTS measurements we have to separate QD electronic features from deep donors inside the surrounding AlGaAs-matrix. Therefore we have characterized the deep donor levels in AlGaAs as function of the Al concentration.

[1] D.V. Lang, JAP 45, 3023 (1974)
[2] Z. M. Wang, B. L. Liang, K. A. Sablon, G. J. Salamo, Appl. Phys. Lett. 90, 113120 (2007)

HL 69.4 Wed 18:00 EW 203

The influence of charged quantum dots on the transport properties of a two dimensional system — •Simon Wisotzki[1], Andreas Beckel[1], Bastian Marquardt[1], Martin Geller[1], Tobias Nowozin[2], Andreas Marent[2], Dieter Bimberg[2], and Axel Lorke[1] — [1]Faculty of Physics and CeNIDE, University of Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany — [2]Institute for Solid State Physics, Technische Universitaet Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

A crucial point for electrically controlled quantum and memory devices, based on self-assembled quantum dots (QDs), is the read-out of their charge/spin state. Coupling the zero-dimensional QDs to a two-dimensional electron or hole gas (2DEG, 2DHG) by Coulomb interaction enables a non-destructive read-out by a measurement of the conductivity of the two-dimensional system. A time-resolved transport spectroscopy technique was used to separately determine the contributions of the change in charge carrier concentration and mobility to the overall change of conductivity of a 2DEG while charging the QDs with electrons. Here, the influence of individual holes stored inside these QDs on the transport properties of the 2DHG was investigated. We were able to separately determine the contribution of charged QDs as Coulomb scatterers and their influence on the charge carrier density in the 2DHG. Our results enable a deeper understanding of the interfacing between QDs and a 2DEG/2DHG, which is essential for the development of QD based memories, quantum devices or velocity modulated transistors (VMT).

HL 69.5 Wed 18:15 EW 203

Deep-Level Transient Spectroscopy on GaSb/GaAs and $In_{0.25}Ga_{0.75}As$/GaP quantum dots — •Leo Bonato[1], Tobias Nowozin[1], Gernot Stracke[1], Alexander Glacki[1], Andreas Marent[1], Dieter Bimberg[1], Robert Young[2], and Manus Hayne[2] — [1]Institut für Festkörperphysik, TU Berlin, Hardenbergstr. 36, 10623 Berlin — [2]Department of Physics, Lancaster University, Lancaster, LA1 4YW, United Kingdom

Aiming to use self-organized quantum dots (QDs) as storage units for novel memory devices [1], we studied the charge-carrier dynamics during the processes of charging and discharging QDs by using Deep-Level Transient Spectroscopy (DLTS). Since they are the most promising material systems for increasing the storage time in a quantum dot based memory, we investigated type-II GaSb/GaAs QDs and type-I $In_{0.25}Ga_{0.75}As$ QDs on a GaAs interlayer in GaP and extracted localization energies and capture cross sections.

[1] A. Marent et al., *The QD-Flash: A quantum dot-based memory device*, Semicond. Sci. Technol. 26 (2011) 014026

HL 69.6 Wed 18:30 EW 203

HRTEM investigation of InAs/GaAs sub-monolayer structures — •Felix Kiessling[1], Tore Niermann[1], Jan-Hindrik Schulze[2], Tim David Germann[2], André Strittmatter[2], Udo W. Pohl[2], Dieter Bimberg[2], and Michael Lehmann[1] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Straße des 17. Juni 135, 10623 Berlin, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

A promising idea of achieving polarization independent quantum dots (QD) is the deposition of InAs-sub-monolayers (SML) above Stranski-Krastanov $In_xGa_{1-x}As$-QDs. The strain of the QDs influences the growth of the SML stacks. We studied stacks of ten nominal 0.18 nm thick SML of InAs above $In_{0.26}Ga_{0.73}As$ QDs in a CS-corrected FEI Titan 80-300 TEM. In high-resolution TEM-images we could resolve the distinct single layers of the SML stacks. In thin areas, Geometric Phase Analysis is useful to find lattice mismatches caused by the Indium deposition. Furthermore we used the chemical sensitive (002) reflection in the systematic row to observe the Indium in the GaAs-substrate. In a specimen with 1.7 monolayer thick InAs depositions, this chemical sensitive reflection makes it possible to determine the segregation of Indium into the GaAs-substrate.

This work is supported by the DFG Collaborative Research Centre 787 "Semiconductor Nanophotonics".

HL 69.7 Wed 18:45 EW 203

Carrier dynamics in MODFETs with embedded quantum dots — •Michael Narodovitch, Tobias Nowozin, Andreas Marent, and Dieter Bimberg — Institut für Festkörperphysik, TU Berlin, Hardenbergstr. 36, 10623 Berlin

Due to their confining properties self-organized quantum dots (QDs) could have the potential to be used as storage units inside future memory devices. We have studied an AlGaAs-MODFET structure with an embedded layer of self-organized InAs quantum dots. Since the hole charge inside the QDs is coupled to the two-dimensional hole gas (2DHG) underneath the QD layer, the emission and capture processes between the QDs and the 2DHG can be directly observed in the source/drain current. By using the 2DHG as detector, we have studied the carrier dynamics of the QDs at various temperatures for different initial charge states in the QDs.

HL 69.8 Wed 19:00 EW 203

Growth of InN based nanostructures on patterned substrates using MOVPE — •Andreas Winden[1,2], Martin Mikulics[1,2], Toma Stoica[1,2], Martina von der Ahe[1,2], Anna Haab[1,2], Hilde Hardtdegen[1,2], and Detlev Grützmacher[1,2] — [1]Peter Grünberg Institute -9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA – Fundamentals of Future Information Technology

Due to its small direct band gap indium nitride expands the potential of group III-nitride optoelectronic device applications to the telecommunication wavelength range. Since InN layers exhibit a large lattice mismatch to commonly used substrates, the growth of nanostructures could provide a way to more crystalline perfection and therefore better optical properties. However, the control of their position and size is

still challenging. In this contribution we report on the heteroepitaxial selective area growth (SAG) of InN nanostructures on hole-patterned SiO_2/GaN/sapphire templates. The influences of growth temperature and time as well as V/III ratio on morphological and optical properties were investigated by scanning electron microscopy, room- and low-temperature (micro-)photoluminescence and Raman spectroscopy. It is found that especially the growth temperature has a major influence on the selectivity. Hence, nucleation on the patterned mask could be avoided and pyramidal shaped InN nanostructures with a base side length down to 40 nm could be achieved in a small growth temperature window around 650 °C. Furthermore micro-PL measurements demonstrate a band edge luminescence at room temperature even from individual InN nanostructures.

HL 70: Devices II

Time: Wednesday 17:15–19:00 Location: EW 015

HL 70.1 Wed 17:15 EW 015

(Al,In)GaN laser diodes — •Thomas Weig, Katarzyna Holc, Wilfried Pletschen, Klaus Köhler, Joachim Wagner, and Ulrich Schwarz — Fraunhofer Institute for Applied Solid State Physics IAF, Tullastraße 72, 79108 Freiburg, Germany, www.iaf.fraunhofer.de

We develop violet-blue (Al,In)GaN double heterostructure laser diodes (LD). The single section, ridge waveguide LDs show threshold currents around 60 mW and slope efficiencies greater than 1 W/A in continuous wave (cw) operation. The internal losses are estimated by Hakki-Paoli gain measurements to be smaller than 25 cm^{-1}. Laser dynamics and charge carrier lifetime are investigated with the help of a Streak-camera.

For picosecond pulse generation we also design multi-section InGaN LDs. The absorber section is placed at the end or in the center of the LD structure along the ridge, and is negatively biased. We observe self-pulsation in the GHz frequency range. The physical mechanism of this self-pulsation is in our case a stabilization of the relaxation oscillations which were observed in the single section LDs. By tuning the length of the driving current pulse we achieve optical pulses in the picosecond regime with arbitrary repetition rates from single shots to GHz by gain switching.

HL 70.2 Wed 17:30 EW 015

Tunnel Junctions on GaAs for cost-effective long-wavelength VCSELs — •Hui Li[1], Shu-Han Chen[2], Werner Hofmann[1], and Dieter Bimberg[1] — [1]Institute of Solid State Physics & Center of Nanophotonics, Technische Universität Berlin — [2]Research Center for Applied Sciences, Academia Sinica, Taiwan

Long-wavelength vertical-cavity surface-emitting lasers (VCSELs) are desired for low-cost broadband access. Cost-effective solutions which are compatible to the widely utilized GaAs technology are desired. High-Speed long-wavelength VCSELs, however, require tunnel-junctions (TJs) for low-loss high-speed performance [1, 2]. TJs, on the other hand, are harder to realize on GaAs due to higher bandgaps. Here we report our recent work on highly efficient tunnel junctions grown on GaAs substrates using the InGaAlAsSb material system. We present a detailed analysis both in theory and experiment on several good candidates of low-resistance TJs that may significantly improve the performance of VCSELs and the realization of high performance of long-wavelength VCSELs on GaAs seems feasible.

[1] W. Hofmann, "Evolution of high-speed long-wavelength vertical-cavity surface-emitting lasers," Semicond. Sci. Technol, 26, pp. 014011, 2011. [2] M. Ortsiefer, et al.: "Low-resistance InGa(Al)As Tunnel Junctions for Long Wavelength Vertical-cavity Surface-emitting Lasers," Jap. J. Appl. Phys., 39, pp. 1727, 2000.

HL 70.3 Wed 17:45 EW 015

Marker process for high overlay accuracy e-beam lithography — •Jürgen Moers[1,3], Stefan Trellenkamp[2,3], and Bert Rienks[4] — [1]Peter Grünberg Institute - 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Peter Grünberg Institute - 8-PT, Forschungszentrum Jülich, 52425 Jülich, Germany — [3]JARA - Fundamentals of Future Information Technology — [4]Vistec Lithography B.V., Technical Support Centre, 5684 PS Best, The Netherlands

High level overlay accuracy for e-beam defined patterns in nanoscaled devices is of crucial importance for industrial high performance devices as well as for devices probing new physical effects. Thw quality of overly depends on the quality of the marker itself and the quality of the positioning of the whole marker set. In this work the influence of the positioning algorithm for e-beam defined markers on the overlay accuracy is investigated for two different marker systems: simple square holes in silicon substrates and squares of metal. Both systems were processed with standard methods of semiconductor technology. While in former work the overlay displacement was (18 ± 8) nm, in this work it is shown, that with an optimized marker positioning algorithm overlay displacement of (1.6 ± 2.1) nm can be achieved.

HL 70.4 Wed 18:00 EW 015

Electrical characterization of C60 molecules embedded in a MOS diode — •Daniel Beckmeier and Hermann Baumgärtner — Universität der Bundeswehr München

Fullerene (C60) molecules were embedded in a SiO2 layer. Around this layer a MOS diode structure was defined to study the charge and discharge of the electronic states caused by the molecules. This structure was formed by evaporating a submonolayer of C60 molecules onto a clean silicon wafer followed by an in situ overgrowth of the molecules with amorphous silicon inside the same UHV system. These samples were then oxidized in a wet atmosphere to achieve a complete encapsulation of the C60 molecules by the thermal oxide without destroying the molecules. Aluminum contacts were defined on these layers to perform capacitance voltage (CV), current voltage (IV) and electrical stress measurements on the diodes. CV measurements showed a shift of the flatband voltage caused by the injected charge carriers. This shift was reversible for small voltages of opposite signs. The IV measurements showed a Fowler-Nordheim tunneling current for diodes without and with C60. For samples with C60 the electron current injected from the silicon into the oxide started at smaller fields and had a smaller slope compared to the metal electrode-injected current. We propose a model including trap assisted current injection to explain this behavior.

HL 70.5 Wed 18:15 EW 015

Spectroscopic characterization of silicon photomultipliers on wafer level — •Thomas Ganka[1], Christoph Dietzinger[1], Peter Iskra[2], Florian Wiest[2], and Walter Hansch[1] — [1]Universität der Bundeswehr München, Fakultät für Elektrotechnik und Informationstechnik — [2]KETEK GmbH, München

Silicon photomultipliers (SiPMs) are state-of-the-art sensors, which facilitate measurement of ultra low level light down to single photon resolution. SiPMs are based on an array of avalanche photodiodes operating above the breakdown voltage. In this operation mode single photons can trigger an avalanche and generate a measurable signal. As small technological changes can strongly affect the spectroscopic characteristics of these devices, a setup was built to study the effects already on wafer level. This enables cost-effective and fast development of high-end SiPMs. The developed setup enables fully automatic low-noise measurement of the photon detection efficiency, spectral sensitivity, dark noise, crosstalk and afterpulsing. The results measured on wafer level will be compared with results measured with packaged devices.

HL 70.6 Wed 18:30 EW 015

Embedding submicrometer sized GaN stripes with semipolar quantum wells for application in light emitting diodes — •Robert A. R. Leute[1], Dominik Heinz[1,2], Frank Lipski[1], Tobias Meisch[1], Kamran Forghani[1], Junjun Wang[1], Klaus Thonke[2], and Ferdinand Scholz[1] — [1]Institut für Optoelektronik, Universität Ulm — [2]Institut für Quantenmaterie / Gruppe Halbleiterphysik, Universität Ulm

Laser interference lithography is used to create stripe patterns with 240 nm period on silicon doped c-oriented gallium nitride layers grown on 2-inch sapphire substrates. The pattern which was aligned parallel to the a-direction of gallium nitride is transfered to a mask enabling subsequent selective epitaxy. The resulting stripes exhibit triangular cross-section with semipolar $\{10\bar{1}1\}$ side facets. After epitaxy of In-

GaN quantum wells on these stripes, Mg doped GaN is grown in a two-step process to planarize the samples which results in a planar c-oriented surface. We present morphological characterization of the final devices as well as electroluminescence results obtained by on-wafer-testing with evaporated contacts.

HL 70.7 Wed 18:45 EW 015

Quenching Resistors for Silicon Photomultipliers — •Christoph Dietzinger[1], Thomas Ganka[1], Peter Iskra[2], Florian Wiest[2], and Walter Hansch[1] — [1]Universität der Bundeswehr München, Fakultät für Elektrotechnik- und Informationstechnik — [2]KETEK GmbH, München

The silicon photomultiplier (SiPM) is a novel photon detector for detecting low levels of lights for medical and analytical applications. The SiPM consists of an array of many single avalanche photodiodes, which operate above the breakdown voltage in reverse direction, the so called Geiger mode. The triggering of one cell by an incoming photon, leads to a voltage drop over the quenching resistor, allowing the regeneration of this cell. Typical values of these resistors are about 0.2 MΩ up to 2 MΩ.

In the first part of this talk, a typical application and the functioning of the SiPM will be presented. The next section describes the process flow and the parameters of the test devices, e.g. the geometry of the resistors and the ion implantation dose. Finally the resistance values will be discussed.

HL 71: Poster Session: Graphene / Topological Insulators / Interfaces and Surfaces

Time: Wednesday 16:00–19:00 Location: Poster D

HL 71.1 Wed 16:00 Poster D

Nanomachining of mono- and bilayer graphene with the atomic force microscope — •Johannes Rode, Hennrik Schmidt, Dmitri Smirnov, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hannover, Germany

We investigate the effects of mechanical manipulation on mono- and bilayer graphene via atomic force microscope (AFM). Graphene flakes are obtained by micromechanical cleavage of natural graphite and are placed on a silicon substrate with a top layer of silicon dioxide. Mono- and bilayers are spotted and identified, using the optical microscope. Detailed height profiles can then be obtained by AFM, which also serves as a tool to mechanically manipulate the graphene by controlled tip movements at higher contact forces. This manipulation is performed in two ways: The effects of scratching lines into graphene with a diamond coated AFM-tip are investigated for different parameters. Furthermore we show AFM-induced folding of mono- and bilayer graphene on a μm-scale. These twisted bilayers (in case of folded monolayers) form decoupled systems which hold interesting electronic properties like a screening effect and reduced Fermi velocities.

HL 71.2 Wed 16:00 Poster D

Magnetism of Dirac Fermions — •Stephan Albert, Stefanos Chalkidis, Amadeus Mlynarski, Marc Wilde, and Dirk Grundler — James-Franck-Straße 1, 85747 Garching, Deutschland

The two-dimensional electron system of graphene exhibits a quasirelativistic dispersion relation with high mobility. Torsional cantilever magnetometry might be powerful to investigate the intriguing electronic properties via the magnetization. The ground state density of states can be mapped out which allows insight into electron-electron interaction, energy gaps and the predicted divergence of the magnetic susceptibility for vanishing magnetic field at the neutrality point. We introduce our measurement technique, and our experimental setup adapted for graphene. We report on the development of tailor-made microcantilevers by etching of SOI wafers and on sample preparation as well as the electronic characterization of exfoliated graphene prior to the magnetization measurements. Financial support by the DFG via project no. WI3320/1-1 in the priority programme "Graphene" as well as experimental support by the Nanosystems Initiative Munich is gratefully acknowledged.

HL 71.3 Wed 16:00 Poster D

Influence of structural properties on ballistic transport in nanoscale epitaxial graphene cross junctions — •Epaminondas Karaissaridis[1], Sonja Weingart[1], Claudia Bock[1], Ulrich Kunze[1], Florian Speck[2], and Thomas Seyller[2] — [1]Werkstoffe und Nanoelektronik, Ruhr-Universität Bochum — [2]Technische Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg

We have investigated the influence of important material and device properties on ballistic transport in conventionally grown [1] and additionally hydrogen intercalated [2] epitaxial graphene cross junctions. Our studies comprise a) magneto-transport in 2D Hall bars, b) temperature- and magnetic-field-dependent bend resistance of unaligned and step edge-aligned 1D orthogonal cross junctions and c) the influence of the cross junctions' lead width on ballistic transport. We found that ballistic transport is highly sensitive to scattering at the silicon carbide step edges [3]. A suppression of ballistic transport is also observed when the lead width of the cross junctions is reduced from 50 to 30 nm. Furthermore, in a 50 nm wide 1D device prepared on quasi-freestanding graphene we observe a gradual transition from the ballistic to the diffusive transport regime when temperature is increased from 4.2 K to 30 K, although the 2D devices show a temperature-independent mean free path. Both results demonstrate that the influence of different scattering mechanisms must be studied in detail.

[1] K.V. Emtsev, *et al.*, Nature Mater. **8**, 203 (2009).
[2] F. Speck, *et al.*, Mat. Sci. Forum **645-648**, 629 (2010).
[3] S. Weingart, *et al.*, Appl. Phys. Lett. **95**, 262101 (2009).

HL 71.4 Wed 16:00 Poster D

Landau level splitting in monolayer and bilayer graphene superlattices — •George Pal, Walter Apel, and Ludwig Schweitzer — Physikalisch-Technische Bundesanstalt (PTB), Bundesalee 100, 38116 Braunschweig, Germany

The application of periodic potentials to graphene tailors its electronic and transport properties in a unique way, leading to novel features and interesting physics. We employ a lattice model to investigate the Landau level spectrum of graphene in perpendicular magnetic fields and an additional one-dimensional superlattice made of square potential barriers. When the potential barriers are oriented along the arm-chair direction of graphene, we find for strong magnetic fields that the zeroth Landau level of both monolayer and bilayer graphene splits into two well separated sublevels. This splitting occurs only when the superlattice barrier width is smaller than the magnetic length. In this situation, which persists even in the presence of disorder, a plateau with zero Hall conductivity is supposed to be observed around the Dirac point. The splitting occurs also in the presence of truly two-dimensional (chess-board type) superlattices, and it remains robust even in the presence of additional on-site disorder. The superlattice induced Landau level splitting is a true lattice effect that cannot be obtained from the usual continuum Dirac-fermion model of graphene.

[1] G. Pal, W. Apel, and L. Schweitzer, submitted (2011)

HL 71.5 Wed 16:00 Poster D

Non-local Andreev reflection as a probe of spin entanglement in graphene nanostructures — •Hans Hettmansperger[1], Patrik Recher[2], and Björn Trauzettel[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, 97074 Würzburg, Germany — [2]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany

The controlled production and detection of spin-entangled electronic states without the use of ferromagnetic reservoirs is a major challenge in solid state physics. Non-local Cooper pair injection from ordinary superconductors into graphene nanostructures can be used to generate spin entanglement. The advantage of graphene is twofold: (i) spin is long-lived in graphene because it only weakly couples to the environment; (ii) graphene nanoribbons have specific properties that allow for a spin detection in the absence of ferromagnetic reservoirs.

In our numerical analysis, we solve the Bogoliubov-de Gennes equation for the tight binding model of graphene by applying the recursive Green's functions method for phase-coherent transport to multi-terminal devices. We study the average current and the current noise within and between different electron reservoirs and identify ideal situations to generate and detect spin entanglement. To do so, we employ

graphene-specific physics such as valley filtering and magnetic ordering due to electron-electron interactions in zigzag nanoribbons.

HL 71.6 Wed 16:00 Poster D

Resonant scattering in graphene: adsorbate fingerprints from ab initio calculations — •Karri Saloriutta[1], Martti J. Puska[1], and Antti-Pekka Jauho[2] — [1]Department of Applied Physics, Aalto University School of Science, Finland — [2]Department of Micro- and Nanotechnology, DTU Nanotech, Technical University of Denmark, Denmark

We have recently shown that by using a scaling approach for randomly distributed defects reliable estimates for transmission properties can be calculated based on even single defect calculations. This is done by defining a scattering cross-section, a quantity that only depends on energy and defect type. Estimates of transmission and all the related transport properties, such as localization lengths and mean free paths, can then be calculated for a macroscopic system with an arbitrary defect density.

We now extend our analysis to the case of adsorbates on graphene by studying the experimentally important epoxide and hydroxyl groups. We show that a qualitative understanding of resonant scattering can be gained even from a single bulk graphene calculation, which thus provides an useful transmission "fingerprint" for each adsorbate. For graphene nanoribbons on the other hand the scattering cross section needs to be calculated from an ensemble containing all the relevant adsorption sites across the whole ribbon. The transmission in ribbons is also strongly affected by the van Hove singularities at band edges making the scattering cross section specific to a particular ribbon width.

HL 71.7 Wed 16:00 Poster D

Defect controlled conductivity of graphene with vacancies and N impurities — •Karel Carva[1], Biplab Sanyal[2], Jonas Fransson[2], and Olle Eriksson[2] — [1]Department of Condensed Matter Physics, Charles University, Ke Karlovu 5, CZ-12116 Prague 2, Czech Republic — [2]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden

The possibility to influence the electronic structure of graphene and hence control its conductivity by adsorption or doping with adatoms is crucial in view of electronics applications. We study electronic structure and transport properties of single and bilayer graphene with vacancy defects, as well as N doped graphene. The theory is based on first principles DFT calculations employing coherent potential approximation (CPA) to describe disorder. We show that increasing the defect concentration increases drastically the conductivity in the limit of zero applied gate voltage [1], by establishing mid-gap states and carriers in originally carrier-free graphene, a fact which is in agreement with recent observations [2]. We calculate the amount of defects needed for a transition from a non-conducting to a conducting regime (i.e. a metal-insulator transition) and establish the threshold of the defect concentration where the increase of impurity scattering dominates over the increase of carrier induced conductivity [1].

[1] K. Carva, B. Sanyal, J. Fransson, O. Eriksson, Phys. Rev. B 81 (2010) 245405.

[2] S. H. M. Jafri et al., J. Phys. D: Applied Physics 43 (2010) 045404.

HL 71.8 Wed 16:00 Poster D

Superlattice Effects on Transport in Graphene and Graphene Nanoribbons — •Fedor Tkatschenko, Jan Bundesmann, Viktor Krückl, Dmitry Ryndyk, and Klaus Richter — Universität Regensburg Germany

Motivated by interesting superlattice effects on bulk graphene such as the emergence of new Dirac points and an anisotropic velocity renormalization[1], we numerically investigated the effects of a one dimensional superlattice potential on the electronic properties of graphene nanoribbons (GNR). We found that the formation of the miniband structure depends on the direction of the ribbon axis. The arising miniband structures of armchair GNRs exhibit striking differences, depending on whether the ribbon is metallic or semiconducting. In case of zigzag GNR the miniband structure forms only for ribbons where the width has an even number of chains. We also investigated the current voltage characteristic through modulated GNR which shows a negative differential conductance and an oscillatory behavior due to Bloch-oscillations in presence of Zener tunneling[2].

[1] M. Barbier, F.M. Peeters, P. Vasilopoulus and J.M. Pereira, Phys. Rev. B **77**, 115446 (2008),

[2] Viktor Krückl and Klaus Richter, arXiv:1109.5541v1

HL 71.9 Wed 16:00 Poster D

Modulating Charge Carrier Concentration using Patterned Top Gates in Graphene Structures — •Franz-Xaver Schrettenbrunner, Dominik Koch, Dieter Weiss, and Jonathan Eroms — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany

We report on the fabrication and the measurements of graphene single layers with structured top gates. Starting from exfoliated graphene on SiO_2 surfaces, a thin Al_2O_3 top gate dielectric was fabricated by atomic layer deposition (ALD). Subsequently a top gate electrode consisting of an array of lateral stripes with periodicities down to 100 nm was fabricated by electron beam lithography (EBL). The interplay of both patterned top- and extended back gate allows to tune type and concentration of charge carriers as well as the modulation strength. Different configurations like n^+nn^+, npn or p^+pp^+ can be realized. For npn configuration in single layer graphene, magnetotransport measurements show an unusual linear increase and additional dips in the magnetoresistance. Furthermore, we obtain quantum Hall states corresponding to locally modulated filling factors achieved by tuning the patterned top gate.

HL 71.10 Wed 16:00 Poster D

Crystallographically Anisotropic Etching of Graphene — •Florian Oberhuber, Paula Giudici, Stefanie Heydrich, Tobias Korn, Christian Schüller, Dieter Weiss, and Jonathan Eroms — Institut für Experimentelle und Angewandte Physik, Universtität Regensburg, 93040 Regensburg, Germany

We report the crystallographically anisotropic etching of exfoliated graphene on SiO_2 substrates by a carbothermal reaction. The etching mechanism was suggested to take place between graphene and oxygen from the SiO_2 substrate and leading to graphene with zigzag edges [1]. Before exposing samples to this carbothermal reaction, they were patterned with circular antidots by electron beam lithography and reactive ion etching with oxygen plasma. In the following carbothermal etching samples were exposed to temperatures around 800°C in a flow of argon gas (purity 6.0) and the predefined holes evolved into larger hexagonal antidots. Samples were characterized by Raman spectroscopy focussing on G ($\sim$1580cm^{-1}), D ($\sim$1350cm^{-1}) and D' ($\sim$1620cm^{-1}) peaks. On the other hand we investigated electron transport on a set of samples patterned with square lattices of hexagonal holes. By analizing the weak localization peak we obtain the phase coherence length as well as lengths for intra- and intervalley scattering. The results will be compared to graphene patterned with circular holes investigated previously [2].

[1] P. Nemes-Incze et al., Nano Res. 3 (2010)

[2] J. Eroms et al., New J. Phys. 11 (2009)

HL 71.11 Wed 16:00 Poster D

Nanoscale control of the dielectric environment of graphene — Vitalij Scenev, •Nikolaj Severin, and Jürgen Rabe — Humboldt Universität Berlin zu Berlin, Institut für Physik, D-12489 Berlin

The quantitative understanding of charge transfer at interfaces and the spatial distribution of the resulting charge carriers is a critical input to electronic device design. Particularly, the performance and reliability of a graphene field effect transistor (FET) can be dominated by the graphene/substrate environment. Electrostatic force microscopy (EFM) is a versatile tool for quantitative and qualitative investigations of electronic properties of surfaces on the nanoscale, providing high spatial resolution, with no need for electrical contacts. We exfoliated graphenes onto muscovite mica under variable relative humidities. Topography images of graphenes reveal flat plateaus of three different heights, which can be attributed to molecular water layers confined between graphene and mica. EFM revealed reproducible surface potential differences between the plateaus. The variation of the surface potential may be attributed to charge transfer between graphene and the underlying substrate and the orientation of polar water molecules within the molecular layers. We show that the water monolayers can modify the interface between graphene and the substrate and may control the doping level of graphene on the nanoscale.

HL 71.12 Wed 16:00 Poster D

Transport Properties of Graphene on Atomically Flat Substrates — •Jens Mohrmann[1], Hilbert v. Löhneysen[1,2], and Romain Danneau[1,2] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Germany — [2]Physikalisches Institut, KIT, Germany

Graphene is commonly described as a perfect two dimensional crystal. But although this is true with respect to the electronic properties, TEM and SPM investigations showed that the structure in real space is not perfectly flat. Instead, both suspended and SiO2 supported graphene show ripples. In case of substrate supported graphene, these ripples originate from graphene conforming to the substrate's roughness. Different mechanisms that may lead to interactions between the topographical corrugations and electronic transport properties have been proposed, and recently atomically flat hexagonal boron nitride was found to be an ideal substrate, leading to extremely high charge carrier mobilities. Yet, the influence of the ripples on electronic properties is under debate. Using a graphene transfer technique, we investigate this effect by placing graphene on hexagonal boron nitride and mica and comparing electronic transport measurements and roughness.

HL 71.13 Wed 16:00 Poster D

Contact Resistance in Graphene Field Effect Transistors — •Renjun Du[1], Kristina Hönes[1], Pablo Robert[1,2], Fan Wu[1], Hilbert von Löhneysen[1,2,3], and Romain Danneau[1,2] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institute of Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Institute for Solid-State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany

A high-quality junction between graphene and metallic contacts is crucial in the creation of high-performance graphene field effect transistors. In an ideal metal-graphene junction, the contact resistance is determined solely by the number of conduction modes in graphene. However, measurements of contact resistance have been inconsistent, and the factors that determine the contact resistance remain unclear. In this work, we achieved conduct patterns on the exfoliated graphene by performing e-beam lithography and evaporated palladium through ultra high vacuum (UHV) system. The contact resistance between palladium and graphene is measured at room temperature. Additionally, the dependence of extracted mobility on channel dimensions is studied.

HL 71.14 Wed 16:00 Poster D

Ultrafast phonon relaxation in graphite — •Martin Scheuch[1], Tobias Kampfrath[1], Martin Wolf[1], Konrad von Volkmann[2], Christian Frischkorn[3], and Luca Perfetti[4] — [1]Fritz-Haber-Institut der MPG, Faradayweg 4-6, 14195 Berlin — [2]APE GmbH Plauener Str. 163-165 Haus N, 13053 Berlin — [3]Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin — [4]Laboratoire des Solides Irradiés, Ecole polytechnique, 91128 Palaiseau cedex, France

A nonequilibrium population of high energy optical phonons (SCOPs) is generated in graphite following the excitation of electron-hole pairs with an 800-nm, 10-fs pump pulse. The energy relaxation of these phonons can be probed by means of time-resolved terahertz spectroscopy of the electronic subsystem because an equilibrium between electrons and SCOPs is established immediately after excitation [1]. To avoid transport effects, measurements are taken on homogenously excited thin films. We find an increase of the hot-phonon lifetime by a factor of two when the sample temperature decreases from 300 K to 5 K. These results suggest that the energy relaxation in graphite is dominated by the anharmonic decay of hot A_1' phonons at the K point into acoustic phonons with energies of about 10 meV [2]. Our results are qualitatively valid for graphene as well [3].

[1] T. Kampfrath *et al.*, Phys. Rev. Lett. **95**, 187403 (2005).
[2] M. Scheuch *et al.*, Appl. Phys. Lett. **99**, 211908 (2011).
[3] N. Bonini *et al.*, Phys. Rev. Lett. **99**, 176802 (2007).

HL 71.15 Wed 16:00 Poster D

The detection of terahertz radiation via graphene based devices at low magnetic field — •Majdi Salman[1,2], Markus Golla[2], Yu. B. Vasilyev[3], Fathi Gouider[2], Miriam Friedemann[4], Franz. J Ahlers[4], Hennrik Schmidt[2,5], Rolf Haug[5], and Georg Nachtwei[2] — [1]NTH Nano School for Contacts in Nanosystems, Germany — [2]Institut fuer Angewandte Physik, Technische Universitaet Braunschweig, Braunschweig, Germany — [3]Ioffe Physical Technical Institute, Russian Academy of Science, St. Petersburg, Russia — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [5]Institut für Festkörperphysik, Universität Hannover, Appelstraße 2, Hannover, Germany

The influence of a magnetic field on Landau levels (LLs) in graphene-based devices is described via the magneto- optical response induced by terahertz (THz) radiation. For single-layer graphene, the resonance energies of the transitions between the LLs such as L1, L2 and L3, fit quite well to the terahertz spectral range at low magnetic fields. Also, the calculations for the terahertz photoresponse in the in presence of low magnetic field, the reported calculations for the scattering rate of LLs, recent and our primary experimental results of transmission and photoresponse measurements implying that single-layer graphene can be suitable for the detection of terahertz radiation. On the other the hand, temperature dependence of full width at half maximum (FWHM) of infrared transmission measurements were utilized in our calculation to argue that the graphene based devices can be also suitable for the detection of terahertz radiation at room temperature.

HL 71.16 Wed 16:00 Poster D

Edge Functionalization of Graphene Nanoribbons — •Eric Parzinger, Max Seifert, Lucas Hess, Martin Stutzmann, and Jose Antonio Garrido — Walter schottky Institut, TU München, Germany

Due to its unconventional electronic properties, graphene is a suitable material for investigating low dimensional effects e.g. quantized conductance even at room temperature. When shrinking down the dimensions of graphene field effect transistors to the nanoscale, the sheet edges gain more and more importance and are known to have a strong influence on the device performance. It has been shown that proper functionalization of the edges and, thus, passivation of dangling bonds can greatly improve the performance of nanoscale devices. We use CVD grown graphene and electron beam lithography to produce nanoscale graphene field effect transistors, and we investigate the effect of different functionalization methods on the electronic properties of such devices.

HL 71.17 Wed 16:00 Poster D

Cell Bioelectronics using Graphene Transistors — •Liding Zhang, Lucas Hess, Max Seifert, Christoph Becker-Freyseng, Martin Stutzmann, Ian D. Sharp, and Jose A. Garrido — Walter Schottky Institut, TU München

In this work, we present results on the interaction of graphene solution-gated field effect transistors (G-SGFETs) with living cells. The biocompatibility of graphene was tested by growing different types of cells on bare graphene substrates as well as on arrays of G-SGFETs. Cardiomyocyte-like HL-1 cells, Human Embryonic Kidney (HEK) cells and pure retinal ganglion cells from postnatal rats have been cultured successfully. Using the transistors beneath, action potentials generated by the cells could be detected and resolved. By means of the patch clamp technique, additional detail on these action potentials is obtained leading to a more detailed understanding of the cell-transistor interface.

HL 71.18 Wed 16:00 Poster D

Direct growth of few-layer graphene on mica — Gunther Lippert, •Marvin Zöllner, Jarek Dabrowski, and Grzegorz Lupina — IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany

In many potential technological applications of graphene a transfer-free, low-temperature graphene deposition method on insulating substrates is required. We present a Van der Waals epitaxy-based approach enabling direct growth of few-layer graphene on freshly cleaved mica surfaces at temperatures below 1000°C. Graphene growth is accomplished in an ultra high vacuum molecular beam epitaxy chamber equipped with a high purity pyrolytic graphite source. According to the optical microscopy and Raman spectroscopy, the deposition of carbon onto mica surfaces results in the formation of micrometer-size islands of few-layer graphene (<10 monolayers). Analysis of the relative intensities of the characteristic 2D, G, and D Raman peaks implies a good crystalline quality of the deposited layers. The experimental insights are combined with ab-initio calculations to propose a model for graphene growth on mica surfaces.

HL 71.19 Wed 16:00 Poster D

Resist-free patterning and transport measurements on graphene layers — •Benedikt Sommer, Arkadius Ganczarczyk, Martin Geller, and Axel Lorke — Faculty of Physics and CeNIDE, Universität Duisburg-Essen

Graphene is expected to have an exceptional high charge carrier mobility even at room temperature. However, high mobility in patterned graphene layers may be hampered by the patterning process, as many processes involve a lithographic step, which requires that the graphene is covered with an organic resist. This step may compromise the trans-

port properties of graphene permanently, as the resist can not be removed completely. A lot of effort is being invested into finding ways to pattern graphene in a mask- and resist-free manner.

In this work, we show resist-free patterning of graphene sheets using different techniques within a focused ion beam (FIB) system. Care has been taken that the active area of the graphene has not been exposed to either ion or electron beams. Furthermore, the graphene has not been exposed to organic materials or solvents after the exfoliation process. The patterned graphene layers are characterized in transport measurements from low temperatures (4 K) up to room temperature, especially to extract the mobility of the charge carriers.

HL 71.20 Wed 16:00 Poster D

Transport through structured ultra-thin Bi_2Se_3 flakes — •Regine Ockelmann[1,2], Christian Volk[1,2], Anton Maier[1,2], and Christoph Stampfer[1,2] — [1]JARA-FIT and II. Institute of Physics B, RWTH Aachen, 52074 Aachen, Germany — [2]PGI, Forschungszentrum Jülich, 52425 Jülich, Germany

Topological insulators (TIs) are a new class of solid state materials with unique electronic properties showing both carriers mimicking relativistic particles and topological protection of their surface states. Theory predicts topological insulators to exhibit a rich variety of physical phenomena such as anomalous magneto-electric coupling, Majorana excitations and unusual spin-orbit interaction. Bismuth (Bi) based compounds such as Bi_2Se_3 have been shown to be interesting topological insulators with a single Dirac cone surface state and strong spin-orbit interaction.

Here, we present low-temperature transport measurements on structured ultra-thin $3nm$-$20nm$ Bi_2Se_3 flakes, such as Hall bars. The ultra-thin flakes have been prepared by exfoliation of bulk Bi_2Se_3 and are placed on SiO_2 on highly doped Si substrates. The final devices are structured with electron beam lithography followed by ion beam etching and contacted by Ti/Au electrodes. Low temperature $\sim 1,5K$ transport, i.e. conductance measurements have been carried out by driving back gate voltages from $-70V$ to $70V$ and by varying magnetic fields up to $9T$. We observe an ambipolar electric field effect and deduce a carrier mobility of around $\sim 3000cm^2/(Vs)$, and a carrier concentration of around $\sim 3 \cdot 10^{13}cm^{-2}$.

HL 71.21 Wed 16:00 Poster D

MBE-grown HgTe as a 2D and 3D topological insulator — •Philipp Leubner, Christopher Ames, Maximilian Kessel, Matthias Mühlbauer, Luis Maier, Christoph Brüne, Hartmut Buhmann, and Laurens Molenkamp — Physikalisches Institut (EP III), Universität Würzburg, D-97074 Würzburg, Germany

Since the first theoretical prediction of the quantum spin hall effect in 2005 [1], topological insulators (Tis) are receiving ongoing attention due to their unique band structure. In 2007 the first experimental evidence of a 2D TI was found in an HgTe/HgCdTe heterostructure [2].

We have grown HgTe layers of different thicknesses on CdTe substrates via molecular beam epitaxy in order to investigate the transition between 2D and 3D TIs. The effect of strain and relaxation due to lattice mismatch is crucial for the band properties of HgTe and therefore analyzed via HRXRD.

Additionally, we present transport measurements on the grown layers showing indications of 2D or 3D TI behavior depending on layer thickness.

[1] Kane et. al., Phys. Rev. Lett. 95 146802 (2005) [2] König et. al., Science 318, 766 (2007)

HL 71.22 Wed 16:00 Poster D

Kondo Tunneling between 1D Helical Liquids — •Thore Posske, Chao-Xing Liu, Jan Carl Budich, and Björn Trauzettel — Institute for Theoretical Physics and Astrophysics, University of Wuerzburg

Two non-interacting helical edge liquids are coupled via a magnetic impurity. Different chemical potentials are attached to every Fermion species to imitate a four terminal setup and drive the system out of equilibrium. In a special limit of the coupling constants, the Toulouse limit, the system is mapped to a non-interacting one using Bosonization and Refermionization. We explicitly calculate the spatially dependent Kondo screening cloud that is emerging in the edge channels. This allows us to show how the helicity can be used to gain additional information about the Kondo cloud using transport measurements.

HL 71.23 Wed 16:00 Poster D

Analysis and Improvement of the modified Becke-Johnson exchange potential — •David Koller, Fabien Tran, and Peter Blaha — Institute of Materials Chemistry, Vienna University of Technology, A-1060, Vienna, Austria

The modified Becke-Johnson exchange potential [1] (TB-mBJ) is the sum of an approximation to Slater's averaged exchange potential and a response contribution, with the weight of both parts determined by the parameter $c = c(\overline{\nabla\rho/\rho})$. It is a semilocal potential which leads to surprisingly good energy gaps for semiconductors and insulators. Its predictive power is better than that of hybrid-DFT calculations and similar to the much more expensive GW approach. The improvement is explained by the different spatial distribution of electrons in the valence band maximum and conduction band minimum states. For correlated TM compounds TB-mBJ works similarly to LDA+U and improves magnetic moments, band gaps and electric field gradients but (correctly) does not shift the occupied states below the O-p-band.

Although the performance of TB-mBJ is impressive, some cases would be described even better by a different choice of c. Therefore we investigated three strategies for improvement: reparametrization of the relation between c and $(\overline{\nabla\rho/\rho})$, determining c from a different quantity and using a position-dependent $c(\mathbf{r})$. The first strategy turns out to be helpful, especially when grouping the systems into categories like sp-semiconductors, wide band gap insulators or (non-)magnetic transition metal compounds.

HL 71.24 Wed 16:00 Poster D

A functional renormalization group approach for treating interactions in strongly disordered electron systems — •Christian Seiler[1,2] and Ferdinand Evers[1,2] — [1]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Institut für Nanotechnologie, Karlsruhe Institute of Technology, Karlsruhe, Germany

We propose an approach to treat the effects of interactions in disordered electron systems on a numerical level. The idea is to solve the non-interacting disorder problem for a given disorder realization exactly. We then use the functional renormalization group method to introduce interactions on a perturbative level. In contrast to usual applications of the fRG, we formulate it in terms of the eigenfunctions of the disordered non-interacting Hamiltonian. Disorder averaging of physical quantities is performed as the final step. The main advantage of our approach is that we are able to treat disorder exactly from a numerical point of view. We compare our method to exact diagonalization and Hartree-Fock for small systems and discuss its applicability for larger systems.

HL 71.25 Wed 16:00 Poster D

FTIR-Spectroscopy of MOCVD-Prepared Ge(100) and P-rich GaP(100) — •Claas Löbbel[1], Anja Dobrich[1], Johannes Luczak[1], Sebastian Brückner[1,2], Henning Döscher[1,2], Peter Kleinschmidt[1,3], and Thomas Hannappel[1,2,3] — [1]Helmholtz-Zentrum Berlin, Institut Solare Brennstoffe und Energiespeichermaterialien, D-14109 Berlin — [2]TU Ilmenau, Institut für Physik, Fachgebiet Photovoltaik, D-98693 Ilmenau — [3]CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH, D-99099 Erfurt

We have investigated hydrogen bonding in MOVPE-prepared Ge(100) surfaces as well as GaP/Si(100) surfaces using Fourier-transform infrared (FTIR) spectroscopy in an attenuated total reflection (ATR) configuration enabling sensitive measurements of the germanium-hydrogen bonds as well as phosphorus-hydrogen bonds at the surface. MOVPE preparation and in-situ reflectance anisotropy spectroscopy (RAS) measurements were correlated with UHV-based surfaces science techniques such as FTIR, scanning tunnelling microscopy (STM), and low-energy electron diffraction (LEED) by employing a contamination-free MOVPE to UHV transfer system. FTIR measurements showed Ge-H monohydrides as well as P-H semihydrides surfaces, agreeing with results from LEED. Polarization dependend Ge(100) FTIR measurements revealed, matching STM results, a (2x1)/(1x2) reconstructed surface and even allowed a quantization of the domain ratio.

HL 71.26 Wed 16:00 Poster D

Atomic surface structure of Ge(100) surfaces in vapor phase epitaxy ambient — •Sebastian Brueckner[1,2], Oliver Supplie[1], Enrique Barrigon[3], Henning Doescher[1,2], Anja Dobrich[1], Claas Loebbel[1], Johannes Luzcak[1], Peter Kleinschmidt[1,4], and Thomas Hannappel[1,2,4] — [1]Helmholtz-Zentrum Berlin, Institut Solare Brennstoffe und Energiespeichermaterialien, D-14109 Berlin — [2]TU Ilmenau, Institut für Physik, Fachgebiet Photovoltaik, D-98693

Ilmenau — [3]Instituto de Energía Solar, Universidad Politécnica de Madrid, E-28040 Madrid — [4]CiS Forschungsinstitut für Mikrosensorik und Photovoltaik, D-99099 Erfurt

Vicinal Ge(100) substrates represent almost perfect templates for III-V nucleation and are therefore established as substrates for III-V triple junction solar cells grown by metal-organic vapor phase epitaxy (MOVPE). An important requirement to achieve low defect densities in the III-V epilayers is a suitable Ge(100) surface preparation prior to heteroepitaxy. We applied in situ reflectance anisotropy spectroscopy (RAS) to study the Ge(100) surface during preparation. A contamination free MOVPE to ultrahigh vacuum (UHV) transfer system allowed us to correlate the spectra to results from various surface science methods. Processing of Ge(100) in MOVPE environment under hydrogen led to a surface free of oxides and carbon, covered by monohydrides. Vicinal Ge(100) exhibits a preferential (2×1) surface reconstruction domain, i.e. D_B steps. Exposure to arsenic resulted in predominat (2×1) or (1×2) surface reconstruction domains which was controlled in situ by RAS dependent on temperature and source of As (AsH_3 or As_4).

HL 71.27 Wed 16:00 Poster D

Surface chemical and electronic properties of In_2O_3 and In_2O_{3-x} nanoparticles for ozone detection — •Marcel Himmerlich[1], Chunyu Wang[2], Volker Cimalla[2], Oliver Ambacher[2], and Stefan Krischok[1] — [1]Institut für Physik and Institut für Mikro- und Nanotechnologien, TU Ilmenau, PF 100565, 98684 Ilmenau, Germany — [2]Fraunhofer-Institut für Angewandte Festkörperphysik, Tullastr. 72, 79108 Freiburg, Germany

The electrical properties of indium oxide nanoparticle films can be tuned by variation of growth temperature as well as rapid thermal annealing, UV-irradiation and ozone-induced oxidation. The high O_3 sensitivity of indium oxide thin films is strongly linked to their structural and electronic properties. Especially, the alteration of the surface electron accumulation plays an important role in the change of the film resistivity upon O_3 interaction and UV-induced regeneration. We analyse the changes of indium oxide surface properties with respect to varying crystallinity using AFM, XPS and UPS. Compared to stoichiometric In_2O_3 thin films, indium oxide nanoparticles exhibit a high oxygen deficiency and hence a high defect density at the nanoparticle surface. After growth, these defects are saturated by hydrocarbons due to the incomplete decomposition of precursors during low temperature MOCVD. The defects and the changed stoichiometry have impact on the surface band alignment. Upon ozone-induced oxidation and UV photoreduction a reversible change in band bending, surface dipole and O adsorbate density is found and will be discussed in context with electron transport characteristics and thermal properties.

HL 71.28 Wed 16:00 Poster D

Gallium Phosphide - Silicon Interface: Structure and Anisotropy Investigations — •Steinbach Gabi[1,2], Gemming Sibylle[1], Döscher Henning[3], Hannappel Thomas[3,4], and Schreiber Michael[2] — [1]Institute of Ion Beam Physics and Materials Research, HZDR, D-01314 Dresden. — [2]Institute of Physics, TUC, D-09107 Chemnitz. — [3]HZB, D-14109 Berlin. — [4]Ilmenau University of Technology, Inst. of Physics, Dep. Photovoltaics, D-98684 Ilmenau.

Gallium phosphide thin films on cheap silicon substrates are a promising III-V/IV heterostructure to be used in optoelectronic devices. As an almost lattice matched system with a band gap difference of 1.14 eV it includes applicability for multi-junction solar cells. The present study concerns discontinuities emerging at the boundaries of a GaP thin layer on a silicon substrate. The optical anisotropy of the (001) interface has been determined by an optical model applied to reflectance anisotropy spectroscopy measurements of the GaP/Si heterostructure. Density-functional calculations of the interface have been performed with both, the pseudopotential plane wave code ABINIT [1] and the all-electron augmented plane wave code Wien2K [2]. The study distinguishes between the Ga-rich and the P-rich interface termination. At the perfectly flat interface, the latter exhibits higher stability as indicated by the work of separation. More complex interface models also consider defects. The calculated density of states projected onto in-plane directions gives an indication for anisotropy. It aims at distinguishing interface termination and defects as origin of the experimentally observed reflectance anisotropy. [1] www.abinit.org [2] www.wien2k.at

HL 71.29 Wed 16:00 Poster D

Calculation of valence band offsets from tight-binding band structures — •Daniel Mourad and Gerd Czycholl — Institut für Theoretische Physik, Universität Bremen

The anisotropic valence band offset (VBO) across an interface between two semiconductors A and B is an important material parameter, as it (among others) determines the confinement potential and so e.g. the heterostructure type (I or II) and the level structure in low-dimensional systems. Furthermore, the electronic properties of semiconductor alloys are directly influenced by the VBO. A crucial ingredient in the calculation of the VBO is the use of sufficiently accurate band structures. We present different methods of calculation for the VBO by means of a determination of the charge neutrality level in the framework of an empirical tight-binding model (ETBM).The values will be compared for different sets of material parameters and crystalline phases (zincblende and wurtzite). Furthermore, we will use them to calculate the electronic properties of A_xB_{1-x} semiconductor alloys.

HL 71.30 Wed 16:00 Poster D

The Change of Electrical Conductivity in Dependence of UV Illumination of Nano-Porous Titania (TiO_2) Combined with Infrared Spectroscopy (FTIR) — •Thomas Kriesche[1] and Thomas Bürgi[2] — [1]Phys.-Chem.-Institut, Im Neuenheimer Feld 253, 69120 Uni Heidelberg — [2]Faculté des Sciences, Séction de Chimie, Département de Chimie Physique, Quai Ernest-Ansermet 30, CH-1211 Genève 4

The properties of nano-porous TiO_2 is widely investigated by FTIR. In particular this method is used to observe photocatalytic processes on TiO_2. The spectrometer IFS66v Bruker is expanded with an electrometer (Keithley2100), which measures the electrical conductivity during IR-spectroscopy. Absorbed UV-light creates electrons and holes in the semiconductor, which recombine or can do reduction respectively oxidation of adsorbed molecules on surface. The conductivity is measured on top of a TiO_2 pill via a four point method, those is fixed in a Diffuse Reflectance IR (DRIFT) unit (PIKE EasiDiff). The well known degradation of malonic acid [1] has been studied with this setup. The recent work presents results from ATR-FTIR and DRIFT in MIR with the change of the electrical conductivity during UV illumination. [1] I.Dolamic, T.Bürgi: Photoassisted Decomposition of Malonic Acid on TiO_2 Studied by in Situ Attenuated Total Reflection Infrared Spectroscopy, J. Phys. Chem. B 2006

HL 72: Poster Session: Si-based Photovoltaics / Inorganic Photovoltaics / Structure and Transport in Organic Photovoltaics / Organic Semiconductors

Time: Wednesday 16:00–19:00 Location: Poster D

HL 72.1 Wed 16:00 Poster D

Porous silicon antireflective layer fabricated by platinum nanoparticle assisted chemical etching — •Xiaopeng Li[1], Stefan Schweizer[2], and Ralf Wehrspohn[3] — [1]Max-Planck Institute of Microstructure Physics, Weinberg 2, 06120 Halle, Germany — [2]Martin-Luther-Universität Halle-Wittenberg, Germany — [3]Fraunhofer Institute for Mechanics of Materials at Halle, Germany

Meal assisted chemical etching (MaCE), is a purely solution processed, high throughput technique. Si wafers loaded with metal nanoparitcles (NPs) such as Ag, Au or Pt, are immersed in solution containing HF and an oxidant. Etching preferentially occurs beneath the metal NPs, enabling the formation of nanopores and nanowires. Here, we presented for the first time, the formation of uniform porous silicon layer with pore size ranging from meso- to macro-size, by using platinum nanoparticle assisted chemical etching (PaCE). Various factors influencing the porous silicon morphology including PtNP density, silicon doping level, and H2O2 concentration were systematically studied. A new etching mechanism was evaluated. The formed macroporous Si showed the reflectance below 2.5% at the wavelength range of 300 nm to 1000 nm, and mesoporous Si exhibited broadband light absorption,

even in the near infrared range. With perfect light trapping, macroporous silicon demonstrated more than 10 mA/cm2 photocurrent increase than that of controlled planar Si samples.

HL 72.2 Wed 16:00 Poster D

Absorption properties of femtosecond laser microstructured Black Silicon for solar cell application — •Anna Lena Baumann[1], Kay-Michael Guenther[2], Thomas Gimpel[2], Stefan Kontermann[1], Philipp Saring[3], Michael Seibt[3], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich Hertz Institute, EnergieCampus, Am Stollen 19B, 38640 Goslar — [2]Clausthal University of Technology, EFZN, EnergieCampus, Am Stollen 19B, 38640 Goslar — [3]Georg-August-Universität Göttingen, IV. Physikalisches Institut, Semiconductor Physics, Friedrich-Hund-Platz 1, 37077 Göttingen

First deep-level transient spectroscopy (DLTS) measurements indicate the presence of sulfur energy levels in the band gap of femtosecond laser microstructured Black Silicon. Samples featuring different energy levels in DLTS measurements show different absorption properties as well. One way to influence the absorption values and the sulfur energy levels in Black Silicon is an additional post-laser process annealing step. This decreases the infrared absorption and shifts the sulfur energy levels to different values. Another way to affect the Black Silicon absorption works by changing the laser pulse shape. Preliminary double pulse experiments yield samples with different absorption in the near infrared when varying the double pulse distance. Modifying the pulse shape seems to be a promising method to influence absorption properties along with sulfur energy levels in Black Silicon.

HL 72.3 Wed 16:00 Poster D

Black Silicon solar cell emitter doping concentration measured with impedance spectroscopy — •Kay-Michael Günther[1], Alexander Bomm[2], Thomas Gimpel[1], Stefan Kontermann[2], and Wolfgang Schade[1,2] — [1]Clausthal University of Technology, EFZN, Am Stollen 19B, 38640 Goslar, Germany — [2]Fraunhofer Heinrich Hertz Institute, Am Stollen 19B, 38640 Goslar, Germany

Exposing silicon to femtosecond-laser pulses leads to a nanostructured surface which features an enhanced light absorption. Therefore, this material is called Black Silicon. When the laser processing is performed under a sulfur-containing atmosphere, sulfur is incorporated in the silicon lattice. Secondary ion-mass spectroscopy (SIMS) shows that the silicon contains up to 0.5 at% sulfur. A pn-junction is formed for p-type base material which can be used for solar cell applications. For a solar cell solely based on Black Silicon we achieved a record efficiency of 4.5%. Nevertheless, for a device optimization the uncompensated donor concentration has to be determined. We use capacitance-voltage (C-V) measurements for obtaining the doping profiles of our samples. Because of the structured surface and the pn-junction, conventional C-V methods cannot be applied due to the interfering space charges. Therefore, we use a new method which is based on impedance spectroscopy. We can show that only a small fraction of the sulfur is electrically active and acts as a donor.

HL 72.4 Wed 16:00 Poster D

Solution-processed silicon particle semiconductor films — •Sara Jäckle[1,2], Ralf Krause[1], and Hans-Ulrich Krebs[2] — [1]Günther-Scharowsky-Str.1, 91058 Erlangen — [2]Institut für Materialphysik, Universität Göttingen

Conventional PV-modules are mostly based on mono- or polycrystalline silicon wafers. These wafers are produced in expensive vacuum based and/or high temperature processes with large percentages of cutoff (up to 50%). An alternative is given by solution-processed film formation with silicon particles. The particles can be produced by ball milling cutoff of silicon ingots, metallurgical grade silicon or by decomposition of silane. Dispersion of silicon particles holds the possibility of simply printing a silicon film and using a roll-to-roll process to produce solar cells. The particles in the films can easily be sintered or mold together by different heat-treatments to form a percolated conducting film. Doped silicon particles of an average size of smaller than 1μm and a large size distribution are produced and used to form thin films. During handling under air atmosphere a silicon oxide shell forms on the particle surface. The silicon oxide is dissolved by treating the particles with hydrofluoric acid. The silicon particles are characterized, dispersed and spin-coated on quartz glass and silicon wafers. The films are electrically, optically and morphologically characterized and optimized. Annealing up to high temperatures leads to coalescence, sintering and melting of the film. The temperature dependent properties of the film are presented. The applications for pn-junctions and solar cells are discussed.

HL 72.5 Wed 16:00 Poster D

Structural, electronic and optical properties of random-pyramid textured Silicon wafers — •Jan Kegel[1], Heike Angermann[2], Abdelazize Laades[3], Uta Stürzebecher[3], and Bert Stegemann[1] — [1]University of Applied Sciences (HTW) Berlin, Wilhelminenhofstr. 75a, 12459 Berlin — [2]Helmholtz-Zentrum für Materialien und Energie Berlin, Kekuléstr. 5, 12489 Berlin — [3]CiS Institut für Mikrosensorik und Photovoltaik, Konrad-Zuse-Str. 14, 99099 Erfurt

In high-efficiency crystalline silicon solar cells, the surfaces of the Si wafers can be textured to reduce reflection losses and to increase the absorption probability by light trapping. This texturing is produced by anisotropic wet-chemical etching of random pyramid structures. The improvement of the optical properties, however, is associated with a larger effective surface area, which inherently corresponds to an increased number of electrically active defect states in the band gap. In this paper, a detailed, quantitative analysis of the micro-roughness of the textured Si wafers was performed. Subsequent surface conditioning was optimized with respect to efficient interface passivation as elucidated by surface photovoltage (SPV) measurements. Data on surface morphology is correlated to light-trapping behavior and interface state densities in order to identify Si wafer pre-treatment conditions for optimal solar cell performance.

HL 72.6 Wed 16:00 Poster D

Novel multifunctional emitters for heterojunction solar cells — •Henriette Gatz, Oumkelthoum Mint Moustapha, Dieuwertje Schrijvers, Bart Sasbrink, Arjen de Waal, Jatin Rath, and Ruud Schropp — Nanophotonics - Physics of Devices, Debye Institute for Nanomaterials Science, Utrecht University, The Netherlands

Silicon heterojunctions are a promising approach to obtain high efficiency solar cells at low manufacturing costs. Their main parts consist of a silicon wafer, a thin emitter layer, and a Transparent Conductive Oxide (TCO) layer. The purpose of the TCO layer is to act as a perfect window for the incoming light while providing sufficient conductivity to transport the current to the front contact of the cell. The commonly used TCOs have several disadvantages, such as a narrow range of refractive index and work function. This does not allow for tuning in order to optimize the collection and transport of carriers.

To simplify the heterojunction silicon cell structure and its fabrication process, we aim to develop a novel layer that can be made with a single deposition technique, combining the functions of the thin emitter layer and the TCO layer, including the anti-reflection function.

HL 72.7 Wed 16:00 Poster D

Synthesis and Characterization of Kesterite Nanoparticles and Thin Films with XRD and GDOES — •Folker Zutz, Christine Chory, Martin Knipper, Ingo Riedel, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, 26111 Oldenburg, Germany

Cu_2ZnSnS_4 (CZTS) is a promising compound semiconductor for low cost solar cells, because of its non-toxic and abundant precursor elements. An approach for economic manufacturing is an ink-based thin film deposition process. The inks are made from dispersions of CZTS nanoparticles, which were prepared by colloidal synthesis at low temperatures. The thin films were realized by drop casting and treated by a post-deposition annealing in inert gas atmosphere in order to remove organic stabilizers from the film and to enhance growth of polycrystalline structures. Structural investigations of dried CZTS powders with varying chemical compositions at different annealing temperatures were performed via X-ray diffraction. The development of the Kesterite phase and secondary impurity phases was investigated in order to archive a more pure CZTS material. The element distribution in the CZTS thin films was investigated by glow discharge optical emission spectroscopy (GDOES). By this method the CZTS elements and also organic compounds like precursors used during synthesis or high-boiling solvents used for the nano-ink formulation were probed. Thus the effectiveness of the NP purification and the film annealing can be analyzed.

HL 72.8 Wed 16:00 Poster D

First-principles electronic structure of β-$FeSi_2$ and FeS_2 surfaces — •Pengxiang Xu, Timo Schena, Stefan Blügel, and Gus-

TAV BIHLMAYER — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Applying density functional theory in the framework of the full potential linearized augmented plane-wave (FLAPW) method FLEUR [1], we investigate the electronic structure of potential future photovoltaic materials, β-$FeSi_2$ and FeS_2, for selected surface orientations and terminations. Surface passivation has become an essential factor for translating high-efficiency solar cell concepts into industrial production schemes due to trapping of charge carriers in surface states at the passivated surface layer.

We study the atomic and electronic structure of β-$FeSi_2$ and FeS_2 thin films for (001) and (100) orientations with different terminations. The most stable orientations are determined by comparing their cohesive energy. Detailed electronic structure calculations show that surface states originating from Fe play an important role and might determine their photovoltaic properties. The effects of passivation on the electronic structure are also presented.

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[1] www.flapw.de

HL 72.9 Wed 16:00 Poster D

Optoelectronic properties of thin film Cu_2S — •HENDRIK STRÄTER[1], RUDOLF BRÜGGEMANN[1], GOTTFRIED H BAUER[1], SEBASTIAN SIOL[2], ANDREAS KLEIN[2], and WOLFRAM JAEGERMANN[2] — [1]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg — [2]Material- und Geowissenschaften, FG Oberflächenforschung, TU Darmstadt, D-64287 Darmstadt

Cuprous sulfide (Cu_2S) is a non-toxic and low-cost p-type semiconductor and therefore considered as an alternative for CdTe or $CuIn_xGa_{1-x}(S,Se)_2$ thin film solar cells. We investigated Cu_2S absorber layers prepared by physical vapor deposition (PVD) with varying pre- and post-treatment processes of the substrate and the Cu_2S absorber. Calibrated photoluminescence experiments with lateral μm and mm resolution were performed to obtain the splitting of the quasi-Fermi levels (QFL) μ, the absorption coefficient α and the optical band gap E_G. Additionally we have determined the local variation of the QFL-splitting across the absorber. The best sample has been prepared with both pre- and post-treatment by annealing and has a QFL-splitting of $\mu \approx 720\,\mathrm{meV}$. All samples show an optical band gap of $E_G \approx 1.3\,\mathrm{eV}$.

HL 72.10 Wed 16:00 Poster D

Cyclic voltammetry of semiconductor nanoparticles and organic materials for solar cells — •DOROTHEA SCHEUNEMANN, MARTA KRUSZYNSKA, JOANNA KOLNY-OLESIAK, HOLGER BORCHERT, and JÜRGEN PARISI — Univ. of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, 26111 Oldenburg

In hybrid solar cells the charge transfer between nanoparticles and conducting polymers at the donor/acceptor interface is influenced by the position of energy levels of donor and acceptor. Thus for the development of efficient solar cells it is crucial to be able to determine and control the band gap and band edge positions of donor and acceptor materials. In particular the absolute position of HOMO and LUMO levels are important. Because these band edge positions are in case of nanoparticles size-dependent, a method to estimate these positions and to relate them to the energy levels of conducting polymers is needed. One suitable method to characterize those materials is cyclic voltammetry. With this electrochemical method it is possible to detect the absolute values of the energetic positions of the HOMO and LUMO as well as non-radiative defect states with respect to the vacuum level. We present cyclic voltammetric measurements of $CuInS_2$ and ZnO nanoparticles which can be used as an acceptor material in hybrid solar cells. In addition measurements on poly(3-hexylthiophene) (P3HT) and Phenyl-C61-butyric acid methyl ester (PCBM) were done to provide electronic structures of relevant materials for hybrid as well as for organic solar cells. The measurements were done on thin films processed from solution by spin-coating.

HL 72.11 Wed 16:00 Poster D

Herstellung und Charakterisierung von Mikro-GaAs-Photovoltaikzellen — •MICHAEL KWIATEK, ARNE LUDWIG, DIRK REUTER, RÜDIGER SCHOTT und ANDREAS D. WIECK — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Deutschland

In der Informationstechnologie spielen optische Übertragungswege eine immer wichtigere Rolle. So können Daten über größere Distanzen mit höherer Bandbreite übertragen werden. Ein Problem ist hierbei jedoch die Energieversorgung der angeschlossenen Endgeräte. Photovoltaik spielt bei der dezentralen Energieversorgung von Systemen eine zunehmend bedeutendere Rolle. Durch die hergestellten Mikro-Solarzellen soll diese Idee auch auf die optische Datenübertragung erweitert werden. Dem eigentlichen optischen Datensignal kann dabei eine kontinuierliche Licht-Energieversorgung überlagert werden. In diesem Beitrag wird die Umsetzung dieses Konzeptes mit Mikro-Photovoltaikzellen auf GaAs-Basis demonstriert. Es wurden auf n-Si-dotiertem GaAs-Substrat mit Molekularstrahl-Epitaxie n-p/n-i-p-Strukturen aufgewachsen. Die p-Dotierung erfolgte dabei mit einer mit Elektronen-Bombardement geheizten Kohlenstoff-Zelle. Es werden Ergebnisse mehrerer Wachstumsreihen vorgestellt, in denen die Schichtstruktur angepasst wurde, um die Charakteristik des Bauelementes zu verbessern und die Einflüsse der verschiedenen Schichtparameter zu untersuchen. Die Ergebnisse zeigen, dass die technische Umsetzung des oben formulierten Ziels prinzipiell möglich ist, so dass diese Experimente als Grundlage für weiterführende Arbeiten dienen können.

HL 72.12 Wed 16:00 Poster D

Silicon and Transparent Conducting Oxides: Si/ZnO and Si/In_2O_3 Interfaces from First Principles — •BENJAMIN HÖFFLING[1,2] and FRIEDHELM BECHSTEDT[1,2] — [1]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität,Max-Wien-Platz 1, 07743 Jena,Germany — [2]Eutropean Theoretical Spectroscopy Facility (ETSF)

The Transparent Conducting Oxides (TCOs) In_2O_3 and ZnO are routinely used as transparent electrodes in Si-based photovoltaics. Their interfaces with Si are consequently of great interest. Electronic band offsets, dangling bonds, and interface states determine the efficiency of charge-carrier separation in solar cells. Sample-preparation problems and difficulties in correctly describing the electronic properties of TCOs make the determination of these important quantities a challenging task to theoreticians and experimentalists alike. We develop a method for the construction of atomic models of heterostructural interfaces based on coincidence lattices, maximum bond saturation, and total energy minimization, which enables us to construct model geometries for the interface between Si and ZnO as well as between Si and In_2O_3. In particular we investigate the Si(001)/ZnO($20\bar{2}3$) and the Si(001)/In_2O_3(001) interface by means of density functional theory (DFT) and modern quasiparticle theory based on semilocal exchange-correlation functionals. We examine electronic band discontinuities and interface states. The influence of dangling bond passivation, strain, and charge transfer is studied by their respective influence on the electronic density of states.

HL 72.13 Wed 16:00 Poster D

Numerical Simulation of Chalcogenide Solar Cells — •OLGA BAKAEVA[1], FELICE FRIEDRICH[1,2], RAINER LEIHKAUF[1], THOMAS UNOLD[3], and CHRISTIAN BOIT[1] — [1]Berlin University of Technology, Sekr. E2, Einsteinufer 19, D-10587 Berlin — [2]PVcomB, Schwarzschildstr. 3, D-12489 Berlin — [3]Helmholtz-Zentrum Berlin, Hahn-Meitner-Platz 1, D-14109 Berlin

Numerical simulation is an essential method for fundamental understanding of solar cell physics and the improvement of the functionality of devices. Grain boundary effects and materials grading, that play an important role in chalcogenide solar cells, make it necessary to develop a model for 2D simulations. In this study, our aim was to compare the well-known one-dimensional simulation tool SCAPS1D with the commercial simulation program Sentaurus TCAD that allows for multidimensional simulation. A model with the same parameter set for Cu(In,Ga)Se2 solar cell was set up in TCAD and SCAPS1D. The effects of band alignment and generation rate on the dark and illuminated I-V characteristics were analyzed. First results of the effects of a Ga-grading in the solar cells will be discussed.

HL 72.14 Wed 16:00 Poster D

Comparative characterisation of sputtered ZnO:Al TCO-layers on float glass produced by large ceramic and metallic — •SEBASTIAN WOHNER[1], HARTMUT WITTE[1], MARTIN BÄHR[2], JÖRG GÜNTHER[2], JÜRGEN BLÄSING[1], and ALOIS KROST[1] — [1]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg — [2]Euroglas GmbH, Haldensleben

One of the main parts of photovoltaic cells is the conductive and transparent front contact which is often realized by wide bandgap ZnO.

D.c. magnetron sputtering with ceramic $ZnO{:}Al_2O_3$ targets is one of the commonly used processes to produce ZnO-layers on float glass. Disadvantages are the fixed stoichiometric proportions and the high temperatures.
Alternatively, Al-doped ZnO-layers were deposited by reactive d.c. magnetron sputtering from a large, planar Zn(Al) under oxygen ambience. Hereby the operating point has to be within the unstable transition region of the power - oxygen pressure characteristic.
For comparison ZnO layers were produced by reactive and by ceramic magnetron d.c. sputtering using large targets. The ZnO layers were characterized and compared by resistivity, Hall-effect as well as by optical transmission- and reflection measurements to get the electron concentration using the Drude-model. The surface and the crystal structure were analysed by AFM and Bragg-Brentano X-ray diffraction, respectively. The results show the potential for the production of qualitatively good ZnO-layers as TCO by reactive d.c. magnetron sputtering on large cathodes using adapted process controlling.

HL 72.15 Wed 16:00 Poster D

Main direction of photoelectric converters research in Georgia — •Ia Trapaidze[1], Raphiel Chikovani[1], Gela Goderzishvili[1], and Lia Trapaidze[2] — [1]Dep.of physics,Georgian Technical University,77 kostava,Tbilisi,Georgia — [2]Dep. of physics,Tbilisi State University, Chavchavadze 3,0128,Tbilisi,Georgia

Georgia together with use of traditional energy resources attaches a very large importance of using renewable energy sources. Solar energy perspective for Georgia, because of its geographical allocation on the territory and application of solar energy is an important term for providing the population with the objects which are so important for life (supply with the energy the mountainous regions of small numbers of population).In most regions of the country there are 250-280 sunny days in a year, which is approximately 1900-2000 hours per year. The prospects of development of photovoltaics in Georgia are analyzed. It is noted that the photoelectric method of conversion of the solar energy based on semiconductor materials is especially promising. Main directions of research photoelectric convertors in Georgia are: *Creation and use law power photoelectric convertors on the based of Silicon. *Processing of convertors on the base of GaAlAs and other semiconductive compounds. At present is very important to obtain high efficiency photoelectric convertors on the based of these compounds with quantum dots and quantum wells creating in nanostructure. -*Research of possibility of creation high efficiency photoelectric convertors by using silicon-germanium.

HL 72.16 Wed 16:00 Poster D

Developing coarse-grained force-fields for semiconducting polymers — •Sergii Donets, Anton Pershin, and Stephan A. Baeurle — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, D-93040 Regensburg

Semiconducting polymers have been extensively studied in the past few years due to their great potential in the solar-cell technology. Typical polymer solar cells are composed of a p-type layer for hole transport and an n-type layer for electron transport. Their perfomance is strongly dependent on the bulk heterojunction morphology, which consists of an interpenetrating network of donor and acceptor phases. In this regard computer simulation techniques can represent a powerful tool to optimize the relationship between their structural characteristics and their photovoltaic efficiency. To cope with large system sizes and lengthy equilibration times, we make use in this work of coarse-graining (CG) procedures, in which the many-particle system described at atomistic resolution is mapped onto a similar system with smaller number of degrees of freedom. To derive a suitable force-field, we use the iterative Boltzmann inversion method by iteratively refining the interaction between CG-beads, until the reference structural distributions are reproduced.

HL 72.17 Wed 16:00 Poster D

Theoretical investigation of the charge transport in nanostructured organic semiconductors — •Anton Pershin, Sergii Donets, and Stephan A. Baeurle — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, D-93040 Regensburg, Germany

Charge transport in organic semiconductors is strongly affected by small-scale loss phenomena, like exciton and charge carrier loss, which reduces the usefulness of such materials for industrial applications. In this presentation we introduce a new simulation approach, which permits to explore the causes for the occurrence of such phenomena on the nanoscale, and provide in this way a new tool for the optimization of charge transport in photovoltaic systems. Our approach models the elementary photovoltaic processes by coupling a mesoscopic simulation technique for reproducing the polymeric phase separation process with a suitable stochastic dynamical algorithm for simulating the charge transport process [1]. Using this method, we study the influence of the composition and timely variable structural factors, like e.g. inhomogeneities, on the efficiency of exciton and charge carrier generation as well as transport in nanostructured polymer systems.

[1] A. Pershin, S. Donets, S.A. Baeurle, submitted.

HL 72.18 Wed 16:00 Poster D

Characterization of hybrid solar cells based on conjugated polymers and $CuInS_2$ nanoparticles with different organic ligands — •Rany Miranti, Nikolay Radychev, Marta Kruszynska, Dorothea Scheunemann, Joanna Kolny-Olesiak, Holger Borchert, and Jürgen Parisi — University of Oldenburg, Department of Physics, Energy and Semiconductor Research Laboratory, Carl-von-Ossietzky-Str, 9-11, 26129 Oldenburg, Germany

The performance of hybrid solar cells demonstrated considerable advances in recent years, especially concerning hybrid blends containing semiconductor nanocrystals of CdS, ZnO, or CdSe. However, materials based on cadmium chalcogenides are highly toxic which severely restricts possible applications. Moreover these materials demonstrate a relatively low absorption coefficient and the band gap of these intensively used semiconductor nanocrystals does not match the solar spectrum well. One of the promising alternative materials is the direct band gap semiconductor $CuInS_2$ (CIS). CIS absorbs up to 820 nm (Eg=1.5eV), is less toxic, and has a high absorption coefficient of about 5×10^5 cm^{-1} (at 500 nm). In the present work, CIS nanoparticles with different shapes were blended with two different kinds of conjugated polymers, namely P3HT and poly[2,1,3-benzothiadiazole-4,7-diyl[4,4-bis(2-ethylhexyl)-4H-cyclopenta[2,1-b:3,4-b']dithiophene-2,6-diyl]] (PCPDTBT). Corresponding solar cells were prepared and studied by current-voltage profiling and measurements of the external quantum efficiency. Furthermore, the influence of various organic capping ligands on the CIS-based hybrid solar cells was investigated.

HL 72.19 Wed 16:00 Poster D

Hybrid solar cells based on ZnO nanorod arrays/ polymer — •Basudev Pradhan and Dieter Neher — Institut für Physik und Astronomie, Universität Potsdam, Potsdam-Golm, Germany

Hybrid solar cells have been fabricated using vertically oriented, high density, and crystalline array of zinc oxide (ZnO) nanorods and low bandgap hole conducting polymer. These hybrid solar cells take advantage of the both materials properties: solution processing of polymers and high electron mobility of inorganic semiconductors. The vertical nanorods provide direct conduction paths for the electrons from the point of injection to the collection electrode while maintaining large interface area between polymer and nanorod arrays. We have found that the device performance improves with deep infiltration of the polymer into the nanorod arrays and also with the improved crystallinity of the polymer induced by post annealing. In addition, the dependence of photovoltaic performance on the ZnO nanorod length was investigated and different low bandgap polymers have been used to achieve optimum performance.

HL 72.20 Wed 16:00 Poster D

Growth and characterization of sublimation grown 9,10-diphenylanthracene single crystals — •T. Schmeiler[1], M. Zellmeier[1], and J. Pflaum[1,2] — [1]Exp. Phys. VI, Julius-Maximilians-University Würzburg, D-97074 Würzburg — [2]ZAE Bayern e.V. , D-97074 Würzburg

Organic single crystals define an important class of solid states due to their structural, chemical and functional homogeneity. In case of polyaromatics, single crystals provide reference systems with respect to optical properties, charge carrier transport and their respective spatial anisotropies. Here we present a study on 9,10-diphenylanthracene (DPA) single crystals grown via sublimation under streaming nitrogen gas. The lateral extension of the DPA crystal reveals (010) facet areas up to 0,5 cm^2 at thicknesses of 100 μm. The high structural quality is confirmed by X-ray diffraction as well as by the charge carrier transport measured by time-of-flight (TOF). To map existing dislocation lines, we developed an etching protocol which, as for the case of 5,6,11,12-tetraphenyltetracene (rubrene), yields to pyramidal-shaped etch pits at termination points of the [001] dislocation lines. Depend-

ing on etching conditions, like concentration and time, the sizes of the epitaxially oriented pits can be tuned in the range of several micrometres thereby promising interference with optical excitation wavelenght. In the case of rubrene, such structures were already investigated by means of Photoluminescence (PL) measurements in combination with FDTD simulations, both revealing enhanced PL-intensities at the pit edges due to waveguiding and enhanced light scattering.

HL 72.21 Wed 16:00 Poster D

Investigation of recombination processes in organic solar cells using a differential photocurrent method. — •Simon Hein[1], Julia Rauh[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, D-97074 Würzburg

To satisfy the world's need for energy organic solar cells offer, due to their low fabrication costs, a promising alternative. Although power conversion efficiencies of 9.2 % have already been achieved on lab scale [1], the fundamental processes taking place in organic solar cells are still not completely understood. One of the currently most discussed topics is the dominating recombination process of charge carriers, as this loss mechanism influences all of the relevant solar cell parameters. Therefor, a detailed understanding of the recombination mechanisms is essential for further efficiency enhancement. Recently, Koster et al. [2] presented a technique to investigate the influence of light intensity on the charge carrier recombination under short-circuit conditions. Thereby, the differential current density, induced by a modulated light of low intensity superimposed to a continuous background light of various intensities, is measured. We present our data obtained by this technique for poly(3-hexylthiophene) solar cells blended with different electron acceptors. The results are discussed with respect to the charge carrier recombination processes under short-circuit conditions in dependence of temperature and a wide range of light intensities.

[1] R. F. Service, Science, 332, 293 (2011)
[2] L. J. A. Koster et al., Adv. Mater., 23, 1670 (2011)

HL 72.22 Wed 16:00 Poster D

Recombination of excited species in organic photovoltaic material systems studied by field dependend transient absorption — •Clemens Grünewald[1], Julia Kern[1], Julien Gorenflot[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, D-97074 Würzburg — [2]ZAE Bayern, D-97074 Würzburg

Organic opto-electronic devices such as bulk heterojunction solar cells are limited in their efficiency due to intrinsic geminate and non-geminate charge carrier losses. The recombination dynamics of the latter mechanism are observed with time resolved photoinduced absorption spectroscopy from submicro- to milliseconds at different temperatures and wavelengths to address polarons. Starting with the well-probed poly(3-hexylthiophene) : [6,6]-phenyl-C61-butyric acid methyl ester (P3HT:PCBM) material system the study also covers promising donor polymers such as PTB7. In addition an external electric field is applied to these organic blends in order to address charge carrier generation and recombination behaviour under bias. The dependence of the photogeneration of free charge carrier on electric field and temperature are described in relation to the Braun-Onsager model.

HL 72.23 Wed 16:00 Poster D

Transient resolved recombination measurements in organic bulk heterojunction solar cells — •Markus Gluecker[1], Alexander Foertig[1], Carsten Deibel[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg, Germany — [2]Bavarian Centre for Applied Energy Research (ZAE Bayern e.V.), Am Hubland, 97074 Würzburg, Germany

The understanding of the current–voltage behavior is a prerequisite for improving the solar cell performance. Transient photovoltage (TPV), transient photocurrent (TPC) and voltage dependent charge extraction (CE) measurements were applied to organic solar cells based on different polymer:fullerene blend systems. From the determined charge carrier decay mechanism under open circuit conditions and voltage dependent charge carrier densities $n(V)$ the measured I/V response can be reconstructed. For material systems such as poly(3-hexyl thiophene)(P3HT):[6,6]-phenyl-C_{61} butyric acid methyl ester (PCBM) characterized by a voltage independent charge generation, we verified that bimolecular recombination is sufficient to describe the I/V behaviour over the entire operational regime. We further address the temperature dependent applicability of this analysis.

HL 72.24 Wed 16:00 Poster D

Optical properties of single crystalline pentacene and perfluoropentacene layers — •Jonatan Helzel, Mathias Schulz, Mira El Helou, Tobias Breuer, Gregor Witte, and Wolfram Heimbrodt — Philipps Universität Marburg department of physics and material sciences centre Germany, Renthof 5, D-35032 Marburg

We prepared pentacene films with thicknesses of 10 nm, 20 nm and 100 nm on different ZnO surfaces by molecular beam deposition under ultra-high vacuum conditions. By varying the growth temperature, we prepared pentacene films in an amorphous phase, in the thin film phase and the Campbell phase. To characterize the films AFM and X-ray diffraction measurements have been done. The pentacene molecules form single crystalline islands with extensions of several μm. So we were able to measure the absorption on single islands and found a polarisation dependence of both Davydov components perpendicularly to each other. The electronic transitions of the pentacene films have been measured in the temperature range between 10 K and room temperature. We observed a thickness dependent shift of the pentacene states upon cooling. At 10 K there is a difference of about 30 meV between the electronic states of a 10 nm and a 100 nm thick pentacene film. The reason for this behaviour is the very different thermal expansion coefficients of substrate and film resulting in a strong in-plane tensile strain. This strain causes little rifts in the film, which leads to a hysteretic temperature shift of the excitons. Analogous measurements have been done on single crystalline perfluoropentacene on KCl and NaF substrates.

HL 72.25 Wed 16:00 Poster D

Organic semiconducting complexes at the molecular scale — •Matthieu Dvorak, Markus Müller, Frank Stienkemeier, and Elizabeth von Hauff — Physics Institute, University of Freiburg, Hermann-Herder Str. 3, 79104 Freiburg, Germany

An improved understanding of the parameters which influence the charge transfer between donor and acceptor molecules is highly important to improve the efficiency of organic solar cells. Different parameters such as the bulk mobility, the molecular structure and the ordering proved to play an important role on the charge transfer.[1] In thin film or solution systems it is most of the time not possible to disentangle these different mechanisms at a molecular scale. On the contrary, helium droplets, due to their cold, superfluid and weak interacting properties, has proved to be the perfect matrix for the study of optical properties at the molecular scale, related to a spectral resolution increased by three orders of magnitude compared to thin film or solution measurements. This precision proved to be helpful to confirm recent calculations on PTCDA complexes (3,4,9,10-perylene-tetracarboxylic- dianhydride) based on a Frenkel exciton model.[2]
Making use of the enhanced spectroscopic resolution to study the charge transfer process at a molecular scale as well as the possibility to vary the donor-acceptor distance are expected to reveal new information to improve the charge transfer in donor-acceptor systems which is relevant in organic photovoltaic.

[1] M. Hallermann *et al.*; Appl. Phys. Lett., 97, 023301 (2010)
[2] J. Roden *et al.*; J. Chem. Phys., 134, 054907 (2011)

HL 72.26 Wed 16:00 Poster D

Charge transport in organic semiconductors - electric potential mapping — •Johannes Widmer, Wolfgang Tress, Karl Leo, and Moritz Riede — Institute für Angewandte Photophysik, TU Dresden, Germany

The charge transport in thin films of organic semiconductors is characterized in single carrier devices of small molecule organic semiconductors. We observe space-charge limited currents (SCLC) in devices with varying layer thicknesses. This enables us to determine the electric field evolution within the material, i.e. we can characterize the charge current in more detail than in individual space-charge limited devices.

Single carrier devices allow for the characterization of current in the same geometry as in typical applications (in contrast to field effect transistors) and with adequate parameters: The current density, the electric field, as well as the charge carrier density in these measurements have similar values as in e.g. organic solar cells or OLEDs.

The presented evaluation method is an extension of single SCLC measurements and can give insight into device-relevant details of the charge transport.

HL 72.27 Wed 16:00 Poster D

Bottom-gated test bed for organic field-effect transistors with

epitaxial graphene electrodes — •Emmanuel Bayaya, Daniel Waldmann, Johannes Schöck, and Heiko B. Weber — Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg, Staudtstr. 7 / Bau A3, 91058 Erlangen

We fabricate organic field-effect transistors with graphene source- and drain electrodes, using epitaxial graphene on silicon carbide (0001).A bottom-gate is provided by implantation prior to graphene growth [1]. This setup provides an ultra flat test bed for organic semiconductors, or other materials. We demonstrate gate operation for Poly(3-hexylthiophene), and critically discuss the role of interface states being created during the fabrication.

[1] D. Waldmann, J. Jobst, F. Speck, T. Seyller. M. Krieger, H.B. Weber, Nature Materials 10, 357-360 (2011).

HL 72.28 Wed 16:00 Poster D

Quantitative Kelvin probe force microscopy investigations of organic field-effect transistor channels — •Jan Murawski, Peter Milde, Moritz P. Hein, Merve Anderson, and Lukas Eng — TU Dresden, Institut für Angewandte Photophysik, George-Bähr-Str. 1, 01069 Dresden

Organic field-effect transistors (OFETs) are popular for several decades by now. Although expected to have a great impact on semiconductor electronics in the near future, OFETs still suffer from drawbacks such as high injection and extraction barriers at the electrodes and low charge carrier mobilities. Typically, only macroscopic values for these parameters are obtained, while the microscopic origins remain unknown.

In this contribution, we investigate channels of pentacene and poly[9,9-dio-ctyl-fluorene-co-N-(4-butylphenyl)-diphenylamine] (TFB) based bottom-gate, bottom-contact OFETs using non-contact atomic force microscopy (nc-AFM) combined with frequency-modulated Kelvin probe force microscopy (FM-KPFM) [1] for mapping the surface potential with high sensitivity in ambient conditions. With this method we are able to visualize the local injection and extraction barriers, quantify their heights, and discover bottlenecks of charge transport within these devices.

[1] U. Zerweck et al., Accuracy and Resolution Limits of Kelvin Probe Force Microscopy. Phys. Rev. B 71:125424 (2005)

HL 72.29 Wed 16:00 Poster D

Charge Transport in organic solar cells studied by Scanning Probe Microscopy — •Michael Scherer[1,2], Dominik Daume[1,2], Rebecca Saive[1,2], Daniela Donhauser[1,3], Michael Kroeger[1,3], Irene Wacker[4], Rasmus Schröder[1,5], and Wolfgang Kowalsky[1,3] — [1]Innovation Lab GmbH — [2]Universität Heidelberg — [3]Technische Universität Braunschweig — [4]Institut für Biologische Grenzflächen, Karlsruher Institut für Technologie — [5]CellNetworks, BioQuant, Universität Heidelberg

We report on the characterization of P3HT:PCBM bulk heterojunction organic solar cells via scanning probe microscopy. We fabricated OPV devices on various substrates to then prepare thin lamellas via micro-cutting techniques to allow for SPM characterization of device cross-sections.

HL 72.30 Wed 16:00 Poster D

Toward the realization of a Scanning Near-field Optical Microscope deploying an Organic Light Emitting Device — Ilja Vladimirov[1,2], •Benjamin Martini[1,4], Daniela Donhauser[1,3], Johannes Ostermann[1,3], Michael Kröger[1,3], and Wolfgang Kowalsky[1,3] — [1]Innovation Lab, Heidelberg — [2]Universität Heidelberg, Kirchhoff-Institut für Physik — [3]TU Braunschweig, Institut für Hochfrequenztechnik — [4]TU München

We investigate a scanning near-field optical microscope (SNOM) employing an organic light emitting device (OLED) fabricated on a commercial atomic force microscope (AFM) cantilever via vacuum thermal evaporation and a method for its characterization. In order to deposit the OLED on a silicon cantilever, the OLED stack based on transparent ITO anode was adapted to silicon, the direction of light emission inverted and the out-coupling efficiency optimized. Employment of luminescent dopants led to OLED luminance values on silicon of about 1000 cd/m^2 at 7 V.

Due to the low photon flux, estimated to be below 1000 photons/second, we use a photon counter, based on a cooled photomultiplier (PMT) to detect photons emitted from the AFM tip. To verify the applicability of near-field condition, we use a tapered optical fiber featuring a distribution of propagating modes significantly beyond the fiber core. This allows to detect coupling between the evanescent near-field of the probe and the modes of the tapered fiber using the PMT. Distance control between tip and sample is accomplished by an AFM.

HL 72.31 Wed 16:00 Poster D

Exploring molecular-scale structure formation of HIOS by all-atom Molecular Dynamics computer simulations — •Karol Palczynski and Joachim Dzubiella — Helmholtz-Zentrum Berlin, Hahn Meitner Platz 1, 14109 Berlin

The optical and electronic properties of Hybrid Inorganic/Organic Semiconductor (HIOS) devices strongly depend on the molecular configuration of the conjugated organic molecules (COM) at the inorganic semiconductor surfaces. The goal of this work is to explore the structure formation of HIOS on a molecular level by applying atomistically resolved molecular dynamics (MD) computer simulations of various COM. The temperature dependent crystal structures of COM such as Diindenoperylene, P-Sexiphenyl and Coronene have been investigated with various MD simulation methods. The sensitivity of the obtained structures to atomic partial charges and charge distributions has been studied. The calculated results have been compared with experimental x-ray measurements. Interaction parameters suitable for coarse-graining simulations have been determined.

HL 72.32 Wed 16:00 Poster D

Influence of charge carrier density and dimensionality on transport properties of (DCNQI-d$_6$)$_2$Cu radical anion salts — •Florian Hüwe[1], Matthias Schmiddunser[1], and Jens Pflaum[1,2] — [1]Experimental Physics VI, Julius-Maximilians-University Würzburg, D-97074 Würzburg — [2]ZAE Bayern e.V., D-97074 Würzburg

Due to their quasi-1D band structure the highly conducting organic (DCNQI-d$_6$)$_2$Cu radical anion salts provide an insight into the physics of low-dimensional metals. Compared to ordinary 3D metals they undergo a first-order Peierls metal-insulator transition upon cooling and show much more pronounced interactions with electrons and phonons.

Our contribution reports on the electrocrystallization of needle-like (DCNQI)$_2$Cu single crystals with extensions of up to $3cm$ along the (001) direction of high conductivity and thicknesses up to $125\mu m$ along the (010) normal. Characterization by XRD, Raman spectroscopy and transport measurements confirms the high quality of the samples. Their room-temperature conductivities reach values up to $\sigma = 1200 Scm^{-1}$ and show Ohmic behaviour. Raman spectra indicate an increase in charge carrier density on the crystallized DCNQI molecules compared to the neutral molecules causing partial filling of the conduction band. Upon cooling the (DCNQI)$_2$Cu crystal undergo a characteristic Peierls transition at $T_p = 75K$. To further elucidate effects by size and carrier concentration, these results will be compared to sub-μm sized crystallites smaller than $5\mu m$ and to crystals with modified charge carrier densities.

HL 73: GaN: Preparation and Characterization IV

Time: Thursday 9:30–11:00 Location: ER 270

HL 73.1 Thu 9:30 ER 270

AlInN/GaN-heterostructures for sensing applications — •Malte Fandrich, Timo Aschenbrenner, Stephan Figge, Thorsten Mehrtens, Andreas Rosenauer, and Detlef Hommel — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee NW1, 28359 Bremen, Germany

Commonly, $Al_{0.28}Ga_{0.72}N$-based heterostructures are applied as open-gate sensors utilizing the 2-dimensional electron gas (2DEG), which originates from the polarization discontinuity between GaN and a thin AlGaN top layer. Since $Al_{0.82}In_{0.18}N$ exhibits a higher polarization difference and is lattice matched to GaN, AlInN is a promising candidate to replace conventionally used AlGaN and to improve the sensor characteristics.

Both, strained AlGaN and lattice matched AlInN layers were grown by MOVPE on GaN buffer layers using c-plane sapphire substrates. All epitaxial structures were charaterized by HRXRD, SEM, AFM and TEM, particularly with respect to strain, defect density, as well as surface and interface roughness of the structures. In addition, sheet carrier density and mobility of the 2DEG were determined by Hall-measurements. The influence of the growth parameters on the structural quality of AlInN and its impact on the electrical properties will be discussed. Based on the heterostructures open-gate sensors were processed and their sensing behavior regarding polar liquids and gases were investigated. A comparison of the device performances proves the superior capability of AlInN/GaN-heterostructures for sensing applications.

HL 73.2 Thu 9:45 ER 270

Development of $Al_xGa_{1-x}N$ MSM photodetectors — •Moritz Brendel, Andrea Knigge, Sven Einfeldt, Frank Brunner, Arne Knauer, and Markus Weyers — Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik,Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany

Photodetectors for the UV spectral region are required to control UV sources, for the usage in UV lithography, disinfection, and also medical applications. Metal semiconductor metal photodetectors (MSM PDs) have a relatively simple layout and can be processed with quick cycle times. This makes them suitable as a tool for the examination of material quality by photocurrent measurements. By varying the Al content x in the $Al_xGa_{1-x}N$ absorber layer the cut-off wavelength can be tuned from 365 nm for $x = 0$ to 200 nm for $x = 1$. With rising Al content the epitaxial growth of $Al_xGa_{1-x}N$ layers on sapphire with a low defect density becomes increasingly challenging. A higher defect density is often associated with enhanced carrier trapping and thus can influence the experimentally accessible responsivity. Traps are also associated with persistent photoconductivity (PPC) after turning off the illumination source. The capture of excess carriers at defect states in either the bulk material, at interfaces or at the semiconductor surface retards the decay of the photoinduced conductivity corresponding to an enhanced recombination lifetime. In this talk MSM photodetectors with different absorber compositions grown by MOVPE are presented. Spectral responsivity, dark current, and switching behavior are discussed in relation to material properties of the absorber layer.

HL 73.3 Thu 10:00 ER 270

Electrical properties of p-type AlGaN/GaN layers on Si substrates — Antje Rohrbeck, •Hartmut Witte, Phannee Sangkaew, Peter Veit, Bernd Garke, Armin Dadgar, Juergen Christen, Ruediger Goldhahn, and Alois Krost — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

AlGaN/AlN layers on Si-substrates are the base of new UV- LEDs with additional applications in sensoring and information storage. Effective p-type doping of AlGaN is hindered by the increase of the Mg acceptor activation energy with increasing Al content and by an increased defect density using Si substrates. For an enhancement of the hole concentration in p-AlGaN layers a p-type AlGaN:Mg/GaN:Mg superlattice(SL) was grown. The doping properties of this SL were compared with single p-type GaN and p-type AlGaN (x=0.1) layers characterized by CV- and impedance spectroscopy and scanning capacitance microscopy. Furthermore, the impact of the density and the character of structural defects of the surface properties were characterized by atomic force microscopy and scanning surface potential microscopy in correlation with transmission electron microscopy. To investigate electrical surface properties X-ray photoemission spectroscopy and the serial resistance of a lateral Schottky junction were applied. Inversion domains and dislocations were observed in the p-GaN and p-AlGaN layers increasing the serial resistances of the Schottky contacts and reducing the forward current densities. In contrast, the AlGaN/GaN SL surface shows only marginal surface defects.

HL 73.4 Thu 10:15 ER 270

High quality n-GaN with carrier concentrations above 10^{20} cm^{-3} using Germanium doping — •Stephanie Fritze, Antje Rohrbeck, Hartmut Witte, Armin Dadgar, and Alois Krost — Institute of Experimental Physics, Otto-von-Guericke-Universität Magdeburg, Germany

For GaN based semiconductor devices, especially for LED manufacturing, a high n-type conductivity is necessary for homogeneous current spreading. Commonly Si is used as n-type dopant in GaN, but it induces additional tensile stress in the GaN layer possibly leading to cracking. Furthermore, exceeding a critical Si doping level of $n = 5 \cdot 10^{19} cm^{-3}$ the GaN surface becomes rough. We demonstrate successful Ge doping for highly conductive n-GaN using two different Germanium sources, GeH_4 and iso-butyl-germane (IBGe). The GaN structures were grown on c-sapphire substrates by the MOVPE technique using standard growth conditions. We realized Ge-doping levels up to $2.5 \cdot 10^{20} cm^{-3}$ without any tensile stress enhancement. All Ge-doped GaN structures show a smooth and crack-free surface in Nomarski microscopy. Even at carrier concentrations of $n = 2.5 \cdot 10^{20} cm^{-3}$, as determined by Hall effect measurements, no surface morphology degradation was visible. In a doping range between $1 \cdot 10^{18}$ and $5 \cdot 10^{19} cm^{-3}$ the XRD ω-FWHM is similar between Si-doped and Ge-doped GaN. But with further increasing the carrier concentration the crystalline quality abruptly improves at a doping concentration around $1 \cdot 10^{20} cm^{-3}$. In this case both Ge dopant sources show equal characteristics.

HL 73.5 Thu 10:30 ER 270

Reliable defect energetics in GaN:Mg — •Björn Lange[1], Christoph Freysoldt[1], Jörg Neugebauer[1], Qimin Yan[2], John L. Lyons[2], Anderson Janotti[2], and Chris G. Van de Walle[2] — [1]Max-Planck Institut für Eisenforschung GmbH, 40237 Düsseldorf, Deutschland — [2]University of California Santa Barbara, CA 93106-5050, USA

Density-functional theory (DFT) is a widely used method for electronic structure calculations. The modeling of defects within this method allows us to calculate their formation energies and concentrations in dependence of experimental growth parameters. In the plane-wave DFT description there are several approximations for modeling the electron-ion interaction (pseudo potentials or the PAW approach) and the exchange-correlation functional (LDA, GGA, or hybrid functionals such as HSE). Calculated formation energies of defects with respect to standard reference systems (bulk solids or molecules) may strongly depend on these computational details. In this work we show that the differences arise mainly from the varying quality of description between defects and the reference systems. A new reference system which uses defect states allows for a fair comparison, showing a much better agreement between the different approaches. We discuss the remaining differences for various defects related to Mg doped GaN. The obtained formation energies are then used to calculate defect concentrations in dependence of the Mg concentration. Based on this analysis we identify the mechanism behind the experimental observed drop of the relative hydrogen concentration occurring in highly Mg-doped GaN samples.

HL 73.6 Thu 10:45 ER 270

Investigating Highly Doped Marker Layers in GaN on Sapphire using Scanning Microwave Microscopy — •Matthias A. Fenner[1] and Rachel A. Oliver[2] — [1]Agilent Technologies, Lyoner Straße 20, 60528 Frankfurt, Germany — [2]Department of Materials Science and Metallurgy, University of Cambridge, Cambridge, UK

Gallium nitride films grown on sapphire substrate were investigated using Scanning Microwave Microscopy (SMM). During the growth thin, highly doped layers were included to mark the shape of the surface at regular intervals. The SMM*s capability to measure dopant densities was employed to reconstruct cross sections of these surfaces. An unintentionally doped region was found for the initial stages of the growth. The growth surface at this stage is rough with most parts of the surface tilted out of the substrate plane. This suggests a model in which inclined surfaces promote the unintentional uptake of dopant material. Later stages of the growth result in smooth surfaces without unintentional doping.

HL 74: Focus Session: Semiconductor-based Quantum Communication I

Recent advances in the field of photonic quantum dot structures allow now for the implementation of semiconductor-based quantum optical functionalities, which are essential for future quantum communication networks. Within the scope of this focus-session, leading groups in the field will present their latest results on single photon physics and technologies to a broader audience. (Organizers: Manfred Bayer, University of Dortmund, and Artur Zrenner, University of Paderborn)

Time: Thursday 9:30–12:30 Location: ER 164

Invited Talk HL 74.1 Thu 9:30 ER 164

A highly efficient single photon - single quantum dot interface — •P. Senellart, O. Gazzano, S. Michaelis de Vasconcellos, C. Arnold, V. Loo, A. Nowak, A. Dousse, A. Lemaitre, I. Sagnes, J. Bloch, P. Voisin, and L. Lanco — CNRS, Laboratoire de Photonique et de Nanostructures, UPR20, 91460 Marcoussis, France

A quantum dot (QD) in a microcavity is a promising system to build a solid-state quantum network. It can be an efficient quantum light source as well as a quantum memory, a Bell-state analyser or a remote photon entangler when the QD embeds a spin. However, for these applications, one needs a perfect interface between the QD and the external electromagnetic field. We report on the scalable fabrication of ultrabright sources of indistinguishable single photons. Full control of the coupling of QDs to well designed micropillar cavity modes allows to obtain sources with collection efficiencies as high as 70%. Moreover, the Purcell effect as well as the spectral filtering of the QD emission by the cavity mode allows to further increase the effective brightness of the source by an order magnitude. Indistinguishability of the photons is demonstrated with a mean-wave packet overlap around 75%. Using high quality factor cavities operating in the strong coupling regime, we also report on resonant reflectivity measurements. When increasing the excitation power, optical non-linearities are observed when the intracavity photon number reaches 0.5. The good matching of the pillar mode with a Gaussian laser beam ensures that one out of three external photons couples to the quantum dot optical transition.

Topical Talk HL 74.2 Thu 10:00 ER 164

Electro-elastic Control of Excitons in Semiconductor Quantum Dots — •Armando Rastelli[1], Rinaldo Trotta[1], Paola Atkinson[1], Eugenio Zallo[1], Johannes D. Plumhof[1], Santosh Kumar[1], Fei Ding[2], Andreas Herklotz[2], Kathrin Dörr[1], and Oliver G. Schmidt[1] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Institute for Metallic Materials, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany

Optically active semiconductor quantum dots (QDs) fabricated by epitaxial growth are excellent quantum emitters which may find application in the field of quantum communication. Unavoidable fluctuations inherent to the fabrication process, which lead to a spread in the light emission properties of QD ensembles, hinder the use of most QDs in advanced quantum optics experiments. Post-growth techniques are therefore required to fine-tune the electronic structure of single QDs.

In this talk we will introduce new hybrid devices obtained by integrating semiconductor diode-membranes with embedded QDs onto piezoelectric actuators made of lead magnesium niobate-lead titanate (PMN-PT) single crystals. This combination allows us on one hand to study in detail the effects produced by variable tensile and compressive strains (with magnitude up to about 0.2%) on the excitonic emission of single QDs and on the other to control the emission properties in a broad range by simultaneous application of electric fields and stress. Obtained results and envisioned perspectives will be discussed.

Topical Talk HL 74.3 Thu 10:30 ER 164

Electrically contacted quantum dot - micropillars: building blocks for future quantum communication systems — •Stephan Reitzenstein[1,2], Tobias Heindel[2], Peter Gold[2], Manuel Gschrey[2], Christian Schneider[2], Sven Höfling[2], Martin Kamp[2], and Alfred Forchel[2] — [1]Present address: Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Technische Physik, Universität Würzburg, Würzburg, Germany

Future quantum communication systems such the a quantum repeater will rely strongly on the availability of compact quantum light sources, quantum memories and interfaces for the interconversion between local qubits and flying qubits. In this respect, quantum dot (QD) - microcavity systems exploiting cavity quantum electrodynamics (cQED) effects are of particular interest. Indeed, cQED effects allow one to enhance the efficiency of QD based single photon sources and to realize coherent coupling between light and matter.

In this contribution, we will address the potential of high quality electrically contacted QD - micropillar cavities to act as building blocks for quantum communication systems. We will show that these structures can act as highly efficient single photon emitters and as such are very suitable sources for quantum key distribution systems. Moreover, electrically contacted QD - micropillars could pave the way for qubit interconversion which will be demonstrated by means of single quantum dot photocurrent spectroscopy.

Coffe Break (30 min)

Invited Talk HL 74.4 Thu 11:30 ER 164

Semiconductor photonics for quantum information applications — •Andrew Shields — Toshiba Research Europe, 208 Cambridge Science Park, Milton Road, Cambridge UK

We discuss recent progress in generating and detecting quantum states of light using semiconductor devices. Single photon light emitting diodes (LEDs) generate quantum light states via the electroluminescence of a single self-assembled quantum dot. Recently the viability of these sources for quantum information applications has been greatly enhanced by voltage-controlled wavelength tuning that allows indistinguishable photons to be generated from different, spatially-separated devices. Quantum dot LEDs may also be used to generate polarization-entangled photon pairs. Semiconductor detection technology has also advanced remarkably in recent years, now allowing high efficiency detection with photon number resolution. We discuss the application of these devices to photonic quantum logic and long distance quantum communication.

Topical Talk HL 74.5 Thu 12:00 ER 164

Towards On-Chip Quantum Optics using Superconducting Single Photon Detectors coupled to Photonic Crystal Waveguides — •Günther Reithmaier[1], Jörg Senf[1], Arne Laucht[2], Max Bichler[1], Rudolf Gross[3], and Jonathan Finley[1] — [1]Walter Schottky Institut, TU München, Germany — [2]Centre for Quantum Computation Communication Technology, Sydney, Australia — [3]Walther-Meißner-Institut, TU München, Germany

We report on-chip generation of single photons in a GaAs 2D photonic crystal waveguide (PCW) and progress towards integration with NbN superconducting nanowire single photon detectors (SNSPDs) [2]. Single self-assembled InGaAs QDs inside the waveguide are located using spatially resolved microscopy. Detection from the waveguide facet shows a 55x more efficient coupling to the PWG mode compared to detection along an axis perpendicular to the sample surface. Time-resolved PL measurements show that the fraction of all spontaneous emission emitted into the waveguide mode is 85-96% and clean single photon emission is observed. We also describe first steps to integrate SNSPDs directly onto such a GaAs photonic crystal. SNSPDs combine high detection efficiency, low dark count rates and picosecond timing resolution [1], properties that depend strongly on the crystal quality of the NbN film [2]. By optimizing the nitrogen pressure and substrate temperature, NbN films on GaAs exhibit a superconducting T_c=11.2K and ΔT=0.5K. [1]G. N. Goltsman et al., APL 79,6 (2001) [2]F. Marsili et al., Supercond. Sci. Technol. 22 (2009) 095013

HL 75: Invited Talk: Kathrin Sebald

Time: Thursday 9:30–10:00 Location: EW 201

Invited Talk HL 75.1 Thu 9:30 EW 201

Weak and strong coupling in wide-gap semiconductor based monolithic microcavities — •Kathrin Sebald — Institute of Solid State Physics, University of Bremen, Germany

Semiconductor microcavities are a versatile system to investigate and manipulate the light-matter interaction in the weak and strong coupling regime. Weak coupling has profound effects on the spatial and spectral characteristics of the spontaneous emission yielding an increase of the out-coupling efficiency. In the strong-coupling regime, the exciton and photon states lose their individual identities, and the normal modes of the coupled system become a pair of mixed exciton-photon states. The resulting polaritons have very original properties, thus, and a lot of new physics and applications is expected. Due to their large excitonic binding energy and the high oscillator strengths, wide-gap semiconductor based microcavities are particularly well suited for the investigation of photon-exciton coupling and possess a huge potential for technological applications at elevated temperatures. However, their fabrication is challenging due to the difficulty in realizing lattice-matched distributed-Bragg-reflector layers. In this talk, the optical properties of all-epitaxial wide-bandgap based microcavity structures with quantum wells or quantum dots embedded in the cavity are presented. Examples of the influence of lateral optical confinement on the optical properties will be shown for pillar structured samples with different geometries in the strong and weak coupling regime.

HL 76: Heterostructures

Time: Thursday 9:30–11:00 Location: EW 202

HL 76.1 Thu 9:30 EW 202

Nanowire heterojunction devices with tunable light emission — •Martin Hetzel, Alois Lugstein, and Emmerich Bertagnolli — Institut für Festkörperelektronik, TU Wien, Floragasse 7, 1040 Wien

The results of synthesis as well as the electrical and optical characterization of a heterojunction device with tunable light emission, based on silicon and germanium nanowires and epitaxially grown on GaAs and InAs, are presented. Nanowire growth was performed by means of a VLS process in a LPCVD reactor with the assistance of either catalytic gold seed particles or a thin gold layer. Both silicon and germanium nanowires with a length of a few microns and a diameter of about 100nm are realized. The results depend strongly on the substrate, for which highly p- and n-doped GaAs as well as highly n-doped InAs are used. After growth, thin layers of aluminium oxide and indium tin oxide (ITO), respectively, are deposited on the surface, thus forming a wrapped gate around the nanowires. Then the samples are coated with photoresist which completely encapsulates the nanowires. Consecutively, the nanowire tops are revealed by an O2/SF6 reactive-ion etch, while optical lithography is used to define top contacts consisting of ITO or gold, respectively. Electrical measurements of individual nanowires as well as of nanowire ensembles reveal characteristic diode-like behavior in dependance on growth epitaxy, substrate type and nanowire material. Optical measurements with a tunable monochromatic light source are discussed as well. It is shown that dependent on wavelength and the applied gate voltage, nanowires can be stimulated to light emission, thus enabling tunable heterojunction devices.

HL 76.2 Thu 9:45 EW 202

High quality MgZnO/ZnO Quantum wells on polar and non-polar Substrates — •Jan Zippel, Gabriele Benndorf, Michael Lorenz, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig, Germany

ZnO has promising properties for the application in blue and ultraviolet light-emitting diodes. An increase in the internal quantum efficiency can be achieved by the growth of quantum well heterostructures. The quality of the interfaces and the control of the growth mode is necessary to achieve efficient heterostructures. Here, we present the growth of MgZnO/ZnO quantum wells heteroepitaxially as well as homoepitaxially by pulsed-laser deposition (PLD). Adopting the strategy of fairly low growth temperatures proposed in [1], we grow ZnO quantum wells on commercially available *a*-sapphire substrates in a layer by layer growth mode showing reflection high energy electron diffraction (RHEED) oscillations over the whole quantum well thickness. In the case of homoepitaxially grown MgZnO/ZnO quantum wells, we focus on non-polar ZnO substrates to avoid the quantum confined Stark effect observable in polar MgZnO/ZnO structures. Quantum confinement in MgZnO/ZnO heterostructures grown on non-polar *m*-plane ZnO substrates as well as on non polar *a*-plane ZnO substrates is presented. Additionally, ZnO thin films grown by an interval PLD approach on *c*-plane ZnO substrates showing smooth surfaces and RHEED oscillations over the whole layer are presented. [1] S. Sadofev et *al.*, Appl. Phys. Lett **87**, 091903 (2005).

HL 76.3 Thu 10:00 EW 202

Control of the population decay time in submonolayer-stacks by spatial coupling to Stranski-Krastanow-QDs — •Thomas Switaiski[1], Jan-Hindrik Schulze[2], Tim David Germann[2], André Strittmatter[2], Udo W. Pohl[2], Dieter Bimberg[2], and Ulrike Woggon[1] — [1]Inst. f. Optik und Atomare Physik, TU Berlin, Germany — [2]Inst. f. Festkörperphysik, TU Berlin, Germany

Superlattices of submonolayer depositions (SML-stack) based on InAs/GaAs provide high power conversion efficiencies and low threshold current densities when used as an active medium in laser diodes. In addition, these SML-stacks offer controllable tuning parameters.

Here, an approach to introduce an additional parameter to control the properties of a SML-stack is presented. We investigated the impact of coupling between a SML-stack and a Stranski-Krastanow (SK) grown quantum dot layer, as this coupled nanostructured system offers further parameters to control the decay dynamics. The studied samples contain one layer of InGaAs-SK-QDs, which is overgrown with the matrix material GaAs of a defined thickness d, followed by an InAs/GaAs-SML-stack. The presence of the energetically lower SK-QDs introduces an additional, nonradiative decay channel to the carriers inside the SML-stack. Hence, the decay time for the SML-luminescence is dependent on the vertical distance between the two different nanostructures.

We present time-resolved photoluminescence measurements and a model of a conventional rate equation system to simulate the observed data and to approximate the coupling time constant of the SML-stack to the SK-QDs.

HL 76.4 Thu 10:15 EW 202

Strain relaxation in metamorphic InAlAs buffers — •Boris Landgraf, Slobodskyy Taras, Christian Heyn, and Wolfgang Hansen — Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

Modulation-doped high-mobility InAs heterostructures are of current interest owing to the small effective mass and strong spin-orbit coupling [1]. The heterostructures are prepared on molecular beam epitaxy grown virtual substrates strain engineered to match the lattice constant of the electronically active layers. The virtual substrates contain metamorphic buffer layers to compensate for the lattice mismatch. Recent developments in the design of the metamorphic buffers have made possible high-quality epitaxial InAs heterostructures.
This talk will be about the strain relaxation in metamorphic $In_xAl_{1-x}As$ buffers with and without an underneath grown AlAs/Gas superlattice. The structure of the virtual substrate was analyzed using high-resolution x-ray diffraction. Pole figures were collected to characterize the strain relaxation and twist in the metamorphic buffer layers, AlAs/GaAs superlattice and GaAs substrate. Our results indicate that an AlAs/GaAs superlattice in the virtual substrate is essential for strain relaxation in these virtual substrates.

[1] S. Löhr et al., Highly anisotropic transport in shallow InGaAs heterostructures, Physical Review B 67, 045309 (2003)

HL 76.5 Thu 10:30 EW 202

Analysis of the oxygen vacancy induced metallic state in $SrTiO_3$ — •Juan Shen, Hunpyo Lee, Harald O. Jeschke, and Roser Valentí — Institut für Theoretische Physik, Goethe-Universität Frankfurt, Max-von-Laue-Straße 1, 60438 Frankfurt am Main

Strontium titanate ($SrTiO_3$) is one of the typical perovskite oxides and has been considered for use in oxide electronics. Recently, high carrier mobilities on the fractured bare (001) surface have been found, and the source of the 2D electron gas (2DEG) at the surface is still not clear. Oxygen vacancies are assumed to be one of the origins for the conductivity. By using density function theory (DFT), we investigate the electronic structure of $SrTiO_3$ surfaces in the presence of different oxygen vacancy concentrations both in SrO and in TiO_2 terminated (001) slabs. We find that the conductivity is caused by the extra electrons due to the oxygen vacancy which are transferred to Ti 3*d* states. In this talk we will discuss our results in comparison with available experimental measurements.

HL 76.6 Thu 10:45 EW 202

***Ab-Initio* Investigation of graphene based one-dimensional superlattices** — •Lars Matthes[1,2], Karsten Hannewald[1], and Friedhelm Bechstedt[1] — [1]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Dipartimento di Fisica, Università di Roma "Tor Vergata", via della Ricerca Scientifica 1, 00133 Rome, Italy

Since the two-dimensional material graphene was rediscovered in 2004 by Geim et al. there has been a strong interest in tailoring its properties in order to achieve a broad usability in manifold applications. Furthermore, due to massless electrons appearing in graphene it is also a sandbox for theoretical physicists for testing basic physical theories of high energy physics in a solid state system.
Here we present first-principles studies of electronic and structural properties of various graphene-based one-dimensional superlattice including modifications of pristine graphene by means of hydrogen adsorption, substitution of carbon atoms with boron-nitride as well as a heterostructure including the very recently discovered silicene. [1] We discuss the occurrence of an electronic band gap in these systems, while we focus in particular on the interesting case of graphene-silicene superlattices which provides insights to the physics of heterostructures consisting of materials where both may contain massless Fermions and a vanishing electronic gap around the Fermi-energy. Finally, we also discuss the importance of the 1D interface between those 2D crystalss.

[1] B. Lalmi et al., Applied Physics Letters 97, 223109 (2010)

HL 77: Quantum Dots and Wires: Optical Properties II (mainly Luminescence and Electronic Structure)

Time: Thursday 9:30–11:30 Location: EW 203

HL 77.1 Thu 9:30 EW 203

Optical properties of Arsenide-based nanowire heterostructures — •Lucas Schweickert[1], Daniel Rudolph[1], Watcharapong Paosangthong[1], Dance Spirkoska[1], Max Bichler[1], Gerhard Abstreiter[1,2], Gregor Koblmüller[1], and Jonathan J. Finley[1] — [1]Walter Schottky Institut, TU München, Garching, Germany — [2]TUM Institute for Advanced Study, Garching, Germany

We report the investigation of the optical properties of single AlGaAs/GaAs core/shell nanowires using low temperature microphotoluminescence (PL) spectroscopy. The nanowires are grown using a catalyst free method using molecular beam epitaxy on lithographically patterned SiO_2-Si(111) substrates [1]. Capping the GaAs nanowires with a thin AlGaAs shell is found to result in a drastic $> 10^3$ enhancement of the PL intensity. The influence of the capping shell thickness on the PL intensity was investigated for shell thicknesses in the range 8-100nm, under conditions where free carriers are photo-generated in the entire structure and solely in the GaAs core. Time-resolved and temperature-dependent PL studies were performed to obtain a better understanding of the mechanisms that limit the internal quantum efficiency. Furthermore, we will present first results obtained on GaAs-AlGaAs axial nanowires with axial In-containing segments. It is envisaged that optically active quantum dots can be controllably incorporated into axial core-shell nanostructures.

[1] D. Rudolph *et al.*, Nano Lett. **11**, 3848 (2011)

HL 77.2 Thu 9:45 EW 203

Geometry and electric field dependence of exciton fine structure in semiconductor quantum dots — •Erik Welander and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

We investigate theoretically the exciton fine structure splitting (FSS) in semiconductor quantum dots. The exciton, the bound state of an electron and a hole, plays the important role of the intermediate step in the biexciton cascade recombination, potentially a source of entangled photons. The two relevant states of the exciton, $|X\rangle$ and $|Y\rangle$, where X and Y correspond to polarization directions, are energetically split by the FSS. For the production of entangled photons it is essential that the FSS vanishes so that the intermediate exciton states are degenerate and the which-way information separated from frequency. Hence, a rigorous understanding of the exciton FSS is important for an accurate study of the light from a biexciton cascade recombination. Experiments have also shown a non-trivial dependence of the FSS on an external electric field. We develop a model incorporating the particle-antiparticle nature of the exciton system and find that the FSS depends on the QD geometry. Further, we investigate the effects of an external in-plane electric field, focusing on the possibility to eliminate the FSS completely.

HL 77.3 Thu 10:00 EW 203

Vertical electric field tuning of exciton fine structure splitting in strain-free GaAs/AlGaAs(001) quantum dots — ranber singh and •gabriel bester — Max-Planck-Institut für Festkörperforschung, Heisenbergstrasse 1, 70569 Stuttgart, Germany

We investigate the vertical electric field tuning of exciton fine structure splitting (FSS) in strain-free GaAs/AlGaAs(001) quantum dots. We find that the bright exciton lines anticross. However, the anticrossing is very small so that the FSS in strain-free GaAs/AlGaAs quantum dots can be easily tuned to below the radiative linewidth ($\approx 1\mu$eV) by applying vertical electric field along the growth direction. The vertical electric field tuning of FSS is also advantageous because it does not reduce the oscillator strength of exciton transitions in contrast to the significant reduction in case of lateral electric field.

HL 77.4 Thu 10:15 EW 203

Excitonic lifetimes in single GaAs quantum dots fabricated by local droplet etching — •Christian Heyn[1], Christian Strelow[2], and Wolfgang Hansen[1] — [1]Institute of Applied Physics, University of Hamburg, D-20355 Hamburg, Germany — [2]Institute of Physical Chemistry, University of Hamburg, D-20146 Hamburg, Germany

We fabricate GaAs quantum dots (QDs) embedded in an AlGaAs matrix by filling of nanoholes, that are drilled in an AlAs/AlGaAs heterostructure surface utilizing self-assembled Al droplet etching. The time-dependent optical emission of the QDs is studied using single-dot photoluminescence (PL) spectroscopy with quasi resonant excitation into the QD d-shell. The analysis of the time-dependent PL data yields a lifetime of 390 ps for excitons and 426 ps for biexcitons. In comparison to most other types of self-assembled QDs, the present GaAs QD lifetimes are short, which we attribute mainly to the influence of the emission energy. We describe the time dependent PL data by a three-level rate model, that quantitatively reproduces both the experimental decay times and the influence of the excitation power on the absolute exciton and biexciton peak intensities.

HL 77.5 Thu 10:30 EW 203

Size dependent excitonic states in self-assembled GaAs quantum dots: theory and experiment — •Andreas Graf[1], David Sonnenberg[1], Vera Paulava[1], Andrei Schliwa[2], Chris-

tian Heyn[1], and Wolfgang Hansen[1] — [1]Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Local droplet etching (LDE) allows for a molecular beam epitaxy compatible self-assembled patterning of semiconductor surfaces. Using LDE with aluminium droplets, nanoholes with 12 nm depth are drilled in AlAs capped AlGaAs layers. Partial filling of these nanoholes with GaAs provides quantum dots (QD) with a precisely defined size. We present photoluminescence measurements of single GaAs QDs. The QD size dependent exciton and biexciton recombinations and in particular the splitting of exciton and biexciton peaks are studied. Calculations based on $\boldsymbol{k}\cdot\boldsymbol{p}$ theory and configuration interaction scheme were performed, in order to investigate the general behavior of the excitonic states in GaAs QDs as well as the influence of QD size. The comparison between measured and calculated recombination energies and intensities demonstrates good agreement.

HL 77.6 Thu 10:45 EW 203

Fundamentale Photolumineszenzuntersuchungen von Tieftemperatureigenschaften der Silizium-Nanokristall-Bandlücke — •Andreas Markus Hartel, Sebastian Gutsch, Daniel Hiller und Margit Zacharias — IMTEK, Faculty of Engineering, Albert-Ludwigs-University Freiburg, Georges-Köhler-Allee 103, 79110 Freiburg, Germany

Im Allgemeinen werden zur Beschreibung der Temperaturabhängigkeit der Bandlückenenergie von Halbleitern die empirischen Formeln nach Varshni oder Cardona angewendet. Seit der Entdeckung von Photolumineszenz von Silizium-Nanokristallen (SiNC) in oxidischer Matrix, wurde erfolglos versucht diese Beziehungen auch darauf anzuwenden. Wenngleich sich der Verlauf der Bandlücke von SiNCs sehr gut für Temperaturen bis ca. 50K anpassen lässt, gibt es aufgrund starker Blauverschiebung der PL für Temperaturen zwischen 50K und 4K starke Abweichung von den "konventionellen" Modellen. Diese Diskrepanz ist bis heute Bestandteil kontroverser Diskussionen in der Literatur und deren Herkunft bislang nicht vollständig geklärt. Anhand von größenkontrollierten SiNCs (1.5 bis 4.5nm) ist es uns gelungen die Gültigkeit der "konventionellen" Modelle auch für nanostrukturierte Materialien zu belegen. Unsere Analysen zeigen, dass sich die Abweichungen ausschließlich auf zu hohe Anregungsleistungsdichten zurückführen lassen. Weiterhin konnte ein theoretisches Modell entwickelt werden, welches es gestattet den Temperaturverlauf der PL-Intensität von SiNCs in Abhängigkeit der Anregungsleistung zu simulieren. Dieses Modell wird unter Zuhilfenahme unserer experimentellen Ergebnisse diskutiert.

HL 77.7 Thu 11:00 EW 203

Ultrasmall silicon nanoclusters, an *ab-initio* study of the photoluminescence lineshapes — •Davoud Pouladsaz — Department of Biological Physics, Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

In recent years the observations in the Red Rectangle nebula, which is famous for its extended red emission, show a blue luminescence centered at 375 nm. Although it was first supposed to be associated with small neutral PAHs, small silicon nanocrystals with diameters of 1 nm are thought to be very good candidates for the carrier of this phenomenon. In this work, the optical properties of tetrahedral silicon nanocrystals Si_{17} and Si_{29} with hydrogen- and oxygen-passivation of surface dangling bounds are determined by the energetics of frontier orbitals and their dependence on the deformation in the relaxed excited state, using DFT, TD-DFT, and post Hartree-Fock methods. The results show a quantitative agreement between the calculated photoluminescence (PL) energy and the observed spectra better than 0.2 eV. Besides, the calculated PL linewidth agrees with experimental values within a factor of 1.2.

HL 77.8 Thu 11:15 EW 203

Computational characterisation of optical properties of CdSe nanostructures — •Farzana Aslam[1] and Christian von Ferber[1,2] — [1]Applied Mathematics Research Centre, Coventry University, UK — [2]Physikalisches Institut, University Freiburg

Quantum dots have numerous potential applications1 because their optical and electronic properties can be readily tuned by varying their size, shape, structure and composition. Rational engineering of optoelectronic devices is enabled by high quality, highly monodisperse and trap-free nanoparticles. The main focus of experimental and theoretical research on nanoparticles so far has been on the properties resulting from the quantum confinement effect and still there are many unanswered questions about the fundamental properties of nanoparticles and their surfaces.

We report the systematic investigations of the optical, electrostatic and structural trends of nanostructures using empirical potentials, dynamical simulations, time *dependent density functional theory and non-linear regime. The stability and properties of the structure of the nanostructure are studied as a function of the size, shape, structure and surface of the nanostructures. Furthermore the optical properties of different nanostructures as a result of laser matter interaction are also investigated.

[1] F. Aslam , D.J.Binks , M.D.Rahn, D.P.West, P.O*Brien , N.Pickett and S.Daniels , J.Chem. Phys,122 , 184713 (2005) [2] F. Aslam and C.von Ferber ; Shape dependent properties of CdSe nanostructures, Chemical Physics

HL 78: Transport: Graphene 1 (jointly with TT, MA, DY, DS, O)

Time: Thursday 9:30–13:00 Location: BH 334

HL 78.1 Thu 9:30 BH 334

Spin relaxation in graphene induced by adatoms — •Jan Bundesmann and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

By means of a recursive Green's function method we study diffusive spin-dependent transport through graphene and graphene nanostructures. Diffusion in graphene mainly originates from charges trapped in the substrate. In addition we assume the presence of adsorbed atoms or molecules. These are the origin of a locally fluctuating spin-orbit coupling. While both intrinsic spin-orbit interaction and spin-orbit coupling induced by electric fields or curvature are rather weak (typically $\mathcal{O}(\mu eV)$), underneath adatoms these values can reach the height of meV. Our results show that adatoms clearly reduce the spin relaxation time in graphene. The ones we obtain are on the order of magnitude as the ones found in experiments ($\mathcal{O}(ns)$).

Depending on the type of adatom, the effect on intrinsic and extrinsic spin-orbit interaction is of different strength. We study how this influences the relaxation of in-plane or out-of-plane polarized spins.

Lastly we plan to address the questions if adatoms tend to relax spins via the Elliot-Yafet or rather via the Dyakonov-Perel mechanism.

HL 78.2 Thu 9:45 BH 334

Emergent Gauge Fields in Bilayer Graphene — •Roland Winkler[1,2,3] and Ulrich Zülicke[4] — [1]University of Basque Country and IKERBASQUE Foundation, Bilbao, Spain — [2]Northern Illinois University, DeKalb, Illinois 60115, USA — [3]Argonne National Laboratory, Argonne, Illinois 60439, USA — [4]School of Chemical and Physical Sciences and MacDiarmid Institute for Advanced Materials and Nanotechnology, Victoria University of Wellington, Wellington 6140, New Zealand

We present a detailed study of the electronic properties of bilayer graphene. Group theory is used to derive an invariant expansion of the Hamiltonian for electron states near the **K** point taking into account the effect of electric and magnetic fields, strain and spin-orbit coupling. We obtain several new gauge fields for band electrons in bilayer graphene, resulting in novel orbital and spin-related effects.

RW is supported by IKERBASQUE Foundation, Bilbao, Spain. Work at Argonne was supported by DOE BES under Contract No. DE-AC02-06CH11357. UZ is supported by MacDiarmid Institute for Advanced Materials and Nanotechnology.

HL 78.3 Thu 10:00 BH 334

Single-parameter pumping in graphene — •Sigmund Kohler[1], Pablo San-Jose[2], Elsa Prada[1], and Henning Schomerus[3] — [1]Instituto de Ciencia de Materiales de Madrid, CSIC, 28049 Madrid, Spain — [2]Instituto de la Estructura de la Materia, CSIC, 28006 Madrid, Spain — [3]Department of Physics, Lancaster University, Lancaster, LA1 4YB, United Kingdom

The ratchet or pump effect, which is the induction of a dc current by an ac force in the absence of any net bias, represents one of the most intriguing phenomena in non-equilibrium transport. For graphene, one expects that its gapless and chiral nature negatively affects pumping, because it hinders the confinement of electrons. Despite this expectation, a pump mechanism that is particularly efficient in graphene exists [1]: It is based on barriers in which the, say, left half is modulated by an ac gate voltage. Then electrons entering the barrier in evanescent modes from that side may be excited to propagating modes. Evanescent mode entering from the right, by contrast, decay before reaching the driving region. This mechanism is rather efficient in graphene, because all evanescent modes within a certain energy range contribute. The corresponding mechanism in a two-dimensional electron gas works only with modes that fulfill certain resonance conditions, which leads to a much smaller pump current.

[1] P. San-Jose, E. Prada, S. Kohler, and H. Schomerus, Phys. Rev. B **80**, 155408 (2011)

HL 78.4 Thu 10:15 BH 334

Self-consistent theory of the second-harmonic generation in graphene — •Sergey Mikhailov — Institute of Physics, University of Augsburg, 86135 Augsburg, Germany

A self-consistent-field theory of the second-order nonlinear electromagnetic response of graphene is developed. The second-order polarizability and the corresponding second-order self-consistent dielectric response function of graphene are calculated for the first time. The second harmonic generation in graphene is shown to be about two orders of magnitude stronger than in typical semiconductor structures. Under the conditions of 2D plasmon resonances the second harmonic radiation intensity is further increased by several orders of magnitude.

HL 78.5 Thu 10:30 BH 334

The Hubbard model on the bilayer honeycomb lattice with Bernal stacking — •Thomas C. Lang[1], Stefan Übelacker[1], Zi Yang Meng[2], Michael Scherer[1], Carsten Honerkamp[1], Alejandro Muramatsu[3], Fakher F. Assaad[4], and Stefan Wessel[1] — [1]RWTH Aachen, Aachen, Germany — [2]Louisiana State University, Baton Rouge, USA — [3]Universität Stuttgart, Stuttgart, Germany — [4]Universität Würzburg, Würzburg, Germany

Using a combination of quantum Monte Carlo, the functional renormalization group and mean-field theory we study the Hubbard model on the bilayer honeycomb as a model for interacting electrons on bilayer graphene. The free bands consisting of two Fermi points with quadratic dispersions lead to a finite density of states, which triggers the antiferromagnetic instability and spontaneously breaks sublattice and spin rotational symmetry once a local Coulomb repulsion is introduced. We show that the antiferromagnetic instability is insensitive to the inclusion of extended Coulomb interactions and discuss effects on the sublattice magnetization and of finite size systems in numerical approaches.

HL 78.6 Thu 10:45 BH 334

Coulomb drag in graphene via kinetic equation approach — •Michael Schuett[1], Pavel M. Ostrovsky[1,2], Igor V. Gornyi[1,3], Mikhail Titov[4], Boris N. Narozhny[5], and Alexander D. Mirlin[1,5,6] — [1]Institut für Nanotechnologie, Karlsruhe Institute of Technology, 76021 Karlsruhe, Germany — [2]L. D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia — [3]A.F. Ioffe Physico-Technical Institute, 194021 St. Petersburg, Russia. — [4]School of Engineering & Physical Sciences, Heriot-Watt University, Edinburgh EH14 4AS, UK — [5]Institut für Theorie der kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [6]Petersburg Nuclear Physics Institute, 188350 St. Petersburg, Russia.

We calculate the Coulomb drag resistivity at finite temperature for two graphene monolayers within the kinetic equation approach. The emphasis is put on the case of fast electron-electron collisions compared to disorder induced scattering. We obtain the asymptotic behavior of the Coulomb drag resistivity ρ_D both for small chemical potentials (μ_1, μ_2) in the two layers as well as chemical potentials larger than temperature. When only one layer is at the Dirac point the Coulomb drag resistivity is zero. However when approaching the Dirac point of both layers simultaneously, the Coulomb drag resistivity does not vanish as long as $\mu_1 \propto \mu_2 \to 0$. For any finite disorder strength or alternating current Coulomb drag resistivity obeys again $\rho_D(\mu_1 = 0, \mu_2 = 0) = 0$, as expected from the particle hole symmetry argument. When both layers have large chemical potentials we recover the Fermi liquid behavior.

HL 78.7 Thu 11:00 BH 334

Manifestation of electron-electron interaction in the magnetoresistance of graphene — •Johannes Jobst[1], Daniel Waldmann[1], Igor V. Gornyi[2,3], Alexander D. Mirlin[2,4,5], and Heiko B. Weber[1] — [1]Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Institut für Nanotechnologie, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]A.F. Ioffe Physico-Technical Institute, St. Petersburg, Russia — [4]Inst. für Theorie der kondensierten Materie, Karlsruhe Institute of Technology, Karlsruhe, Germany — [5]Petersburg Nuclear Physics Institute, St. Petersburg, Russia

We investigate the magnetotransport in large area graphene Hall bars epitaxially grown on silicon carbide. In the intermediate field regime between weak localization and Landau quantization the observed temperature-dependent parabolic magnetoresistivity is a manifestation of electron-electron interaction. We can consistently describe the data with a model for diffusive (magneto)transport that covers the crossover to the ballistic regime. We find a temperature-driven crossover related to the reduction of the multiplet modes contributing to electron-electron interaction from 7 to 3 due to intervalley scattering. In addition we find a field-driven crossover from purely diffusive to partially ballistic behavior.

15 min. break.

HL 78.8 Thu 11:30 BH 334

Orbital Magnetism in graphene bulk and nanostructures — •Lisa Hesse, Jürgen Wurm, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, Germany

We study the magnetic response of finite and bulk graphene structures due to orbital motion of the charge carriers. Besides a semiclassical approach we use exact quantum mechanical calculus within the Dirac formalism to derive different analytic expressions for the magnetic susceptibility of extended systems at various field regimes. This allows us to study on the one hand edge effects which are accessible through our semiclassical treatment but also to gain profound knowledge of the importance of bulk effects in finite systems. In order to provide an independent confirmation of the theory we also perform numerical calculations on graphene nanostructures based on a tight-binding approximation.

HL 78.9 Thu 11:45 BH 334

Klein paradox for arbitrary spatio-temporal scalar potential barrier and Josephson-like current in graphene — Sergey E. Savel'ev[1], •Wolfgang Häusler[2], and Peter Hänggi[2] — [1]Department of Physics, Loughborough University, Loughborough LE11 3TU, United Kingdom — [2]Institut für Physik Universität Augsburg, D-86135 Augsburg, Germany

We derive the exact time evolution according to the Dirac-Weyl equation, describing a mono-layer of graphene, in the presence of a scalar potential $U(x,t)$ of arbitrary spatial and temporal dependence at normal incidence, $p_y = 0$. This solution shows that the Klein paradox (the absence of backscattering) persists even for arbitrary temporal modulations of the barrier. Moreover, we identify an unusual oscillating current j_y running along the barrier, despite of the vanishing momentum in y-direction. This current exhibits resemblence to the Josephson current in superconductors, including the occurance of Shapiro steps and its sine-like dependence on the phase difference of wave functions.

HL 78.10 Thu 12:00 BH 334

Relaxation in graphene quantum dots — •Christoph Neumann[1], Christian Volk[1,2], Sebastian Kazarski[1], Stefan Fringes[1], Stephan Engels[1,2], Bernat Terres[1,2], Jan Dauber[1,2], Stefan Trellenkamp[2], and Christoph Stampfer[1,2] — [1]JARA-FIT and II. Institute of Physics B, RWTH Aachen, 52074 Aachen, Germany — [2]Peter Grünberg Institut (PGI-8/9), Forschungszentrum Jülich, 52425 Jülich, Germany

Graphene quantum dots (QDs) have received increasing attention over the last years as interesting candidates for the future implementation of spin qbits. Compared to GaAs-based QDs, their smaller hyperfine and spin-orbit coupling promises more favorable spin coherence times. However, while the preparation, manipulation, and read-out of single spins has been demonstrated in GaAs structures, research on graphene QDs is still at an early stage. Although Coulomb blockade phenomena and excited state spectroscopy is already well established, experimental signatures allowing the identification of relaxation times have been

hard to trace. Here we report on pulse gating experiments on graphene quantum devices. We will present measurements of the relaxation rates in single-layer graphene QDs. The investigated devices consist of an island with a diameter of 120 nm, 4 lateral graphene gates and 2 charge detectors. From so-called diamond measurements we extract a charging energy of 11 meV and excited state level spacings of 2-4 meV. The gates enable us to tune the tunnelling rates from the GHz down to the low MHz regime. Finally low-bias pulse gate measurements allow us to extract relaxation rates on the order of 50 ns.

HL 78.11 Thu 12:15 BH 334

Minimal tight-binding model for transport in graphene heterojunctions — •Ming-Hao Liu, Jan Bundesmann, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

A real-space Green's function formalism based on a minimal tight-binding model is adopted to efficiently simulate ballistic transport in graphene heterojunctions. The basic idea is to make use of the Bloch theorem along the transverse dimension of the bulk graphene, which greatly reduces the computation load and hence allows experimental sizes in the longitudinal dimension. Numerically, we will show (i) consistency with the existing results based on the effective Dirac theory for chiral tunneling through *pnp* junctions in monolayer graphene (MLG) and bilayer graphene, (ii) good agreement with recent ballistic experiments on *pnp* junctions in MLG, and (iii) new predictions for spin-dependent tunneling through *pn* junctions in MLG in the presence of the Rashba spin-orbit coupling.

HL 78.12 Thu 12:30 BH 334

Quantum Hall effect in graphene with superconducting electrodes — •Markus Weiss, Peter Rickhaus, and Christian Schönenberger — Departement Physik, Universität Basel, Klingelbergstrasse 82, CH-4056 Basel

We report on the realization of an integer quantum Hall system with superconducting electrodes. Graphene was contacted to niobium electrodes that show a critical field of about 4 tesla, where electronic transport passes mainly through quantum Hall edge-states and bulk transport is largely suppressed. We find a magnetic field range of more than one tesla where well developed quantum Hall plateaus coexist with superconductivity in the leads. In high magnetic fields with the electrodes in the normal state we observe plateaus at G=$\nu e^2/h$ for ν=2, 4, and 10. Reducing the magnetic field to below the upper critical field of the electrodes, the conductance on the plateaus shows a sudden increase. Whereas the conductance on the ν=2 plateau increases only by 10%, the increase on the ν=6 and ν=10 plateau is considerably larger with 60% and 80%, respectively. We attribute this conductance enhancement to multiple Andreev reflection processes along the graphene-superconductor interface, that lead to the formation of Andreev edge-states. The observed conductance enhancement of the ν=6 and 10 plateaus is consistent with a doubling of the conductance contribution of the second and third edge-states. We attribute the small conductance increase on the ν=2 plateau to the special nature of the zero energy Landau level, that makes the corresponding edge-state sensitive to the structure of the graphene edge.

HL 78.13 Thu 12:45 BH 334

Klein paradox for arbitrary spatio-temporal scalar potential barrier and Josephson-like current in graphene — Sergey E. Savel'ev[1], •Wolfgang Häusler[2], and Peter Hänggi[2] — [1]Department of Physics, Loughborough University, Loughborough LE11 3TU, United Kingdom — [2]Institut für Physik Universität Augsburg, D-86135 Augsburg, Germany

We derive the exact time evolution according to the Dirac-Weyl equation, describing a mono-layer of graphene, in the presence of a scalar potential $U(x,t)$ of arbitrary spatial and temporal dependence at normal incidence, $p_y = 0$. This solution shows that the Klein paradox (the absence of backscattering) persists even for arbitrary temporal modulations of the barrier. Moreover, we identify an unusual oscillating current j_y running along the barrier, despite of the vanishing momentum in y-direction. This current exhibits resemblence to the Josephson current in superconductors, including the occurance of Shapiro steps and its sine-like dependence on the phase difference of wave functions. [1] S.E. Savel'ev, W. Häusler, and P. Hänggi, ArXiv: 1107.4983 .

HL 79: Photovoltaics: General Aspects

Time: Thursday 10:30–12:00 Location: EW 201

HL 79.1 Thu 10:30 EW 201

First principles study of photoinduced charge separation in an artificial light harvesting complex — •Carlo Andrea Rozzi[1], Sarah Maria Falke[2], Nicola Spallanzani[1], Angel Rubio[3], Elisa Molinari[1], Daniele Brida[4], Margherita Maiuri[4], Giulio Cerullo[4], Heiko Schramm[2], Jens Christoffers[2], and Christoph Lienau[2] — [1]CNR - Istituto Nanoscienze, Modena, Italy — [2]Carl von Ossietzky Universität, OIdenburg, Germany — [3]Fritz-Haber-Institut der MPG, Berlin, Germany — [4]Politecnico di Milano, Italy

Nature has developed sophisticated and highly efficient molecular architectures to convert sunlight energy into chemical energy. It is known that the primary steps, specifically both energy and charge transfer, occur on extremely fast time scales. These processes have traditionally been interpreted in terms of the incoherent kinetics of optical excitations and of charge hopping, but recently signatures of quantum coherence were observed in energy transfer in photosynthetic bacteria. We have studied a carotene-porphyrin-fullerene triad, which is a prototypical artificial reaction center, by Time-dependent Density Functional Theory simulations of the quantum dynamics. In combination with high time resolution femtosecond spectroscopy our results provide clear evidence that the driving mechanism of the charge separation process is a quantum correlated wavelike motion of electrons and nuclei on a timescale of few tens of femtoseconds, thus establishing the role of quantum coherence in artificial light harvesting.

HL 79.2 Thu 10:45 EW 201

Towards intermediate-band formation in solar cells with AlGaInAs quantum dots — •Tristan Braun[1], Christian Schneider[1], Stefan Kremling[1], Nadezda V. Tarakina[2], Maxwell Adams[1], Matthias Lermer[1], Stephan Reitzenstein[1,3], Lukas Worschech[1], Sven Höfling[1], Alfred Forchel[1], and Martin Kamp[1] — [1]Technische Physik, Universität Würzburg, Germany — [2]Experimentelle Physik III, Universität Würzburg, Germany — [3]Present adress: Institute of Solid State Physics, Technische Universität Berlin, Germany

Increasing the efficiency of state-of-the-art solar cells is considered as one of the most important challenges nowadays in the quest for sustainable energy resources. In this work, we report on a solar cell design based on the intermediate-band approach, which theoretically allows to reach efficiencies of up to 63% for single intermediate-band cells. Our test device comprises spectrally detuned AlGaInAs/AlGaAs and InAs/GaAs quantum dot (QD) layers in an AlGaAs p-i-n structure, leading to a spectrally large absorption range. By adjusting the material composition in the different QD layers, we can cover a spectral range from 680 to 1150 nm by QD absorption. In addition, we propose a device design allowing for the generation of an hybridized QD subband for the application in future intermediate band solar cell devices with increased efficiency.

HL 79.3 Thu 11:00 EW 201

Laser structuring of solar glasses for light management — •Stephan Krause[1], Paul-Tiberiu Miclea[1,2], Gerhard Seifert[1,2], and Stefan Schweizer[1,3] — [1]Fraunhofer Center for Silicon Photovoltaics CSP, Walter-Hülse-Str. 1, 06120 Halle (Saale) — [2]Institute of Physics, Martin Luther University of Halle-Wittenberg, Heinrich-Damerow-Str. 4, 06120 Halle (Saale) — [3]Centre for Innovation Competence SiLi-nano®, Martin Luther University of Halle-Wittenberg, Karl-Freiherr-von-Fritsch-Str. 3, 06120 Halle (Saale)

Glass is an important component in solar modules. Structuring of the glass surface offers a fundamental approach to increase solar module efficiency. Ultra-short laser pulses allow for a flexible and innovative micro-structuring of the glass surface for light management. The micro-structures analyzed for light management were 2D-grids consisting of many fine, parallel and equally spaced grooves. Transmission

and scattering measurements showed that the untreated solar glass has an average transmittance of 85% in the spectral range from 400 nm to 1100 nm; the glass showed no significant light scattering (less than 1%). Laser structuring, however, leads to a significant increase in the forward scattering whereas the total transmittance remains almost unchanged. For 1030 nm fs-laser structuring, the forward scattering of the 2D-grid structures with a line spacing of 50 μm, 25 μm and 10 μm could be gradually increased to more than 20%, 40% and nearly 80%, respectively, for the spectral range from 400 to 1100 nm.

HL 79.4 Thu 11:15 EW 201

Application of series resistance imaging techniques to Cu(In,Ga)Se_2 solar cells — •Felix Daume[1,2], Andreas Rahm[1], and Marius Grundmann[2] — [1]Solarion AG, Ostende 5, 04288 Leipzig, Germany — [2]Institut für Experimentelle Physik II, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany

Cu(In,Ga)Se_2 thin film solar cells on flexible polyimide foil enable innovative applications as well as a fabrication in a continuous roll-to-roll process and currently reach efficiencies up to 18.7 %. In order to optimize the solar cell efficiency via reduction of inherent losses in the cell, a spatially resolved access to parameters characterizing ohmic losses, i.e. the series resistance, is highly advantageous.

We apply two different interpretation methods from the literature to our material system which enable the calculation of a mapping of the series resistance from electroluminescence images taken at different voltages. Both methods will be demonstrated, compared and discussed on an example. Furthermore, the benefit of such a method for the characterization of solar cells under accelerated aging conditions (damp heat) which is important for the estimation of the long-term stability will be shown.

HL 79.5 Thu 11:30 EW 201

The band offsets of Cu_2O/ZnO and Cu_2O/GaN heterointerfaces — •Benedikt Kramm, Andreas Laufer, Daniel Reppin, Achim Kronenberger, Philipp Hering, Angelika Polity, and Bruno K. Meyer — 1. Physikalisches Institut, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany

As known from Minemoto et al. [1] the band offsets of heterostructures affect the electron transport in device applications. Using photoelectron spectroscopy (XPS) we investigate the band alignments of the heterointerfaces mentioned above. We found a conduction band offset (CBO) value of 0.97 eV for Cu_2O/ZnO and 0.24 eV for Cu_2O/GaN. The large CBO between ZnO and Cu_2O will very likely result in low photovoltaic power conversion efficiencies as is the current status of Cu_2O/ZnO solar cells. However, the low conduction band offset of Cu_2O/GaN making GaN a more suitable candidate for the front contact of Cu_2O based solar cells.

[1] Minemoto, T. et al., Solar Energy Materials and Solar Cells, **67**(1-4):83-88(2001)

HL 79.6 Thu 11:45 EW 201

Degradation Analysis of Polymer Solar Cells by Imaging Methods — •Harald Hoppe — Institut für Physik, TU Ilmenau, 98693 Ilmenau, Deutschland

Accelerated progress in device performance and processing technology of organic solar cells opens up the opportunity of their commercialization. Besides high performance, good processability and prospected low production costs, the photovoltaic devices require long term stability in order to face practical applications. Hence investigations of device degradation and improvements of their stability are one of the most actual research topics that need to be addressed. It is shown that imaging methods such as luminescence or thermography imaging are powerful tools to learn about the dominant degradation mechanisms of to dates state-of-the-art polymer solar cell architectures. An overview of most probably origins for device failure is presented, which provides valuable hints for constructive device stabilization.

HL 80: GaN: Preparation and Characterization V (mainly Cathodoluminescence)

Time: Thursday 11:15–13:30 Location: ER 270

HL 80.1 Thu 11:15 ER 270

Optical properties of ZnO/GaN/InGaN core-shell nanorods — •Ingo Tischer[1], Mohamed Fikry[2], Ren Zhe[2], Manfred Madel[1], Matthias Hocker[1], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institut für Quantenmaterie, Gruppe Halbleiterphysik, Universität Ulm, 89069 Ulm — [2]Institut für Optoelektronik, Universität Ulm, 89069 Ulm

ZnO/GaN/InGaN core-shell nanorods standing upright in a well defined pattern can be used for sensing applications. As a first step, we grew ZnO nanopillars on top of GaN pyramids resulting in an ordered array of upright ZnO nanorods with average distance of 6 μm and $\approx$ 500 nm thickness. This structure was coaxially overgrown with GaN and a subsequent single InGaN quantum well. We report about the different spectral features that are found in these structures. We investigated the various contributions from Zn doping and from the quantum well by spatially resolved cathodoluminescence, transmission electron microscopy, and photoluminescence.

HL 80.2 Thu 11:30 ER 270

Growth and optical properties of mask-free and uncatalyzed GaN nanorods by metal-organic vapor phase epitaxy — •Christian Tessarek and Silke Christiansen — Max Planck Institute for the Science of Light, Erlangen, Germany

Nanorod (NR) structures have the potential to significantly reduce the defect density in heteroepitaxially grown GaN. Furthermore, in case of a high density and high aspect ratio the surface to volume ratio is increased in comparison to a two dimensional film.

Our approach is the growth of mask-free and uncatalyzed GaN nanorods by metal-organic vapor phase epitaxy. A simple three step method is utilized consisting of nitridation of the sapphire substrate, deposition of a GaN nucleation layer and finally the growth of GaN NRs. Vertically aligned and hexagonal shaped NR structures were achieved with a density of up to 10^8 cm^{-2}, diameters in the range from 100 nm to some μm, heights up to 30 μm or aspect ratios of up to 30, depending on the growth parameters.

Optical properties of the GaN NRs were determined using spatially and spectrally resolved room temperature cathodoluminescence. It will be shown that the yellow defect band luminescence can be suppressed while the GaN near band edge emission is increased. Finally, the appearance of whispering gallery modes in regular hexagonal shaped GaN NRs will be presented.

HL 80.3 Thu 11:45 ER 270

Cathodoluminescence investigation of polarization field effects in InGaN MQWs with AlInGaN barriers — •Silvio Neugebauer, Sebastian Metzner, Frank Bertram, Jürgen Christen, Lars Groh, Jürgen Bläsing, Armin Dadgar, and Alois Krost — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany

The optical properties of $In_{0.25}Ga_{0.75}N$ multiple quantum wells (MQWs) with quaternary AlInGaN barriers have been investigated using highly spatially, spectrally and time-resolved cathodoluminescence (CL) microscopy. The samples were grown on c-plane sapphire substrates by MOVPE using an optimized AlGaN/GaN template. The Indium and Aluminum content of the barriers were increased systematically starting with binary GaN towards matched polarization with respect to the InGaN quantum well. In time-resolved CL measurements, the polarization unmatched reference sample with GaN barriers exhibits a blue-shift of the QW emission wavelength during the onset of the e-beam excitation. The blue-shift clearly indicates the screening of polarization fields. In complete contrast, the polarization matched sample shows a red-shift during onset which indicates that relaxation of carriers into potential fluctuations is the dominant process of the recombination kinetics. During decay both samples consistently show a red-shift of the emission wavelength (field effects as well as potential fluctuations). The results clearly indicate drastically reduced polarization fields when using quaternary barriers.

HL 80.4 Thu 12:00 ER 270

Optical and Structural Properties of an AlInN/AlGaN Distributed Bragg Reflector using Scanning Transmission Electron Microscopy Cathodoluminescence — •Gordon Schmidt,

Peter Veit, Alexander Franke, Frank Bertram, Jürgen Christen, Christoph Berger, Armin Dadgar, and Alois Krost — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Magdeburg, Germany

We present a direct nano-scale correlation of the optical properties and crystalline real structure of a lattice matched distributed Bragg reflector (DBR) using cathodoluminescence spectroscopy (CL) in a scanning transmission electron microscope (STEM).

The structure was grown by metal organic vapor phase epitaxy on sapphire substrate using an optimized buffer. The highly reflective DBR consits of 35 periods of AlInN and AlGaN $\lambda/4$ layers and is capped by a 200 nm thick $3\lambda/2$ GaN cavity. The STEM-CL images clearly resolve the complete sequence of the DBR structure.

The $Al_{0.2}Ga_{0.8}N$ buffer layers emit intense CL at a wavelength of 318 nm. The DBR layers are laterally and vertically homogeneous with sharp AlInN/AlGaN interfaces. Local spectra show a blueshift of the DBR emission from 327 nm to 323 nm in growth direction. The direct comparison of the STEM image with the simultaneously recorded monochromatic CL mapping of the DBR luminescence clearly identifies the AlGaN/AlInN interfaces as the origin of this emission. This indicates the formation of a 2D electron gas in the polarization field induced potential well at these interfaces.

HL 80.5 Thu 12:15 ER 270

Spontaneous polarization of GaN derived from stacking fault luminescence — •Jonas Lähnemann[1], Oliver Brandt[1], Uwe Jahn[1], Carsten Pfüller[1], Claudia Roder[1], Pinar Dogan[1], Frank Grosse[1], Abderrezak Belabbes[2], Friedhelm Bechstedt[2], Achim Trampert[1], and Lutz Geelhaar[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin — [2]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Wurtzite crystals exhibit a spontaneous polarization P_{sp} in equilibrium, which together with the piezoelectic polarization leads to electric fields in heterostructures and thus has an immediate impact on device design. Amongst these, GaN stands out as the material used for solid-state lighting. So far, only an indirect experimental determination of P_{sp} for GaN has been reported using a thermodynamic approach and theoretical predictions exhibit a significant variation.

We derive P_{sp} for GaN from the emission energies of excitons bound to different types of stacking faults (SFs). Employing microphotoluminescence and cathodoluminescence spectroscopy, we observe emission lines from the intrinsic and extrinsic SFs in strain-free GaN micro-crystals. By treating the sheet charges associated with these SFs as a plate capacitor, we obtain P_{sp} from the observed transition energies. To support our model, we use self-consistent Poisson-Schrödinger calculations and density functional theory. This approach should be applicable also to other wurtzite semiconductors.

HL 80.6 Thu 12:30 ER 270

Electro- and cathodoluminescence microscopy of an InGaN/GaN LED structure based on semipolar {10-11} faceted GaN pyramids — •Martin Thunert[1,3], Sebastian Metzner[1], Thomas Hempel[1], Frank Bertram[1], Jürgen Christen[1], Clemens Wächter[2], Michael Jetter[2], and Peter Michler[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Universität Stuttgart, Institut Für Halbleiteroptik und Funktionelle Grenzflächen, Germany — [3]Universität Leipzig, Institut für Experimentelle Physik II, Linnéstraße 5, 04103 Leipzig

The luminescence distribution of an InGaN/GaN LED structure grown by selective MOVPE is analyzed by spatially and spectrally resolved electroluminescence (EL) and cathodoluminescence (CL) microscopy at room temperature. Self organized grown hexagonal GaN pyramids have been selectively overgrown by an InGaN/GaN MQW and subsequently metal contacts complete the LED structure. By CL measurements a homogeneous InGaN luminescence distribution over the semipolar side facets as well as a red shifted emission on the top and the corner of the pyramid was observed due to higher indium incorporation. In contrast, EL investigations of the identical pyramid show a continuous shift of the InGaN emission caused by inhomogeneous lateral current distribution. With increasing injection current the spatially averaged EL peak of the investigated pyramid reveals a very strong blueshift of 290 meV and a high increase in intensity indicating screening of the QCSE and filling of potential fluctuations or local inhomogeneities due to the formation of new current paths.

HL 80.7 Thu 12:45 ER 270

Optical and Structural Nano-Characterization of 62x InGaN MQW on GaN/AlInN DBR — •Marcus Müller[1], Gordon Schmidt[1], Peter Veit[1], Thomas Hempel[1], Frank Bertram[1], Jürgen Christen[1], Munise Cobet[2], Raphaël Butté[2], Jean-Françcois Carlin[2], and Nicolas Grandjean[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute of Condensed Matter Physics, École Polytechnique Fédérale de Lausanne (EPFL), Switzerland

Using low temperature cathodoluminescence spectroscopy (CL) directly performed in a scanning transmission electron microscope (STEM) we present optical and structural properties of a 62x InGaN multi quantum well (MQW) on top of a AlInN/GaN distributed Bragg reflector (DBR). The structure was grown by MOVPE on a sapphire substrate using an optimized GaN buffer.

Direct comparison of the STEM images with simultaneously recorded CL mappings resolve the complete layer sequence, especially the MQW. In particular, the DBR layer stack is laterally and vertically homogeneous with sharp AlInN/GaN interfaces. CL mappings of the DBR show a luminescence at 352 nm originating exclusively from AlInN layers.

A dominant emission with a broad spectral range of the InGaN MQW can be observed. Low temperature mappings ($T < 20$ K) exhibit a systematic redshift of the spectral position of the MQW from the bottom (410 nm) to the top (460 nm), indicating strain relaxation, higher indium incorporation, and/or increasing quantum well thickness.

HL 80.8 Thu 13:00 ER 270

Cathodoluminescence microscopy and X-ray diffraction measurements of semipolar $(1\bar{1}01)$ **GaN structures with InGaN SQWs on patterned Si(001) substrate** — •Christopher Karbaum[1], Frank Bertram[1], Sebastian Metzner[1], Jürgen Christen[1], Jürgen Bläsing[1], Alois Krost[1], Shujian Liu[2], Vitaliy Avrutin[2], Natalia Izyumskaya[2], Ümit Özgür[2], and Hadis Morkoç[2] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Depart. of Electrical and Computer Engineering, VCU, Richmond, USA

The optical and crystalline properties of GaN bars with $(1\bar{1}01)$ faceted surfaces were investigated using spatially and spectrally resolved cathodoluminescence (CL) at liquid helium temperature and high resolution X-ray diffraction (HRXRD), respectively. Triangular-shaped GaN bars with semipolar $(1\bar{1}01)$ facets and an InGaN LED structure atop were grown on a structured Si(001) substrate exhibiting V-shaped grooves aligned along Si[110]. In the c^+-wing near the Si side facet the (D^0,X) emission of GaN is shifted to lower energies (3.451 eV) due to tensile strain. Intense CL from basal plane stacking faults (BSF) at 3.424 eV can be found in the c^--wing. The CL from the top view reveals intense and broad InGaN emission with an inhomogeneous distribution of the peak energy on the micrometer-scale and emission maxima centered at about 2.48 eV and 3.10 eV. The temperature dependence of the above mentioned CL will be presented. HRXRD measurements indicate an orientation disorder of about one degree of the GaN bars in each direction.

HL 80.9 Thu 13:15 ER 270

Cathodoluminescence study of InGaN quantum wells grown in different crystallographic orientations — •Sebastian Metzner[1], Frank Bertram[1], Holger Jönen[2], Torsten Langer[2], Uwe Rossow[2], Andreas Hangleiter[2], Stephan Schwaiger[3,4], Ferdinand Scholz[3], and Jürgen Christen[1] — [1]Inst. of Experimental Physics, Otto-von-Guericke-Univ. Magdeburg — [2]Inst. of Applied Physics, Technische Universität Braunschweig — [3]Inst. of Optoelectronics, University of Ulm — [4]now with OSRAM Herbrechtingen

The optical properties of very thin (∼1.5 nm), high indium containing (∼30 %) InGaN QWs which had been grown on conventional polar c-plane GaN/sapphire as well as on semi- and non-polar GaN templates were investigated using spatially, spectrally, and time-resolved cathodoluminescence microscopy. The non-polar QWs were heteroepitaxially grown on m-plane SiC, a-plane GaN/r-plane sapphire templates and homoepitaxially grown on freestanding m-plane GaN. For the semi-polar sample, a planar template of (11-22)GaN grown directly on pre-patterned (10-12)sapphire has been used. Therefore, the sapphire substrate was structured into trenches providing c-plane like sidewalls for the subsequent GaN growth. With the c-direction being

inclined to the normal of the surface, the coalescence of GaN stripes forms a planar semipolar (11-22)GaN surface. Especially the local indium incorporation causing lateral fluctuations and the impact of the polarization fields on the recombination kinetics for the various orientations were analyzed in detail at liquid helium and room temperature.

HL 81: Graphene: Transport incl. Spin Physics and Magnetic Fields I

Time: Thursday 15:00–16:45 Location: ER 270

HL 81.1 Thu 15:00 ER 270

Aharonov-Bohm effect in an electron -hole graphene system — •Dmitri Smirnov, Hennrik Schmidt, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2 30167 Hannover, Germany

We analyze the electronic properties of a monolayer graphene ring. The sample and structured by standard procedures: micro-mechanical cleavage for preparation on a Si-wafer with a 285 nm thick layer of SiO2, electron beam lithography, active oxygen etching for structuring and contacting the ring shaped sample. The sample is measured in a He3-cryostat system with a base temperature of 500 mK and is identified as monolayer first via optical microscopy and later based on the magnetotransport measurements. In addition to the Si-backgate we place a topgate on top of one arm of the ring to manipulate the charge carrier concentration and to be able to create a pnp- (npn-) junction inside the ring. We observe Aharonov-Bohm oscillations by variation of the magnetic field around 0 T. The period of the oscillation is approx. 16.5 mT and fits the size of the ring well. The maximum visibility of the oscillations in all measurements is about 1%. We are also able to observe the oscillations when a pnp-junction is created inside the ring. The period is independent of the existence of a pnp-junction and stays constant in all situations. We analyze the amplitude in dependence of the charge carrier type and concentration. The absolute amplitude is constant in the bipolar and unipolar region. The relative amplitude has a dependence that is based on the changing background resistance.

HL 81.2 Thu 15:15 ER 270

Magnetotransport through graphene nanoribbons at high magnetic fields — •Silvia Schmidmeier[1], Sung Ho Jhang[1], Jürgen Wurm[2], Iurii Skourski[3], Joachim Wosnitza[3], Christoph Strunk[1], Dieter Weiss[1], Klaus Richter[2], and Jonathan Eroms[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Germany — [2]Institute of Theoretical Physics, University of Regensburg, Germany — [3]Dresden High Magnetic Field Laboratory, Helmholtz-Zentrum Dresden-Rossendorf, Germany

For the application of graphene in nanoelectronics one has to understand the behavior of graphene nanostructures, in particular graphene nanoribbons. They were theoretically predicted to show either metallic or insulating behavior around the charge neutrality point, depending on their crystallographic orientation. In experiment, however, graphene nanoribbons always exhibit an insulating state close to the charge neutrality point, which is dominated by disorder rather than a confinement-induced gap in the spectrum. At present, the behavior of GNRs is mainly governed by extrinsic defects rather than their intrinsic properties, and information on the nature of those defects is highly desired.

We have investigated the magnetoresistance of lithographically prepared single-layer graphene nanoribbons as narrow as 70 nm in pulsed, perpendicular magnetic fields up to 60 T and performed corresponding transport simulations using a tight-binding model and several types of realistic bulk and edge disorder. Thus we can disentangle their contributions to transport in graphene nanoribbons.

HL 81.3 Thu 15:30 ER 270

Terahertz radiation driven chiral edge currents in graphene — •C. Drexler[1], J. Karch[1], P. Olbrich[1], M. Fehrenbacher[1], M. Hirmer[1], M. M. Glazov[2], S. A. Tarasenko[2], B. Birkner[1], J. Eroms[1], D. Weiss[1], R. Yakimova[3], S. Lara-Avila[4], S. Kubatkin[4], M. Ostler[5], T. Seyller[5], E. L. Ivchenko[2], and S. D. Ganichev[1] — [1]Terahertz Center, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia — [3]Linköping University, Linköping, Sweden — [4]Chalmers University of Technology, Göteborg, Sweden — [5]University of Erlangen-Nürnberg, Erlangen, Germany

Here we report on photocurrents induced in single layer graphene samples by illumination of the graphene edges with circularly polarized terahertz radiation at normal incidence. The photocurrent flows along the sample edges and forms a vortex. Its winding direction reverses by switching the light helicity from left- to right-handed. We demonstrate that the effect is directly coupled to electron scattering at the graphene edge which reduces the spatial symmetry and vanishes in bulk graphene. The developed theory based on Boltzmann's kinetic equation is in good agreement with the experimental findings. Our results suggest that the circular photocurrents can be effectively used to study edge transport in graphene even at room temperature.

[1] J. Karch *et al*, *Phys. Rev. Lett.* (in print); arXiv:1107.3747v1

HL 81.4 Thu 15:45 ER 270

Spin transport and relaxation in single and bilayer graphene — •Bastian Birkner, Daniel Pachniowski, Dieter Weiss, and Jonathan Eroms — Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

We achieved electrical spin injection with a DC current from a ferromagnetic material (Co) into both single layer graphene (SLG) and bilayer graphene (BLG). In order to circumvent the conductivity mismatch problem a thin AlOx tunnel barrier is placed in between graphene and the ferromagnetic contacts. This AlOx layer is produced by depositing Al atoms over the entire sample at 180 K and subsequent oxidation at room temperature. For both SLG and BLG, we obtain a clear switching of the non-local magnetoresistance whose sign depends on the magnetization orientation (parallel/antiparallel) of the ferromagnetic electrodes. By applying a perpendicular magnetic field we also detect spin precession (Hanle effect). Fitting of these Hanle curves yields the spin relaxation time and the spin injection efficiency as well as the spin diffusion constant. The latter is nearly identical with the charge diffusion constant in SLG. For BLG this is also valid if one considers a realistic band structure with a bandgap. Furthermore we find by analyzing the relationship between spin and momentum scattering that the Elliot-Yafet spin relaxation mechanism dominates in SLG at low temperature. In contrast to this result, we find a opposite behavior of the temperature dependence of the spin relaxation time and the diffusion constant which suggests the importance of the Dyakonov-Perel mechanism in BLG.

HL 81.5 Thu 16:00 ER 270

Temperature Dependent Magnetotransport Studies of Graphene on GaAs — •Nils Gayer, Karen Peters, and Wolfgang Hansen — Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Germany

We utilize temperature dependent magnetotransport measurements to investigate the electronic properties of graphene on (001)-GaAs. Our substrates contain a Si-doped GaAs backgate grown by means of molecular beam epitaxy. The investigated graphene flakes were prepared by mechanical cleavage of natural graphite. We were able to determine the number of layers of the graphene flakes by using Raman spectroscopy.

Shubnikov-de Haas oscillations in the longitudinal resistance allow for determination of the charge carrier densities and subsequently the carrier mobilities. The gate-voltage dependency of the resistance suggests that the samples are p-doped. The observed weak localization enables the extraction of the temperature dependent dephasing time τ_ϕ. The temperature dependency reveals diffusive electron-electron scattering to be the phase breaking process.

HL 81.6 Thu 16:15 ER 270

Polarization resolved magneto-Raman scattering of graphene on natural graphite — •Matthias Kühne[1,2], Clément Faugeras[2], Piotr Kossacki[2,3], Aurélien L. L. Nicolet[2], Milan Orlita[2,4], Yu. I. Latyshev[5], and Marek Potemski[2] — [1]Karlsruher Institut für Technologie, Physikalisches Institut, 76131 Karlsruhe — [2]LNCMI-CNRS (UJF, UPS, INSA), 38042 Grenoble, France — [3]Institute of Experimental Physics, University of Warsaw, 00-681 Warsaw, Poland — [4]Institute of Physics, Charles University,

121 16 Praha 2, Czech Republic — [5]Institute of Radio Engineering and Electronics, RAS, 125009, Moscow, Russia

It was recently demonstrated that purely electronic Raman scattering can be measured in graphene flakes on bulk natural graphite subject to a quantizing magnetic field [1]. We investigate a similar graphene flake by micro-Raman scattering at 4.2K and in magnetic fields up to 29T. Different types of electronic excitations are observed and identified in circular polarization resolved experiments. The magnetic field evolution of these excitations reveals details of the graphene band structure, such as the electron-hole asymmetry, as well as possible signs of an interaction with the underlying substrate. The latter is further suggested by an unusually rich coupling between the zone-center E_{2g}-phonon and the electronic excitations.

[1] C. Faugeras et al., Phys. Rev. Lett. 107, 036807 (2011)

HL 81.7 Thu 16:30 ER 270

Relaxation dynamics in Landau-quantized graphene probed in the mid-infrared range — •Martin Mittendorff[1], Stephan Winnerl[1], Harald Schneider[1], Manfred Helm[1], Milan Orlita[2], Marek Potemski[2], Mike Sprinkle[3], Claire Berger[3], and Walter A. de Heer[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ionebeamphysics and material research, Germany — [2]Grenoble High Magnetic Field Laboratory, France — [3]Georgia Institute of Technology, Atlanta, USA

In contrast to conventional semiconductors the Landau levels (LLs) in graphene are not equidistant. This feature allows us to investigate a single LL transition selectively. By applying magnetic fields of up to 7 T we could investigate three different transitions at a fixed wavelength of 16.5 μm via pump-probe measurements. By varying the magnetic field the photon energies were brought into resonance with the different transitions. For the transition $LL_{0(-1)}- > LL_{1(0)}$ we could not only observe an increase of the pump-probe signal by a factor of 2.5 but also a decrease of the relaxation time from 20 ps to 5 ps. Interestingly, the reduced relaxation time is observed in a wider range of magnetic fields than the increase of the signal amplitude. Additionally the minimum of the relaxation time is shifted in respect to the maximum signal. For the transitions $LL_{-1(-2)}- > LL_{2(1)}$ and $LL_{-2(-3)}- > LL_{3(2)}$ we could only observe an slight increase of the pump-probe signal.

HL 82: Focus Session: Semiconductor-based Quantum Communication II

(Continuation of Part I)

Time: Thursday 15:00–16:30 Location: ER 164

Invited Talk HL 82.1 Thu 15:00 ER 164

Quantum dot - nanocavity QED for quantum information processing — •Jelena Vuckovic — Ginzton Laboratory, Stanford University, Stanford, CA 94305-4088

Single quantum dots (QDs) in photonic crystal nanocavities are interesting both as a testbed for fundamental cavity quantum electrodynamics (QED) experiments, as well as a platform for quantum and classical information processing. In addition to providing a scalable, on-chip, platform, these systems also enable large dipole-field interaction strengths, as a result of the localization of the field to very small optical volumes. Such a platform could be employed to demonstrate a number of devices, including nonclassical light sources, electro-optic modulators and switches operating at the single photon level, and quantum gates. QD-cavity QED systems also exhibit interesting phonon-assisted off-resonant interaction between the QD and the cavity which can be employed for spectral filtering, as well as for coherent optical spectroscopy and quantum dot state readout, thereby overcoming issues coming from quantum dot inhomogeneous broadening. In order to make the platform compatible with fiber-optic telecommunication wavelengths, the intrinsic optical nonlinearity of the semiconductor employed to make a nanocavity can be employed for frequency conversion.

Topical Talk HL 82.2 Thu 15:30 ER 164

The Single-Quantum-Dot Laser — •Christopher Gies[1], Matthias Florian[1], Paul Gartner[1,2], and Frank Jahnke[1] — [1]Institut für Theoretische Physik, Universität Bremen — [2]National Institute of Materials Physics, Bucharest-Magurele, Romania

A single quantum-dot emitter coupled to a single microcavity mode represents a model system for fundamental quantum optical effects and various applications. We study the emission properties of this system for different excitation regimes from a single-photon source to lasing on the basis of a semiconductor model. As a function of the excitation conditions we investigate the onset of stimulated emission, the possibility to realize stimulated emission in the strong-coupling regime, as well as the excitation-dependent changes of the photon statistics and the emission spectrum. The role of possible excited charged and multi-exciton states and the different sources of dephasing for various quantum-dot transitions are discussed.

Topical Talk HL 82.3 Thu 16:00 ER 164

Coherence and photon statistics of the Mollow triplet sideband emission of a quantum dot — •Sven M. Ulrich, Ata Ulhaq, Stefanie Weiler, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Universität Stuttgart

Analysis and minimization of dephasing processes in quantum light emitters is a central research issue for future quantum information processing schemes. Single quantum dot (QD) resonance fluorescence has proven to be nearly Fourier transform-limited for excitation powers below emitter saturation [1]. Here we present detailed investigations of QD resonance emission above saturation, where the 'dressed' character confirms by the so-called Mollow triplet. Single InGaAs/GaAs QDs in planar waveguide structures and high-quality pillar cavities have been studied. By high-resolution photoluminescence, we trace Mollow triplet spectra under variable excitation powers and detuning conditions. Photon correlation measurements demonstrate both 'single' and 'cascaded' emission from the Mollow triplet sidebands. By laser detuning the very bright emission can be frequency-tuned over 15 times its linewidth. Furthermore, the effect of dephasing in terms of systematic spectral broadening of the triplet sidebands and oscillation damping in g(1) coherence are observed as a strong fingerprint of excitation-induced dephasing [2]. Our results are consistent with predictions of a recently presented model on phonon-dressed QD Mollow triplet emission in the cavity QED regime [3]. [1] S. Ates et al., Phys. Rev. Lett. 103, 167402 (2009). [2] S.M. Ulrich et al., Phys. Rev. Lett. 106, 247402 (2011). [3] C. Roy and S. Hughes, Phys. Rev. Lett. 106, 247403 (2011).

HL 83: Focus Session: III-Nitride Heterostructures for Optoelectronics - Polarization Reduction, Green Gap and High In-containing Alloys

Despite tremendous progress, the optoelectronic properties of GaN and related compounds still pose a rich field for scientific research. The aim of this session is to bring together leading experts on materials, characterization, and theory in order to discuss the physics of group-III nitride-based heterostructures and various approaches to realize future optoelectronic devices. Open questions are in particular the so-called *green gap* describing lower efficiency in GaN based green light emitters as opposed to their blue and ultraviolet counterparts, polarization of the crystal structure, as well as high-In containing alloys

for light emitters in the entire visible range. (Organizers: Bernd Witzigmann, University of Kassel and Frank Bertram, University of Magdeburg)

Time: Thursday 15:00–18:15 Location: EW 201

Invited Talk HL 83.1 Thu 15:00 EW 201

Compositional instability in InGaN and InAlN thick films with high indium content — •Fernando Ponce — Department of Physics, Arizona State University, Tempe, AZ 85287, USA

Control on the indium content in InGaN and AlGaN alloys is important to achieve high efficiency light emitting devices operating in the visible regime, or to achieve ultraviolet light emitting structures that are lattice matched to GaN. For existing growth methods, there seems to exist limits at ~ 20% in the indium content for both the InGaN and AlGaN alloys. This talk will cover the microstructural and optical manifestations of compositions instability in thick epilayers.

Topical Talk HL 83.2 Thu 15:30 EW 201

Nitride laser diodes - from arrays to tapered resonator devices — •Piotr Perlin — Institute of High Pressure Physics, Sokolowska 29/37, 01-142 Warsaw, Poland

We presently observe, an increasing demand for high optical power laser diodes operating in the wavelength range between 370 and 530 nm. This demand is biased by new applications like UV curing, printing or RGB sources for large optical displays. In order to construct truly high power laser diodes, nitrides technology should go along the similar (though not identical) way the arsenide devices went years ago. Laser diode arrays including large arrays and mini-arrays belong to this class of previously tested solutions. Within this presentation I will discuss perspectives and challenges related to the construction of multi-emitters devices, demonstrating the capabilities of reaching multi-Watt range of optical powers. I will also point out the possibility of dramatically improve the optical beam quality of high power nitride laser diode by using a tapered resonator. I will show that by using this geometry a M2=1.5 high power devices could be demonstrated.

Topical Talk HL 83.3 Thu 16:00 EW 201

Advantages and issues of m-plane freestanding GaN substrates grown by halide vapor phase epitaxy for InGaN and AlGaN epitaxial growth — •Shigefusa Chichibu[1], Kouji Hazu[1], Pierre Corfdir[2], Jean-Daniel Ganière[2], Benoît Deveaud-Plédran[2], Nicolas Grandjean[2], Shuich Kubo[3], Hideo Namita[3], Satoru Nagao[3], Kejji Fujito[3], and Kenji Shimoyama[3] — [1]Tohoku Univ., Sendai, Japan — [2]EPFL, Lausanne,Switzerland — [3]Mitsubishi Chemical Corp., Ushiku, Japan

We will discuss the subject given in the title. As long as coherent growth is maintained, the degree of tilt and twist mosaics of the epilayers is similar to the substrate. However, the formation of basal-plane stacking faults (BSFs) is hard to avoid in the case of lattice-mismatched thick films. For the pseudomorphic $In_xGa_{1-x}N$ ($x \leq 0.14$) films, improved quantum efficiency and short radiative lifetime are achieved for the near-band-edge emission. As the surface flatness is improved, however, the In-incorporation efficiency becomes lower than the cases for c-plane growth and m-plane growths on defective GaN bases. Atomically smooth and coherent m-plane AlGaN/GaN heterostructures exhibit a luminescence signal originating from the recombination of 2DEG and photoexcited holes. Slight but nonzero, grown-in anisotropic tilt mosaics of the substrates give rise to the formation of surface striations and inclined planes, and also planar-defect networks in the epilayers. The origins of characteristic CL intensity patterns will be discussed, using the spatio-time-resolved CL and conventional time-resolved PL measurements.

Coffee Break (15 min)

Invited Talk HL 83.4 Thu 16:45 EW 201

Low Temperature Growth Methods for Overcoming Perceived Limitations in III-Nitride Epitaxy — •W. Alan Doolittle, Michael Moseley, and Brendan Gunning — Georgia Institute of Technology, Atlanta GA, USA

Historically, III-Nitride epitaxy has been performed at relatively high temperatures leading to excellent material quality in the wide bandgap regime. However, this mindset when applied to the moderate to low bandgap alloys, has resulted in serious issues with phase separation, loss of uniformity and limitations in the ability to p-dope materials. Herein, a new approach centered around substantially colder epitaxy is described and is shown to result in non-phase separated InGaN grown throughout the immiscibility gap and p-type GaN and InGaN with hole concentrations well above the previously perceived limits. High structural and electronic quality is maintained even at significantly lower temperatures using extremely metal rich growth conditions. Structural, electronic and optical properties are presented and the compromises versus benefits low temperature epitaxy imposes are discussed.

Topical Talk HL 83.5 Thu 17:15 EW 201

Nonpolar and semipolar GaN on GaN, Si, and Sapphire substrates — Vitaliy Avrutin, Natalia Izioumskaia, Ümit Özgür, and •Hadis Hadis Morkoç — Virginia Commonwealth University, Richmond, VA 23284-3072

Polar nature of GaN necessitates investigating non-polar and semipolar orientations to circumvent adverse effects. In this presentation, mainly the growth and optical properties of non-polar, namely (11bar00) orientation, and semi-polar, namely (11bar01) and (112bar2) orientations, of GaN and InGaN/GaN heterostuctures will be discussed. (11bar00) and (11bar01)-oriented GaN layers were grown on patterned Si substrates, while (112bar2) GaN films on m-sapphire by metal organic chemical vapor deposition (MOCVD). For (11bar01)GaN films grown at high reactor pressure (200 Torr), steady-state and time-resolved PL measurements have revealed bright luminosity and very long carrier decay times (1.8 ns), which are comparable to those for the state-of-the-art c-plane GaN templates prepared by in situ epitaxial lateral overgrowth using silicon nitride nano-network. Low reactor pressure of 30 Torr required for the growth of m-plane GaN on Si(112) leads to weaker luminescence and rapid carrier decay likely due to carbon contaminations, which both could be improved significantly by subsequent overgrowth at higher pressures. The long radiative lifetimes for the (11bar01)GaN layers show that the semipolar material has a great promise for light emitting and detecting devices.

Topical Talk HL 83.6 Thu 17:45 EW 201

What causes the efficiency droop in GaN-based LEDs ? — •Joachim Piprek — NUSOD Institute, Newark, DE 19714-7204, USA

GaN-based light-emitting diodes (LEDs) suffer from a reduction (droop) of the quantum efficiency with higher injection current. This droop phenomenon is subject to intense research worldwide, as it delays general lighting applications of GaN-based LEDs. Many proposals have been published in recent years to explain the efficiency droop, but none is generally accepted today. Among the proposed droop mechanisms are enhanced Auger recombination, reduced hole injection, and density-activated Shockley-Read-Hall recombination within the quantum wells. However, different sample preparation and measurement conditions as well as the application of different mathematical models and material parameters lead to a confusing and sometimes contradicting variety of efficiency droop observations and explanations. This talk reviews and contextualizes different droop models within a simple framework and it intends to bring more clarity to the ongoing droop discussion.

HL 84: Quantum Dots and Wires: Transport Properties III (mainly Thermal Gradients)

Time: Thursday 15:00–16:15 Location: EW 202

HL 84.1 Thu 15:00 EW 202

Nanocaloritronics of thermoelectric transport across interacting quantum dots. — •Bhaskaran Muralidharan and Milena Grifoni — Institut I - Theoretische Physik Universität Regensburg D-93040 Regensburg

By subjecting a weakly coupled quantum dot system to an applied voltage and temperature gradient, we present notable subtleties involved in its thermoelectric energy conversion efficiency. First, is the well known, but non-intuitive aspect in the non-interacting case, of achieving a reversible operation with Carnot efficiency. Second, is the rather surprising result in the presence of Coulomb interactions that similar operating conditions lead to zero efficiency [1]. It is then shown that even in this case, operating efficiencies close to the Carnot value may be attained, but, under non-equilibrium conditions [1]. Consequently, the inadequacies of traditionally employed performance metric zT in capturing the aforementioned non-equilibrium conditions are pointed out.

Reference:

[1]"Nanocaloritronic performance analysis of an interacting quantum dot thermoelectric", B. Muralidharan and M. Grifoni, cond-mat/1110.4357 (2011).

HL 84.2 Thu 15:15 EW 202

Noise-induced currents in open quantum dots — •Björn Sothmann[1], Rafael Sánchez[2], Andrew N. Jordan[3], and Markus Büttiker[1] — [1]Département de Physique Théorique, Université de Genève — [2]Consejo Superior de Investigaciones Científicas — [3]Department of Physics and Astronomy, University of Rochester

Recently, the influence of fluctuations on transport through quantum dots has generated quite some interest. In Ref. [1], it was shown how a double dot in a three-terminal device can convert a heat current into a charge current. This converter is optimal in the sense that it transfers one electron for every heat quantum delivered by the hot dot. However, the currents generated are very small. Of interest is the scaling of this effect as the system size increases.

Here, we consider transport through two open quantum dots coupled to leads via quantum-point contacts with energy-dependent transmissions. We, additionally, take into account fluctuations of the cavity potentials. Using a semiclassical analysis, we calculate the charge current through one cavity as a response to a heat gradient between the reservoirs of the two cavities. We, furthermore, evaluate the heat currents in the system to discuss its thermodynamic efficiency.

[1] R. Sánchez and M. Büttiker, Phys. Rev. B **83**, 085428 (2011).

HL 84.3 Thu 15:30 EW 202

Thermal gradients and noise thermometry in 2D and 1D electron systems — •S.S. Buchholz[1], E. Sternemann[1], P. Miechowski[1], D. Reuter[2], A.D. Wieck[2], and S.F. Fischer[1] — [1]Neue Materialien, Humboldt-Universität zu Berlin, D-10099 Berlin — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44801 Bochum

Thermoelectric (TE) and out-of-equilibrium thermal properties of nanostructured semiconductors are of increasing research interest with respect to the improvement of the TE efficiency. A particular challenge is the determination of the charge carrier temperature at the nano-scale.

Here, we performed cross-correlated thermal voltage noise measurements under applied dc current heating in nanopatterned (2D and 1D) channels of a GaAs/AlGaAs heterostructure at bath temperatures of 1.4 K and above.

Via the current heating technique, we heat the electron system up to several K above the lattice temperature and measure the electron temperature by Nyquist-noise thermometry. In narrow 2D channels, the temperature dependence of the electron energy-loss rate is reduced compared to wider 2D systems [1], which may be attributed to the strong lateral confinement of the etched channels. In a 1D quantum interferometer sandwiched between a hot and a cold electron reservoir, we show the decoherence due to the diffusion of hot electrons by the thermal gradient.

[1] S.S. Buchholz et al., arXiv:1111.1591 (2011).

HL 84.4 Thu 15:45 EW 202

Thermopower of a Coupled Quantum Dot System — •Holger Thierschmann[1], Michael Henke[1], Johannes Knorr[1], Wolfgang Hansen[2], Hartmut Buhmann[1], and Laurens W. Molenkamp[1] — [1]Physikalisches Institut (Experimentelle Physik III), Universität Würzburg, Germany — [2]Institut für Angewandte Physik und Zentrum für Mikrostrukturforschung, Universität Hamburg, Germany

We perform electrical characterization and thermopower measurements on lateral gate patterned coupled quantum dot systems based on a GaAs/AlGaAs HEMT structure. The two quantum dots are connected in series and are tuned into the strong coupling regime. A temperature difference of a few 10mK is established using the current heating technique [1]. We observe strong asymmetries in the thermovoltage signal around the tripel points, which we can explain within an electrostatic capacitance model and also between two tripel points, which we believe are caused by molecular-like electron states. Due to strong interdot tunnel coupling we find thermovoltages in regions with finite conductance, which is in strong contrast to the thermopower of a single quantum dot [2]. [1] R. Scheibner, H. Buhmann, D. Reuter, M. N. Kiselev and L.W. Molenkamp, PRL 95, 176602 (2005). [2] R. Scheibner, E.G. Novik, T. Borzenko, M. König, D. Reuter, A.D. Wieck, H. Buhmann and L.W. Molenkamp, Phys. Rev. B 75, 041301(R) (2007).

HL 84.5 Thu 16:00 EW 202

Phonon-drag thermopower of a Si/SiGe quantum point contact — •Joeren von Pock[1], Daniel Salloch[1], Ulrich Wieser[1], Ulrich Kunze[1], and Thomas Hackbarth[2] — [1]Lehrstuhl für Werkstoffe und Nanoelektronik, Ruhr-Universität Bochum, D-44780 Bochum — [2]DaimlerChrysler Forschungszentrum Ulm, D-89081 Ulm

We investigate the influence of phonon-drag thermopower on a gate-modulated inertial ballistic rectifier. Our devices are fabricated from a high mobility Si/SiGe heterostructure with an electron mobility of $\mu_{2D} = 18.3\ \mathrm{m^2V^{-1}s^{-1}}$ and a density of $n_{2D} = 6.3 \cdot 10^{15}\ \mathrm{m^{-2}}$ at 1.4 K. The confinement is realized by low damage CF_4/O_2 plasma etching. Two quantum point contacts (QPCs) are directed parallel and perpendicular to a heating wire and are electrically isolated from it. A gradient of temperature from the heating wire generates phonons which drag electrons through QPC constriction. In case of the perpendicular QPC the electrons relax behind the constriction and create a measurable thermopower signal of about 10^{-3} times smaller magnitude than hot-electron thermopower. Because of the absence of a gradient of temperature on each side of the constriction, the QPC parallel to the heating wire shows no signal. The measured phonon-drag thermopower is strongly dependent on the phonon priority direction [100] in Si/SiGe. The temperature dependence shows a decrease of the phonon-drag induced thermopower in the region of $4.2K \leq T \leq 30$ K which is not yet understood. At 1.5 K no phonon-drag effect is observed as in [1].

[1] W. E. Chickering *et al.*, PRL **103**, 046807 (2009).

HL 85: Organic Semiconductors: Transistors and OLEDS

Time: Thursday 15:00–17:30 Location: EW 203

HL 85.1 Thu 15:00 EW 203

New material combinations for ion gel gated organic thin film transistors — •Johannes Schöck[1], Daniel C. Frisbie[2], and Heiko B. Weber[1] — [1]Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, USA

Ion gels can efficiently gate thin film transistors made from small

molecules. Sharing the same benefits as ionic liquids, they are easier to handle and promise better reproducibility. n- and p-type transistors were fabricated from PCBM and custom-made pentacene dimer derivatives. PVdF/[BMP+][FAP-] and PVdF/[EMIm+][TFSi-] ion gels were used as top gates, using P3HT as a standard semiconductor for comparison.

HL 85.2 Thu 15:15 EW 203

IR spectroscopy at the ITO-organic interface — •Milan Alt[1], Ahmad Shazada[3], Akemi Tamanai[2], Jens Trollmann[2], Tobias Glaser[2], Sebastian Beck[2], Sven Tengeler[2], and Annemarie Pucci[2] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Kirchhoff-Institut für Physik, Heidelberg, Germany — [3]Max-Planck Institut für Polymerforschung, Mainz, Germany

Thin films of P3HT have been prepared by spin coating and electrooxidative polymerization on platinum- and ITO-coated substrates. Additionally, P3HT-films on silicon substrates have been prepared by spin coating only. The measured IR spectra of the spin coated films allowed for an elaboration of a detailed optical model for P3HT, which has been used to simulate IR reflection-absorption spectra on ITO and Pt substrates. Comparison of simulated spectra with measurements revealed no substrate influence on the IR spectra for the spincoated films. In case of spincoated P3HT-films on ITO-substrate, the obtained IR spectra correspond to simulation data very well up to 6000 wavenumbers. In the electropolymerized P3HT films we have identified residuals of the electrolyte ionic liquid, acting as dopand for P3HT. While IR spectra of the electropolymerized P3HT films on Pt substrate could be explained reasonably well as a superposition of chemically doped P3HT and the ionic electrolyte, the IR spectra of electropolymerized P3HT films on ITO substrates showed strongly deposition-time dependent deviations. These were most likely related to varying properties of the ITO surface between reference and sample measurement due to an interaction of ITO and the electrolyte at the film-substrate interface.

HL 85.3 Thu 15:30 EW 203

Tuning the Surface Properties of Gold Electrodes in Organic Field-Effect Transistors Using Self-Assembled Monolayers — •Janusz Schinke[1], Sebastian Hietzschold[3], Rebecca Saive[2,3], Lars Müller[3], Manuel Hamburger[4], Wolfgang Kowalsky[1,2], and Michael Kröger[1,2] — [1]TU Braunschweig, Institut für Hochfrequenztechnik — [2]Innovation Lab GmbH — [3]Universität Heidelberg, Kirchhoff-Institut für Physik — [4]Universität Heidelberg, Organisch-Chemisches Institut

In organic electronic devices, charge injection at the contacts is crucial for better electrical performance. In bottom-contact p-channel organic field-effect transistors (OFET), Au electrodes are very often used for drain and source contacts. A smart way of enhancing the device's performance is the use of self-assembled monolayers (SAMs) to tune the electrodes' work function or substrate conditions for deposition of the organic semiconductor. We have studied the properties of SAM-treated gold surfaces via Atomic Force Microscopy (AFM), Kelvin Probe (KP) and contact angle measurements. SAMs used for this work include fluorinated and non-fluorinated alkyl thiols. We compare the characteristics of SAM-treated OFETs using TIPS-pentacene as an organic semiconductor to standard devices. The gold electrode is subsequently treated by several SAM solutions to manipulate the effective work function and the device performance. Comparing to untreated OFETs, we see an enhancement of the mobility by two orders of magnitude and a significant reduction of the threshold voltage.

HL 85.4 Thu 15:45 EW 203

Structural and Electrical Characterization of 3D Gate Organic Field Effect Transistor — •S S Phani Kanth Arekapudi[1], Daniel Lehmann[1], Danny Reuter[2], and Dietrich R T Zahn[1] — [1]Semiconductor Physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany — [2]2Center for Microtechnologies (ZFM), Chemnitz University of Technology, D-09126 Chemnitz, Germany

Recent implementation of 3D gate transistors proven to have high performance, power efficiency, and improved switching behavior with less leakage current, we present an investigation of structural and electrical properties of advanced 3D gate organic field effect transistors. In this work we prepared the structures on silicon substrates. To pattern the gate, source, and drain with desired mask dimensions, stepper lithography is employed. Using deep reactive ion etching the gate trenches with channel lengths (L) ranging between L = (500 - 1500) nm, channel widths (W) ranging between W = (150 - 700) nm, and channel depth (d) 500 nm are formed. As a dielectric layer 100 nm thick SiO2 is thermally deposited on prepatterned silicon. As an active layer pentacene (<400 nm thick) is deposited on to the SiO2 layer using organic molecular beam deposition under high vacuum (HV) condition. Gold deposition for source and drain electrodes is performed using thermal evaporation under HV conditions. The 3D gate confines the organic material inside the trench, which provides high durability with less leakage current and improved mobility for the device. Further details concerning the structure preparation and electrical characterization results will be presented and discussed.

HL 85.5 Thu 16:00 EW 203

Bio-functionalization of electrolyte-gated organic transistors — •Felix Buth, Andreas Donner, Aiswarya Pillai, Martin Stutzmann, and Jose Antonio Garrido — Walter Schottky Institut, Technische Universität München, Garching, Germany

Electrolyte-gated organic field-effect transistors (EGOFETs) can be operated at low voltages in aqueous environments, paving the way to the use of organic semiconductors in bio-sensing applications. However, it has been shown that these devices exhibit inherently a rather weak sensitivity to relevant electrolyte parameters such as pH and ionic strength. In order to increase this sensitivity and add specificity towards a given analyte, the covalent attachment of functional groups to the device surface would be desirable.

In this contribution we demonstrate the successful attachment of different silane molecules, which serve as linker molecules for the subsequent grafting of bio-molecules, to the surface of α-sexithiophene-based thin film transistors. Using surface characterization techniques like X-ray photoemission and infra-red spectroscopy we could confirm the presence of functional groups on the surface, which are stable under standard electrolytic conditions. As expected, the presence of these amphoteric groups (e.g. amino or carboxylic moieties) increases the pH-sensitivity of the EGOFETs. In addition, they can serve as anchoring sites for further bio-functionalization steps. These results confirm the potential of the EGOFETs for chemical- or biochemical-sensing applications.

Coffee Break (15 min)

HL 85.6 Thu 16:30 EW 203

Investigation of Triplet Exciton Dynamics in Fluorescent Polymer Light-Emitting Diodes — •Bodo Wallikewitz, Simon Gélinas, Dinesh Kabra, and Richard Friend — University of Cambridge, Optoelectronics Group, Cavendish Laboratory, JJ Thomson Avenue, Cambridge, CB3 0HE, UK

We report on fluorescent, polymer light-emitting diodes with a high external quantum efficiency of 6.5 %. To understand the high efficiency of these PLEDs, we investigated excited state dynamics on working devices. Emissive and non-emissive excited states were monitored by their characteristic absorption and emission features using transient optical absorption spectroscopy and transient, time-resolved electroluminescence measurements. By fitting a model for triplet decay to the experimental triplet and electroluminescence dynamics, we are able to quantitatively characterize triplet-triplet annihilation as the dominant triplet decay mechanism. Singlet states generated from triplet-triplet annihilation contribute up to 33% of the total amount of singlets generated in these fluorescent devices. To model these results, we require that triplet states can undergo bimolecular annihilation several times. With this model, we show that singlets can reach a maximum fraction of 40% of all excitons generated by charge recombination, without violating spin statistics. Singlet states generated from triplet-triplet annihilation are one important explanation for high external quantum efficiencies found in these fluorescent devices.

HL 85.7 Thu 16:45 EW 203

Extraction of trapped modes in organic light-emitting diodes via high-index coupling — •Bert Jürgen Scholz, Jörg Frischeisen, and Wolfgang Brütting — Institute of Physics, University of Augsburg, Germany

The efficiency of organic light-emitting diodes (OLEDs) is still limited by poor light outcoupling efficiency. In particular, the excitation of wave-guided modes in the organic layers and surface plasmon polaritons at metal-organic interfaces represent major loss channels.
By combining optical simulations and experiments on simplified luminescent thin-film structures we elaborate the conditions for the extraction of surface plasmons via coupling to high-index media. As a proof-of-concept, we demonstrate the possibility to extract light from

wave-guided modes and surface plasmons usually trapped in the OLED by a high-index prism.

HL 85.8 Thu 17:00 EW 203

Single Molecule Electroluminescence — •Maximilian Nothaft[1], Steffen Höhla[2], Fedor Jelezko[3], Jens Pflaum[4], and Jörg Wrachtrup[1] — [1]3. Phys. Ins., Univ. Stuttgart, 70550 Stuttgart — [2]Institut für Großflächige Mikroelektronik, Univ. Stuttgart, 70550 Stuttgart — [3]Institut für Quantenoptik, Univ. Ulm, 89081 Ulm — [4]Exp. Phys. VI, Univ. Wuerzburg und ZAE Bayern, 97074 Wuerzburg

In this study we present the feasibility of detecting single electrically driven molecules at room temperature. Thereby, phosphorescent iridium based dye molecules were employed as dopants in organic light emitting diodes (OLEDs). To be sensitive on electroluminescent emission from single isolated guest molecules we chose concentrations sufficiently low to render distances between next-neighboring molecules larger than the optical diffraction limit. By spectrally separating host-guest emission, optical properties and photon emission statistics of single electrically driven phosphorescent molecules could be analyzed. Besides proving that spectral properties of the dopant molecules are identical in optical and electrical excitation mechanisms, sub-poissonian non-classical photon statistics can be observed in the electroluminescence light of a single phosphorescent dye molecule at room temperature. This approach thereby shows a possible strategy towards electrically driven single photon sources at room temperature based on phosphorescent emitters.

HL 85.9 Thu 17:15 EW 203

Untersuchung der Degradationsmechanismen in organischen Licht-emittierenden Dioden — •Mustapha Al Helwi[1,2,4], Alexander Badinski[2], Ute Heinemeyer[2], Soichi Watanabe[2], Gerhardt Wagenblast[2], Ingo Münster[2] und Wolfgang Kowalsky[1,3,4] — [1]KIP, Universität Heidelberg, Heidelberg, Deutschland — [2]BASF SE, Ludwigshafen, Deutschland — [3]IHF, Technische Universität Braunschweig, Braunschweig, Deutschland — [4]Innovation Lab GmbH, Heidelberg, Deutschland

Organische Leuchtdioden (OLEDs) sind selbstleuchtende dünne Filme aus organischen Molekülen und werden für Beleuchtungs- und Display-Anwendungen benutzt. Diese innovative Technologie wird die Welt, wie wir sie heute kennen, revolutionieren. Die OLEDs sind flexibel, transparent, druckbar und damit sehr günstig produzierbar. Wie alle neuen Technologien, bringt auch die OLED-Technologie ihre eigenen Herausforderungen mit sich. Das Verständnis der Stabilität bzw. der Degradation gehört zu den wichtigsten, noch weitergehend ungelösten Fragestellungen. In diesem Vortrag wird eine Lebensdauermessmethode und erste Ergebnisse vorgestellt. Darüber hinaus wird die Anwendung verschiedener analytischer Methoden, wie etwa der Impedanz-Spektroskopie, bei der Untersuchung degradierter Proben gezeigt. Ein theoretisches Modell zur Beschreibung der Alterung wird erläutert und zum Fitten der experimentellen Daten benutzt. Das Zusammenspiel zwischen Experiment und Modellierung erlaubt durch die Diskriminierung und Quantifizierung der Degradationsmechanismen ein tieferes Verständnis der OLED-Stabilität.

HL 86: Semiconductor Lasers

Time: Thursday 15:00–17:45 Location: EW 015

HL 86.1 Thu 15:00 EW 015

Many-Body Effects in Optically Injected Quantum-Dot Lasers — •Benjamin Lingnau[1], Kathy Lüdge[1], Weng W. Chow[2], and Eckehard Schöll[1] — [1]Institut f. Theo. Physik, Sekr. EW 7-1, Technische Universität Berlin, Hardenbergstr. 36, 10623Berlin, Germany — [2]Sandia National Laboratories, Albuquerque, New Mexico 87185-1086, USA

We investigate the reaction of a quantum-dot (QD) laser to external optical injection. The QD laser device is described using a semiclassical approach, based on the semiconductor-Bloch and Maxwell's equations, describing the material-light interaction in a quantum-mechanical framework and the electric field dynamics classically. The optical QD transition is modeled using a finite spectral width, accounting for inhomogeneities of the QDs. Carrier-carrier and carrier-phonon scattering of charge carriers in bulk, quantum well (QW) and QD states are considered within the relaxation rate approximation, where the QD-QW scattering rate exhibits a strongly nonlinear dependence on the QW charge carrier density. Furthermore, many-body Coulomb interactions, leading to renormalizations of the single-particle energies, are taken into account within the screened Hartree-Fock approximation.

When subjecting the laser to external optical injection, the dynamical shift of the band-gap energy due to the Coulomb interactions gives rise to modifications in the locking behavior of the laser, which can not be explained with simpler free-carrier models.

HL 86.2 Thu 15:15 EW 015

Absorption Spectra and Modulation Response of a Quantum Dot Laser Device With Integrated Electro-Optic Modulator — •Miriam Wegert, Kathy Lüdge und Eckehard Schöll — TU Berlin, Institut für Theoretische Physik, Berlin, Germany

In this work we theoretically study the influence of modulator voltage, optical input and band structure on the absorption spectrum and the small-signal modulation response of a quantum dot (QD) electrooptic modulator (EOM) and investigate the dynamics of a laser device with integrated EOM.

Our theoretical model is based upon semiconductor Bloch equations which describe the coupled polarization and population dynamics and a traveling wave field equation. The impact of the quantum confined Stark effect, a red shift of the wavelength of the optical transition and a decrease of the oscillator strength through the shift of the energy levels and the distortion of the wave functions when a voltage is applied to the modulator, is included in the model.

Our simulations show that it is crucial both to include the QD excited state and to distinguish between electrons and holes to describe the absorption recovery properly. The absorption recovery time can be optimized by tuning the energy spacing. That makes a laser device with integrated EOM an excellent candidate for switching applications in an optical communication system. The simulated absorption spectra as well as the small-signal modulation response are in good agreement with experimental results.

HL 86.3 Thu 15:30 EW 015

Influences on random laser modes in dependence of their localization strength — •Janos Sartor, Daniel Schneider, Felix Eilers, and Heinz Kalt — Karlsruher Institut für Technologie (KIT) Karlsruhe

In a strongly scattering medium that provides optical gain, laser activity can be observed without an external resonator. In a so called random laser the coherent feedback is provided by multiple scattering. Optically pumped ZnO powders with a grain size in the order of the emitted wavelength provide optical gain and strong scattering at the same time and can therefore be used to examine random lasing activity. In our work we want to discuss important influences on the lasing properties like the temperature or the mean free path of light, which can be controlled by using powders with different grain sizes. When the mean free path is close to the limit where localization of light can occur, two different kinds of modes can be observed. Either modes that extend over large areas of the sample or strongly localized ones. We use samples of reduced size to reduce the strong fluctuations usually found for random lasers in order to be able to examine the behavior of single lasing modes. They behave different under influences like sample size or excitation density.

HL 86.4 Thu 15:45 EW 015

MBE-grown InAs/InP-based quantum dot lasers with high modal gain at 1.55 μ emission wavelength — •Christian Gilfert[1], Vitalii Ivanov[1], Johann Peter Reithmaier[1], David Gready[2], and Gadi Eisenstein[2] — [1]Technische Physik, Institute of Nanostructure Technologies and Analytics, Universität Kassel, 34132 Kassel, Germany — [2]Technion - Israel Institute of Technology, Haifa 32000, Israel

Self-organized InAs/InP(100) quantum dot systems are promising candidates for future telecommunication applications at 1.55 μm. Several groups have reported on a variety of nano species ranging from quan-

tum wires over elongated quantum dashes to quantum dots in this material system. Quantum dots are, however, the preferred choice due to their 0-dimensional confinement. A recently developed growth method allows engineering the shape of the growing species by molecular beam epitaxy. Quantum dot like ensembles exhibiting much smaller photoluminescence line widths than comparable dash structures are achieved. Diode lasers, in which stacks of such structures are used as active region, emit around 1550 nm with good internal characteristics. In particular, a high modal gain of 10 cm^{-1} per active layer. Consequently, ridge waveguide lasers with 4 active layers could be operated down to cavity lengths as short as 340 μm at room temperature. The threshold current was measured to 35 mA and a cw output power of 16 mW was obtained. Such short cavities are a prerequisite for directly modulated high-speed lasers.

HL 86.5 Thu 16:00 EW 015

Room temperature, continuous wave lasing in microcylinder and microring quantum dot laser diodes — Ferdinand Albert[1], Fabian Langer[1], Thomas Schlereth[1], Maciej Michal Pieczarka[1], Sven Höfling[1], Stephan Reitzenstein[1,2], and •Martin Kamp[1] — [1]Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Present address: Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany

Whispering gallery mode (WGM) optical resonators made of semiconductors have a wide range of applications, ranging from cavity quantum electrodynamics studies to integrated planar photonic circuits. Most of these resonators investigated so far were based on suspended microdisks supported by a pedestal with a smaller diameter. However, this geometry puts severe limitations to electrical current injection and heat removal from the resonator. Better geometries as far as these parameters are concerned are microcylinders or microrings.

We've achieved room temperature, continuous wave operation of laser diodes based these structures. The active region consists of six layers of InGaAs quantum dots (emission wavelength around 1.3μm) embedded in a quantum well. Current injection in the active part of the device is improved in ring resonators, leading to a reduction of the lasing thresholds to a few mA. This geometry also suppresses whispering gallery modes with a high radial order, thus simplifying the lasing spectra. Under these conditions, single-mode and two-color lasing can be obtained simply by adjusting the injected current.

Coffee Break (15 min)

HL 86.6 Thu 16:30 EW 015

Interband Cascade Lasers Operating in cw-Mode at Room Temperature — •Robert Weih, Adam Bauer, Alfred Forchel, Sven Höfling, and Martin Kamp — Technische Physik, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

Within the last years, interband cascade lasers (ICLs) have become the most promising devices to cover the mid-infrared wavelength range between 3 and 4 μm. They are able to deliver large optical output powers of several hundred milliwatts while consuming less power than quantum cascade lasers (QCLs). Like in traditional diode lasers, amplification of light in ICLs is based on interband transitions. However, the unique band alignments in the GaSb material system - in particular the broken gap of a InAs/GaSb junction - allow a recycling of carriers via a tunnel process. This enables cascaded active regions like in QCLs. The ICLs in this work were grown by molecular beam epitaxy and characterized via temperature dependent electro-optical measurements. In order to lower the threshold current density, design variations concerning the active region and the waveguide structure were made. Changing the composition and thickness of the GaInSb hole quantum well significantly increases the spatial overlap of the wavefunctions involved in the optical transition. This results in a higher recombination probability and hence decreases the threshold current. Furthermore, optical losses could be reduced by increasing the lower cladding thickness from 1.9 μm to 3.4 μm. Laser structures incorporating these optimizations were able to operate up to 20°C in cw mode. The latest structures showed threshold currents as low as $400 A/cm^2$.

HL 86.7 Thu 16:45 EW 015

Quantum dot microlasers with external feedback — •Ferdinand Albert[1], Caspar Hopfmann[1,2], Christian Schneider[1], Sven Höfling[1], Lukas Worschech[1], Martin Kamp[1], Wolfgang Kinzel[3], Alfred Forchel[1], Stephan Reitzenstein[1,2], and Ido Kanter[4] — [1]Technische Physik, Universität Würzburg, Germany — [2]Present address: Institute of Solid State Physics, Technische Universität Berlin, Germany — [3]Institute for Theoretical Physics, Universität Würzburg, Germany — [4]Department of Physics, Bar-Ilan University, Ramat-Gan, 52900 Israel

Advances in semiconductor nanotechnology have triggered considerable research and development of photonic devices on the nanoscale, which feature specific emission characteristics that are related to the quantum nature of the involved emitters. In this work we address the unexplored field of lasing in microcavities with self-feedback close to the quantum limit. A finite fraction of the emission of an electrically driven quantum dot micropillar laser is reflected back into the microcavity by an external mirror. This self-feedback results in a dramatic change in the photon statistics, where the second order photon autocorrelation function at times zero, $g^{(2)}(0)$, exhibits super-thermal values up to 3.51±0.06. This unique type of strong photon bunching fundamentally differs from $g^{(2)}(0) = 2$ and $g^{(2)}(0) = 1$ expected for thermal and coherent light, respectively. It occurs simultaneously with a revival of the bunching signal with a round trip time of the external cavity and is as such indicative of random intensity fluctuations associated with the spiked emission of light at the nW level.

HL 86.8 Thu 17:00 EW 015

Exceeding 100 mW UV laser emission around 330 nm via intracavity frequency doubling of a tunable red AlGaInP-VECSEL — •Hermann Kahle, Thomas Schwarzbäck, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Center SCoPE, Universität Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

The wide range of applications in biophotonics, television technologies, spectroscopy and lithography made the vertical external cavity surface-emitting laser (VECSEL) an important category of power scalable lasers. The possibility of bandgap engineering, inserting frequency selective and converting elements into the open laser cavity and laser emission in the fundamental Gaussian mode leads to ongoing growth of the area of applications for VECSELs. We present an intra cavity frequency doubled VECSEL with emission wavelength around 330 nm, a maximum tuning range of more than 7 nm and output powers exceeding 100 mW. Frequency doubling is realized with a beta barium borate crystal, while a birefringent filter, placed inside the laser cavity under Brewster's angle, is used for frequency tuning. The laser-chip is realized by a 55 $\lambda/4$ pairs $Al_{0.50}Ga_{0.50}As$/AlAs Bragg mirror on a GaAs substrate, followed by a n-λ cavity multi quantum well structure consisting of 20 compressively strained GaInP quantum wells in an $Al_xGa_{1-x}InP$ separate confinement heterostructure for an emission wavelength of around 660 nm. We show results of different arrangements of the quantum wells and investigate further innovative approaches for the active region.

HL 86.9 Thu 17:15 EW 015

Investigation of the 2-color emission from a vertical-external-cavity surface-emitting laser — •Matthias Wichmann[1], Alexej Chernikov[1], Mohammad Khaled Shakfa[1], Stephan W. Koch[1], Martin Koch[1], Maik Scheller[2], and Jerome V. Moloney[2] — [1]Department of Physics and Materials Sciences Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany — [2]College of Optical Sciences, University of Arizona, 1630 E University Boulevard, Tucson, AZ, 85721, USA

Vertical-external-cavity surface-emitting lasers (VECSELs) combine an excellent output beam quality and high power operation. Furthermore, the external cavity makes the VECSEL ideally suited for intra-cavity frequency conversion. Recently, a high power, room temperature continuous wave terahertz source was demonstrated based on difference frequency generation within a nonlinear crystal that was placed inside a VECSEL cavity. For this kind of application, a stable two color operation is mandatory. Here, we present systematic measurements on the time dynamics of the two-color emission from a VECSEL using a streak camera. With this, time- and frequency resolved "snapshots" of the VECSEL emission are acquired and analyzed with respect to correlation and relative stability. By varying the pump power, different operation regimes could be realized. The results show that the VECSEL can be operated in a broad stable regime with both colors emitting simultaneously. Near the lasing threshold and the thermal roll-over, a breakdown of stability is observed.

HL 86.10 Thu 17:30 EW 015

Green II-VI-based electron beam pumped vertical-cavity surface-emitting laser — •Thorsten Klein[1], Sebastian

Klembt[1], Vladimir I. Kozlovsky[2], Michael D. Tiberi[3], and Carsten Kruse[1] — [1]Institute of Solid State Physics, University of Bremen, Germany — [2]P.N. Lebedev Physical Institute, Moscow, Russia — [3]Principia Lightworks, Inc., Woodland Hills, USA

Laser light sources for projection applications have distinct advantages over the commonly used light sources. The color gamut of an RGB laser light based display is closer to the range of the human visual system, and the operating lifetime is significantly extended. Optical coupling is simple due to the small divergence angle of vertical-cavity surface-emitting laser (VCSEL). Color filters are not needed, leading to an improvement in power efficiency. Moreover, UV and IR emission is eliminated. An electron beam pumped VCSEL (eVCSEL) based on II-VI semiconductors has been developed for emission in the green spectral region. The structure was grown using molecular beam epitaxy on (001)-GaAs substrates misoriented 10° towards the (111)A crystal plane. The 10.5 fold bottom DBR consists of a MgS-ZnCdSe-superlattice as low index material and ZnSSe as high index material. The cavity contains 20 ZnCdSSe-QWs in ZnSSe barriers, the 4 fold dielectric top DBR consists of SiO_2/Ta_2O_5. Structural characterization was carried out by HRXRD, SEM and TEM. Luminescence properties were investigated by CL and PL. Room temperature lasing was achieved at 522 nm. The output power is about 2.5 - 3 W using 45 keV of acceleration voltage and 1.5 mA of current for the electron beam.

HL 87: Graphen: Spin Transport (jointly with MA, DS, DY, O, TT)

Time: Thursday 15:00–16:45 Location: H 1012

Topical Talk HL 87.1 Thu 15:00 H 1012

Spin transport in graphene — •Bernd Beschoten — II. Institute of Physics, RWTH Aachen University and JARA: Fundamentals of Future Information Technology, 52074 Aachen

Graphene is considered as promising candidate for spintronics applications. The reason is the weak spin-orbit coupling, the absent hyperfine interaction and the observation of micrometer long spin relaxation lengths [1]. So far most spin transport studies have focused on single layer graphene (SLG). However, bilayer graphene (BLG) has unique electronic properties, which differ greatly from those of SLG by its effective mass of carriers, interlayer hopping and electric-field induced band gap. Our studies of spin transport in BLG as a function of mobility μ, minimum conductivity, charge carrier density and temperature reveal the importance of the D'yakonov - Perel' (DP)-type spin scattering mechanism [2]. In BLG samples, the spin relaxation time τ_s scales inversely with μ both at room temperature and at low temperatures. τ_s times of up to 2 ns are observed in samples with the lowest mobility. We discuss the role of intrinsic and extrinsic factors that could lead to the dominance of the DP-type spin scattering mechanism in BLG. Remarkably, similar spin transport properties are also observed in large area graphene grown by the CVD method on copper foils demonstrating the potential of CVD graphene in spintronics devices [3].

Work supported by DFG/FOR 912.

[1] N. Tombros *et al.*, Nature 448, 571 (2007).
[2] T.-Y. Yang *et al.*, Phys. Rev. Lett. 107, 047206 (2011).
[3] A. Avsar *et al.*, Nano Letters 11, 2363 (2011).

Invited Talk HL 87.2 Thu 15:30 H 1012

Long spin relaxation times in epitaxial graphene on SiC(0001) — •Thomas Maassen[1], Jan Jasper van den Berg[1], Natasja IJbema[1], Felix Fromm[2], Thomas Seyller[2], Rositsa Yakimova[3], and Bart Jan van Wees[1] — [1]Zernike Institute for Advanced Materials, University of Groningen, The Netherlands — [2]Lehrstuhl für Technische Physik, Universität Erlangen-Nürnberg, Germany — [3]Department of Physics, Chemistry and Biology (IFM), Linköping University, Sweden

Spin transport in graphene draws great interest because of recent promising measurements at room temperature (RT). At the same time the limiting factor for spin relaxation seems to be the substrate. By replacing the commonly used SiO_2 substrate we aim to observe improved spin transport. We developed an easy process to prepare lateral spin-valve devices on epitaxial grown monolayer graphene on SiC(0001), that enables us to upscale the production to wafer size. We examine the spin transport properties of this material by performing nonlocal spin-valve and Hanle spin precession measurements. We observe the longest spin relaxation time τ_S in single layer graphene at RT (1.5 ns) and $T = 4.2$ K (2.3 ns), while the spin diffusion coefficient is strongly reduced by nearly 2 orders of magnitude. The increase in τ_S is probably related to the changed substrate, while the small value for D_S is until now unexplained. Nevertheless, the high values for τ_S, combined with the easy production method on a large scale, clear the way for graphene based spintronic devices and applications in the future.

HL 87.3 Thu 16:00 H 1012

Manipulation of spin transport properties in graphene — •Frank Volmer[1,2], Tsung-Yeh Yang[1,2], Eva Maynicke[1,2], Marc Drögeler[1,2], Sebastian Bläser[1,2], Gernot Güntherodt[1,2], and Bernd Beschoten[1,2] — [1]II. Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany — [2]JARA: Fundamentals of Future Information Technology, 52074 Aachen, Germany

It has been shown that the dominant spin relaxation mechanism in bilayer graphene is of the D'yakonov-Perel' type [1]. In this case the spin dephasing time increases with decreasing momentum scattering time or, respectively, with decreasing charge carrier mobility.

Therefore, it is desirable to control and to manipulate the mobility of a single device in order to get a further insight into the dephasing mechanisms. As the charge transport through the two-dimensional graphene is known to be strongly affected by adatoms, it is furthermore interesting to explore their influence on the spin transport. Hence we use current annealing, chemical solvents and electron beam induced deposition to add or to remove impurities on the graphene surface and study their influence on the spin transport properties.

First results indicate that even in single-layer graphene devices (nonlocal spin valves with Co/MgO injectors) a D'yakonov-Perel'-type dephasing mechanism is dominating.

This work has been supported by DFG through FOR 912.

[1] T.-Y. Yang *et al.*, Phys. Rev. Lett. 107, 047206 (2011)

HL 87.4 Thu 16:15 H 1012

Anisotropic super-spin at the end of a carbon nanotube — •Manuel J. Schmidt — RWTH-Aachen, Deutschland

The interplay of edge magnetism and spin-orbit interactions is studied theoretically on the basis of zigzag ends of carbon nanotubes. Spin-orbit coupling, generally weak in ordinary graphene, is strongly enhanced in nanotubes and thus cannot be neglected at low energies. In the present case it leads to a magnetic anisotropy on the order of 10 mK. Also the relation to correlated topological edge states is shortly discussed.

Carbon nanotubes with zigzag ends have localized electronic states at those ends. These localized states correspond to the edge states in graphene and are equally susceptible to Coulomb interactions. The latter drive a transition, known as edge magnetism in graphene. However, due to the very limited spatial size of this magnetic state, it should not be considered as a symmetry broken state but rather as a super-spin, composed of a few individual electron spins. Without spin-orbit interaction, the ground state of this super-spin would be 2S+1 fold degenerate. Finite spin-orbit coupling, however, breaks this degeneracy in such a way that the true ground state is unique and time-reversal invariant. Furthermore, it turns out that the magnitude of this effect may be tuned by a partial suppression of the magnetism (tunable edge magnetism).

15 min. break

HL 88: Quantum Dots and Wires: Transport Properties IV (mainly Double Dots and Point Contacts)

Time: Thursday 16:30–18:15 Location: EW 202

HL 88.1 Thu 16:30 EW 202

A hybrid double-dot in silicon — •Miguel Fernando Gonzalez Zalba, Dominik Heiss, and Andrew Ferguson — Microelectronics Research Centre, Cavendish Laboratory, Cambridge, CB3 0HE, UK

We report electrical measurements of a single arsenic dopant atom in the tunnel-barrier of a silicon Single Electron Transistor (SET). As well as performing electrical characterization of the individual dopant, we study series electrical transport through the dopant and SET. We measure the triple points of this hybrid double dot system, using simulations to support our results, and show that we can tune the electrostatic coupling between the two sub-systems.

HL 88.2 Thu 16:45 EW 202

Spin Based Quantum Computation with Quantum Dots Including Micro-Magnet Technique — •Roland Brunner[1,2], Yun Suk Shin[2], Toshiaki Obata[3], Michel Pioro-Ladriere[4], Toshihiro Kubo[5], Koji Yoshida[3], Tomoyasu Taniyama[6], Yasuhiro Tokura[5], and Seigo Tarucha[3] — [1]Institute of Physics, Montanuniversitaet Leoben, 8700, Austria — [2]Quantum Spin Information Project, ICORP, Japan Science and Technology Agency, Atsugi-shi, Kanagawa, 243-0198, Japan — [3]Department of Applied Physics, University of Tokyo, Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan — [4]Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, J1K-2R1, Canada — [5]NTT Basic Research Laboratories, NTT Corporation, Atsugi-shi, Kanagawa, 243-0198, Japan — [6]Materials and Structures Laboratory, Tokyo Institute of Technology, 4259 Nagatsuta, Yokohama, 226-8503, Japan

Here, we present in a semiconductor double quantum dot, the realization of a two-qubit quantum gate. The approach is based on the combination of spin exchange control and on single spin rotations [1]. The all-electrical two-qubit quantum gate [1] is accomplished in an GaAs/AlGaAs double quantum dot with a novel split micro-magnet. The micro-magnet is used to generate an inhomogeneous magnetic field necessary for the manipulation of the single electron spin [2,3,4]. References: [1] Brunner et al. Phys. Rev. Lett. 107 146801 (2011). [2] Pioro-Ladrière, M. et al. Nature Physics 4, 776 (2008). [3] Obata, T. et al. Phys. Rev. B 81, 085317 (2010). [4] Y. Tokura et al. Phys. Rev. Lett. 96, 047202 (2006).

HL 88.3 Thu 17:00 EW 202

Magnetotransport in single and double quantum dots in the Kondo regime — •Alexander W. Heine, Daniel Tutuc, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hannover, Germany

We analyse the magnetotransport of quantum dots (QD) in the Kondo regime. The sample consists of two lateral QDs produced by local anodic oxidation on a GaAs/AlGaAs heterostructure, containing a two-dimensional electron system (2DES) 37 nm below the surface. Transport measurements on each single QD, and both QDs in parallel respectively, are performed in a ^{3}He/^{4}He dilution refrigerator with a base temperature of 20 mK, using standard lock-in technique. The QDs are separately tuned by six sidegates into the Kondo regime. A magnetic field applied perpendicular to the 2DES gives rise to the so-called *Kondo chessboard*. We investigate the QDs' non-linear transport properties in fields up to 5 T, as well as the temperature dependence of the linear conductance.

HL 88.4 Thu 17:15 EW 202

Magnetic focusing of ballistic photocurrents in mesoscopic circuits — Markus Stallhofer[1], •Christoph Kastl[1], Christoph Karnetzky[1], Dieter Schuh[3], Werner Wegscheider[4], Gerhard Abstreiter[1], Jörg Kotthaus[2], and Alexander Holleitner[1] — [1]Walter Schottky Institut and Physik-Department, TU München — [2]Fakultät für Physik and Center for NanoScience (CeNS), LMU München — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg — [4]Laboratorium für Festkörperphysik, ETH Zürich, Switzerland

We exploit GaAs-based quantum point contacts (QPCs) as mesoscopic detectors for analyzing the flow of photogenerated electrons in a two-dimensional electron gas (2DEG) [1]. At moderate, perpendicularly applied magnetic fields, we resolve circular electron trajectories. We extract the cyclotron radius and the electron momentum of the photogenerated electrons at varying magnetic fields and irradiation intensities. The extracted values surprisingly exceed the ones derived from a single-particle cyclotron motion. With the help of Monte Carlo simulations, this deviation is related to the effects of electron-electron scattering on the propagation of the photo-excited electrons.
[1] K.-D. Hof et al., Nano Letters, 10, 3836 (2010).

HL 88.5 Thu 17:30 EW 202

Ballistic photocurrents at the presence of electron-electron scattering — Markus Stallhofer[1], •Christoph Karnetzky[1], Marcel Brändlein[1], Christoph Kastl[1], Dieter Schuh[3], Werner Wegscheider[4], Jörg Kotthaus[2], and Alexander Holleitner[1] — [1]Walter Schottky Institut and Physik-Department, TU München — [2]Fakultät für Physik and Center for NanoScience (CeNS), LMU München — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg — [4]Laboratorium für Festkörperphysik, ETH Zürich, Switzerland

We demonstrate that GaAs-based quantum point contacts (QPCs) can be employed to resolve the non-equilibrium dynamics of photogenerated charge carriers in a mesoscopic circuit [1]. To this end, electron-hole pairs are optically created in a two-dimensional electron gas (2DEG) and the resulting current through an adjacent QPC is measured as a function of the laser spot position. We particularly investigate the characteristic spatial decay length of the photocurrent as a function of the optical excitation power and the excitation energy. We identify two transport regimes, dominated either by the effects of electron-electron scattering or the formation of an optically induced Quasi-Fermi level.
[1] K.-D. Hof et al., Nano Letters, 10, 3836 (2010).

HL 88.6 Thu 17:45 EW 202

Metastable charge states in a few electron double quantum dot — •Daniel Biesinger[1], Martin Brühlmann[1], Christian Scheller[1], Dominik M. Zumbühl[1], Jeramy Zimmerman[2], and Art C. Gossard[2] — [1]Dep. of Physics, University of Basel, Switzerland — [2]Materials Dep., University of California, Santa Barbara, California, USA

We are presenting quantum transport experiments on a lateral GaAs double quantum dot in the few electron regime. Adjacent quantum dots are used as real-time charge sensors, allowing single-shot charge readout with ms rise time and sensitivities as large as $\delta g/g \sim 0.7$ per electron. The tunneling-rates of the double dot can easily be widely tuned. At low enough dot-lead tunneling rates detectable in real-time, a sharply defined diamond-shaped region centered between the (0,0) and the (1,1) triple points appears in the charge stability diagram, displaying metastable charge-state switching between (0,1) and (1,0) as a function of time. The diamond is repeatable and does not show hysteresis. The timescale of the switching-process depends strongly on the coupling to source and drain, while it appears independent of the inter-dot coupling. The bistability disappears at higher tunneling-rates, returning to the usual honeycomb structure, but is also seen for larger electron numbers, making it unlikely that it is caused by random impurities or charge traps in a device that otherwise displays excellent stability. Further, we can rule out co-tunneling, latching and charge-sensor back action effects. We are currently looking for a model, and are in particular considering Fermi edge singularity physics.

HL 88.7 Thu 18:00 EW 202

Large nuclear spin polarization in gate-defined quantum dots using a single-domain nanomagnet — •Gunnar Petersen[1], Eric A. Hoffmann[1], Dieter Schuh[2], Werner Wegscheider[2,3], and Stefan Ludwig[1] — [1]CeNS und Fakultät für Physik, Ludwig-Maximilians-Universität, München — [2]Institut für Angewandte und Experimentelle Physik, Universität Regensburg — [3]Solid State Physics Laboratory, ETH Zurich, Schweiz

Double quantum dots (QD) defined electrostatically in a two-dimensional electron system provide a versatile platform for investigating electron spin phenomena. In a GaAs based double QD system electrons are not completely isolated but weakly coupled to the host

nuclei by hyperfine interaction. Such a coupling of electrons to a nuclear bath is common to a variety of material systems and gives rise to future applications in quantum information processing. For example, nuclear spins are a possible candidate for quantum memory[1]. Here we present experimental data demonstrating the manipulation of nuclear spins of the host material by hyperfine coupling to the electronic system. Nuclear polarization on the order of 50 percent is reached with the aid of a nanomagnet in the vicinity of the double QD. A phenomenological model is used to describe the dynamic build-up and decay of nuclear polarization. It provides a detailed understanding of the dynamic polarization process driven by electron-nuclear interaction.

[1] Morton, J. J. L. et al. Solid-state quantum memory using the (31)p nuclear spin. *Nature* **455**, 1085-1088 (2008).

HL 89: Focus Session: Quantum Information Systems (jointly with MA,TT)

Time: Thursday 16:45–18:15 Location: ER 164

HL 89.1 Thu 16:45 ER 164

Non-local coupling between spin qubits via a transmission line shuttle — •Peiqing Jin[1], Michael Marthaler[1], Alexander Shnirman[2,3], and Gerd Schön[1,3] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [2]Institut für Theorie der Kondensierten Materie, Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany — [3]DFG Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, 76128 Karlsruhe, Germany

Quantum dots with long lived spin states are promising systems for qubit realizations [1]. Coherent single qubit manipulations have been demonstrated in such systems. However, generating a non-local qubit-qubit interaction, which is crucial for the scalability of quantum computation, is still challenging. Stimulated by recent progresses in circuit quantum electrodynamics setups [2], we propose a mechanism of coupling distant spin qubits formed in double quantum dots via a superconducting transmission line resonator. A strong qubit-resonator interaction arises based on the exchange splitting between the singlet and triplet states. The mechanism allows the system to be operated at the charge degeneracy point where the dephasing is minimized. Remarkably, due to a finite longitudinal qubit-resonator coupling, a strong blue-sideband transition is accessible as a first order process, which favors a fast generation of an entangled qubit pair.

HL 89.2 Thu 17:00 ER 164

Towards quantum information devices based on NV center in low temperature — •Sen Yang[1], Petr Siyushev[1], Seyed Ali Momenzadeh[1], Nan Zhao[1], Naofumi Abe[2], Hideo Kosaka[2], Helmut Fedder[1], and Jörg Wrachtrup[1] — [1]3rd Physics Institute and Research Center SCoPE, Universität Stuttgart, Stuttgart, Germany — [2]Research Institute of Electrical Communication, Tohoku University, Sendai, Japan

The Nitrogen-Vacancy (NV) center in diamond is a promising system for quantum communication/computation. Long coherence time and ultra-clean system make diamond an ideal candidate even in ambient condition. Low temperature gives us ability to address excited states individually [1]. Optically resonant excitation of spin-selective transitions and single shot readout of electron spin become possible [2,3]. This opens up the opportunities of making quantum devices based on the fine structure of excited states and photon NV interaction. One example is quantum repeater. Long coherence time makes spin a good choice as memory. $M_s = \pm 1$ ground states and A1/A2 excited state form Λ system which make writing, reading and flying qubit generation possible. Here, we presents recent results on coherent spin manipulation of NV center in low temperature and results towards quantum devices like quantum repeater.[1] A. Batalov, et al, PRL 102, 195506(2009).[2] L. Robledo, et al, Nature 477, 574(2011).[3] E. Togan, et al, Nature 478, 497(2011).

HL 89.3 Thu 17:15 ER 164

A quantum memory intrinsic to single nitrogen-vacancy centres in diamond — Gregory D. Fuchs[1], •Guido Burkard[2], Paul V. Klimov[1], and David D. Awschalom[1] — [1]Center for Spintronics and Quantum Computation, University of California, Santa Barbara, California 93106, USA — [2]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

A quantum memory, composed of a long-lived qubit coupled to each processing qubit, is important to building a scalable platform for quantum information science. These two qubits should be connected by a fast and high-fidelity operation to store and retrieve coherent quantum states. Here, we demonstrate a room-temperature quantum memory based on the spin of the nitrogen nucleus intrinsic to each nitrogen-vacancy (NV) centre in diamond [1]. We perform coherent storage of a single NV centre electronic spin in a single nitrogen nuclear spin using Landau-Zener transitions across a hyperfine-mediated avoided level crossing. By working outside the asymptotic regime, we demonstrate coherent state transfer in as little as 120 ns with total storage fidelity of 88±6%. This work demonstrates the use of a quantum memory that is compatible with scaling as the nitrogen nucleus is deterministically present in each NV centre defect.

[1] G. D. Fuchs, G. Burkard, P. V. Klimov, and D.D. Awschalom, Nature Physics 7, 789 (2011).

HL 89.4 Thu 17:30 ER 164

Spin decoherence in graphene quantum dots due to hyperfine interaction — •Moritz Fuchs, Valentin Rychkov, and Björn Trauzettel — Institut für Theoretische Physik und Astrophysik, University of Würzburg, 97074 Würzburg, Germany

Carbon based systems are prominent candidates for a solid-state spin-qubit due to weak spin-orbit and hyperfine interactions in combination with a low natural abundance of spin carrying isotopes. We consider the effect of the hyperfine interaction on the coherence of an electron-spin localized at gate-defined graphene quantum dots. It is known, that the hyperfine interaction in these systems is anisotropic promising interesting physics. We calculate the dynamics of an electron spin surrounded by a bath of nuclear spins in a non-Markovian approach, where we find, that the electron spin state is conserved up to small corrections. These corrections, however, show an intriguing interplay of power-law and exponential decaying behavior depending on the orientation of an external magnetic field.

HL 89.5 Thu 17:45 ER 164

Noise spectroscopy using single-shot qubit readout — •Thomas Fink and Hendrik Bluhm — 2nd Institute of Physics C, RWTH Aachen University, 52074 Aachen, Germany

Understanding the noise limiting the dephasing time of qubits and mitigating its effects is crucial for improving qubit performance. For this purpose, dynamical decoupling schemes such as the spin echo and more sophisticated pulse sequences have been developed, which can also be used for noise spectroscopy. We propose an alternative method to investigate the magnitude of the bath fluctuations in the frequency domain using the correlations of single-shot measurements. It consists of correlating the single shot measurement outcomes of subsequent free induction decay pulses. Because our approach is applicable to a broad range of frequencies by simply varying the delay between pulses, it can give insight into spectral ranges where the sensitivity of pulse sequence-based spectroscopy is limited.

We compute the outcome of our procedure applied to GaAs-based electron spin-qubits, for which the coupling of the electron spins to $\sim 10^6$ nuclear spins of the host material has been identified as the dominant source of dephasing. We discuss how this procedure can be used to directly probe the suspected high frequency cutoff in the nuclear spin diffusion spectrum.

Comparing this procedure with spin-echo measurements may also reveal if the bath needs to be treated quantum-mechanically or can be considered as classical.

HL 89.6 Thu 18:00 ER 164

Entangled photons from the polariton vacuum in a switchable optical cavity — •Adrian Auer and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

We study theoretically the entanglement of two-photon states in the ground state of the intersubband cavity system, the so-called polariton vacuum. The system is formed by a sequence of doped quantum wells (QWs) located inside a microcavity and the photons can inter-

act with intersubband excitations inside the QWs, which leads to the formation of polariton states. In the ultrastrong coupling regime, the polariton vacuum already contains a finite number of photons. In an explicit solution for the polariton vacuum, we only consider certain two-photon states by post-selection and analyze them for mode entanglement. We find an analytical expression for the entanglement using the concurrence and it depends on the absolute values of the in-plane wave vectors of the photons. For photon energies around the intersubband resonance in the mid infrared regime, the photons are almost maximally entangled, what is fundamentally important for their possible use in quantum information processing. Furthermore, there exists a continuous set of mode pairs, for which the photons are maximally entangled.

HL 90: Graphene: Transport incl. Spin Physics and Magnetic Fields II

Time: Thursday 17:00–18:30 Location: ER 270

HL 90.1 Thu 17:00 ER 270

Launching surface plasmons on a metal/dielectric interface by emission from graphene — •Matthias Handloser[1], Sebastian Böcklein[1], Jürgen Kraus[2], Sebastian Günther[2], and Achim Hartschuh[1] — [1]Department Chemie und CeNS, LMU, München, Germany — [2]Department Chemie, TUM, München, Germany

Graphene could eventually play an important role in photonics and optoelectronics due to its particular physical properties. We report on the excitation of propagating surface plasmons in thin metal films launched by photoexcited graphene. Graphene was deposited on a thin dielectric spacer layer on top of a thin metal film. Broadband non- linear photoluminescence (PL) of graphene [1,2] created by femtosecond pulsed excitation at 800 nm launches surface plasmons that are detected via leakage radiation microscopy [3]. Coupling to plasmons almost completely reshapes the emission both spatially and with respect to polarization as compared to graphene on a dielectric substrate. The angular dependence of plasmon coupled emission is used to map the dispersion relation of surface plasmons from 450-1000 nm. We further investigate the role of local defects and graphene edges on the emission characteristics. [1] R.J. Stöhr, et. al., Phys. Rev. B 82, 121408(R) (2010) [2] W-T Liu, et. al., Phys. Rev. B 82, 081408(R) (2010) [3] B. Hecht, et.al., Phys. Rev. Lett. 77,1889 (1996)

HL 90.2 Thu 17:15 ER 270

Does contact induced doping limit the measurable spin dephasing time in graphene non-local spin valves? — •Marc Drögeler[1,2], Frieder Reichenzer[1,2], Stefan Göbbels[1,2], Frank Volmer[1,2], Eva Maynicke[1,2], Gernot Güntherodt[1,2], and Bernd Beschoten[1,2] — [1]II. Institute of Physics, RWTH Aachen University, 52074 Aachen — [2]JARA: Fundamentals of Future Information Technology, 52074 Aachen

With respect to spintronics, graphene has the advantage to consist of light atoms and, thus, exhibits negligible spin-orbit coupling and hyperfine interaction in isotopically pure material. This leads to long spin dephasing times with values predicted in the range of μs. The first spin transport measurements, however, revealed spin dephasing times in the range of a few hundred ps. In the meantime, values of 6.2 ns at 20 K [1] and 1.9 ns at room temperature [2] have been reported, which are still far below predicted values. A possible source of spin dephasing may arise from contact-induced carrier doping and consequential local electric fields in the graphene sheet. Here we use photo-current measurements to determine the contact induced doping in graphene-based non-local spin valves, which may be correlated to spin dephasing times as extracted from conventional Hanle spin precession measurements. Furthermore, we investigate the dependence of the photo-current on the polarization angle and helicity of the light.

This work has been supported by DFG through FOR 912.

[1] Han *et al.* Phys. Rev. Lett. 107, 047207 (2011).
[2] Yang *et al.* Phys. Rev. Lett. 107, 047206 (2011).

HL 90.3 Thu 17:30 ER 270

Graphene Field-Effect Transistors on Hexagonal Boron Nitride Operating at Microwave Frequencies — •Christian Benz[1,4], Emiliano Pallecchi[2], Andreas C. Betz[2], Kenji Watanabe[3], Takashi Taniguchi[3], Hilbert v. Löhneysen[1,4], Bernard Plaçais[2], and Romain Danneau[1,4] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Germany — [2]Laboratoire Pierre Aigrain, Ecole Normale Supérieure, Paris, France — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan — [4]Physikalisches Institut, KIT, Germany

Due to the high charge carrier mobility in graphene, it is an ideal candidate for devices operating at microwave frequency. We have investigated RF graphene field-effect transistors (GFETs) on hexagonal boron nitride. Atomically flat boron nitride crystals are known to increase the mobility by reducing scattering in the graphene. At the same time, the boron nitride serves the purpose of dielectric between graphene sheet and prepatterned gate electrode. Thus, a minimum of charge impurities is introduced to the graphene and current annealing remains possible since the graphene channel is not covered by an oxide. Our GFETs were prepared from exfoliated mono- and bi-layer graphene with a subsequent dry transfer technique onto sapphire, a fully insulating substrate. To improve the flatness, we employed an all-graphene layout with graphene gate fingers. Several devices with gate lengths down to 100 nm were produced and measured. Our GFETs allow for integration into circuits like amplifiers or mixers and are well suited for cryogenic applications.

HL 90.4 Thu 17:45 ER 270

Influence of indium contacts on electronic transport in graphene — •Felix Nippert, Harald Scheel, Janina Maultzsch, and Christian Thomsen — Insititut für Festkörperphysik, Technische Universität Berlin

We study the influence of micro-soldered indium contacts on electronic transport in graphene. In four point transport measurements using a variable back gate voltage V_G we observe a strong electron-hole-asymmetry that is associated with a Fermi energy shift in the vicinity of the contacts. This is due to n-type doping caused by differing work functions of graphene and indium. We propose a simple analytical model based on different mobilities for electrons and holes and a standard distribution of the Fermi level position to explain this asymmetry and the observed minimum conductivity.

We notice an additional resistance on the hole side, which we associate with a graphene pn-junction that arises when the bulk graphene is p-type while the region influenced by the contacts is still n-type. We compare our results with similar measurements in the literature involving other contact metals and show that they support our model.

HL 90.5 Thu 18:00 ER 270

Length dependence of the resistance in graphite: influence of ballistic transport — •Pablo Esquinazi[1], Jose Barzola-Quiquia[1], Srujana Dusari[1], and Nicolas Garcia[2] — [1]Division of Superconductivity and Magnetism, Institut für Experimentelle Physik II, Universität Leipzig, Linnéstraße 5, D-04103 Leipzig, Germany — [2]Laboratorio de Física de Sistemas Pequeños y Nanotecnología, Consejo Superior de Investigaciones Científicas, E-28006 Madrid, Spain

Using a linear array of voltage electrodes with a separation of several micrometers on a 20 nm thick and 30 μm long multigraphene sample we show that the measured resistance does not follow the usual length dependence according to Ohm's law. The deviations can be quantitatively explained taking into account Sharvin-Knudsen formula for ballistic transport. This allows us to obtain without free parameters the mean free path of the carriers in the sample at different temperatures. In agreement with recently reported values obtained with a different experimental method, we obtain that the carrier mean free path is of the order of ~ 2 μm with a mobility $\mu \sim 10^7$ cm^{2}V^{-1}s^{-1}. The results indicate that the usual Ohm's law is not adequate to calculate the absolute resistivity of mesoscopic graphite samples.

HL 90.6 Thu 18:15 ER 270

solution-based fabrication of thin film transistors with single-walled carbon nanotube — •alireza mousavi[1,2], veit wagner[1], vincenzo tucci[2], patrizia lamberti[2], and jürgen fritz[1] — [1]jacobs university bremen — [2]university of salerno

Thin film of single-walled Carbon nanotubes (SWCNTs) offers great promise for a variety of application due to exceptional electrical and

mechanical properties. The ability to tune SWCNTs topology is crucial for fabrication of SWCNT-thin film transistors (TFTs). Thin films of SWCNTs network represent a promising track to scalable device manufacturing and to fabricate devices at low temperatures. Insolubility of the CNTs in most solvents and mixture of semiconducting and metallic CNTs are major challenges towards real application. To improve solubility while preserving the properties of SWCNTs are needed for low-cost and industry feasible approaches. In this paper, two methods, vacuum filtration and dielectrophoresis, based on different solvents are compared. As solvents, aqueous solution of sodium dodecylbenzene sulfonate, SDBS, as surfactant and N-Methyl-2-pyrrolidone, NMP, are used to disperse CNTs noncovalently by help of sonication. The devices preparation, Au electrodes with various channel lengths are patterned on silicon wafers. Subsequently, the surface is treated with Amine terminated self-assembled monolayers to selectively adsorb carbon nanotube. All approaches showed promising results, e.g. mobility of 0.3 cm2/Vs was found for vacuum filtration and CNTs dissolved in SDBS. Moreover, it will be shown how quantitatively the metallic part of SWCNT is contributed to the output performance of device.

HL 91: Poster Session: Spintronics / Magnetic Semiconductors / Transport

Time: Thursday 16:00–19:00 Location: Poster D

HL 91.1 Thu 16:00 Poster D

Microwave influence on the electroluminescence of single InGaAs quantum dots — •Benjamin Wolter, Andreas Merz, Robert Schittny, Robin Schwerdt, Gunter Wüst, Pablo Asshoff, Michael Hetterich, and Heinz Kalt — Karlsruhe Institute of Technology (KIT) and DFG Center for Funtional Nanostructures (CFN), 76131 Karlsruhe, Germany

We investigate the effects of high-frequency microwave radiation (53 GHz) in different intensity regimes on the emission of single quantum dots in spin-injection light emitting diodes (spin-LEDs). A specially prepared spin-LED is placed in a microwave cavity and is exposed to the microwave radiation with different powers and frequencies. At low microwave powers an enhancement of the electro-luminescence emission was detected whereas at higher power the emission quenches due to thermal heating. Furthermore the influence at high static magnetic fields is investigated to proceed towards spin manipulation of single electron spins in InGaAs quantum dots.

HL 91.2 Thu 16:00 Poster D

Time-resolved spectroscopy of a three-terminal semiconductor structure for electrical spin-storage and read-out — •Helge Wurst, Andreas Merz, Johannes Zeller, Robert Schittny, Benjamin Wolter, Christoph Krämmer, Heinz Kalt, and Michael Hetterich — Karlsruhe Institute of Technology (KIT) and DFG Center for Funtional Nanostructures (CFN), 76131 Karlsruhe, Germany

In recent years, spin light-emitting diodes have become well-established devices in the spintronics community. In this contribution, we present time-resolved measurements performed at a transistor-like structure aiming at spin-injection, prolonged spin storage and spin-readout with all of these processes controlled individually and all-electrically. This structure consists of a diluted magneti semiconductor as spin-injector and quantum dots which are selectively loaded with electrons and holes, respectively.

HL 91.3 Thu 16:00 Poster D

Temperature dependence of the spin relaxation length in spin quantum dot LEDs — •Carola Fritsche[1], Henning Höpfner[1], Arne Ludwig[2], Astrid Ebbing[2], Frank Stromberg[3], Heiko Wende[3], Werner Keune[3], Dirk Reuter[2], Andreas D. Wieck[2], Nils C. Gerhardt[1], and Martin R. Hofmann[1] — [1]Photonics and Terahertz Technology, Ruhr-University Bochum, Germany — [2]Applied Solid State Physics, Ruhr-University Bochum, Germany — [3]Faculty of Physics and Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, Germany

Over the last two decades remarkable progress has been seen in the field of spintronics and spin-optoelectronics in particular. Spin injection into spin light-emitting diodes (LEDs) using ferromagnetic contacts has greatly improved, resulting in higher polarization of the emitted light.

Here we present an investigation of the spin relaxation length in actual spin-LED devices. Our devices consist of self-assembled InAs quantum dots in the active region and a Fe/Tb multilayer spin injector with a MgO tunnel barrier for improved injection efficiency. Operation of our devices in magnetic remanence enables measurements without the influence of external magnetic fields (Appl. Phys. Lett. 99 (5), 051102 (2011)).

Although our devices implement spin injection both in magnetic remanence and at room temperature, we performed a systematic study of the spin relaxation length as a function of device temperature. Additionally, we study the homogeneity of our samples and influences of diode current on spin polarization.

HL 91.4 Thu 16:00 Poster D

Higher order correlation spectroscopy: Theoretical foundation and application — •Sebastian Starosielec, Jörg Rudolph, and Daniel Hägele — AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, Germany

Fluctuation spectroscopy and spin noise spectroscopy in specific have opened a growing research field [1,2]. Recently, we implemented higher order correlation spectroscopy up to radio frequencies, significantly extending the usual determination of the (only second order) noise power spectrum [3]. There are recent proposals for identifying physical properties from higher order spectra [4]. As opposed to usual power spectra, the implication of finite frequency resolution (temporal windowing) and finite measurement time to higher order spectra are no longer trivial. Here, we present first steps towards a mathematical framework for practical higher order noise spectroscopy and show a few examples of its application.

[1] M. Oestreich *et al.*, Phys. Rev. Lett. **95**, 216603 (2005)
[2] S. Starosielec *et al.*, Appl. Phys. Lett. **93**, 051116 (2008)
[3] S. Starosielec *et al.*, Rev. Sci. Instr. **81**, 125101 (2010)
[4] R.B. Liu *et al.*, New J. Phys. **12**, 013018 (2010)

HL 91.5 Thu 16:00 Poster D

Electron spin dynamics in wurtzite GaN — Jan Heye Buss, Jörg Rudolph, Arne Schaefer, •Jago Döntgen, and Daniel Hägele — AG Spektroskopie der kondensierten Materie, Ruhr-Universität Bochum, Germany

The semiconductor GaN is well established in modern optoelectronics and is considered a candidate for semiconductor spinelectronics due to its small spin-orbit splitting. However, electron spin lifetimes were found to hardly exceed 50 ps at room temperature [1, 2] whereas GaAs with its larger spin-orbit splitting shows RT lifetimes of about 200 ps. The symmetry of wurtzite GaN is found to cause a k-linear dependence of the effective magnetic field (effective Rashba field) in the conduction band whereas cubic semiconductors show a k^3-dependence. As a direct consequence of the linear Rashba field we observe by time-resolved Kerr-rotation spectroscopy an anisotropic spin relaxation tensor [3], and a weaker dependence of spinlifetimes on temperature [2] and doping density [4] as compared to e.g. cubic GaAs. All results are quantitatively explained without any fitting parameter by a newly derived analytic expression for Dyakonov-Perel spin relaxation in wurtzite semiconductors [3,4].

[1] B. Beschoten *et al.*, Phys. Rev. B **63**, 121202 (2001)
[2] J. H. Buß *et al.*, Phys. Rev. B **81**, 155216 (2010)
[3] J. H. Buß *et al.*, Appl. Phys. Lett. **95**, 192107 (2009)
[4] J. H. Buß *et al.*, Phys. Rev. B **84**, 153202 (2011)

HL 91.6 Thu 16:00 Poster D

Evidence for an efficient dynamical nuclear polarization process in a high-mobility (110)-grown two-dimensional electron system — •M. Griesbeck[1], B. Erbe[1], M. Glazov[2], E. Sherman[3], T. Korn[1], D. Schuh[1], W. Wegscheider[4], J. Schliemann[1], and C. Schüller[1] — [1]Department of Physics, Regensburg University, Germany — [2]Ioffe Physical-Technical Institute, St. Petersburg, Russia — [3]Department of Physical Chemistry, The University of the Basque Country, Bilbao, Spain — [4]Solid State Physics Laboratory,

ETH Zürich, Switzerland

As a consequence of the limited electron spin lifetime, the intensively studied concept of dynamical nuclear polarization (DNP) using two-dimensional electron gases still lacks an experimental implementation [1]. Recently, the spin dephasing time along the growth direction in (110)-grown zinkblende-based heterostructures, especially in symmetrically grown and doped two-dimensional electron systems, has been demonstrated to reach extremely high values [2]. By means of the all-optical resonant spin amplification technique [3], we study the anisotropic spin dynamics. Our sample consists of a 30 nm wide double-sided δ-doped single quantum well with a very high mobility of about 3 million cm^2/Vs. At low temperatures, we find evidence for a very efficient DNP process. We clearly map the expected strong dependence of the DNP on the initial spin polarization of the electron system.

[1] I. Ţifrea and M. Flatté, Phys. Rev. B 84, 155319 (2011)
[2] M. Griesbeck et al., preprint: http://arxiv.org/abs/1111.5438
[3] J. M. Kikkawa et al., Phys. Rev. Lett. 80, 4313 (1998)

HL 91.7 Thu 16:00 Poster D

Spin dynamics and anomalous spin diffusion in high-mobility (110) GaAs-based quantum wells — •R. Völkl[1], T. Korn[1], S.A. Tarasenko[2], M. Griesbeck[1], M. Schwemmer[1], D. Schuh[1], W. Wegscheider[3], and C. Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]A. F. Ioffe Physical-Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia — [3]ETH Zurich, Switzerland

Here, we present a study of electron spin dynamics in symmetrical, high mobility (110)-grown, GaAs-based quantum wells, focusing on spin lifetimes and the motion of spin-polarized electrons in the sample, as well as creating spin polarization due to a nonzero electron drift velocity. The Hanle-MOKE method is used to determine the spin lifetime and for mapping the motion of spin-polarized electrons. Spin lifetimes up to 54 ns are found for weak optical pumping, for stronger pumping the lifetime decreases rapidly. High excitation intensity entails an ascent of the hole-density, which leads to a faster decay of electron spin via the Bir-Aronov-Pikus mechanism, as well as to more recombination. Spin diffusion is studied by moving the pump beam using a motorized mirror. A maximum of the net spin polarization is observed a few microns away from the pump spot, due to a reduced influence of photo generated holes. An applied electric field yields a nonzero electron drift velocity. Due to the spatial dependence of the Dresselhaus field, an out-of-plane spin polarization is observed while an electric current runs along [1-10] direction. Financial support by the DFG via SFB 689 and SPP 1285 is gratefully acknowledged

HL 91.8 Thu 16:00 Poster D

Effects of low temperature annealing on the magnetic properties of (Ga,Mn)As/GaAs core-shell nanowires — •Alexander Eckrot[1], Christian Butschkow[1], Elisabeth Reiger[1], Andreas Rudolph[1], Dieter Schuh[1], Werner Wegscheider[2], and Dieter Weiss[1] — [1]Universität Regensburg, Germany — [2]ETH Zürich, Switzerland

We investigate the effect of low temperature annealing on the magnetic properties of GaAs/(Ga,Mn)As core-shell nanowires. The nanowires are grown via the vapor-liquid-solid (VLS) mechanism with gold as catalyst and molecular beam epitaxy (MBE). Depending on the growth parameters we achieve either wurtzite or zinc-blende core-nanowires. When the (Ga,Mn)As shell is grown axially on the side facettes of the nanowires at low temperatures it adopts the crystal structure of the core. The nanowires are contacted electrically using E-beam lithography (EBL) in order to monitor the resistance during the annealing process. The Curie-Temperature (T_C) and the magnetic anisotropies are determined by magnetotransport measurements. For annealing temperatures between 160°C and 230°C and an annealing duration of up to 350 hours we observe a resistance decrease of up to 20%. The annealing procedure can affect significantly the magnetic hysteresis of a single nanowire.

HL 91.9 Thu 16:00 Poster D

Ground-state properties of Kondo-lattice from spin dynamics — •Alexander Baral and Hans Christian Schneider — Physics Department, University of Kaiserslautern, 67653 Kaiserslautern, Germany

We present theoretical results on the spin dynamics in a Kondo-Lattice using an equation-of-motion approach for one and two-particle correlation functions. We use a s(p)-d model, which describes the exchange interaction between localized magnetic moments and itinerant electrons, in a parameter range typical of the magnetic semiconductor GaMnAs[1]. We set up dynamical equations for the relevant distributions and (spin) correlation functions, and employ different approximations, i.e., truncations of the equation-of-motion hierarchy, up to the level of scattering between correlations and distributions. To keep the numerics tractable, we employ a virtual-crystal approximation and investigate the properties of this system in one dimension. We obtain information on the correlation function between itinerant and localized spins in the ground state by evolving the dynamical equations starting from an uncorrelated initial state. We find long-range spin correlations at low temperatures, with a Kondo-like maximum of the correlation length at finite temperatures. Further, for very low temperatures, Cooper-pair like correlations between different spins and momenta emerge.

[1] L. Cywinski and L. J. Sham, Phys. Rev. B 76, 045205 (2007)

HL 91.10 Thu 16:00 Poster D

Cobalt-vacancy complexes and ferromagnetism in $Zn_{1-x}Co_xO$ — •Paola Alippi[1], Gianluca Ciatto[2], Antonio Di Troilo[1], and Aldo Amore Bonapasta[1] — [1]CNR-ISM, Rome, Italy — [2]Synchrotron SOLEIL, Gif-sur-Yvette, France

The field of dilute magnetic semiconductors has gained increasing interest in the past decade both for the potential technological applications of spintronic devices and from a fundamental viewpoint due to the controversial mechanism that are at the basis of ferromagnetic ordering in these materials. Co- and Mn-doped ZnO are especially appealing materials, as they seem to exhibit ferromagnetism (FM) at room temperature (RT) and have low toxicity. Experimental and theoretical studies have attributed RT FM in these systems to a variety of origins including intrinsic defects, non-homogeneity of the dopant spatial distribution, formation of secondary phases. In particular, the role of oxygen vacancies V_O on the magnetic properties of $Zn_{1-x}Co_xO$ has been debated. We investigate the local structure of ferromagnetic $Zn_{1-x}Co_xO$ by coupling polarization- dependent x-ray absorption spectroscopy with Density Functional Theory calculations of selected defect structures. We give clear evidence of the presence of V_O located close to Co atoms in a specific complex configuration with the Co-V_O direction aligned along the wurtzite c axis. We also establish the upper concentration limit of metallic parasitic nanophases and their contribution to magnetism. Our results lead to the conclusion that oxygen vacancies play a major role in originating the high temperature ferromagnetism of $Zn_{1-x}Co_xO$.

HL 91.11 Thu 16:00 Poster D

Antiferromagnetic semiconductors of I-Mn-As type — •Stepan Svoboda[1], Vit Novak[1], Miroslav Cukr[1], Zbynek Soban[1], Helena Reichlova[1], Xavier Marti[1], Peter Wadley[1,2], Richard Campion[2], and Tomas Jungwirth[1,2] — [1]Institute of Physics AS CR, Prague, Czech Republic — [2]School of Physics and Astronomy, University of Nottingham, UK

Antiferromagnetic materials offer an alternative to ferromagnetic or multiferroic materials utilized so far in spintronic applications [1]. Compounds of the I-Mn-V family have been theoretically predicted to exhibit simultaneously semiconductance and room-temperature antiferromagnetism which makes them particularly appealing for spintronics. Although some of these compounds were chemically synthesized already thirty years ago, there has been virtually no experimental data on their electronic properties, mainly due to the limited quality of the material. Here we report on investigation of structural, electronic and magnetic properties of LiMnAs and CuMnAs. Both materials have been prepared in form of high-quality monocrystalline thin films by molecular beam epitaxy. Crystal structure of LiMnAs grown on InAs corresponds to that of the known cubic bulk material. Crystal structure of CuMnAs grown on GaAs substrate shows tetragonal symmetry with lattice parameters consistent with the strained bulk material.

[1] B.-G. Park et al., Nature Materials 10, 347-351 (2011)

HL 91.12 Thu 16:00 Poster D

Interference in single quantum Hall point contacts — •Martin Treffkorn, Timo Hyart, and Bernd Rosenow — Institut für Theoretische Physik, Universität Leipzig, Germany

Recent experiments on quantum Hall interferometers have shown evidence of resistance oscillations that originate from partitioning a wave packet at a quantum point contact (QPC), letting the two partial waves propagate along different one-dimensional channels, and inter-

fering them at a second QPC. A further miniaturization of devices is possible if one achieves interference within a single QPC. While this possibility is absent in a QPC modeled be a harmonic saddle point potential as suggested in [Phys. Rev. B, 1987, 36, 7969-7976], anharmonicities in the potential result in the appearance of backscattering paths in the open quantum system. These give rise to an interference area and explain the observed resistance oscillations [Phys. Rev. B, 1988, 38, 10162-10165]. In order to study resitance oscillations of a realistic QPC, we use a potential that is calculated self-consistently from the electrostatics of a semi-conductor heterostructure with top gates and numerically calculate the magnetoresistance of such a device.

HL 91.13 Thu 16:00 Poster D

Magneto Thermopower Measuremtents on Rolled-Up 2DEGs — •Gunnar Schneider, Matthias Schmidt, David Sonnenberg, Christian Heyn, and Wolfgang Hansen — Institut fuer Angewandte Physik, Universitaet Hamburg, 20355 Hamburg, Germany

We present magneto thermopower measurements on an evenly curved two-dimensional electron gas (2DEG). The 2DEG is confined in a rolled-up GaAs/AlGaAs high electron mobility heterostructure (HEMT). The HEMT is grown by molecular beam epitaxy and, after a suspension step, it rolls up by the relaxation of strain that is intentionally introduced in the HEMT during the growth. Under a magnetic field, the 2D electronic density of states condensates into the Landau levels (LL). The number of filled LLs depends on the strength of the magnetic field component perpendicular to the 2DEG plane. Thus in a rolled-up 2DEG, where the field component is sinusoidally modulated, the density of states changes along the perimeter of the roll. We rotate the rolled up structure in the magnetic field and show the dependence of the diagonal and the off-diagonal (Nernst-Ettinghausen) magneto thermopower on the rotation angle.

HL 91.14 Thu 16:00 Poster D

Spin-splitting and g-factor of confined hole states in differently strained Ge quantum dots — •Alexei B. Agafonov, Kai-Martin Haendel, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany

In this work we have investigated experimentally hole transport through vertical resonant tunneling structures of different lateral dimensions of the order of 1 micron using resonant magnetotunneling spectroscopy at low temperatures. The studied samples were prepared from the same double-barrier Si/Ge heterostructure containing Ge quantum dots sandwiched between two Si tunnel barriers.

For a smaller sample a considerable shift in the voltage position of current resonances arising in its current-voltage characteristic (IVC) at high bias in comparison with the position of the correspondent resonances in the IVC of a bigger one was found. This shift indicates a partial relaxation of the built-in strain in Ge layer of the smaller sample caused by the decrease of its lateral dimensions.

It was also found that the downscaling of the sample lateral size gives rise to a noticeable variation of g-factor of heavy hole states confined in quantum dots. The g-factor values were obtained from the splitting of the differential conductance peaks under the influence of the static homogeneous magnetic field. This splitting reflects the Zeeman spin-splitting of the above mentioned states and turned out to be field orientation dependent. The observed difference in g-factor is attributed to the partial strain relaxation in Ge layer of the samples as well.

HL 91.15 Thu 16:00 Poster D

Spin Injection from Ferromagnetic Contacts into InAs Nanowires — •Isabel Wehrmann[1,2], Sebastian Heedt[1,2], Torsten Rieger[1,2], Kamil Sladek[1,2], Daniel Bürgler[2,3], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2,4] — [1]Peter Grünberg Institut -9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]Peter Grünberg Institut -6, Forschungszentrum Jülich, 52425 Jülich, Germany — [4]II. Physikalisches Institut, RWTH Aachen, 52056 Aachen, Germany

InAs nanowires grown either by MBE (molecular beam epitaxy) or by MOVPE (metalorganic vapour phase epitaxy) are contacted by two ferromagnetic strips (Co) to inject a spin-polarized current into the semiconducting nanowire. Because of the "conductivity mismatch" (difference in carrier concentration of InAs NW and Co contacts), a tunnel barrier, e.g. a thin layer of MgO or Al_2O_3, is required. In order to obtain a well-defined axis of magnetization and to achieve a continuous ferromagnetic contact area, the structure has to be planarized by using HSQ (hydrogen silsesquioxane) resist before Co is deposited. To prepare a defined thickness of the tunnel barrier, the native oxide is removed by in situ sputtering before the oxide layer is deposited by MBE. The ferromagnet-insulator-semiconductor junctions are characterized electrically. To prove whether spin injection has occurred, spin-valve measurements are performed in a non-local measurement geometry as well as the measurement of the spin dephasing in a Hanle setup.

HL 91.16 Thu 16:00 Poster D

Transport measurements on individual selective-area grown MnAs nanoclusters — •Martin Fischer[1], Matthias T. Elm[2], Shinjiroh Hara[2], Christian Heiliger[1], and Peter J. Klar[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Deutschland — [2]Research Center for Integrated Quantum Electronics, Hokkaido University, Sapporo, Japan

Selective-area grown MnAs nanoclusters are promising components for applications in highly miniaturized future information storage devices. Due to the tuneability of parameters such as size, shape and arrangement of the clusters, their magneto-electronic behaviour can be widely tuned. As a starting point for the investigation of microscopic ordered cluster arrangements, we have studied the transport behaviour of single clusters of different shapes and sizes. For the contacting of the clusters, we used Au contacts structured by electron-beam lithography. The clusters were grown by selective-area MOVPE on GaAs (111)B substrates.

HL 91.17 Thu 16:00 Poster D

Hall effect in Cu-doped GaN films grown by molecular beam epitaxy — •Michael Maschek[1], Philipp R. Ganz[2], Christoph Sürgers[1], Hilbert v. Löhneysen[1,2], and Daniel M. Schaadt[2,3] — [1]Karlsruhe Institute of Technology, Physikalisches Institut, D-76049 Karlsruhe — [2]Karlsruhe Institute of Technology, Center for Functional Nanostructures, D-76049 Karlsruhe — [3]Institut für Energieforschung und Physikalische Technologien, TU Clausthal, D-38678 Clausthal-Zellerfeld

Group-III nitride semiconductors are attractive for spintronic device applications. A possible candidate for a nitride-based spin-aligner is Cu-doped GaN which exhibits ferromagnetic behavior at room-temperature, although Cu is an intrinsic non-magnetic material. However, the origin of the ferromagnetic behavior is not clear. Here we report on measurements of the Hall effect, resistivity, and magnetoresistance for temperatures T = 2 - 300 K and in magnetic fields up to 1 T performed on GaN:Cu films grown by plasma-assisted MBE. Films prepared under different growth conditions and of different thickness were investigated. With increasing Cu-to-Ga beam equivalent pressure (BEP) ratio the charge carrier density increases and the Hall mobility decreases due to defects introduced by Cu. Remarkably, samples with BEP ratio close to 1% show a strongly reduced charge carrier density and deviate from the general behavior. This suggests that Cu, which is preferentially substituted on Ga sites, acts as an acceptor up to a BEP ratio of 1%, whereas for higher concentrations Cu precipitates in Cu-Ga islands at the surface.

HL 91.18 Thu 16:00 Poster D

Ballistic Hall voltage in an asymmetric cross junction — •Michael Szelong[1], Ulrich Wieser[1], Michael Knop[1], Ulrich Kunze[1], Dirk Reuter[2], and Andreas Wieck[2] — [1]Lehrstuhl für Werkstoffe und Nanoelektronik, Ruhr-Universität Bochum — [2]Lehrstuhl für angewandte Festkörperphysik, Ruhr-Universtät Bochum

We are interested in the influence of asymmetry of a cross junction on ballistic Hall voltage in linear and nonlinear transport regime. The junction consists of a straight 200 nm wide stem and two 140 nm wide branches which merge into the stem at an angle of 30° (60°, 90°) and serve as voltage probes. Devices with different stem widths are processed on a high-mobility GaAs/AlGaAs heterostructure with a two-dimensional electron density and mobility of $n_{2D} = 3.6 \cdot 10^{11}$ cm^{-2} and $\mu_n = 8 \cdot 10^5$ cm^2/Vs, respectively, resulting in a mean free path of about 8 μm at $T = 4.2$ K.

A current driven through the stem induces a Hall voltage which is expected to be dependent on the current polarity, larger where electrons flow easier into the tilted probes, smaller in the opposite case. Linear and nonlinear transport regimes as well as the transition are to be considered and compared to theoretical simulations, which are based on time-resolved propagation of electron wave packets.

HL 91.19 Thu 16:00 Poster D

Shubnikov-de Haas oscillations and quantum Hall effect in Gd-implanted $Al_xGa_{1-x}N/GaN$ heterostructures — •Stepan Shvarkov[1], Dirk Reuter[1], Yvon Cordier[2], and Andreas D. Wieck[1] — [1]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CRHEA-CNRS, F-06560 Valbonne, France

We present a study of the magnetotransport properties of $Al_xGa_{1-x}N$/GaN heterostructurs. The samples were grown by molecular beam epitaxy on Si(111) substrates. The transport properties of the samples doped with Gd and undoped samples are compared. The Gd ions were introduced by focused ion beam implantation with fluences from 8×10^{10} cm^{-2} to 1×10^{12} cm^{-2} . As-grown samples reveal quantum interference effects such as weak localization and electron-electron interactions in low magnetic fields. At high magnetic fields B > 6 T, Shubnikov-de Haas (SdH) oscillations and quantum Hall effect (QHE) were observed. In analyzing the measured data, elastic and inelastic scattering times, mobility, carrier concentration and effective mass of the electrons in unimplanted and implanted samples were determined. The implantation strongly affects the quality of the heterostructures, causing strong decrease in carrier mobility at low temperatures. Nevertheless, SdH-oscillations and the QHE are still well pronounced in samples implanted with a fluence of 1×10^{11} cm^{-2}.

HL 92: Poster Session: II-VI Semiconductors & ZnO and related Materials

Time: Thursday 16:00–19:00 Location: Poster D

HL 92.1 Thu 16:00 Poster D

Optical spectroscopy of MBE grown $ZnSe_xTe_{1-x}$ and ZnS_xTe_{1-x} layers — •Tobias Bertram[1], Christian Karcher[1], Carsten Kruska[1], Henning Klaer[2], Sebastian Klembt[2], Carsten Kruse[2], Detlef Hommel[2], and Wolfram Heimbrodt[1] — [1]Department of Physics and Material Sciences Centre, Philipps University of Marburg, Germany — [2]Institute of Solid State Physics, University of Bremen, Germany

This study aims to produce a comprehensive understanding of the band formation processes in $ZnSe_xTe_{1-x}$ and ZnS_xTe_{1-x} semiconductor alloys. These solid solutions are known to feature large bowing parameters which cannot be explained solely by disorder as demonstrated in other II-VI systems, e.g. $ZnSe_xS_{1-x}$. This behaviour has previously been observed in II(N, VI) alloys, where it stemmed from the high differences in electronegativity and size between the substitutional N and the replaced ion. Such conditions create a strong interaction between the localized electronic states and the band structure of the host. This can be described by the band anticrossing (BAC) model, which results in a respective formation of two subbands E_- and E_+. To evaluate the applicability of this model to mixed II-VI semiconductors, e.g. the case of Se or S impurities in the ZnTe host, high quality layers grown by molecular beam epitaxy were studied using photoluminescence, photo- and electromodulated reflectance and absorption spectroscopy. These measurements reveal the emission and absorption characteristics of the systems between room temperature and 10 K.

The relevance of the BAC model will be discussed in detail.

HL 92.2 Thu 16:00 Poster D

Raman- and photoluminescence-spectroscopy studies of $CdSe_xS_{1-x}$ under hydrostatic pressure — •Markus S. Rinn, Thomas Sander, and Peter J. Klar — I. Physikalisches Institut, Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, 35392 Gießen

$CdSe_xS_{1-x}$ samples (x: 0.0 to 0.6) were studied by Raman spectroscopy at room temperature under the application of hydrostatic pressure. The spectra were recorded in backscattering geometry using a 633 nm excitation laser. The hydrostatic pressure was applied by a diamond anvil cell using the pressure induced shift of the ruby fluorescence as a pressure gauge. Furthermore, photoluminescence (PL) measurements were performed in the temperature range between 80 and 300 K. The influence of pressure and Se concentration on the Raman and PL spectra will be discussed.

HL 92.3 Thu 16:00 Poster D

Optische Beobachtung der Au-Diffusion in CdTe — •Robert Gerten, Florian Strauss, Herbert Wolf, Manfred Deicher und Thomas Wichert — Technische Physik, Universität des Saarlandes, 66123 Saarbrücken

Ortsaufgelöste Photolumineszenzmessungen (μPL) erlauben die gleichzeitige Beobachtung der Diffusion aller optisch aktiven Defekte in einem Halbleiter. In CdTe wurde mit Radiotracer-Experimenten gezeigt, dass ^{193}Au nach Implantation und Tempern unter Cd-Atmosphäre bei 800 K ein zur Probenmitte symmetrisches Uphill-Diffusionsprofil ausbildet [1]. Zur Untersuchung des zugrundeliegenden Mechanismus wurden μPL-Messungen an Te-reichen, einseitig mit Au implantierten CdTe-Kristallen durchgeführt. Nach Tempern unter den obigen Bedingungen stimmt die Form des Intensitätsprofils des mit Au-korrellierten PL-Signals sehr gut mit den Konzentrationsprofilen aus Radiotracer-Experimenten überein [1]. Die Intensitätsprofile der gleichzeitig beobachteten anderen Akzeptor- oder Donator-korrelierten Defekte stimmen mit den Beobachtungen von Horodyský et al. [2] an nominell undotiertem CdTe überein und liefern Informationen über das Diffusionsverhalten von Verunreinigungen und intrinsischen Defekten in CdTe. Diese mit der Radiotracer-Methode nicht zugänglichen Informationen bestätigen das Modell über die Entstehung solcher Konzentrationsprofile [1] und zeigen, dass diese Verunreinigungen ebenfalls entgegen ihres Konzentrationsgradienten diffundieren.

[1] H. Wolf *et al.*, Phys. Status Solidi B **247** (2010) 1405
[2] P. Horodyský *et al.*, Phys. Status Solidi C **2** (2005) 1189

HL 92.4 Thu 16:00 Poster D

Ground state properties, excitation spectra and formation energies for the mercury chalcolgenide HgS, mercury chloride Hg2Cl2 and sulfochloride mineral Hg3S2Cl2 — •Fabiana Da Pieve[1], Dirk Lamoen[1], Johan Verbeeck[1], Koen Janssens[2], and Gustav Van Tendeloo[1] — [1]EMAT, Physics, Department, University of Antwerp, Groenenborgerlaan 171, B-2020 Antwerp, Belgium — [2]XMBA, Chemistry Department, University of Antwerp, Campus Drie Eiken, Universiteitsplein 1, B-2610 Wilrijk, Belgium

We perform a study of stuctural, electronic properties and EELS response in the core loss region for several Hg compounds, with the aim of understanding the evolution of the red cinnabar (alpha-HgS) observed in several historical paintings. Calculations are performed within DFT-GGA and give results for the structural and electronic properties of alpha-HgS,beta-HgS,Hg2Cl2, and Hg3S2Cl2 polymorphs which are in good agreement with previous experimental and computational results. The electron energy loss spectra at the Cl and S K edge of the different compounds and an analysis based on energies of formation gives new insights into the darkening process.

HL 92.5 Thu 16:00 Poster D

Connecting ZnO nanowires for light emitting devices. — •Yaser Haj Hmeidi, Rapheal Niepelt, Martin Gnauck, Frank Schmidl, and Carsten Ronning — Institut für Festkörperphysik, Universität Jena, Max-Wien-Platz 1, 07743 Jena

ZnO nanowires can be easily grown via vapor-liquid-solid (VLS) mechanism and are suitable for optoelectronic applications. Furthermore, they have an emission wavelength in the UV region. We developed a simple and powerful approach on basis of spin-on-glass SiO2 [1]. This approach is intrinsically scalable since every step involved can be carried out in parallel over an entire wafer. The challenge in this particular geometry is the fabrication of top metallic contacts to the nanowires in a way that the contact dose not short. In this presentation, we will demonstrate how this approach can be utilized for assembling ZnO nanowires devices. These light emitting devices are based on p-n heterostructure between ZnO nanowires and highly doped substrate. The obtaining devices show rectifying properties and under certain conditions, also light emission.

HL 92.6 Thu 16:00 Poster D

Persistent Ion Beam Induced Conduction in Zinc Oxide Nanowires — •Andreas Johannes, Raphael Niepelt, Martin Gnauck, and Carsten Ronning — FSU Jena, Max-Wien-Platz 1, Jena, Deutschland

Ion implantation gives access to adjustable doping of semiconductor nanowires. However, in several cases not all of the implanted doping species are in fact contributing to the doping level, even after annealing. Additionally, ion implantation is also known to induce radiation damage that can also affect the electrical properties of the nanowires. As a predictable and reliable doping method is of huge necessity for a further integration of nanowires into technology, interest is directed to a closer investigation of implantation induced effects inside nanostructures. In this work, we report persistently increased conduction in ZnO nanowires irradiated by ion beam with various ion energies and species. This effect is shown to be related to the already known Persistent Photo Conduction (PPC) in ZnO and dubbed Persistent Ion beam induced Conduction (PIC). Both effects show similar excitation efficiency, decay rates and chemical sensitivity. PIC will potentially allow countable (i.e. single dopant) implantation in ZnO nanostructures and other materials showing PPC.

HL 92.7 Thu 16:00 Poster D

Microstructures and photoluminescence properties of one-dimensional ZnO nanostructures — •Peter Hess[1], Yong Lei[1,2], Martin Peterlechner[1], and Gerhard Wilde[1] — [1]Inst. f. Materialphysik, WWU Münster — [2]Inst. f. Physik & IMN (ZIK) MacroNano, TU Ilmenau

One-dimensional (1-D) ZnO nanostructures were systematically investigated concerning their microstructures and their photoluminescence properties. The main focus of this work is on the assembly of nanowires of different shapes and sizes by a CVD process to investigate their properties. For the Chemical Vapour Deposition (CVD) system ZnO/C mixtures was used as sources, Au-coated silicon or sapphire as substrates, and an argon and oxygen gas flow as a distributor and oxidation source. Depending on the growth conditions during the CVD process, different kinds of 1D and 2D ZnO nanostructures were obtained. The morphology of the ZnO nanostructures was checked by SEM and the photoluminescence properties were investigated using a spectrometer. Additionally, the crystalline structures, the growth direction, and the lattice spacing of ZnO nanostructures were characterized using TEM. Also the effects of different annealing temperatures and durations on the green band photoluminescence were investigated.

HL 92.8 Thu 16:00 Poster D

Micro-patterned, hydrothermally grown ZnO nanowire arrays for light-emitting devices — •Jonas Conradt[1,2], Marco Braun[1,2], Mario Hauser[1,2], Julian Fischer[3], Torsten Beck[1,2], Janos Sartor[1,2], and Heinz Kalt[1,2] — [1]Karlsruhe Institute of Technology (KIT), Institute for Applied Physics (AP), Karlsruhe, Germany — [2]Karlsruhe Institute of Technology (KIT), Center for Functional Nanostructures (CFN), Karlsruhe, Germany — [3]Karlsruhe Institute of Technology (KIT), Institut für Angewandte Materialien, Karlsruhe, Germany

Hydrothermal, aqueous synthesis represents a simple and low-cost method easily adaptable to industrial scale for the synthesis of ZnO nanostructures on various substrates, including flexible polymer foils, inorganic semiconductors and organic layers. We report on a micropatterning technique for hydrothermally grown ZnO nanowire arrays using a femtoliter droplet spotter. By selectively depositing ZnO nanocrystals, which act as nuclei during the latter growth of the wires, almost arbitrary patterns can be plotted using the nanowires, with a dot size of less than $20\,\mu m$. Blue light-emitting diodes, based on micro-patterned ZnO nanowire arrays grown on p-doped GaN, are built, characterized and discussed.

HL 92.9 Thu 16:00 Poster D

Ab initio study of ZnO dual doping with Ag and N acceptors in the presence of H — Oksana Volnianska and •Piotr Boguslawski — Institute of Physics PAS, al. Lotnikow 32/46, 02-668 Warsaw, Poland

In spite of considerable recent effort in the last years, stable and efficient p-doping of ZnO is not satisfactorily solved yet. Recently, good results were obtained by using Ag [1] and N [2], or the dual doping with both species [3]. Here, we investigate theoretically efficiency of ZnO doping with Ag and N shallow acceptors, which substitute respectively cations and anions. First principles calculations indicate a strong tendency towards formation of nearest neighbor Ag-N pairs and N-Ag-N triangles. Binding of acceptors in driven by the formation of quasi-molecular bonds between dopants, and has a universal character in semiconductors. In the considered case, the Ag-N binding energy is higher than that of both Ag-Ag and N-N pairs, which are more distant. The pairing increases energy levels of impurities in the band gap, and thus lowers doping efficiency. In the presence of donors, pairing is weaker or even forbidden. However, hydrogen has a tendency to form clusters with Ag and N, which favors the Ag-N aggregation and lowers the acceptor levels of such complexes.

[1]. H.S. Kang et al., App. Phys. Lett. 88, 202108 (2006); E. Kaminska et al., in Proc. ICPS 2008, p.120. American Institute of Physics.

[2] J. M. Bian et al., Appl. Phys. Lett. 85, 4070 (2004); Z. P. Wei et al., Appl. Phys. Lett . 89, 102104 (2006).

[3]. A. Krtschil et al., Appl. Phys. Lett. 87, 262105 (2005).

HL 92.10 Thu 16:00 Poster D

TLM measurements of sheet and contact resistance of different ZnO layers produced by wet chemical or sputtering methods — •Julia Waltermann[1], Kay-Michael Günther[2], Stefan Kontermann[1], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich-Hertz-Institute, Am Stollen 19B, 38640 Goslar, Germany — [2]Clausthal University of Technology, EFZN, EnergieCampus, Am Stollen 19B, 38640 Goslar, Germany

Within the last few decades zinc oxide emerged as a new material for wide band gap optoelectronic devices. In photovoltaics, ZnO is tested as a transparent electrode or as part of the heterojunction to improve the open circuit voltage. In any case the understanding and control of the electric contacts to ZnO are imperative to realize high performance devices. Considerable studies about metal contacts on crystalline ZnO were published during the last decade. Nevertheless, from an economic point of view low-quality ZnO layers, made by wet chemical or sputtering methods, are still interesting and their contacting has not been investigated in detail. In this work we compare different sputtered or sol gel produced ZnO-layers regarding their sheet and contact resistances to different metals using the transmission line method (TLM). First results show that wet chemical ZnO layers possess a very high sheet resistance due to the large number of grain boundaries. Moreover, even metal contacts like Ti/Au, which were reported to form an ohmic contact to ZnO, show a Schottky like behavior in the IV-characteristics.

HL 92.11 Thu 16:00 Poster D

Nonlinear magneto-optical study of excitons in ZnO — •Marco Lafrentz[1], David Brunne[1], Benjamin Kaminski[1], Victor V. Pavlov[2], Roman V. Pisarev[2], Dmitri R. Yakovlev[1,2], Dietmer Fröhlich[1], and Manfred Bayer[1] — [1]Experimentelle Physik 2, Technische Universitaet Dortmund, D-44221 Dortmund, Germany — [2]Ioffe Physico-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

We show that application of magnetic field causes in bulk wurtzite ZnO the optical second-harmonic generation (SHG) at energies of $2s/2p(A/B)$-excitons in the Voigt geometry for $\mathbf{B} \perp \mathbf{k} \parallel [0001]$, where SHG should be forbidden in the electric-dipole (ED) approximation. Investigations of magnetic- and electric field, temperature and azimuthal dependencies of SHG intensity allow us to deduce that this phenomenon arises from the higher order magnetic field perturbation known as magneto-Stark effect for excitons. This pertubation transforms like an effective electric field and leads to admixture of exciton wave functions of different parity and thus to resonant SHG enhancement.

HL 92.12 Thu 16:00 Poster D

Designing a dense blocking layer of electrochemically grown zinc oxide for hybrid solar cell applications — •Thilo Richter, Miriam Schwarz, and Veit Wagner — School of Engineering and Science, Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany

Electrochemical deposition of zinc oxide (ZnO) provides a low temperature, cost effective approach to designing crystalline, inorganic scaffolds in hybrid photovoltaics. In this context, a blocking layer between the p-type semiconductor and the anode is generally desired to prevent shunting in photovoltaic devices. We show that generating such a dense blocking layer during electrochemical growth of ZnO is not simply achievable by adjusting the main deposition parameters such as temperature, electrolyte concentration or voltage. Though, we demonstrate that the application of voltage variation during electrocrystallization is a possible way of controlling the ZnO growth. Dense blocking layers are possible if proper voltage variations are applied. Theoretical modeling of the results is presented based on solving the field diffusion equation of the relevant ions.

HL 92.13 Thu 16:00 Poster D

Anisotropic dielectric properties of MgZnO in the energy range from 2 to 25 eV — •Maciej D. Neumann[1], Christoph Cobet[1], Norbert Esser[1], and Rüdiger Goldhahn[2] — [1]Leibniz-Institut für Analytische Wissenschaften – ISAS – e.V., 12489 Berlin, Germany — [2]Otto-von-Guericke-Universität Magdeburg, 39106 Magdeburg, Germany

An accurate determination of the complex dielectric function (DF) of MgZnO is of great interest for the fundamental understanding of its electronic properties and is a key to optimize optoelectronic devices. Especially in the band gap region the DF is strongly affected by coulomb interaction and the polar character of the material. Even at room temperature this leads to characteristic features connected to free excitons and exciton-phonon complexes (EPC).

Using a home-made VUV ellipsometer at the Berlin synchrotron radiation facility BESSY II, nonpolar MgZnO samples were investigated with very high spectral resolution at temperatures between 10 and 300 K and photon energies ranging from 2 to 25 eV. We present the ordinary and extra ordinary DFs of the dielectric tensor obtained by employing an anisotropic model. The results are in remarkable agreement to novel *ab-initio* calculations and confirm the importance of excitonic effects in the entire VUV DF of MgZnO. The high resolution of around 0.5 meV allows us to extract all free band gap excitons ($n = 1$ and $n = 2$) and to elucidate the fine structure of the accompanying EPC.

HL 92.14 Thu 16:00 Poster D

Polarisation dependence of UV Raman scattering in ZnO — •Christian Kranert, Rüdiger Schmidt-Grund, and Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Semiconductor Physics Group, Leipzig, Germany

The usage of UV lasers for the excitation of Raman scattering in wide-bandgap semiconductors has become popular in recent times. This is mainly due to the fact that their light is strongly absorbed in the material allowing for a higher depth (and lateral) resolution which is particularly attractive for micro- and nanosized samples. However, there is a lack of basic research in this field which we show to be essential for a correct interpretation of the acquired spectra.

We present polarisation dependent Raman scattering spectra of bulk ZnO excited by the 325 nm line of a HeCd laser. These are dominated by peaks attributed to "forbidden" (=Fröhlich interaction induced, exciton mediated) scattering from longitudinal optical (LO) phonons. In contradiction to commonly made assumptions, the spectral position as well as lineshape and relative intensity of these peaks show a clear dependence on the applied polarisation configuration, i.e. polarisation of the scattered light relative to the incident light and polarisation of the incident light relative to the *c*-axis, respectively. A discussion on the observed effects will be given.

HL 92.15 Thu 16:00 Poster D

ZnO-based planar and nanowire heterostructures emitting in the visible spectral range — •Martin Lange, Christof P. Dietrich, Michael Lorenz und Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, D-04103 Leipzig, Germany

The rising complexity and efficiency of optoelectronic devices is based on heterostructures and therefore band gap engineering is essential. A reduction of the ZnO bandgap is possible when Cd is incorporated [1] whereas a larger bandgap is obtained for MgZnO. By applying a low substrate temperature of ≈ 300°C the ZnCdO related luminescence can be tuned down to energies of 2.5 eV for samples grown by puled-laser deposition [2].

By combining ZnCdO with ZnO or MgZnO the fabrication of quantum well (QW) heterostructures is possible. In such structures the QW-related emission energy can be tuned between the ZnCdO and the ZnO or MgZnO emission energy, by changing the QW-thickness only. For ZnCdO/MgZnO heterostructures the accessible spectral range is larger due to the larger bandgap in comparison to ZnO. An additional advantage is a reduced lattice mismatch for this combination due to an increasing *a*-lattice constant with increasing Cd/Mg-content for both alloys. In this regard, ZnCdO/ZnO and ZnCdO/MgZnO planar and nanowire heterostructures were fabricated. We report on the study of their luminescence properties.

[1] S. Sadofev *et al.*, Appl. Phys. Lett. **89**, 201907 (2010)

[2] M. Lange *et al.*, Phys. Status Solidi RRL, 10.1002/pssr.201105489

HL 92.16 Thu 16:00 Poster D

Tungsten trioxide as high-κ gate dielectric for highly transparent and temperature-stable zinc-oxide-based thin-film transistors — •Michael Lorenz, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig

We demonstrate metal-insulator-semiconductor field-effect transistors with high-κ, room-temperature deposited, highly transparent tungsten trioxide (WO_3) as gate dielectric [1]. The channel material consists of a zinc oxide (ZnO) thin-film. The transmittance and resistivity of WO_3 films was tuned in order to obtain a highly transparent and insulating WO_3 dielectric. The devices were processed by standard photolithography using lift-off technique. On top of the WO_3 dielectric a highly transparent and conductive oxide consisting of ZnO: Al 3% wt. was deposited. The gate structure of the devices exhibits an average transmittance in the visible spectral range of 86%. The on/off-current ratio is larger than 10^8 with off- and gate leakage-currents below 3×10^{-8} A/cm^2. Due to the high relative permittivity of $\varepsilon_r \approx 70$, a gate voltage sweep of only 2 V is necessary to turn the transistor on and off with a minimum subthreshold swing of 80 mV/decade. The channel mobility of the transistors equals the Hall-effect mobility with a value of 5 cm^2/Vs. It is furthermore shown, that the devices are stable up to operating temperatures of at least 150°C.

[1] M. Lorenz, H. von Wenckstern, M. Grundman, Adv. Mater. 2011, doi: 10.1002/adma.201103087

HL 92.17 Thu 16:00 Poster D

Microscopic identification of hot spots in multi-barrier Schottky contacts on pulsed laser deposition grown zinc oxide thin films — •Stefan Müller[1], Holger von Wenckstern[1], Otwin Breitenstein[2], Jörg Lenzner[1], and Marius Grundmann[1] — [1]Universität Leipzig, Semiconductor Physics Group, Institut für Experimentelle Physik II, Leipzig, Germany — [2]Max-Planck-Institut für Mikrostrukturphysik Weinberg 2, 06120 Halle, Germany

We report on investigations of Schottky contacts (SC) on ZnO thin films that exhibit spatially discrete variations of the barrier height. For this study we used nominally undoped ZnO thin films grown on a ZnO:Al buffer on a-plane sapphire substrates by pulsed-laser deposition. On the nominally undoped layer circular Pd(Au)O_y/ZnO-SC were fabricated by reactive dc-sputtering. The areas of the SCs are in the range from $1.8 - 44 \times 10^{-4}$ cm^2. About 50% of the prepared SCs exhibit one or more kinks in the room temperature IV-characteristic being a clear indication for the existence of at least two different barrier heights. The characteristics were modelled by assuming a parallel connection of a respective number of individual diodes individual diodes. Using dark lock-in thermography low-barrier patches were visualized for small forward currents. Current transport at low forward voltages for low temperatures is primarily through these patches. The origin of the local decrease of barrier height was traced by energy dispersive X-ray spectroscopy on a cross section prepared by focused ion beam and is due to aluminium oxide particles in the buffer layer[1].

[1] S.Müller *et al.*, IEEE Transaction on Electron Devices, in press.

HL 92.18 Thu 16:00 Poster D

Wavelength selective photodetectors based on (Mg,Zn)O-heterostructures — •Zhipeng Zhang, Holger von Wenckstern, Matthias Schmidt, and Marius Grundmann — Universität Leipzig, Fakultät für Physik und Geowissenschaften, Institut für Experimentelle Physik II, Linnéstraße 5, 04103, Leipzig

We report on ultraviolet metal-semiconductor-metal (MSM) photodetectors based on $Mg_yZn_{1-y}O/Mg_xZn_{1-x}O$ heterostructures ($0 < y < x \leq 0.5$, wurtzite modification) allowing to design wavelength selective detectors with narrow bandwidth [1]. The $Mg_xZn_{1-x}O$ thin film acts as optical edge filter and the $Mg_yZn_{1-y}O$ layer is the active layer of the devices. Therefore, ideally only light in a defined photon energy range of $E_g^y < E_{ph} < E_g^x$ contributes to the photoresponse. The spectral bandwidth is given by the bandgap difference ΔE_g of the two (Mg,Zn)O layers. The interdigital MSM-electrodes were fabricated by photolithography and reactive dc-sputtering of palladium (Pd) with an additional metallic Pd-capping layer [2]. A FWHM of only 7 nm was achieved for a photodetector operating around 3.4 eV and the center of band was shifted by using different $y : x$-combinations between 370 and 325 nm. A maximum spectral photoresponse of about 1.8 A/W was achieved. An internal gain mechanism in the device was observed and is attributed to trapping of minority carriers at PdO_z/(Mg,Zn)O-interface [3].

[1]: Z. Zhang et al., Appl. Phys. Lett. **99**, 083502 (2011)

[2]: A. Lajn et al., J. Vac. Sci. Technol. B, **27**, 1769 (2009)
[3]: O. Katz et al., Appl. Phys. Lett. **84**, 4092 (2004)

HL 92.19 Thu 16:00 Poster D

ZnO-$ZnCo_2O_4$-diodes — •Markus Winter, Friedrich Schein, Holger von Wenckstern und Marius Grundmann — Universität Leipzig, Institut für Experimentelle Physik II, Linnéstr. 5, 04103 Leipzig, Germany

The wide band gap semiconductor ZnO is a promising material for UV optoelectronic applications, photodetectors, front contacts of solar cells or transparent electronics. However, the growth of high quality p-type ZnO remains challenging. Therefore we investigated $ZnCo_2O_4$ as a suitable p-conducting oxide and fabricated semitransparent pn-diodes with n-ZnO.

The samples were grown by pulsed-laser deposition on a-plane sapphire substrates. We deposited ZnO:Al and ZnO at 680 °C and then amorphous $ZnCo_2O_4$ at room temperature, followed by dc-sputtered Au as ohmic contact. Transmittance of the ZnO/$ZnCo_2O_4$ layer structure is about 60%. The pn-diodes exhibit current on/off ratios (± 2 V) up to 10^{10} and typically in the range of 10^7. Temperature-dependent current voltage measurements will be discussed. The spectral dependence of the photocurrent was determined and it was found that photocurrent is generated primarily in the ZnO-layer.

HL 92.20 Thu 16:00 Poster D

The 3.06 eV-Donor-Acceptor-Pair Recombination in homoepitaxial grown ammonia doped ZnO — •Melanie Pinnisch[1], Sebastian Eisermann[1], Markus R. Wagner[2], Christian Nenstiel[2], Matthew Phillips[2], Detlev M. Hofmann[1], and Bruno K. Meyer[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen — [2]UT Sidney, Institute for Nanoscale Technology, PO Box 123, Broadway NSW 2007, Australia

In ammonia doped ZnO films grown, between sample temperatures of 350 °C and 400 °C, by chemical vapour deposition (CVD), two donor-acceptor-pair recombinations (DAP) were observed in steady state photoluminescence (PL) experiments. One is the well known DAP-band with its zero-phonon-line (ZPL) at 3.24 eV [1], and additionally a second DAP-band with the ZPL-position at 3.03 eV. This DAP-band shows a similar LO-phonon coupling (Huang-Rhys factor) as the 3.24 eV DAP-band, but its intensity decreases much faster with increasing measurement-temperature. A deep PL-band at 3.03 eV was only detected in films grown on non-polar substrates, and is absence in samples grown on c-plane ZnO-substrates. Cathodoluminescence (CL) and Raman experiments were performed to get more insight in the complex recombination behaviour of the samples.

[1] S. Lautenschlaeger et al., PSS B, 1-5 (2011)

HL 92.21 Thu 16:00 Poster D

Characterization and fabrication of ZnO/GaN heterostructures — •Julian Benz, Achim Kronenberger, Sebastian Eisermann, Stefan Lautenschläger, Torsten Henning, Bruno K. Meyer, and Peter J. Klar — I. Physikalisches Institut, Justus-Liebig-Universität, Heinrich-Buff-Ring 16, 35392 Gießen

Zinc oxide (ZnO) is a n-type semiconductor with a wide direct band gap of 3.37 eV. The abundance of the resources zinc and oxygen make it a promising candidate for the development of sustainable optoelectronic devices in the UV spectral range. A reproducible way of p-type doping ZnO has not been reported yet. A possible approach is to replace the p-ZnO by p-GaN. We report on the fabrication of ZnO/GaN heterostructures. Thin films of ZnO can be prepared by several methods, such as sputter deposition and chemical vapor deposition. Electrical and optical characteristics of samples prepared by those methods are compared.

HL 92.22 Thu 16:00 Poster D

Structural parameters of ZnMgO from first principles and experiment — •Marcel Giar[1], Thomas Wassner[2], Bernhard Laumer[1,2], Martin Eickhoff[1], and Christian Heiliger[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität, D-35392 Giessen — [2]Walter Schottky Institut, Technische Universität München, Am Coulombwall 3, D-85748 Garching

Recent experimental research on the evolution of the lattice parameters of wurtzite ZnMgO alloys with Mg content x show that due to relaxation processes the lattice parameter a strongly depends on the film thickness. For layers with a thickness of about 300 nm grown by molecular beam epitaxy a is found to be independent of x [1] whereas for a thickness of 1 μm we find an increase in a with increasing x. We conduct cell relaxation calculations keeping the lattice parameter a fixed in the basal plane as well as complete cell relaxations and we determine the resulting a lattice parameters from an a-plane-growth modeling. All calculations are based on the LDA and a supercell approach in combination with alloy statistics to consider different alloy configurations inside the supercell.

[1] T. A. Wassner, B. Laumer, S. Maier, A. Laufer, B. K. Meyer, M. Stutzmann, M. Eickhoff, J. Appl. Phys. 105, 023505 (2009)
[2] M. Heinemann, M. Giar, C. Heiliger, Mater. Res. Soc. Symp. Proc. 1201, H05-33 (2010)

HL 92.23 Thu 16:00 Poster D

two unique photoluminescence emissions in vapor phase grown ZnO single crystals — •xi zhang, frank herklotz, and jörg weber — Institut für Angewandte Physik, Technische Universität Dresden, 01062, Dresden, Germany

Defects play a crucial role in the optical and electrical properties of wide bandgap semiconductor ZnO. We detect two unidentified defects with low temperature photoluminescence lines at 3.3643 eV (P1) and 3.3462 eV (P2) in vapor phase grown ZnO single crystals [1]. The P1 line is observed in the as-grown samples. From the position of the associated two-electron-satellite, P1 is attributed to the recombination of an exciton bound to a shallow donor with a donor binding energy of 42.2 meV. Hydrogenation of the sample by annealing in hydrogen atmosphere at 700 oC leads to the appearance of the P2 line and a reduction of the P1 line. The results of isochronal annealing series suggest a correlation between P2 and the interstitial hydrogen donor HBC, which exhibits an excitonic recombination at 3.3601 eV. The possible microscopic origins of the P1 line and P2 line will be discussed. This work was supported by the European Regional Development Fund and the Free State of Saxony. SAB project 14253/2423

[1] X. Zhang, F. Herklotz, E. Hieckmann, J. Weber, P. Schmidt, J. Vac. Sci. Technol. A 29, 03A107 (2011)

HL 92.24 Thu 16:00 Poster D

Temperaturabhängigkeit des elektrischen Feldgradienten von In in ZnO bei verschiedener Dotierung — •Philipp Krumbholz und Reiner Vianden — Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Bonn, Deutschland

Es wird die Temperaturabhängigkeit des elektrischen Feldgradienten (EFG) von implantiertem ^{111}In als Sonde in ZnO bei unterschiedlicher Dotierung mit der Methode der gestörten Winkelkorrelation (PAC) untersucht.

Dazu wurde einkristallines ZnO mit den Dotierungen ^{27}Al, ^{115}In (Donator), ^{87}Rb (wahrscheinlicher Akzeptor) und ^{51}V, ^{52}Cr (Ferromagnetismus) implantiert und mit ^{111}In als Sonde nachimplantiert, um durch die Ladungsträgerkonzentration den EFG zu beeinflussen. Anschließend wurde das Ausheil- und Temperaturverhalten des EFG beobachtet.

Ergebnisse werden präsentiert und mit den Ergebnissen von Sato et al. [1] verglichen.

[1] W. Sato, et al., Phys. Rev. B 78, 045319 (2008)

HL 92.25 Thu 16:00 Poster D

Dependence of impurity incorporation on the surface termination of ZnO — •Alba Seibert[1], Andreas Laufer[1], Niklas Volbers[1], Sebastian Eisermann[1], Kay Potzger[2], Sebastian Geburt[3], Carsten Ronning[3], and Bruno K. Meyer[1] — [1]1. Physikalisches Institut, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [3]Institut für Festkörperphysik, Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Zinc oxide (ZnO) is regarded as a promising material for optoelectronic devices, due to its electronic properties. The severe difficulties in obtaining p-type ZnO have been partially attributed to intrinsic defects and impurities that act as compensating donors. To avoid these effects, the identification and quantification of impurities is a major demand. For quantitative information using secondary ion mass spectrometry (SIMS), so-called relative sensitivity factors (RSF) are essential. We present the determined RSF values for ZnO using primary (ion implanted) as well as secondary (bulk doped) standards. These RSFs have been applied to commercially available ZnO substrates of different surface termination (a-plane, Zn-face, and O-face) to quantify the contained impurities. Although these ZnO substrates originate from

the same single-crystal, we observe discrepancies in the impurity concentrations. These results cannot be attributed to surface termination dependent RSF values for ZnO.

HL 92.26 Thu 16:00 Poster D

Spectroscopic and Morphological Studies of Zinc Oxide Sprayed Films — •Iulia G. Korodi, Falko Seidel, Daniel Bülz, Ovidiu D. Gordan, and Dietrich R. T. Zahn — Semiconductor Physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany

Nowadays, one way of producing "green" energy can be achieved via photovoltaic cells. For such devices, ZnO can be used as a transparent window, or if doped as a transparent electrode material. Moreover, its transparency and wide bandgap makes it suitable for future transparent electronics. In this work, highly pure (99.995 %) zinc acetylacetonate hydrate ($Zn(acac)_2$) was used as a precursor for obtaining ZnO layers. The $Zn(acac)_2$ powder was solved in ethanol and the saturated solution was sprayed on heated silicon substrates (T = 150°C) in a glove box under nitrogen (N_2) atmosphere. Three different treatments were applied to these samples with the purpose of achieving ZnO films: flashing with a Xenon lamp (in N_2 environment immediately after spraying), illumination with a UV lamp (in ambient atmosphere) and annealing on a heating plate (in ambient atmosphere). The observed changes in the films obtained after employing the three different post-spraying treatments were investigated using Spectroscopic Ellipsometry, UV-Raman Spectroscopy, Fourier Transform Infrared Spectroscopy and Atomic Force Microscopy techniques. The investigation was performed varying the number of the applied flashes, the time during illumination, and the annealing. The results of this study will be presented and discussed.

HL 92.27 Thu 16:00 Poster D

Analysis of nitrogen doped ZnO via SIMS — •André Portz, Andreas Laufer, Michael Hofmann, Stefan Lautenschläger, Sebastian Eisermann, and Bruno K. Meyer — 1. Physikalisches Institut, Justus-Liebig-Universität Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany

During the last years the II-VI compound semiconductor zinc oxide (ZnO) has experienced a renaissance due to its interesting characteristics such as resistivity against high energy radiation, its transparency for visible light or also the possibility to achieve high crystal quality in epitaxial growth. But even more interesting seems the effort to accomplish reproducable p-conductivity by appropriate doping with group V-elements replacing oxygen in the crystal and creating the requested acceptor-level. This would form the foundation for numerous new applications in semiconductor-technology like efficient LEDs in the blue and ultraviolet spectral range. In the presented work nitrogen-doped zinc oxide (ZnO:N) was analysed using secondary ion mass spectrometry. Two series of samples were investigated. Both were homoepitaxially grown using CVD. In the first case the influx of NH_3, acting as nitrogen source, was varied. In the second case the substrate temperature was changed. The resulting nitrogen concentrations were determined and consequences are discussed.

HL 93: Poster Session: Metal-Semiconductor Hybrid Systems, Plasmonic Systems / Photonic Crystals / Carbon: Diamond & CNT / Quantum Information Systems

Time: Thursday 16:00–19:00 Location: Poster D

HL 93.1 Thu 16:00 Poster D

Optical properties of hybrid semiconductor-metal structures — •L.E. Kreilkamp[1], M. Pohl[1], V.I. Belotelov[2], A.K. Zvezdin[2], G. Karczewski[3], T. Wojtowicz[3], A. Rudzinski[4], M. Kahl[4], I.A. Akimov[1], D.R. Yakovlev[1], and M. Bayer[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, 119992 Moscow, Russia — [3]Institute of Physics, Polish Academy of Sciences, 02668 Warsaw, Poland — [4]Raith GmbH, Konrad-Adenauer-Allee 8, 44263 Dortmund, Germany

We study the optical properties of hybrid nanostructures comprising a semiconductor CdTe quantum well (QW) separated by a thin CdMgTe cap layer of 40 nm from a patterned gold film. The CdTe/CdMgTe QW structure with a well width of 10nm was grown by molecular beam epitaxy. The one-dimensional periodic gold films on top were made using e-beam lithography and lift-off process. The investigated structures can be considered as plasmonic crystals because the metal films attached to the semiconductor are patterned with a period in the range from 475 to 600 nm, which is comparable to the surface plasmon-polariton (SPP) wavelength. Angle dependent reflection spectra at room temperature clearly show plasmonic resonances. PL spectra taken at low temperatures of about 10 K under below- and above-barrier illumination show significant modifications compared to the unstructured QW sample. The number of emission lines and their position shift change depending on the excitation energy. The role of exciton-SPP coupling and Schottky barrier at the semiconductor-metal interface are discussed.

HL 93.2 Thu 16:00 Poster D

Fabrication of plasmonic nanoantenna/nanocrystal hybrid structures — •Heiko Linnenbank[1,2], Stephan Irsen[2], and Stefan Linden[1] — [1]Physikalisches Institut Universität Bonn, 53115 Bonn, Germany — [2]Forschungszentrum caesar, 53175 Bonn , Germany

Plasmonic nanoantennas are known for their ability to focus visible and near infrared light far beyond the diffraction limit. The intensity in the nano foscus can exceed the intensity of the incident light field by orders of magnitude. Our aim is to combine this property with the second order nonlinear response of, e.g., nanocrystaline barium titanate or lithium niobate in order to achieve resonant second harmonic generation or optical parametric oscillation. A big challenge for the experimental realization of such a nanoantenna / nanoparticel hybrid structure is the controlled placement of the two components relative to each other.

To overcome this issue, we use a two step electron-beam lithography scheme, where in the first lithography step the antennas are fabricated by a standard metal lift-off technique. In the second lithography, we create holes in a PMMA resist layer with a well defined diameter at the desired positions of the nanoparticles. Afterwards, the sample is immersed in a nanoparticle solution and slowly extracted. Convective assembly leads to the exclusive deposition of the nanoparticles in the predefined holes. With this technique the precision of the placement is in the order of the diameter of the nanoparticel and we are able to produce multiple arrays of thousands of structures in a feasible time.

HL 93.3 Thu 16:00 Poster D

Optical Investigations on Rolled-up Active Metamaterials including Plasmonic Structures — •Lena Simone Fohrmann, Stephan Schwaiger, Aune Koitmäe, Matthias Klingbeil, Andreas Rottler, Yuliya Stark, David Sonnenberg, Christian Heyn, Detlef Heitmann, and Stefan Mendach — Institut für Angewandte Physik, Universität Hamburg, Jungiusstraße 11, 20355 Hamburg

By the relaxation process of strained metal/semiconductor layers one can fabricate a rolled-up microtube whose wall consists of a metal/semiconductor superlattice representing a metamaterial. Quantum well heterostructures embedded into the semiconductor component enhance the transmission through the rolled-up metamaterial upon optical pumping [1]. A silver grating is integrated into these active metamaterials to investigate the coupling between surface plasmons on the silver grating and the quantum well. Simulations show that the integration of grating structures in rolled-up active metamaterials influences the transmission of light through the material drastically [2]. In this work I present a fiber based transmission measurement setup which is able to measure the transmission enhancement of a rolled-up metamaterial depending on the polarization of the transmitted light. Furthermore I present first results showing a polarization dependent transmission enhancement of up to 3.5%. We gratefully acknowledge support from the Deutsche Forschungsgemeinschaft (DFG) through GrK 1286. [1] S. Schwaiger et al., Phys. Rev. B 84, 155325 (2011). [2] A. Rottler et al., J. Opt. Soc. Am. B 28, 2402 (2011).

HL 93.4 Thu 16:00 Poster D

Optical Near Field Measurements on a Plasmonic Luneburg Lens — •Hoan Vu, Jens Ehlermann, Robert Blick, Detlef Heitmann, and Stefan Mendach — Institute of Applied Physics, University of Hamburg, Germany

We use a scanning near field optical microscope (SNOM) to investigate the interaction of surface plasmon polaritons (SPP) with dielectric nanostructures on gold films. For that purpose, a metal coated optical fiber with a 100 nm aperture is scanned over the samples surface in order to collect topographical and optical information simultaneously [1].

SPP properties, especially the propagation direction can be modified by varying the effective refractive index on the sample's surface. This is predominately achieved using gray scale lithographic techniques to locally modulate the height of polymeric nanostructures [2].

We present near field measurements on a plasmonic Luneburg lens [3]. Depending on the wavelength this lens focuses the SPPs to different spots on the sample.

We gratefully acknowledge support by the DFG via the Graduiertenkolleg 1286.

[1] A. Lewis et al., Ultramicroscopy 13, 227-232 (1984)
[2] P. A. Huidobro et al., Nano Letters 10(6), 1985-1990 (2010)
[3] T. Zentgraf et al., Nature Nanotechnology 6, 151-155(2011)

HL 93.5 Thu 16:00 Poster D

FDTD Simulations on three-dimensional plasmonic metamaterials containing optically active quantum wells — •Andreas Rottler, Malte Harland, Stephan Schwaiger, Aune Koitmäe, Detlef Heitmann, and Stefan Mendach — Institute of Applied Physics, University of Hamburg, Germany

Rolled-up metal/semiconductor multilayers containing optically active quantum wells opened up a new path for loss reduction in three dimensional metamaterials [1]. Recently, it was also shown that the embedding of plasmonic structures into these metamaterials can result in pumping induced transparency [2].

In this contribution we report on our recent finite-difference time-domain simulations on metamaterials consisting of alternating layers of plasmonic silver gratings and optically active semiconductor quantum wells. We investigated structure-design improvements in order to reduce the pumping power that is needed for optical net-gain.

We gratefully acknowledge support by the DFG via the Graduiertenkolleg 1286.

[1] S. Schwaiger et al., Phys. Rev. B 84, 155325 (2011).
[2] A. Rottler et al., J. Opt. Soc. Am. B 28, 2402-2407 (2011).

HL 93.6 Thu 16:00 Poster D

Transmission enhancement in three-dimensional rolled-up metamaterials including plasmonic structures — •Aune Koitmäe, Andreas Rottler, Stephan Schwaiger, Detlef Heitmann, Cornelius Bausch, Stefan Mendach, Eric Stava, and Robert Blick — Institut für Angewandte Physik, Universität Hamburg

We present numerical finite difference time domain (FDTD) simulations on three-times rolled-up semiconductor/metal microtubes (RUMMs) including an active InGaAs layer and a Ag grating [1]. The thickness of the metal layer and the grating periodicity have an influence to the wavelength of the SPP resonance and are chosen such that the resonance matches the wavelength of the quantum well emission. The simulations show a strong transmission enhancement when the RUMM is illuminated with p-polarized light. This is due to the coupling between the SPP resonance and the emission of the quantum well. Simulations using s-polarized light do not show strong transmission enhancement, and are comparable with the simulations including planar Ag layers instead of Ag gratings. Measurements of transmission enhancement on RUMMs including planar Ag film are presented in [2].

Semiconductor tubes can be used for biological applications [3].

[1] A. Rottler et al., J. Opt. Soc. Am. B 28, 2402 (2011).
[2] S. Schwaiger et al., Phys. Rev. B 84, 155325 (2011).
[3] M. Yu et al., American Chemical Society (2011).

HL 93.7 Thu 16:00 Poster D

Transformation optics with radial metamaterials — •Daniel Diedrich, Andreas Rottler, Detlef Heitmann, and Stefan Mendach — Institute of Applied Physics, University of Hamburg, Germany

Metamaterials are artificially structured materials which obtain their optical properties from the structure of the unit cell rather than from the constituent materials.

In this poster we discuss the possible realizations of transformation-optics devices with radial metamaterials, e.g. for cylindrical cloaking [1]. To obtain the required anisotropic permittivity values, we utilized finite-integration technique simulations and investigated the properties of a composite material made of silver spheres embedded into a PMMA host. By varying the distances and hence the interaction strength between the silver spheres, one can control the change in the permittivity.

With this method, a design of a cylindrical cloaking device operating in the visible regime was achieved. Furthermore we introduce designs for devices with an isotropic permittivity distribution, like the optical black hole or the Luneburg lens.

We gratefully acknowledge support by the DFG via the Graduiertenkolleg 1286.

[1] W. Cai, U.K. Chettiar, A.V. Kildishev, V.M. Shalaev, Nature Photonics 1, 224-227 (2007).

HL 93.8 Thu 16:00 Poster D

Gold diffusion into silicon during thermal annealing — •Anne-Dorothea Müller[1], Falk Müller[1], Stephanie Wengel[1], Christine Baumgart[2], Ilona Skorupa[2], Helfried Reuther[2], Arndt Mücklich[2], and Heidemarie Schmidt[2] — [1]Anfatec Instruments AG, Melanchthonstr. 28, 08606 Oelsnitz, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Gold was found to diffuse into silicon by a complex mechanism involving a vacancy-controlled interstitial-substitutional equilibrium. We investigated the Au diffusion into silicon using differently thick Au layers on n-Si and thermal annealing in a tube furnace at 800°C for 20 h in an argon atmosphere. After thermal treatment the lateral inhomogeneity in the Au distribution has been probed by Auger electron spectroscopy (AES) scans, Scanning electron microscopy, High resolution transmission electron microscopy (HRTEM), and by Kelvin probe force microscopy (KPFM) measurements [1]. The Au diffusion led to very complex diffusion concentration profiles which deviate from the ideal ones for Au diffusion into dislocation-free silicon. The resulting depth distribution of Au in Si has been determined by AES measurements. The KPFM contrast is independent of the surface topography and reveals different long-range chemical and local electrostatic interaction between the conducting KPFM tip and sample surface. HRTEM on cross-sections prepared from the sample with a nominal 10 and 20 nm thick Au layer reveal different phases of silicide formation. [1] C. Baumgart, A.-D. Müller, F. Müller, H. Schmidt, phys. stat. sol. (a), 2011, 208, 777-789.

HL 93.9 Thu 16:00 Poster D

Photon statistics of the quantum emission of a metallic nanoparticle and quantum dot hybrid system — •Thorsten Sverre Theuerholz, Oliver Esser, Andreas Knorr, and Alexander Carmele — Institut für Theoretische Physik EW 7-1, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin

Electrons in a metallic nanoparticle (MNP) exhibit collective oscillations with frequencies in the range of visible light. In our contribution, we derive the second order photon correlation function of a hybrid system made of a MNP and a semiconductor quantum dot (QD) driven coherently [1]. For this purpose, we treat the hierarchy problem by expressing the dynamical quantities in number states [2]. Within our theoretical framework, we discuss bunching and antibunching effects for the plasmons, depending on the frequency and intensity of the driving field.

[1] A. Ridolfo, O. Di Stefano, N. Fina, R. Saija and S. Savaste, Phys. Rev. Lett. 105 (26), 263601-263605 (2010)
[2] M. Richter, A. Carmele, A. Sitek and A. Knorr, Phys. Rev. Lett. 103 (8), 0874707-0874711 (2009)

HL 93.10 Thu 16:00 Poster D

Photonic Crystal Cavities for Temperature and Refractive Index Measurement — •Niko Nikolay[1], Carlo Barth[1], Andreas W. Schell[1], Jürgen Probst[2], Max Schoengen[2], Bernd Löchel[2], Janik Wolters[1], and Oliver Benson[1] — [1]Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany — [2]Department for Micro- and Nanostructured Optical Systems, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Straße 15, D-12489 Berlin, Germany

Nano-photonic devices based on quantum optical effects at the single-emitter and single-photon level are promising for integrated quantum technology [1]. In particular, photonic crystal cavities attracted intense research effort, as the electromagnetic field is strongly localized and the interaction with incorporated emitters is strongly enhanced.

However, the transition frequency of solid-state quantum emitters typically exhibits a strong temperature dependence. Thus, a precise thermometer to monitor and control the local temperature close to the emitter is needed. We demonstrate how higher order modes in photonic crystal cavities can be used to tackle this problem. As a side-effect the method can be used to measure the refractive index of semiconductors in a wide temperature and wavelength range.

[1] J.L. O'Brien, A. Furusawa, J. Vučković, *Photonic quantum technologies*, Nature photonics **3**:687, 2009.

HL 93.11 Thu 16:00 Poster D

Design and Optimization of Photonic Crystal Waveguides and Grating Couplers for Single Photon Applications — •Carlo Barth, Niko Nikolay, Andreas W. Schell, Janik Wolters, and Oliver Benson — Nano-Optics, Institute of Physics, Humboldt-Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany

Photonic crystals are a promising platform for integrated quantum optical networks. Recently, the controlled coupling of single emitters to photonic crystal cavities has been strikingly demonstrated in several experiments [1]. However, for future integrated single photon devices efficient waveguides and out-coupling structures will be needed. The latter ones are particularly important, as they form the interface between photonic chips and the macroscopic measurement equipment. We present our latest results on the design and optimization of high efficient couplers with large directivity and their integration into photonic networks.

[1] J. Wolters, A.W. Schell, G. Kewes, N. Nüsse, M. Schoengen, H. Döscher, T. Hannappel, B. Löchel, M. Barth, O. Benson. *Enhancement of the zero phonon line emission from a single nitrogen vacancy center in a nanodiamond via coupling to a photonic crystal cavity.* Applied Physics Letters **97**(14):141108, 2010.

HL 93.12 Thu 16:00 Poster D

Enhanced spontaneous emission from quantum dots in short photonic crystal waveguides — •Johannes Beetz[1], Thang Hoang[2], Leonardo Midolo[2], Matthias Skacel[2], Matthias Lermer[1], Sven Höfling[1], Laurent Balet[2,3], Nicolas Chauvin[2], Andrea Fiore[2], and Martin Kamp[1] — [1]Universität Würzburg, Technische Physik, Am Hubland, 97074 Würzburg, Germany — [2]COBRA Research Institute, Eindhoven University of Technology, P.O. Box 513, NL-5600MB Eindhoven, The Netherlands — [3]École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

Single photon emitters are key building blocks for the implementation of many quantum information processing schemes. Photonic crystal waveguides (WGs) which contain semiconductor quantum dots (QDs) are perfectly suited for this purpose because they can be easily integrated into on-chip photonic circuits. We fabricated WGs with short lengths (10-25 μm) to avoid localization of light and probed the photoluminescence from the top of the WG and from the cleaved facet. In agreement with simulations, we observe Fabry-Pérot modes formed by the two WG end facets in the slow-light regime of the dispersion curve.

The spontaneous emission of the QDs within the WGs is enhanced by a factor of 1.7. Furthermore, the coupling efficiency of the QD emission into the slow-light mode is estimated to be around 50%. The broad spectral range of the slow-light mode and the large WG mode volume allow for large photon collection efficiencies even in the case of limited spectral and spatial matching.

HL 93.13 Thu 16:00 Poster D

Semiconductor Colloidal Nanocrystals in PMMA Microresonators — •Felix Büchle, Daniel Rülke, Tobias Grossmann, Michael Hetterich, and Heinz Kalt — Institut für Angewandte Physik and Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology (KIT), Wolfgang-Gaede-Straße 1, 76131 Karlsruhe, Germany

Our work is based on the incorporation of colloidal CdSe/ZnS core-shell quantum dots (QDs) into the light-confining environment of high-Q (up to 10^6) optical PMMA microresonators fabricated by standard e-beam lithography and a subsequent etching process. QDs have been embedded into the PMMA matrix, mainly by direct mixing into the resist or via layer-by-layer deposition of QD films sandwiched between the resonator-forming PMMA layers, respectively. We focus on the investigation of the interaction between the nanocrystal emitter and the surrounding modal structure of the high-Q conical microresonators in the context of cavity-quantum-electrodynamics as well as on a possible realisation of low-threshold lasing from densely packed QD layers inside the resonator.

HL 93.14 Thu 16:00 Poster D

High-Q Polymer Goblet Resonators for Biosensing Applications — •Torsten Beck[1], Saskia Becker[1], Tobias Grossmann[1,2], Patrik Rath[1], Assegid Flatae[1], and Heinz Kalt[1] — [1]Institut für Angewandte Physik, KarlsruherInstitut für Technologie (KIT), Karlsruhe, Germany — [2]Institut für Mikrostukturtechnik, KarlsruherInstitut für Technologie (KIT), Karlsruhe, Germany

Biosensors for label-free molecule detection with high sensitivity are of great interest for many applications in life sciences. We developed a new type of whispering gallery mode (WGM) resonator made of out of low-loss polymer poly (methyl methacrylate) (PMMA). These optical cavities are fabricated using standard semiconductor processing methods in combination with a specific thermal reflow process. A significantly reduced surface roughness results in low surface scattering losses of the WGMs, as lithographic blemishes vanish. The Q-factor of these goblet resonators is above two million in the 1310 nm wavelength range. The high optical quality and the fabrication method suitable to mass production make these resonators promising candidates for low-cost bio-sensing devices with low limit of detection. Various surface functionalization methods for selective binding of specific molecules were investigated. The influence on the optical properties of the resonators was determined. In order to demonstrate the applicability of the goblet resonators for bio-sensing, Bovine Serum Albumin was detected by monitoring the spectral shift of resonator modes due to protein adsorption.

HL 93.15 Thu 16:00 Poster D

Wave packet dynamics of coherent states in waveguiding structures with quantum emitters — •Julia F. M. Werra[1], Paolo Longo[1], and Kurt Busch[2] — [1]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik, Newtonstr. 15, 12489 Berlin, and Max-Born-Institut, Max–Born–Str. 2A, 12489 Berlin, Germany

We present our recent results on the wave packet dynamics of coherent states in waveguiding structures coupled to artificial atoms. Physical realizations of such systems include coupled-resonator optical waveguides, defect structures in tailored nanophotonic media and microwave photonics in superconducting circuits.

The differences of the transport properties between a coherent state and a single-photon Fock state ([1]-[4]) in terms of various parameters such as the atom-photon coupling strength and the intensity of the light field is investigated numerically. Furthermore, quantum effects such as the atom-photon bound-state, which is a spatially localized, mixed excitation of light and matter, and nonlinear effects such as self-induced transparency that does not occur in the single-photon case are compared to the known results on single-photon excitations ([2]-[4]).

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[2] P. Longo e al., J. Opt. A: Pure Appl. Opt. 11, 114009 (2009)
[3] P. Longo et al., Phys. Rev. Lett. 104, 023602 (2010)
[4] P. Longo et al., Physical Review A 83, 063828 (2011)

HL 93.16 Thu 16:00 Poster D

Deterministic aperiodic photonic structures based on woodpiles — •Michael Renner and Georg von Freymann — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schrödinger-Str. 56, 67663 Kaiserslautern, Germany

Unlike most random photonic structures deterministic aperiodic structures (DAS) offer the possibility to reproducibly create specific potential landscapes whose Fourier components are determined by the underlying aperiodic sequence. In accordance with Lebesgue's spectral theorem the Fibonacci, Thue-Morse and Rudin-Shapiro sequences are examples of the three basic spectral measures, namely pure-point, singularly-continuous and absolutely-continuous, respectively.

We choose the woodpile structure as a starting point which can be routinely produced with a very small degree of structural imperfections. Minimizing these is crucial since intrinsic and extrinsic sample properties are often inseparable. Two layers of a fcc woodpile are grouped (bi-layer) and their rods are modulated in size by varying the laser power according to a binary deterministic aperiodic sequence. Rods which represent element 1 are written with raised laser power compared to the periodic case, rods representing element -1 were con-

sequently lowered in power. Along the stacking direction the original bi-layer and its inverse are also arranged following the sequence in order to introduce aperiodicity in three dimensions. Structures derived from the above mentioned sequences are fabricated with increasing modulation depth and thickness. The transition from order to disorder is investigated in their optical transmission and reflection spectra.

HL 93.17 Thu 16:00 Poster D

Distribution of NV optical centers in nitrogen-implanted diamond: Effects of radiation-induced defects and the surface potential — •Torsten Rendler[1], Andrej Denisenko[1], Jan Meijer[2], and Joerg Wrachtrup[1] — [1]3rd Physics Instiute and Research Center SCoPE, University of Stuttgart, Germany — [2]RUBION, Ruhr-Unveristaet Bochum, Germany

In this contribution we present the results on vertical distribution of nitrogen-vacancy (NV) centers in diamond, evaluated using step-etching in Ar/O2 plasma and confocal microscopy analysis. A nitrogen-free single crystal diamond was co-implanted by 15N and 12C atoms and subjected to thermal annealing in high vacuum to activate the NV defects.It was revealed that the optical centers are distributed in depth with different conversion rates of nitrogen atoms to NV defects (yield): about 10% within the stopping range of the implanted atoms and below 0.1% within the channeling tail at the implantation at 0° tilt. The concentration of electrically active defects (traps) within the implanted region was estimated by changing the surface potential of the initially O-terminated diamond in a microwave hydrogen-plasma. It was concluded that the thickness of the sub-surface region depleted with NV- was limited by charged defects in the bandgap of diamond. Subsequent wet-chemical oxidation of the H-terminated surface increased the contribution of NV- centers within the evaluated profile, consistent with the model of surface band bending and charged defects in the implanted region.

HL 93.18 Thu 16:00 Poster D

Ab initio simulations of CNTs for sensor application — •Christian Wagner[1], Jörg Schuster[1,2], and Thomas Gessner[1,2] — [1]Center for Microtechnologies, Chemnitz University of Technology, 09107 Chemnitz — [2]Fraunhofer Institute for electrical nanosystems ENAS, Technologie-Campus 3, 09126 Chemnitz

Carbon nanotubes (CNTs) are of great interest e.g. for sensor application because of their unique properties. Small-gap single-wall CNTs (sgSWCNTs) show a change of resistivity over several orders of magnitude while being strained only by a few percent. This is due to strain-induced band gap opening of sgSWCNTs. They are mechanically stable as well and show high fracture strain. Thus, they are favorable candidates for the application in nano-scaled, mechanical sensors.

Within the group of sgSWCNTs only a few are of practical relevance due to chemical selection methods. Thus we present DFT-calculations of the piezoresistive effect of such application-relevant CNTs. We investigated the band gap by means of DFT and compare our results with analytical tight-binding models, accessible in literature [1, 2], and published DFT-results.

Until now, only ideal CNTs have been considered for ab-initio, piezoresistance calculations. As real CNTs contain defects, we present first results of defective CNTs.

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[2] Kleiner, A. and Eggert, S., Band gaps of primary metallic carbon nanotubes, *Phys. Rev. B 63*, 073408, **2001**

HL 93.19 Thu 16:00 Poster D

Growth of carbon nanotubes for transistor applications — •Michael Trefz, Kerstin Schneider, Ronny Löffler, Monika Fleischer, and Dieter Kern — Institute for Applied Physics, University of Tübingen, Auf der Morgenstelle 10, 72076 Tübingen, Germany

Carbon nanotube field effect transistors (CNTFETs), that utilize a single carbon nanotube (CNT) as the channel material instead of bulk silicon in the traditional metal-insulator-semiconductor field effect transistor (MOSFET) structure could play a decisive role in the continuing path of miniaturization of electronic devices. In particular the possible narrow channels and the high electrical conductivity of the CNTs are attractive features. However, besides low resistance contacting issues the targeted and reliable preparation of individual transistors still presents problems. Control over the position of a nanotube has been achieved via positioning of catalyst material by lithographic means, followed by chemical vapour deposition (CVD) growth from this catalyst island. The orientation of the growing CNTs may be controlled by an electric field generated by a voltage applied between micro electrodes underneath the catalyst island. Strong van der Waals interaction with the surface impedes this orientation. We present a method to increase the yield of the oriented CNTs by applying an additional electric field so that a contact of the CNTs with the substrate during the growth is avoided. Results from growth experiments and electrical characterization of completed CNTFETs will be presented.

HL 93.20 Thu 16:00 Poster D

Functionalization of carbon nanotubes with Mn_4-clusters — •Anna-Katharina Saelhoff[1], Robert Frielinghaus[1], Claire Besson[1], Henrik Flötotto[1], Lothar Houben[1,2], Paul Kögeler[1], Claus M. Schneider[1], and Carola Meier[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich and JARA Jülich Aachen Research Alliance, 52425 Jülich, Germany — [2]Ernst Ruska-Center for Microscopy and Spectroscopy with Electrons, Forschungszentrum Jülich, 52425 Jülich, Germany

Due to their exceptional mechanical and transport properties, carbon nanotubes (CNTs) are a promising material for various applications in nanoelectronics. Their properties can be modified by different chemical functionalizations.

Here, we present covalent functionalization of CNTs with magnetic Mn_4-clusters. The route for this functionalization is very general, based on ligand exchange and can be applied for different types of molecules. The yield of the functionalization depends on the number of carboxylic groups on the CNTs created by oxidation. This process is monitored using Raman spectroscopy. However, the specific atomic structure can only be investigated by transmission electron microscopy (TEM).

Thus, for comprehensive characterization, CNTs are grown on patterned Si_3N_4 membranes by chemical vapor deposition. These suspended CNTs are contacted using e-beam lithography. The transport behaviour of such a device is then correlated to the information obtained by TEM and Raman spectroscopy.

HL 93.21 Thu 16:00 Poster D

Er-ion implantation in Si-based materials — •Nadezhda Kukharchyk[1], Stepan Shvarkov[1], Pavel Bushev[2], Alexey Ustinov[2], and Andreas D. Wieck[1] — [1]Angewandte Festkoerperphysik, Ruhr-Universitaet Bochum, Deutschland — [2]Physikalisches Institut, Karlsruhe Institut fuer Technologie, Deutschland

Erbium, embedded in a solid state matrix, is one of the most promising elements for future quantum information processing. The crystal structure as well as its magnetic impurities plays a quite important role for the magnetic properties of Er-ions. As silicon-based materials proved to be the base of the modern electronics world, they are also of high interest for future implementation in quantum data processing. In the following work, the behaviour of implanted Er species in Si-containing materials is discussed. Czochralski Si, float-zone Si, SiO2 and Y2SiO5 are taken as possible matrix (substrate materials). The electron parametric resonance study of implanted Er3+ ions is presented and discussed.

HL 93.22 Thu 16:00 Poster D

Broad-band electrically detected magnetic resonance experiments and electroelastic hyperfine tuning of phosphorus donors in silicon — •Florian M. Hrubesch[1], Lukas Dreher[1], Timon A. Hilker[1], Andreas Brandlmaier[2], Sebastian T.B. Goennenwein[2], Hans Huebl[2], Martin Stutzmann[1], and Martin S. Brandt[1] — [1]Walter Schottky Institut, Technische Universität München, Am Coulombwall 4, 85748 Garching — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Walther-Meißner-Strasse 8, 85748 Garching

We performed broad-band electrically-detected magnetic resonance (EDMR) experiments of ^{31}P in Si using short-circuited coplanar strip lines (CPS) for on-chip microwave magnetic field generation. With this approach, EDMR measurements with frequencies from 1-20 GHz are possible, demonstrating a cost effective way of performing multi-frequency experiments. Using the CPS technique, we demonstrate the electroelastical control of the hyperfine interaction between phosphorus nuclear and electronic spins opening an effective way to address spin-based qubits [1]. The hyperfine interaction is measured employing a hybrid structure consisting of a Si:P layer, a SiGe virtual substrate, and a piezoelectric actuator. By applying a voltage to the actuator,

the hyperfine interaction is changed by up to 0.9 MHz, demonstrating the feasibility of electroelastic hyperfine tuning.

[1] L. Dreher, *et al.* Phys. Rev. Lett. **106**, 037601 (2011)

Funding: DFG via SFB 631, C3

HL 93.23 Thu 16:00 Poster D

Coherent Photon-spin Transfer with NV Center in Diamond — •Seyed Ali Momenzadeh[1], Sen Yang[1], Petr Siyushev[1], Naofumi Abe[2], Hideo Kosaka[2], Helmut Fedder[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Research Institute of Electrical Communication, Tohoku University, Japan

Nitrogen vacancy (NV) center in diamond is a solid state single photon source which has been under renewed research interest since decade. Possessing several remarkable advantages like photostability, relatively long coherence time, high ability for readout and manipulation of the spin state [1][2], etc, give it unique highlighting applications such as coherent multi-qubit registers. The NV center can be considered as an artificial atom inside diamond being served as a qubit for quantum information processing. In this scence, the interaction (markedly entanglement) between two NVs (as stationary qubits) or between an NV and photons (as flying qubits) is of great importance to study. In this work, I present the development of a cryogenic setup based on a commercial cold-finger cryostat equipped with a home-made confocal setup, ESR, and NMR instrumentations. Furthermore, I show our results studying the coherent spin-photon interactions. The better coherence conditions and other unique features observable at low temperatures [3] offer NV center as a promising system candidate for future applications in quantum information field like quantum repeaters.

[1] Science,329,542,(2010) [2] Nature,466,730,(2010) [3] NJP,11,113029,(2009)

HL 94: Invited Talk: Martin Eickhoff

Time: Friday 9:30–10:00 Location: ER 270

Topical Talk HL 94.1 Fri 9:30 ER 270

Group III-Nitride nanowires and nanowire heterostructures: growth, properties and application as optochemical nanosensors — Jörg Teubert[1], Pascal Becker[1], Jens Wallys[1], Florian Furtmayr[1,2], Lorenzo Rigutti[3], Jordi Arbiol[4], and •Martin Eickhoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Giessen — [2]Walter Schottky Institut, Technische Universität München — [3]Institut d'Electronique Fondamentale, University of Paris Sud XI, UMR 8622 CNRS, Orsay, France — [4]Institució Catalana de Recerca i Estudis Avançats (ICREA), Barcelona, CAT, Spain

Group III-nitride (III-N) nanostructures, such as quantum dots, nanowires (NWs) and nanowire heterostructures (NWHs) are a current topic of intense research. Part of these activities is motivated by the possibility of realizing novel, nanoscaled optoelectronic devices with improved stability and efficiency or the perspective of realizing novel optochemical nanosensors.

We review the growth and structural properties of III-N NWs and NWHs and discuss the relation of their structural characteristics and optical properties. Here, GaN nanodiscs embedded in AlGaN/GaN NWs present an ideal model system to study the influence of confinement, internal electric fields and mechanical strain gradients.

We also discuss the photoluminescence response of III-N NWs and NWHs upon exposure to oxidizing and reducing gases as well as the photoelectrochemical properties of III-N nanostructures in electrolyte solutions.

HL 95: Quantum Dots and Wires: Optical Properties III (mainly Cavities and Ultrafast Response)

Time: Friday 9:30–11:30 Location: EW 201

HL 95.1 Fri 9:30 EW 201

Directional whispering gallery mode lasing in limaçon shaped electrically driven quantum dot micropillars — •Caspar Hopfmann[1,2], Ferdinand Albert[1], Christian Schneider[1], Alfred Forchel[1], Martin Kamp[1], and Stephan Reitzenstein[1] — [1]Technische Physik, Universität Würzburg, D-97074 Würzburg, Germany — [2]Present address: Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany

High quality factor and low mode volume microresonators featuring pronounced cavity quantum electrodynamics (cQED) effects are attracting considerable scientific attention with respect to efficient light sources. In this respect, electrically driven quantum dot based micropillar lasers are of particular interest because of straightforward current injection by a top contact. While standard micropillar lasers show highly directional emission normal to the sample surface, we report on directional lasing of whispering gallery modes (WGMs) confined in the central cavity layer of the micropillar. The in-plane directionality of emission is achieved by a controlled deformation of the pillar's cross-section using the limaçon-geometry. We present distinct directional WGM high β lasing with Q-factors up to 15.000 and laser threshold currents below 40 μA at 20 K, where the directionality of emission depends sensitively on the limaçon-parameter ε, i.e. the strength of deformation. Our devices provide a significantly better heat sinking compared to standard WGM lasers based on microdisks and have high potential to act as integrated light sources in planar photonic networks.

HL 95.2 Fri 9:45 EW 201

Single Quantum Dot Photocurrent Spectroscopy in high-Q Micropillar Cavities — •Manuel Gschrey[1], Peter Gold[1], Andreas Löffler[1], Sven Höfling[1], Alfred Forchel[1], Martin Kamp[1], and Stephan Reitzenstein[1,2] — [1]Universität Würzburg, Technische Physik, Am Hubland, 97074 Würzburg — [2]Present address: Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, 10623 Berlin, Germany

We report on single quantum dot controlled photocurrent (PC) measurements in electrically contacted high-Q micropillar cavities in the cavity quantum electrodynamics (cQED) regime. The micropillars consist of single layer of InGaAs QD in a one λ cavity that is sandwiched between two distributed Bragg reflectors (DBR). The devices are contacted via a ring-shaped gold contact on the upper facet of the pillar. This enables the control of the emission properties of the coupled QD-cavity system via the quantum confined Stark effect. As such, PC-spectroscopy opens up the possibility of investigating and controlling the transmission properties of the coupled QD-microcavity system on a single QD level. To address the influence of cQED effects on the PC, the structure is probed under non-resonant as well as strictly resonant conditions using either sidewall excitation or excitation through the top facet of the micropillar. Single QD effects are identified via high-resolution PC spectroscopy under variation of temperature, bias voltage and excitation power. We observe pronounced changes of the photocurrent response when single QD emission lines are tuned in and of resonance with the fundamental cavity mode of a micropillar cavity.

HL 95.3 Fri 10:00 EW 201

Strong Quantum Dot - Cavity coupling in submicron diameter AlAs/GaAs micropillar cavities — •Matthias Lermer[1], Niels Gregersen[2], Florian Dunzer[1], Jesper Mørk[2], Stephan Reitzenstein[1], Alfred Forchel[1], Sven Höfling[1], and Martin Kamp[1] — [1]Technische Physik and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]DTU Fotonik, Department of Photonics Engineering, Technical University of Denmark, Building 343, DK-2800 Kongens Lyngby, Denmark

Micropillar (MP) cavities with embedded quantum dots (QD) are a

promising semiconductor based platform for the investigation and application of cavity quantum electrodynamic (cQED) effects, e.g. the strong QD - cavity coupling. A figure of merit for this regime is the ratio Q/sqrt(Vmode), expressing that it is preferable to realize MPs providing not only high Q factors but also small mode volumes Vmode. This puts stringent requirements to the design and the processing of the MPs, which show a drastic decrease of the Q factor in the low diameter limit due to sidewall scattering losses and mode mismatch. These effects limit Q to about 2,000 in the submicron diameter range. To overcome this problem, we have designed and implemented a novel AlAs/GaAs cavity design showing Q factors exceeding 10,000 for MPs with submicron diameters. A record-high vacuum Rabi splitting (VRS = 85 micro eV) of the strong coupling in MPs with modest oscillator strength QDs has been observed for a MP with Q = 13,600 and a diameter of 850 nm.

HL 95.4 Fri 10:15 EW 201

Optimization of InGaN quantum dots for single line emission at elevated temperatures — •Elahe Zakizadeh, Heiko Dartsch, Timo Aschenbrenner, Stephan Figge, Carsten Kruse, and Detlef Hommel — Institute of Solid State Physics, University of Bremen, Germany

Due to the large bandgap and high exciton binding energy of the nitrides, InGaN quantum dots (QDs) are promising candidates for single photon emission at room temperature. In this presentation we show results of micro photoluminescence measurements on InGaN quantum dots formed by a spinodal decomposition process in MOVPE [1]. The samples show quantum dot related photoluminescence in the blue-green spectral region. Simple GaN layers containing InGaN QDs have been investigated as well as a fully monolithically grown cavity structure with InGaN QDs at the antinode position of a cavity between two GaN/AlInN Bragg reflectors. Single line QD emission could be observed up to a temperature of 100 K. In order to achieve single line emission at higher temperatures a novel concept of introducing AlGaN or AlInN barriers for larger carrier confinement will be discussed and first results will be shown.

[1] C.Tessarek, et al., Phys. Rev. B 83, 115316 (2011)

HL 95.5 Fri 10:30 EW 201

Ultrafast switching of a semiconductor quantum dot exciton — •Christian Dicken[1,2], Christian Wolpert[1,2], Klas Lindfors[1,2], Harald Giessen[1,2], and Markus Lippitz[2] — [1]Max Planck Institute for Solid State Research, Ultrafast Nanooptics — [2]University of Stuttgart, 4th Physics Institute

We report on ultrafast switching of the neutral exciton transition of a single GaAs quantum dot on the 50 ps timescale. In our experiment, an electron-hole plasma is created in the vicinity of the quantum dot by a strong 150 fs off-resonant laser pulse. As a consequence we observe in transient reflection a reduction of the transition dipole moment by typically 50 % and a redshift of the absorption line of up to 100 μeV. Both effects follow the dynamics of the electron-hole plasma and are strongly power dependent. We discuss the control and enhancement of the switching by confining the electron-hole plasma spatially.

HL 95.6 Fri 10:45 EW 201

Role of Coulomb correlations and carrier relaxation for pump-probe signals obtained from a single quantum dot — •Jan Huneke[1,2], Irene D'Amico[3], Pawel Machnikowski[4], and Tilmann Kuhn[2] — [1]Instituto de Ciencia de Materiales de Madrid, Sor Juana Inés de la Cruz 3, 28049 Madrid, Spain — [2]Institut für Festkörpertheorie, WWU Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany — [3]Department of Physics, University of York, Heslington York YO10 5DD, United Kingdom — [4]Institute of Physics, Wroclaw University of Technology, PL-50 370 Wroclaw, Poland

We present a theoretical modeling of femtosecond pump-probe experiments performed on a single negatively charged quantum dot. The influence of Coulomb-correlation effects as well as carrier relaxation is investigated. In particular, we study their influence on the fundamental trion absorption line. Our model describes the ultrafast disappearance of the fundamental trion absorption due to instantaneous Coulomb renormalizations and a delayed onset of gain at the same frequency, as found in the measurements[1]. As a result of spin- conserving carrier relaxation, our model predicts the emergence of new optical transitions exhibiting either gain or absorption. The time dependence of these new transitions provides insight into details of the carrier relaxation processes.

[1] F Sotier, T Thomay, T Hanke, J Korger, S Mahapatra, A Frey, K Brunner, R Bratschitsch and A Leitenstorfer, 2009 Nature Physics 5 352

HL 95.7 Fri 11:00 EW 201

On the treatment of carrier scattering in quantum dots beyond the Boltzmann equation — •Alexander Steinhoff[1], Matthias Florian[1], Paul Gartner[1,2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Germany — [2]National Institute of Materials Physics, Bucharest-Magurele, Romania

As quantum dots (QD) can confine a small number of carriers in localized states with discrete energies, it is clearly questionable to neglect correlations between the carriers when describing their dynamics. We discuss the effects of carrier correlations in a single QD in contact with a wetting layer (WL) by comparing the carrier dynamics without correlations between the QD-carriers, as given by a Boltzmann equation, with the correlated dynamics governed by a Liouville-von Neumann equation. In a first step, we take into account correlations generated by the exact treatment of Pauli blocking. Subsequently, we include correlations generated by energy renormalizations due to Coulomb interaction between the QD-carriers. It is shown that at low WL-carrier densities, neither Pauli correlations nor Coulomb correlations can be safely neglected, if the dynamics of single-particle states in the QD are to be predicted qualitatively and quantitatively. In the high-density regime, both types of correlations play a lesser role and thus an uncorrelated description of carrier dynamics by a Boltzmann equation becomes reliable. Furthermore, the efficiency of WL-assisted scattering processes as well as scattering-induced dephasing rates depending on the WL-carrier density are discussed.

HL 95.8 Fri 11:15 EW 201

Low lasing threshold of CdS nanowires — •Robert Röder, Sebastian Geburt, and Carsten Ronning — Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena

Semiconductor nanowires mark the physical size limit for photonic lasers: a further miniaturization can only be achieved by combination of photonic with plasmonic structures. High quality cadmium sulfide nanowires (CdS NW) were synthesized via vapor-liquid-solid (VLS) mechanism. The intense near band edge emission and the minor defect emission at low excitation power indicate the marginal defect concentration. Sharp peaks evolving at moderate excitation powers dominate the luminescence spectrum at higher laser power. The evaluated power dependency clearly shows all characteristics of lasing action in the NW cavity. The low threshold of 10 kW/cm^2 at room temperature was observed as well as its relation to the Q factor of the cavity. The length of the NW resonator was examined as one determining factor for the high Q values of up to 1800. Polarization and angular distribution of the emission from one end of the optically pumped NW can be studied using a "head on" experimental configuration. The lower length and diameter limits for photonic NW lasing were evaluated, but the CdS nanolaser can generate highly localized intense monochromatic light ideally suited for coupling plasmonic structures such as metallic nanoparticles, plasmonic substrates and quantum dots.

HL 96: Focus Session: Semiconductor Nanophotonics - Characterization on the Atomic Scale

For a detailed understanding of complex semiconductor nano- and heterostructures as well as the physics of devices based on them, a systematic determination and correlation of the structural, chemical, electronic, and optical properties on a nanometer or atomic scale is essential. This session brings the atomic structural and chemical imaging using cross-sectional scanning tunneling microscopy, advanced X-ray diffraction, and ultra-high resolution transmission electron microscopy together with the nanoscopic mapping of the optical and electronic properties using scanning transmission microscopy cathodoluminescence spectral imaging. Even more challenging is the atomic scale characterization directly during the epitaxial growth, made possible using in situ scanning tunneling microscopy during MBE growth and in situ synchrotron X-ray studies during metal-organic chemical vapor deposition. (Organizers: Jürgen Christen, Magdeburg University, and Holger Eisele, TU Berlin)

Time: Friday 9:30–12:45 Location: ER 164

Topical Talk HL 96.1 Fri 9:30 ER 164

Atomic Resolution Transmission Electron Microscopy of III-Nitride Nanostructues — •M. Albrecht[1], T. Schulz[1], T. Markurt[1], T. Remmele[1], A. Duff[2], J. Neugbauer[2], V. Grillo[3], J.-L. Rouviere[4], C. Nennstiel[5], and A. Hoffmann[5] — [1]Leibniz-Institut für Kristallzüchtung, Berlin, Germany — [2]Max-Planck-Institut für Eisenforschung, Düsseldorf, Germany — [3]CNR NANO S3, Modena, Italy — [4]CEA/INAC, Grenoble, France — [5]TU Berlin, Institut für Festkörperphysik Berlin, Germany

The influence of compositional fluctuations on carrier localization in III-Nitride base alloys is an ongoing debate. Despite huge efforts in theory and experiment it is still controversial whether the In distribution in an InGaN quantum well is truly random or if small In enriched clusters are present. The progress in aberration corrected transmission electron microscopy offers new possibilities to study alloy fluctuations at atomic scale and with high precision. In this presentation we will summarize recent results obtained by aberration corrected transmission electron microscopy and scanning transmission electron microscopy. We will show that local strain fluctuations can be measured wit 1.5 pm precision. This allows even statistical alloy fluctuations and static atomic displacements to be analyzed in real space. We revise approaches to analyze alloy fluctuations from tetragonal lattice distortions. Our results on the alloy distribution of InGaN quantum wells are compared to optical properties measured by cathodoluminescence, photoluminescence excitation and time resolved photoluminescence.

Topical Talk HL 96.2 Fri 10:00 ER 164

A cathodoluminescence study of a UV detector based on GaN Quantum Discs built in a single nanowire — •Luiz Zagonel[1] and Mathieu Kociak[2] — [1]Laboratorio Nacional de Nanotecnologia (LNNano), Centro Nacional de Pesquisa em Energia e Materiais (CNPEM), 13083-970, Campinas, Brasil — [2]Laboratoire de Physique des Solides/CNRS, Université Paris-Sud

We report the spectral imaging in the UV to visible range with nanometer scale resolution of closely packed GaN/AlN quantum disks in individual nanowires using an improved custom-made cathodoluminescence system. We demonstrate the possibility to measure full spectral features of individual quantum emitters as small as 1 nm and separated from each other by only a few nanometers and the ability to correlate their optical properties to their size, measured with atomic resolution. The direct correlation between the quantum disk size and emission wavelength provides evidence of the quantum confined Stark effect leading to an emission below the bulk GaN band gap for disks thicker than 2.6 nm. With the help of simulations, we show that the internal electric field in the studied quantum disks is smaller than what is expected in the quantum well case. We show evidence of a clear dispersion of the emission wavelengths of different quantum disks of identical size but different positions along the wire. This dispersion is systematically correlated to a change of the diameter of the AlN shell coating the wire and is thus attributed to the related strain variations along the wire. The present work opens the way both to fundamental studies of quantum confinement in closely packed quantum emitters and to characteriza- tions of optoelectronic devices presenting carrier localization on the nanometer scale.

Topical Talk HL 96.3 Fri 10:30 ER 164

Lattice parameter accomodation at the GaAs Nanowire to Silicon (111) substrate interface after Ga-assisted MBE growth — •Ullrich Pietsch[1], Andreas Biermanns[1], Anton Davydok[1], Steffen Breuer[2], Achim Trampert[2], and Lutz Geelhaar[2] — [1]Festkörperphysik, 57068 Universität Siegen — [2]Paul-Drude Institut für Festkörperelektronik, 10117 Berlin

We report on x-ray and TEM studies revealing the mechanism of lattice parameter accommodation of GaAs nanowires (NWs) grown on Si [111] substrate by Ga-assisted MBE. We show that the lattice mismatch between NW and substrate is released by a large procentage immediately after the beginning of NW growth through the inclusion of misfit dislocations. For thick NWs, the interface is rough preventing complete relaxation, whereas the release is nearly complete for thin NWs because the interface is flat. Using a nanosized x-ray beam and synchrotron radiation we could measure the residual strain and the phase composition of individual NWs. We find that even neighbouring NWs grown on the same sample under the same conditions differ significantly in their phase structure. Comparing the strains measured at a set of short nanowires of different height we are able to quantify the residual strain field close to the NW to substrate interface. It decays much faster along the interface compared to decay along the growth direction.

Coffee Break (15 min)

Topical Talk HL 96.4 Fri 11:15 ER 164

Atomic imaging of binary and quaternary semiconductor nanostructures by cross-sectional STM — •Andrea Lenz — Technische Universität Berlin, Berlin, Germany

In cross-sectional STM (XSTM) experiments typically layered semiconductor samples are cleaved in an ultrahigh vacuum system, laying bare an atomically clean cleavage surface. Therewith buried nanostructures can be analyzed with atomic resolution, providing access to their spatial structure and stoichiometry as it also appears in devices.

This contribution will focus first on the atomic structure of binary InAs submonolayer depositions on GaAs(001), demonstrating that the InAs is not located within a single atomic plane, but segregated along growth direction. In addition, the segregation along growth direction is determined in detail by the analysis of the local lattice parameter. Both demonstrate that the strain-induced segregation processes occurring during overgrowth defines the resulting nanostructures. Second, the atomic composition of quaternary InGaAsP layers grown latticed matched on InP(001) is analyzed at both the (110) and the (-110) cleavage surfaces, together yielding two different phase separation effects on different length scales: a formation of columnar structures with widths of some tens of nm and a CuPt-like ordering on the atomic scale. The latter can be identified at the (-110) cleavage surface by alternating brighter and darker atomic rows aligned along the [110] direction, with a periodicity along the [001] growth direction of two lattice constants, as well as by atomic chains of similar brightness oriented along the [-112] and [1-12] directions at the (110) cleavage surface.

Invited Talk HL 96.5 Fri 11:45 ER 164

Atomistic insights and controls for compound semiconductor growth by STMBE: STM obseration during MBE growth — •Shiro Tsukamoto — Anan National College of Technology

High density arrays of quantum dots (QDs) can easily be grown without any need for nano-patterning. These self-assembled QDs are strong candidates for advanced semiconductor laser and quantum devices. However, the precise physical mechanism of self-assembly is not understood, which hampers control over QD size, density and distribution for particular applications. This prototypical self-assembly system also

presents very general challenges for growth modeling over scales from atomic dimensions to hundreds of nanometers. Here we show dynamic images of InAs QD formation on GaAs(001) obtained using a unique scanning tunneling microscope (STM) placed within a molecular beam epitaxy (MBE) growth chamber: STMBE. These elucidate the mechanism of QD nucleation, demonstrating directly that not all deposited In is initially incorporated into the lattice, hence providing a large supply of material to rapidly form QDs via islands containing tens of atoms and Kinetic Monte Carlo (KMC) simulations based on first-principles calculations show that alloy fluctuations in the InGaAs wetting layer (WL) are crucial in determining nucleation sites. [1]S.Tsukamoto and N.Koguchi, J.Cryst.Growth 201, 118 (1999). [2]S.Tsukamoto, et. al., Small 2, 386 (2006). [3]T.Konishi and S.Tsukamoto, Nano.Res.Lett. 5, 1901 (2010); Surf.Sci. 605, L1 (2011).[4]T.Toujyou and S.Tsukamoto, Phys.Stat.Sol. (c) 8, 402 (2011); Nano.Res.Lett. 5, 1930 (2010); Surf.Sci. 605, 1320 (2011).

Invited Talk HL 96.6 Fri 12:15 ER 164

In situ synchrotron x-ray studies during metal-organic chemical vapor deposition of semiconductors — •Carol Thompson[1,2], Matthew J. Highland[2], Edith Perret[2], Marie-Ingrid Richard[3], Paul H. Fuoss[2], Stephen K. Streiffer[2], and G. Brian Stephenson[2] — [1]Northern Illinois Univ., DeKalb, IL, USA — [2]Argonne National Lab., Argonne, IL, USA — [3]Universite Paul Cezanne Aix-Marseille, Marseille, France

In-situ, time-resolved techniques provide valuable insight into the complex interplay of surface structural and chemical evolution occurring during materials synthesis and processing of semiconductors. Our approach is to observe the evolution of surface structure and morphology at the atomic scale in real-time during metal organic vapor phase deposition (MOCVD) by using grazing incidence x-ray scattering and x-ray fluorescence, coupled with visible light scattering. Our vertical-flow MOCVD chamber is mounted on a 'z-axis' surface diffractometer designed specifically for these studies of the film growth, surface evolution and the interactions within a controlled growth environment. These techniques combine the ability of x-rays to penetrate a complex environment for measurements during growth and processing, with the sensitivity of surface scattering techniques to atomic and nanoscale structure. In this talk, we outline our program and discuss examples from our in-situ and real-time x-ray diffraction and fluoresence studies of InN, GaN, and InGaN growth on GaN (0001). Work supported by U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences under contract DE-AC02-06CH11357.

HL 97: Quantum Dots and Wires: Optical Properties IV (mainly Nitrides)

Time: Friday 10:00–11:30 Location: ER 270

HL 97.1 Fri 10:00 ER 270

Exciton-Phonon coupling in single GaN quantum dots — •Juri Brunnmeier[1], Gordon Callsen[1], Andrei Schliwa[1], Johannes Settke[1], Christian Kindel[1], Erik Stock[1], Satoshi Kako[2], Yasuhiko Arakawa[2], and Axel Hoffmann[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institute of Industrial Science, University of Tokyo, Japan

Recently, single photon emission of MOCVD grown GaN quantum dots embedded in an AlN matrix was observed at elevated temperatures ($>$ 200 K) which represents a strong technological advantage in comparison to the well established system of arsenide quantum dots. However, to this day single photon emission of GaN quantum dots at room temperature seems to be hindered by a combination of various effects as the excitonic interaction with defects situated in the vicinity of the GaN quantum dot and a comparably strong exciton-phonon interaction. As a measure of the exciton-LO-phonon coupling strength we determine Huang-Rhys factors between 0.02 and 0.3, scaling with the size of the individual quantum dot, it's emission energy and the related dipole-moment, which is up to 3 orders of magnitude larger than in the arsenide quantum dot system. Furthermore, we compare measured values for the Huang-Rhys factor for a statistically valid ($>$ 100) number of single GaN quantum dots with eight-band k·p model based calculations. As a result we gain detailed insight into the strong piezo- and pyroelectrical fields which are characteristic for wurzite GaN/AlN quantum dots.

HL 97.2 Fri 10:15 ER 270

Modeling polar exciton-LO-phonon interaction in GaN/AlN quantum dots — •Johannes Settke, Andrei Schliwa, Gordon Callsen, Juri Brunnmeier, Axel Hoffmann, and Christian Thomsen — Institut für Festkörperphysik, Technische Universität Berlin, Germany

Recently, strong exciton-LO-phonon interaction for epitaxial GaN/AlN quantum dots (QD) was observed experimentally by analyzing the LO-phonon sidebands of single-QD excitonic peaks. Depending on the exciton energy, ranging from 3 eV to 4.5 eV, values of the Huang-Rhys parameter S between 0.3 and 0.02 were deduced. Since the polar coupling strength (described by S) for an exciton is proportional to the squared absolute value of the Fourier transformed difference of the probability densities of the electron and hole, S provides a measure for the electron-hole separation.

GaN/AlN QDs are well known for their strong intrinsic piezo- and pyroelectrical fields along the c-axis, giving rise to excitonic charge separation analogous the quantum confined Stark effect. As this charge separation is known to be dependent on the QD height, it should be mirrored by a variation of the parameter S.

Here, we calculate the Huang-Rhys parameter for the ground-state exciton as function of size and composition using a strain dependent 3D implementation of the eight-band **k·p** model taking into account piezo- and pyroelectric effects in the adiabatic approximation. We discuss the interrelation of QD size, built-in fields, exciton energy, dipole-moment and Huang-Rhys parameter S.

HL 97.3 Fri 10:30 ER 270

Strong dipole coupling in nonpolar nitride quantum dots due to Coulomb effects — •Kolja Schuh[1], Steffan Barthel[1], Oliver Marquardt[2], Gerd Czycholl[1], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Germany — [2]Tyndall National Institute, Lee Maltings, Cork, Ireland

Due to their wide-range of emission frequencies nitride-based optoelectronic devices are of current interest. However, a major drawback in nitrides is that the optical recombination is hindered by strong intrinsic fields that causes a separation of electrons and holes. In quantum wells, this effect can be avoided by enforcing a nonpolar growth direction, which ensures the absence of fields in the confined direction. However, since quantum-dot states are confined in all directions, there is always a separation of electrons and holes.

We show that in nonpolar nitride quantum dots the dipole transition between the single-particle ground states is only of minor importance for optical spectra. This spectra are dominated by many higher excited single-particle states which contribute to the ground-state transition when taking into account the Coulomb interaction. This finding may resolve existing discrepancies between theory and experiment, as theoretically only a weak ground state transition was obtained because of the spatial seperation of electron and hole ground state due to intrinsic fields, whereas experimentally fast recombinations were observed. Our treatment combines a continuum elasticity approach for the polarization potential, a microscopic tight-binding model for the electronic properties, and a many-body theory for the optical properties.

HL 97.4 Fri 10:45 ER 270

Photoluminescence response of Si doped GaN nanowires to pH variations — •Jens Wallys[1], Florian Furtmayr[1,2], Sebastian Koslowski[1], Jörg Schörmann[1], Jörg Teubert[1], and Martin Eickhoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, — [2]Walter Schottky Institut, Technische Universität München

GaN nanowires (NWs) feature a low density of structural defects, a high surface to volume ratio and an excellent electrochemical stability. Due to these properties they appear as promising candidates for photo electrochemical water splitting and electrochemical sensing.

In this contribution we present photoluminescence (PL) measurements performed on Si-doped GaN NW ensembles in contact with a physiological electrolyte solution of different pH. We demonstrate that the PL response to the ion concentration can be controlled by application of an external bias in a three electrode setup. A systematic in-

vestigation reveals a correlation of the pH-response with the Si-doping concentration and the average NW diameter.

The related response mechanism will be discussed in terms of surface band bending, NW diameter, external bias and non-radiative processes.

HL 97.5 Fri 11:00 ER 270

Luminescence properties of InGaN quantum dots embedded in GaN nanowires — •Pascal Becker[1], Max Kracht[1], Florian Furtmayr[1,2], Sangam Chatterjee[3], Alexej Chernikov[3], Philomela Komninou[4], Thomas Kehagias[4], and Martin Eickhoff[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen — [2]Walter Schottky Institut, Technische Universität München — [3]Fachbereich Physik, Philipps-Universität Marburg — [4]Physics Department, Aristotle University of Thessaloniki

III-N nanowires (NWs) have attracted a lot of attention in recent years due to their high crystalline quality compared to III-N thin films. The realization of InGaN/GaN heterostructures embedded in GaN-NWs allows one to shift the photoluminescence emission energy into the visible spectral range and to improve its temperature stability. We report on the emission properties of InGaN quantum dots (QDs) embedded in GaN NWs grown by plasma assisted molecular beam epitaxy on n-type Si(111) substrates. A series of samples with varied QD-thickness was investigated by low temperature photoluminescence (PL), single wire micro-PL, and time-resolved PL measurements. Emission bands at 3.48 eV, around 2.5 eV and at approximately 3.15 eV are attributed to the GaN band gap, the QD emission, and interfacial defects, respectively. High resolution transmission electron microscopy analysis was performed on selected samples for structural characterization.

HL 97.6 Fri 11:15 ER 270

μ-Photoluminescence of GaN nanowires with different diameters and pitches grown by selective-area epitaxy on Si substrates — •Christian Hauswald[1], Tobias Gotschke[1], Oliver Brandt[1], Namil Koo[2], Jung Wuk Kim[2], Raffaella Calarco[1], Lutz Geelhaar[1], and Henning Riechert[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin — [2]AMO GmbH, Aachen

Selective-area growth (SAG) of nanowires (NWs) by molecular beam epitaxy constitutes an important step towards uniform III-V NW arrays on Si. A homogeneous size and a controlled position are desirable for processing NWs into optoelectronic devices with predictable characteristics. In this work, we study the influence of different diameters and pitches of selectively grown NWs on their optical properties.

We use μ-photoluminescence (μ-PL) to investigate GaN NWs grown in pre-patterned holes defined by electron beam lithography in a SiO_x-mask. The holes have various shapes (hexagons, triangles, and squares) with diameters and periods in the range of 30–300 nm and 0.3–3.0 μm, respectively. All investigated NW arrays have been grown side by side on the same sample to ensure similar growth conditions. We compare the μ-PL spectra and integrated intensities of various NW diameter and pitch configurations and discuss the spatial homogeneity.

Finally, the coupling of light with GaN NWs fabricated using different mask geometries is simulated with a finite-element software to gain insight into the effects of the in-plane light propagation in SAG NW arrays. The potential of these ordered GaN NW arrays to form a photonic crystal is explored.

HL 98: Electronic Structure Theory

Time: Friday 9:30–12:30 Location: EW 202

HL 98.1 Fri 9:30 EW 202

Defect levels hiden by the Kohn-Sham band gap — •Bockstedte Michel — Theoretische Festkörperphysik, FAU Erlangen-Nürnberg, Staudtstr 7B2, 91058 Erlangen

Defects in semiconductors are decisive for the electronic properties. Furthermore they can implement Q-bits for quantum computing. To access the underlying physics, the accurate theoretical description of defect levels and excited states is highly desirable. Yet, the theoretical work horse, density functional theory (DFT) with (semi-)local XC-functionals, suffers from the well-known Kohn-Sham band-gap error. This not only affects defect states within the gap, but may turn otherwise localized ones into resonances outside the gap. Many-body perturbation theory (MBPT) on top of the DFT electronic structure was shown recently to yield excellent results for ionization levels and excited states, however, the latter problem of the DFT may easily hamper such calculations. Here we investigate this problem for a defect in SiC for the polytypes 3C and 4H with different band gaps using MBPT on top of DFT with LDA and HSE06 functionals. While in 4H-SiC G_0W_0 ionization levels for both functionals agree well, the proper defect states in 3C remain resonances within the LDA. Here simple ad-hoc corrections yield already good results.

HL 98.2 Fri 9:45 EW 202

Hybrid functionals in WIEN2k: implementation and applications — •Fabien Tran[1], David Koller[1], Ferenc Karsai[1], Peter Blaha[1], and Antia S. Botana[2] — [1]Institute of Materials Chemistry, Vienna University of Technology, A-1060 Vienna Austria — [2]Departamento de Fisica Aplicada, Universidade de Santiago de Compostela, E-15782 Santiago de Compostela, Spain

The screened and unscreened hybrid functionals were recently implemented into the WIEN2k code [1]. Results obtained with the hybrid functionals PBE0 and YS-PBE0 for the calculation of the F center in LiF and the electronic and magnetic properties of CrN will be presented. There will be also a discussion of the various approximations which can be done to make calculations with hybrid functionals faster, e.g., considering only the diagonal elements of the 2nd Hamiltonian [2] or using a reduced k-mesh for the screened Hartree-Fock potential.

[1] F. Tran and P. Blaha, Phys. Rev. B **83**, 235118 (2011).
[2] F. Tran, arXiv:1106.0434.

HL 98.3 Fri 10:00 EW 202

Implementation of NMR into the LAPW method — •Robert Laskowski and Peter Blaha — Vienna University of Technology, Institute of Materials Chemistry, Getreidemarkt 9/165-TC, A-1060 Vienna, Austria

We present an full potential, all electron augmented plane wave (APW) implementation of the first-principle calculation of the NMR chemical shifts. In order to obtain the induced current we follow the perturbation approach [C. J. Pickard and F. Mauri, Phys. Rev. B 63, 245101 (2001)]. The calculated all electron current is represented in traditional APW manner, namely we use Fourier representation in the interstitial region and spherical harmonics representation inside non- overlapping atomic spheres. The current is integrated using a pseudo charge technic of Weinert. The implementation is validated by comparison of the computed chemical shifts for sets of solids and molecules with available published data.

HL 98.4 Fri 10:15 EW 202

From long- to short-range correlations in the many-body perturbation theory — •Andris Gulans[1], Torbjörn Björkman[1], Natalia Berseneva[1], Arkady Krasheninnikov[1,2], and Risto Nieminen[1] — [1]Aalto University School of Science, Espoo, Finland — [2]University of Helsinki, Finland

Exfoliated layered solids commonly exhibit unusual properties in comparison to their bulk counterparts. Reliable theoretical studies of these materials often require more than just the standard density functional theory. Then, it is desirable to apply methods of the many-body perturbation theory, but they converge slowly with respect to the basis size. We argue that this problem stems from the electron-electron interaction cusp of correlated wavefunctions. Our analysis of the uniform electron gas shows that RPA correlation energies as well as GW quasiparticle energies converge as the negative third power of the cut-off wavevector, and also a further asymptotic expansion is possible. This result is applied for a study of binding in 30 layered solids and the quasiparticle band structure of BN and MoS2. Obtained exfoliation energies are surprisingly similar with the typical value of 20 meV/Å2. The quasiparticle calculations show that the band gaps strongly depend on the width of the vacuum gap between periodic images of single layers, which is another long-range correlation effect along with the van der Waals interaction. The accuracy of these results is strongly influenced by the treatment of the short-range electron correlations.

HL 98.5 Fri 10:30 EW 202

Electronic and optical properties of cadmium fluoride: the role of many-body effects — •Giancarlo Cappellini[1], Juergen Furthmueller[2], Friedhelm Bechstedt[2], and Emiliano Cadelano[1] — [1]SLACS-IOM-CNR and UniCA, Cagliari, Italy — [2]IFTO-FSU, Jena, Germany

The electronic excitations and optical spectra of CdF_2 are calculated employing state-of-the-art techniques based on density functional theory and many-body perturbation theory. We use the perturbative GW scheme proposed by Hedin for the electronic self-energy to calculate single-particle excitation properties as the energy bands and the density of states (DOS). The electronic DOS near the gap region and the energy-band structure are compared with existing data from literature. The role of many-body effects turns out to be of fundamental importance for these single-particle properties. We show moreover that also for optical properties many-body effects, treated within the Bethe-Salpeter equation framework, are crucial to allow reasonable comparison with existing experimental spectra. We discuss the existence of a bound exciton located about 1 eV below the quasiparticle gap. For both, single-particle and two-particle effects, we explore the possibility of using simplified schemes and/or approximations which could reduce the computational effort, mantaining the physical results reliable. In addition, we also present preliminary results for the fluoride BaF_2 for comparison.

Coffee Break (15 min)

HL 98.6 Fri 11:00 EW 202

Derivation of effective atomic potentials as new type of pseudopotentials — •Jairo Ricardo Cardenas, Roby Cherian, and Gabriel Bester — Max Planck Institute for Solid State Research

We derive a new type of pseudopotentials from conventional norm-conserving pseudopotentials for the treatment of a large number of atoms. The pseudopotentials are not aimed at the calculation of the total enegy, but of band edge states relevant for optical processes. We describe the pseudopotential construction and benchmark its quality and transferability by comparison to standard DFT calculations.

HL 98.7 Fri 11:15 EW 202

A comparison of density functionals for the charge transfer level of the N defect in ZnO — •Sung Sakong, Peter Kratzer, and Johann Gutjahr — Fakultät für Physik and Center for Nanointegration (CeNIDE), Universität Duisburg-Essen, Duisburg, Germany

Electronic structure of impurity states in semiconducting materials is a very popular research field in both science and industry. However, the most frequently employed density functional theory (DFT) method has a significant problem to reproduce the experimentally measured band gap. As a consequence, recently hybrid functionals are introduced to remedy the underestimated band gap.

We present a comparison of defect calculations between generalized-gradient-approximation (GGA-PBE) and hybrid functionals (HSE and PBE0) for the experimentally well characterized N impurity in ZnO [AIP Advances **1**, 022105 (2011)]. In addition, we test also empirical correction schemes with $+U$ and non-local potential [PRB **77**, 241201 (2008)] methods on top of the GGA functional. By referring all energy levels to the vacuum level of the corresponding method, we are able to compare the results. From the calculations, we notice that the charge transfer level $(0/-)$ of N defects on the O site goes deeper into the gap in the methods that give a larger band gap, in good accordance with experiment and previous calculations [Appl. Phys. Lett. **95**, 252105 (2009)]. Moreover, we find the absolute positions of the charge transfer levels with respect to the vacuum levels to be less dependent on the functionals than the band edges, because the charge states are determined from the more robust DFT total energies.

HL 98.8 Fri 11:30 EW 202

First-principles simulations of catalytic effects of the gold nanoparticle on the GaAs nanowire growth — •Yaojun Du, Peter Kratzer, Sung Sakong, and Volker Pankoke — Fakultät für Physik and Center for Nanointergration

The interface between an Au nanoparticle and a GaAs nanowire can facilitate the nanowire growth due to a segregation of materials to the interface. Previous experimental studies have suggested that an Au nanoparticle alloyed with Ga atoms can supply Ga atoms to the interfacial growth zone. On the other hand, an Au nanoparticle can also absorb As_2 from the vapor phase during molecular beam epitaxy. This allows for a continuous supply of gallium and arsenic which is necessary for a GaAs nanowire growth. Employing density functional theory approaches, we have shown that an Au particle that can alloy with Ga atoms to form a stable surface is capable of catalytically dissociating As_2 impinging from the vapor phase. Moreover, relatively stable As-Ga species can form on the AuGa surface which could build up an As-Ga supply for growth at the interface. We are investigating the As diffusion within GaAs bulk crystal structures and along the interface between an Au nanoparticle and a GaAs nanowire. This should allow us to gain full insight on catalytic effects of the gold nanoparticle on the GaAs nanowire growth.

HL 98.9 Fri 11:45 EW 202

Tight binding in cylindrical coordinates for the electronic states of Si/Ge rolled-up nanotubes — •Giovanni Pizzi[1], Michele Virgilio[2,3], Giuseppe Grosso[2,3], Suwit Kiravittaya[4], and Oliver G. Schmidt[4] — [1]Theory and Simulation of Materials, École Polytechnique Fédérale de Lausanne, Switzerland — [2]NEST, Istituto Nanoscienze-CNR, Italy — [3]Dipartimento di Fisica, Università di Pisa, Italy — [4]Institute for Integrative Nanosciences, IFW Dresden, Germany

We have extended the $sp^3d^5s^*$ tight-binding model to the case of cylindrical symmetry in order to study the electronic states of multiwall rolled-up nanotubes, under the assumption of discrete rotational symmetry around the tube axis. We discuss the modifications that have to be applied to the standard tight-binding model so as to take into account the effects of the curvature on the hopping energies and on the spin-orbit coupling.

The input equilibrium positions of the atoms are obtained by means of continuum elasticity theory [1], and the electronic bands and states can be obtained with the code that we have developed for zincblende-like structures, using the parameters of Ref. [2]. The electronic band structure, the degeneracy liftings and the valley splitting in the conduction band of rolled-up Si/Ge nanotubes are discussed as an application.

[1] M. Grundmann, Appl. Phys. Lett. **83**, 2444 (2003).
[2] Y. M. Niquet, D. Rideau, C. Tavernier, H. Jaouen, and X. Blase, Phys. Rev. B **79**, 245201 (2009).

HL 98.10 Fri 12:00 EW 202

Confinement effects on the vibrational properties of colloidal quantum dots — •Peng Han and Gabriel Bester — Max-Planck-Institut fuer Festkoerperforschung, Heisenbergstrasse 1, 70569 Stuttgart, Germany

Vibrational properties of colloidal III-V and II-VI quantum dots with thousand atoms are studied using first-principle density-functional theory (DFT) calculation. We describe the connection between the vibrational properties (including surface acoustic/optical modes, coherent acoustic modes, blue shifts for small radii and red shifts for large radii) and the structural changes induced by the surface. We can clearly ascribe most of these observations to the large relaxation of the clusters dominated by an inward relaxation of the surface penetrating deep inside the cluster of III-Vs and large distribution of bond length at the surface of II-VIs. These strong confinement effects tend to disappear for clusters with more than thousand atoms, where a small red shift of the Raman peak remains, due to a softening in response to undercoordination. The coherent acoustic modes, which have been viewed as the main cause for the bright-dark transition in the fine-structure splitting of quantum dots, are identified by our DFT calculation and found to agree well with the results from the Lamb model and experiment.

HL 98.11 Fri 12:15 EW 202

Extracting an effective band structure from supercell calculations on alloys and impurities: Evolution of the impurity band with clustering in GaN:P — •Voicu Popescu[1,2] and Alex Zunger[3] — [1]Faculty of Physics, University Duisburg-Essen, 47048 Duisburg, Germany — [2]Colorado School of Mines, Golden, Colorado 80401, USA — [3]University of Colorado, Boulder, Colorado 80302, USA

While the supercell approach to defects and alloys enables to circumvent the limitations of those methods that insist on using artificially high symmetry, this step usually comes at the cost of abandoning the language of E versus $\vec{k}$ band dispersion. We describe a computational method that maps the energy eigenvalues obtained from large supercell calculations into an effective band structure (EBS) and recovers an approximate $E(\vec{k})$ for alloys. Making use of supercells allows one to model a random alloy $A_{1-x}B_xC$ by occupying the sites A and B via a coin-toss procedure affording many different local environments to occur (polymorphic description). We present the supercell EBS methodology and apply it to study the evolution of the impurity band

appearing in the dilute GaN:P alloy. We treat both the perfectly random case as well as the non-random microstructures formation, and investigate how their appearance is reflected in the EBS. It turns out that the EBS is extremely sensitive in determining the critical disorder level for which delocalised states start to appear in the intermediate band. In addition, the EBS allows us to identify the role played by atomic relaxation in the positioning of the impurity levels.

HL 99: Organic Semiconductors: Transport

Time: Friday 9:30–12:30 Location: EW 203

HL 99.1 Fri 9:30 EW 203

Theoretical Studies on the Dynamical Conductivity in Organic Crystals — •André Fischer[1], Frank Ortmann[2], Friedhelm Bechstedt[1], and Karsten Hannewald[1] — [1]European Theoretical Spectroscopy Facility and Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Germany — [2]Institut Català de Nanotecnologia (ICN), Barcelona, Spain

The theoretical description of charge-transport and excitation properties of organic semiconductors is of crucial importance for the understanding and improvement of organic (opto)electronic devices. As an extension of our previous theories for the static conductivity [1,2], we present here a theory for the dynamical conductivity in organic crystals. Based on the Holstein Hamiltonian, we derive an analytical expression for the temperature-dependent intraband absorption of polarons. The methodological development is supplemented by numerical studies for a 1D model crystal [3] and predictions are made for the expected signatures in corresponding THz experiments.

[1] K. Hannewald et al., Phys. Rev. B **69**, 075211 (2004); Phys. Rev. B **69**, 075212 (2004); Appl. Phys. Lett. **85**, 1535 (2004)
[2] F. Ortmann et al., Phys. Rev. B **79**, 235206 (2009); New J. Phys. **12**, 023011 (2010); Phys. Stat. Sol. B **248**, 511 (2011)
[3] A. Fischer et al. (submitted)

HL 99.2 Fri 9:45 EW 203

Understanding charge and spin transport properties of $\pi-$conjugated polymers — •Sandip Bhattacharya, Mauro Ferreira, and Stefano Sanvito — School of Physics and CRANN, Trinity College Dublin, Ireland

An efficient spin polarized transport through Organic Spin Valves, which is quinessential for a high and stable MR, require a much broader understanding of how spins travel through an organic media. In this respect the general consensus among the Organic Spintronics community on the principal spin scattering mechanisms is often quite contentious. In the current work, we discuss our microscopic approach to this problem [1]. Organic π-conjugated polymers are represented by using a Hubbard-Peierls model that also includes Hyperfine (HF) and Spin Orbit interactions (SOC). The phononic degrees of freedom and the nuclear spins in the Hamiltonian are evolved in Monte Carlo simulations. The transport observables investigated are the spin-polarized conductance (Landauer-Buttiker formalism) and the charge carrier mobility (Kubo formula). We are able to extract the spin diffusion length and spin lifetimes of carriers from the observables and thereby compare them directly to experimental results. The problem at hand is quite an intriguing one involving a significant deal of complexity in terms of controlling the number of microscopic parameters. The strengths of the SOC constant and the HF integral are estimated from first-principle calculations. In this work we present our results on spin and charge transport properties calculated in the entire region of parameter space of the problem.

[1] S. Bhattacharya et al JPCM, 23, 316001 (2011).

HL 99.3 Fri 10:00 EW 203

Polaron Transport in Organic Crystals: Temperature Tuning of Disorder Effects — •Frank Ortmann[1,2] and Stephan Roche[2,3] — [1]CEA Grenoble, France — [2]CIN2 (ICN-CSIC), Universitat Autónoma de Barcelona, Catalan Institute of Nanotechnology, Spain — [3]ICREA, Spain

We explore charge transport in three-dimensional models of disordered organic crystals with strong coupling between electronic and vibrational degrees of freedom. [1] By studying the polaron dynamics in a static disorder environment, temperature-dependent mobilities are extracted and found to exhibit different fingerprints depending on the strength of the disorder potential. At low temperatures and for strong enough disorder, coherence effects induce weak localization of polarons. These effects are reduced with increasing temperature (thermal disorder), resulting in mobility increase. However, at a transition temperature, phonon-assisted contributions driven by polaron-phonon scattering prevail, provoking a downturn of the mobility. The results provide an alternative scenario to discuss controversial experimental features in molecular crystals.

[1] F. Ortmann and S. Roche, Phys. Rev. B **84**, 180302R (2011)

HL 99.4 Fri 10:15 EW 203

Multiscale simulations of the density of states, DC and terahertz mobility of charge carriers in disordered conjugated polymers — •Nenad Vukmirovic — Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia

Understanding the relationship between the atomic structure of an organic material and its electrical properties is of utmost importance for the development of materials for organic electronic devices. In this work, recently developed simulation frameworks [1,2,3] were used to understand the factors that determine the density of states, the DC and the terahertz mobility of several materials.

It was found that the size of the torsion barrier between neighbouring polymer units strongly affects the density of electronic states and consequently all electrical properties. Next, it was shown that alkyl chains act not only as insulating barriers that impede the transport but their presence may also reduce the disorder caused by other chains and consequently enhance the transport. Finally, the simulations also give insight into the distribution of carrier energies and transport distances that are probed in measurements of the mobility at terahertz frequencies. Their fingerprint is much weaker dependence of the terahertz mobility on temperature in comparison to the DC case.

[1] N. Vukmirovic and L.-W. Wang, J. Phys. Chem. B 115, 1792 (2011). [2] N. Vukmirovic and L.-W. Wang, Nano Lett. 9, 3996 (2009). [3] N. Vukmirovic and L.-W. Wang, J. Phys. Chem. B 113, 409 (2009).

HL 99.5 Fri 10:30 EW 203

Positive feedback between Joule heating and current density in organic devices based on C_{60} — •Axel Fischer[1], Paul Pahner[1], Björn Lüssem[1], Karl Leo[1], Reinhard Scholz[1], Thomas Koprucki[2], Jürgen Fuhrmann[2], Annegret Glitzky[2], and Klaus Gärtner[2] — [1]Institut für Angewandte Photophysik, Technische Universität Dresden, 01062 Dresden — [2]Weierstraß-Institut für Angewandte Analysis und Stochastik, Mohrenstraße 39, 10117 Berlin

We have studied the influence of heating effects on the device performance in an organic device containing a layer sequence of n-doped / intrinsic / n-doped C_{60} between crossbar metal electrodes. Due to the fact that C_{60} can withstand temperatures above 200°C, these devices give a perfect setting for studying the heat transport. At high current densities beyond 100 A cm^{-2}, a strong positive feedback between current and temperature is observed, as predicted by the extended Gaussian disorder model (EGDM) applicable to organic semiconductors [1]. Approximate analytical studies and detailed 3D numerical simulations for the stationary heat transport problem reveal the temperature distribution. The result is confirmed by thermal imaging of the device. Additionaly, strong heating at the edges of the device is obtained and cannot be understood quantitatively by assuming homogeneous Joule heating in the active volume. Instead, 3D effects have to be included even for the seemingly 1D electrical transport pathways between the two electrodes. [1] R. Coehoorn, W. F. Pasveer, P. A. Bobbert, and M. A. J. Michels, Phys. Rev. B **72**, 155206 (2005).

HL 99.6 Fri 10:45 EW 203

Bipolar organic semiconductors: application in thin film transistors and photovoltaic cells — •Andreas Opitz[1,2], Andreas Wilke[1], Norbert Koch[1], Mark Gruber[2], Ulrich Hörmann[2], Matthias Horlet[2], Michael Kraus[2], Julia Wagner[2], and Wolfgang Brütting[2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Institut für Physik, Universität Augsburg

Organic semiconductors used in thin-film devices have traditionally been reported as either electron or hole transporting materials. For this contribution the transport of electrons and holes in molecular semiconductors is analysed in organic field-effect transistors [1]. Additionally the ability of molecular semiconductors to act as donor or acceptor material was investigated [2,3]. Furthermore the device behaviour is compared to the energy levels of the semiconductors [2].

Our findings show that the classical distinction between hole and electron conducting organic semiconductors is mostly related to the suppression of electron transport due to electron traps at oxide surfaces for the former and the impossibility of hole injection into the deep lying HOMO level for the latter. By adjusting the energy levels for injection at the contacts and for exciton dissociation at the organic/organic interface the same molecular semiconductors (e.g. diindenoperylene) can be used as active material in light-emitting transistors and as donor or acceptor material in solar cells with the appropriate counterpart.

[1] M. Horlet et al., Appl. Phys. Lett. 98 (2011) 233304.
[2] J. Wagner et al., Adv. Func. Mater. 20 (2010) 4295.
[3] U. Hörmann et al., phys. stat. sol. RRL 5 (2011) 241.

Coffee Break (15 min)

HL 99.7 Fri 11:15 EW 203

Charge carrier injection properties of the Au-P3HT interface — Shahidul Alam, •Torsten Balster, and Veit Wagner — School of Engineering and Science,Jacobs University Bremen, Campus Ring 1, 28759 Bremen

The contact between the metal and the organic semiconductor is crucial for the device performance of an organic field effect transistors. To study the injection properties of the holes into the organic semiconductor vertical Au/rr-P3HT/Au structures on PET foil has been prepared and investigated in this study.
This structures with an area varying from 0.05 to 1.0 mm^2 and a P3HT film thickness of 270 nm were characterized using I-V-measurements. The devices showed asymmetric I-V curves, which are attributed to the exposure of the bottom Au contact to air during the processing of the sample in contrast to the top electrode, which was sputter coated on the P3HT film. Additional UV-Ozone treatment of the bottom electrode increased the current ratio between forward and reverse bias by a factor of two.
For lower bias voltages (<0.5V) the data were evaluated using thermionic emission and tunneling models. Whereas the latter gives barrier heights of $\approx$ 0.5 V and rather high ideality factors of more than 10, the tunneling model predicts a much smaller barrier. In the space charge limited region the curves were modelled using the mobility model of Vissenberg and Matters.

HL 99.8 Fri 11:30 EW 203

Transport properties of molecular thin films connected by strained nanomembranes — •Carlos Cesar Bof Bufon[1], Celine Vervacke[1], Dominic J. Thurmer[1], Michael Fronk[3], Georgeta Salvan[3], Dietrich R. T. Zahn[3], and Oliver G. Schmidt[1,2] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Material Systems for Nanoelectronics, Chemnitz University of Technology, Reichenhainerstrasse 70, 09107 Chemnitz, Germany — [3]Institute of Physics, Chemnitz University of Technology, Reichenhainerstrasse 70, 09107 Chemnitz, Germany

In this work, rolled-up metallic nanomembranes are used to contact thin film molecular layers (CuPc) with thickness (10nm) smaller than the interdiffusion length of metallic atoms. The fabrication process is based on a recently developed method where strained nanomembranes are used to create hybrid organic/inorganic heterojunctions[1]. The fabricated heterojunction allow us to precisely control and map the charge transport mechanisms in such devices over a wide range of temperatures and electric fields. The transport characteristics of CuPc thin films resembles what have been reported for molecular wires, namely, the transition from activated hopping to tunneling by changing temperature and voltage. In the Au/CuPc/Au heterojunctions the transport is dominated by impurities/defects states at high temperatures and by cooling down, the continuous transition from direct tunneling to resonant tunneling to field emission is obtained by sweeping the voltage bias up. Such a continuous transition has not been reported so far for this type of heterojunction. [1]Bufon,C.C.B., Nano Lett.11,3727 (2011)

HL 99.9 Fri 11:45 EW 203

Seebeck Measurements on Two Air-Stable n-Dopants for C60 — •Torben Menke[1], Peng Wei[2], Debdutta Ray[1], Zhenan Bao[2], Karl Leo[1], and Moritz Riede[1] — [1]Institut für Angewandte Photophysik, TU Dresden, Germany — [2]Department of Chemical Engineering, Stanford University, USA

Thin layers (30nm) of fullerene C60 are doped, using two different air-stable n-dopants with varying doping concentration. Conductivity and thermovoltage (Seebeck) measurements in vacuum are discussed and the influences of doping ratio and temperature are compared to investigate the nature of the doping process. The n-dopants investigated are the commonly used 3,6-bis(dimethylamino)acridine (acridine orange base, AOB) and a novel 1,3-dimethyl-2-phenyl-2,3-dihydro-1H-benzoimidazole derivate (R-DMBI). With increasing doping concentration the Seebeck coefficient is found to decrease, indicating a Fermi energy shift towards the transport state. For both dopants and different doping concentrations the energetic difference between the Fermi energy and the transport level is observed and compared to the thermal activation energy of the conductivity. Both energies show the same trend of a strong reduction with increasing doping concentration, confirming an increase of the free charge carrier density. Conductivity and Seebeck measurements are combined to estimate the mobility of the layers. These results show that R-DMBI is a promising and air-stable n-dopant for replacing AOB in the future.

HL 99.10 Fri 12:00 EW 203

Characterization of Codeposited Pentacene:Perfluoropentacene Thin-Films via Transmission Electron Microscopy — •Benedikt Haas, Katharina I. Gries, Tobias Breuer, Gregor Witte, and Kerstin Volz — Philipps-University Marburg, Faculty of Physics and Materials Science Center, 35032 Marburg, Germany

Organic semiconductors (OSC) are up-and-coming in research and industry. Perfluoropentacene (PFP) is the perfluorinated sibling of the well-known OSC pentacene (PEN), which exhibits high hole mobilities of up to 40 $\frac{cm^2}{(Vs)}$. The two materials are interesting in combination due to the fact that they have a very similar crystal structure but are p-type (PEN) and n-type (PFP) OSCs.

Samples of coevaporated PEN:PFP (grown by organic molecular beam deposition) on alkali halide substrates (KCl, NaF) were investigated using transmission electron microscopy (TEM). Beam damage is very critical for these materials but adequate sample preparation and microscope operation enables one to obtain invaluable information about the morphology and crystalline orientation.

TEM allows for a high spatial resolution of the occurring phase separation, including a 1:1 PEN:PFP mixed phase. The formation of different phases of the segregated PEN has also been evidenced, depending on the substrate used. First results concerning lattice spacings of the PEN:PFP mixed phase have been obtained and are of special interest because x-ray reflectivity analysis has been shown to be hindered due to the intricate phase separation.

HL 99.11 Fri 12:15 EW 203

Scanning Kelvin Probe Microscopy on FIB-milled crosssections in organic semiconductor devices — •Rebecca Saive[1,2], Florian Ullrich[1,2], Lars Müller[1,2], Michael Scherer[1,2], Dominik Daume[1,2], Michael Kröger[1,2,3], and Wolfgang Kowalsky[1,2,3] — [1]InnovationLab GmbH, Heidelberg, Germany — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Germany — [3]Institut für Hochfrequenztechnik, Technische Universität Braunschweig, Germany

Scanning Kelvin Probe Microscopy (SKPM) offers the possibility to measure the surface potential in operating devices and thus revealing the charge carrier transport. We show that SKPM does not necessarily reflect the potential distribution in the region of charge transport but that measurement results are a superposition of all effects occuring in the bulk. Therefore we introduce a method to directly measure in the charge transport region. Via focused ion beam (FIB) we milled our samples and measure the device's crosssections with SKPM. With our combined SEM-FIB crossbeam and SPM microscope we prepare our devices in-situ which avoids surface degradation by water or oxygen.

HL 100: Resistive Switching I (jointly with DS, DF, KR)

Time: Friday 9:30–10:45 Location: H 0111

HL 100.1 Fri 9:30 H 0111

Ab-initio studies of metal-insulator transitions in defective perovskites — •Gustav Bihlmayer and Kourosh Rahmanizadeh — Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Resistive switching in perovskite materials can be triggered by a variety of external stimuli, like electric fields or oxygen partial pressure. While the role of oxygen defects for the electronic transport is in many cases established, the nature of the metal-insulator transition has still to be explored. Density functional theory calculations including strong correlation effects on a model level can help to gain an understanding here.

We investigate the transition between an insulating state of a correlated, localized level and a partially filled conductive band as function of electron concentration. The band filling can be controlled in a chemical way or via electric fields. A ferroelectric polarization can screen or enhance the effects at the boundaries of a ferroelectric material. We study the localization of defect states in model systems of structurally simple perovskites like $SrTiO_3$ or $PbTiO_3$ to gain a coherent picture of the conductive states that are manipulated in the resistive switching process.

Financial support of the EU grant NMP3-LA-2010-246102 (IFOX) is gratefully acknowledged.

HL 100.2 Fri 9:45 H 0111

Elucidation of the resistive switching in $SrTiO_3$ MIM-structures by μXANES — •Christian Lenser[1,2], Alexei Kuzmin[3], Alexandr Kalinko[3], Juris Purans[3], Rainer Waser[1,2,4], and Regina Dittmann[1,2] — [1]Peter Grünberg Institut 7, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Jülich-Aachen Research Alliance, Section Fundamentals of Future Information Technology (JARA-FIT), Germany — [3]Institute of Solid State Physics, University of Latvia, Kengaraga Street 8, LV- 1063 Riga, Latvia — [4]Institut für Werkstoffe der Elektrotechnik, RWTH Aachen, 52056 Aachen, Germany

The resistive switching effect in Fe-doped $SrTiO_3$ thin films is investigated on 100 μm^2 metal-insulator-metal (MIM) structures by chemical mapping in the μm regime. X-ray absorption fine structure (XAFS) - measured at beamline ID03, ESRF - with a x-ray beam focused to several μm provides information about the absorption fine structure modulations at the Fe K-edge. The increase of pre-edge intensity characteristic of oxygen vacancies in the first coordination shell of the transition metal dopant shows the films to be highly oxygen deficient after growth. In addition to an increase of the Fe-$V_O^{\bullet\bullet}$ concentration over the whole electrode area after electroforming, μm-sized mapping of a MIM-structure reveals the location of the conducting filament by a strong local change in the absorption edge, which is localized to a size of the order of 1 μm. The change of the absorption characteristics is interpreted with full multiple-scattering XANES simulations, suggesting oxygen vacancy clustering around Fe as the likely explanation.

HL 100.3 Fri 10:00 H 0111

A ferroelectric switchable tunnel junction: $KNbO_3/SrTiO_3$ — •Kourosh Rahmanizadeh, Gustav Bihlmayer, Daniel Wortmann, and Stefan Blügel — Peter Grünberg Institut (PGI-1) & Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The properties of thin oxide films and multilayers are strongly influenced by defects and, therefore, can be controllably tuned by the defect concentration at the interface. For example, due to the charge discontinuity at the $SrTiO_3$/KO-$KNbO_3$-NbO_2/$SrTiO_3$ interface only one direction of polarization in $KNbO_3$ film is stable. A switchable polarization in $KNbO_3$ can be realized by creating (oxygen) defects at the interfaces.

We carried out density functional theory (DFT) calculations based on the full potential linearized augmented planewave (FLAPW) method as implemented in the `FLEUR` code [1] for studying the polar interface $SrTiO_3/KNbO_3$ and a $SrRuO_3/SrTiO_3/KNbO_3$ tunnel junction. The electronic transport properties of the switchable multiferroic $SrRuO_3/SrTiO_3$/KO-$KNbO_3$-$NbO_3/SrTiO_3/SrRuO_3$ heterostructure have been investigated using an embedded Green-function approach [2]. A strong dependence of the (magneto electric) transport properties on the polarization is observed. The work was conducted under the auspices of the IFOX consortia under grant agreement NMP3-LA-2010-246102.

[1] http://www.flapw.de
[2] D. Wortmann, H. Ishida, and S. Blügel, PRB **66**, 075113 (2002)

HL 100.4 Fri 10:15 H 0111

Resistive switching in different forming states of Ti/$Pr_{0.48}Ca_{0.52}MnO_3$ junctions — •Chanwoo Park[1], Anja Herpers[1], Rainer Bruchhaus[1], Johan Verbeeck[2], Ricardo Egoavil[2], Francesco Borgatti[3], Giancarlo Panaccione[4], Francesco Offi[5], and Regina Dittmann[1] — [1]PGI-7, FZ Jülich — [2]EMAT, University of Antwerp, Belgium — [3]ISMN-CNR, Bologna, Italy — [4]Laboratorio Nazionale TASC-INFM-CNR, Trieste, Italy — [5]CNISM and Dipartimento di Fisica, Università Roma Tre, Rome, Italy

We investigated the resistive switching (RS) characteristics of Ti/$Pr_{0.48}Ca_{0.52}MnO_3$ (PCMO) junctions. RS characteristics were observed after a first forming (1stF) procedure, which changes the initial resistance state to a high resistance state (HRS) which shows a clear area dependence. By performing Hard X-ray Photoelectron Spectroscopy for different resistive states, we found a change of the Ti2p peak intensity after the 1stF which is associated with the formation of TiO_2 at the interface. Moreover, the shape and position of the Mn2p peak hints on the reduction of Mn. The formation of TiO_x at the Ti/PCMO interface after the 1stF was confirmed by cross-sectional Transmission Electron Microscope investigations. The results indicate that the 1stF step is related to a redox process at the Ti/PCMO interface. Moreover, we were able to perform a second forming step which changes the HRS to the low resistance. The area dependence disappeared after the second forming. This implies that conducting filaments might form at the Ti/PCMO interface.

HL 100.5 Fri 10:30 H 0111

Remanent resistance changes in metal- PrCaMnO-metal sandwich structures — •Malte Scherff, Bjoern Meyer, Julius Scholz, Joerg Hoffmann, and Christian Jooss — Institute of Materials Physics, University of Goettingen, Germany

The non-volatile electric pulse induced resistance change (EPIR) seems to be a rather common feature of oxides sandwiched by electrodes. However, microscopic mechanisms are discussed controversially. We present electrical transport measurements of sputtered $Pr_{0.7}Ca_{0.3}MnO_3$ films sandwiched by metallic electrodes with variation of electrode materials, device geometry and PCMO deposition parameters. Cross-plane transport measurements have been performed as function of temperature and magnetic field. Specifically, the transition from dynamic resistance changes due to non-linear transport to remanent switching is analyzed. By analyzing changes of magnetoresistance at low temperatures in different resistance states we aim for separation between interface and film contributions to switching. Comparing switching behavior in symmetric and asymmetric electrode configuration allows for identification of the active, single interface in the switching process and the origin of an observed switching polarity inversion[1]. The influence of excitation field and power on the switching characteristics of different noble metal electrodes is discussed. Samples from macroscopic devices and in situ stimulated sandwich structures were studied in a transmission electron microscope in order to investigate the induced structural, chemical and electronic changes. [1] M. Scherff et al, J.Appl.Phys. 110, 043718 (2011)

HL 101: Transport: Nanoelectronics II - Spintronics and Magnetotransport (jointly with TT, MA)

Time: Friday 9:30–12:00 Location: BH 243

HL 101.1 Fri 9:30 BH 243

Adiabaticity mediated mesoscopic spin transport — •Tobias Dollinger, Henri Saarikoski, and Klaus Richter — Universität Regensburg, Germany

We examine mesoscopic transport in ballistic and diffusive waveguide geometries with Zeeman coupling by means of a numerical recursive Green's function algorithm and interprete the results using a semiclassical transport formalism. Our discussion is focused on analyzing magnetoconductance traces of two-dimensional systems with spatially nonuniform magnetic moment. We illustrate how controlling magnetic field textures within a sample allows for an efficient manipulation of spin transmission properties, which are determined by nonadiabatic transition probabilities.

HL 101.2 Fri 9:45 BH 243

Electronic transport through EuO spin filter tunnel junctions — •Nuttachai Jutong[1], Ivan Rungger[2], Stefano Sanvito[2], Udo Schwingenschlögl[3], and Ulrich Eckern[1] — [1]Institut für Physik, Universität Augsburg, 86135 Augsburg, Germany — [2]School of Physics and CRANN, Trinity College Dublin, Dublin, Ireland — [3]KAUST, PSE Division, Thuwal 23955-6900, Kingdom of Saudi Arabia

Spin filter tunnel junctions based on europium monoxide (EuO), a ferromagnetic semiconductor, are investigated by means of density functional theory. In particular, the spin transport of Cu/EuO/Cu junctions is investigated by using the self-consistent ab-initio electron transport code SMEAGOL. The dependence of the transmission coefficient on the interface spacing and on the EuO thickness is studied, and explained in terms of the density of states and the complex band structure of EuO. Our calculation indicates that EuO epitaxially grown on Cu can act as a perfect spin filter, with polarization close to 100%, which is related mainly to the Eu-4f states. The transmission coefficient is sensitive to the interface spacing, since this spacing determines the charge transfer between EuO and the Cu leads.

HL 101.3 Fri 10:00 BH 243

Spin transistor action from Onsager reciprocity and SU(2) gauge theory — Inanc Adagideli[1], •Vitalij Lutsker[2], Matthias Scheid[2], Philippe Jacquod[3], and Klaus Richter[2] — [1]Faculty of Engineering and Natural Sciences, Sabanci University, Istanbul, Turkey — [2]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [3]Physics Department, University of Arizona, Tucson, USA

We construct a local gauge transformation to show how, in confined systems, a generic, weak non-homogeneous $SU(2)$ spin-orbit Hamiltonian reduces to two $U(1)$ Hamiltonians for spinless fermions at opposite magnetic fields, to leading order in the spin-orbit strength. Using an Onsager relation, we further show how the resulting spin conductance vanishes in a two-terminal setup, and how it is turned on by either weakly breaking time-reversal symmetry or opening additional transport terminals. We numerically check our theory for mesoscopic cavities as well as Aharonov-Bohm rings.

HL 101.4 Fri 10:15 BH 243

Magnetic impurities on Bi thin films — •Daniel Lükermann[1], Sergii Sologub[2], Christoph Tegenkamp[1], and Herbert Pfnür[1] — [1]Leibniz Universität Hannover, Institut für Festkörperphysik, Appelstr. 2, 30167 Hannover — [2]Institute of Physics, National Ac. of Sc. Ukraine, Nauky Av. 46, 03028 Kyiv, Ukraine

The semimetal bismuth has attracted a lot of interest because of its unique electronic properties such as a low carrier concentration and a large mobility. Furthermore, the surface states reveal a pronounced Rashba splitting and the conductivity can be well discriminated from bulk contributions if thin films are grown on Si(111) substrates, making surface related effects accessible even in macroscopic conductance measurements.

In order to elucidate the effect of spin-related scattering at impurities, magnetic and non-magnetic metals were adsorbed on thin films of epitaxially grown Bi(111) and investigated by means of conductance and magneto-conductance measurements. We observe a very strong reduction of conductance by roughly 30 % for adsorbate concentrations of less than 2% of a monolayer both for Bi- and Co-atoms, whereas Fe-atoms only show an effect of 15 %, ruling out the simple assumption of enhanced spin-flip-scattering of the spin-polarized carriers at magnetic impurities. An evaluation of magneto-conductance and Hall-effect data reveals that the charge transfer from the impurity atoms into the surface states of bismuth plays an important role and can not be neglected in interpreting the data.

HL 101.5 Fri 10:30 BH 243

Adiabatic pumping through an interacting quantum dot with spin-orbit coupling — •Stephan Rojek[1], Jürgen König[1], and Alexander Shnirman[2] — [1]Theoretische Physik, Universität Duisburg-Essen and CeNIDE, 47048 Duisburg, Germany — [2]Institut für Theorie der Kondensierten Materie and DFG-Center for Functional Nanostructures (CFN), Universität Karlsruhe, 76128 Karlsruhe, Germany

We study adiabatic pumping through a two-level quantum dot coupled to two normal metallic leads in the presence of spin-orbit coupling. The variation of the two energy levels of the dot periodically in time leads to finite charge and spin currents.

We calculate the pumped charge and spin using a diagrammatic real-time approach [1]. Going beyond the limit of noninteracting electrons on the quantum dot [2], we study the situation of strong Coulomb interaction. In both limits of noninteracting and strongly interacting electrons, spin-orbit coupling provides the possibility for pure spin current. We introduce an isospin to describe the level degree of freedom. This isospin feels an exchange field similar to the exchange field in a quantum-dot spin valve. The exchange field originates form the Coulomb interaction and its strength is sensitive to the symmetry in the tunneling matrix elements. New features concerning the pure spin pumping as well as the absolute pumped charge of the two-level quantum dot with spin-orbit coupling arises from the Coulomb interaction.

[1] J. Splettstoesser *et al.*, Phys. Rev. B **74**, 085305 (2006).
[2] V. Brosco *et al.*, Phys. Rev. B **82**, 041309(R) (2010).

15 min. break.

HL 101.6 Fri 11:00 BH 243

Anomalous Hall conductivity in Ni and its alloys — •D. Ködderitzsch, K. Chadova, J. Minar, and H. Ebert — Universität München, Department Chemie, Butenandtstraße 5-13, D-81377 München, Germany

The anomalous Hall conductivity (AHC) in Ni as discussed on the basis of the intrinsic contribution shows a strong overestimation of the AHC [1]. Recent studies using the LSDA+U approximation seem to remedy this problem [2]. However, still missing is taking into account the temperature dependence of the AHC which has recently been re-investigated [3] and changes the picture.

Using our recently implemented [4] first-principles approach to describe transverse transport based on the Kubo-formalism in the Kubo-Středa formulation we study the anomalous Hall conductivity (AHC) in Ni. To take into account the effect of correlations we extended our method to employ the LSDA+U, as well as the LSDA+DMFT to go beyond the LSDA approximation to DFT. Furthermore, we study the influence of finite temperatures on the AHC by using an alloy-analogy for a quasistatic representation of the thermal displacements of the atoms. In addition, we performed calculations for dilute impurities in the Ni host.

[1] Nagaosa *et al.* Rev. Mod. Phys. **82**, 1539 (2010) and references therein
[2] Weischenberg *et al.* PRL **107**, 106601 (2011); Fuh and Guo PRB **84**, 144427 (2011)
[3] Xiao, Jin
[4] Lowitzer, Gradhand, Fedorov, Mertig, Ködderitzsch, Ebert, PRL **105**, 266604 (2010) and PRL **106**, 056601 (2011)

HL 101.7 Fri 11:15 BH 243

Investigation of magnetic point contacts irradiated by microwave and THz radiation — •Stefan Egle, Torsten Pietsch, and Elke Scheer — Department of Physics, University of Konstanz

The growing field of spintronics became one of the most intensively studied topics in modern solid-state physics. The possibility not only exploiting the charge of an electron, but also its spin (or magnetic moment), offers the possibility to explore various interesting effects. In this talk, we investigate magnetic point contacts and heterostructures, where a ferromagnet (F) acts as a spin polarizer, injecting hot electrons into a non-magnetic metal (N) or a diluted ferromagnet (f). Thereby, an external magnetic field in case of N is used to generate a Zeeman-splitting between spin-up and spin-down electrons. In case of F/f-contacts, this energy splitting ΔE is given by the exchange energy of f. These energies correspond to electromagnetic frequencies in the GHz (N) and THz regime (f). The highly non-equilibrium spin-population of F is then used to create a spin inversion in N or f, leading to a spin-flip photon emission. By matching the resonant condition hν=ΔE and using an external source in the microwave and THz range, theory predicts an induced spin lasing effect in N/f. Presently, we investigate the influence of the external irradiation on the electronic resistance via transport spectroscopy. In particular, we will present our measurements on the magnetotransport properties, studying the complex interplay between the crucial parameters, namely magnetization, current density and geometry of the point contacts. The results illustrate that a successful spin-population inversion can be detected.

HL 101.8 Fri 11:30 BH 243

Gate dependent TMR-effect in a SWCNT-based spin valve device with exchange biased ferromagnetic contacts — Andreas Prüfling, •Daniel Steininger, Maurice Ziola, Matthias Sperl, Andreas K. Hüttel, and Christoph Strunk — Universität Regensburg, Germany

We report on magneto-transport measurements on a single wall carbon nanotube based spin valve device with Permalloy ($Ni_{81}Fe_{19}$) and $Ni_{81}Fe_{19}/Fe_{50}Mn_{50}$ bilayer contacts. Sputtered thin films and EBL-patterned strip-arrays of these materials were characterized by means of vibrating sample- and SQUID magnetometry and optimized by varying both layer thickness ratios, and material grain size via the sputtering power. Utilizing the magnetic exchange bias effect in these ferromagnet/anti-ferromagnet bilayer systems, the difference in cooercive fields of our contacts is sufficently large to achieve controllable independent switching of two contacts by an external magnetic field. Magneto-transport measurements performed in the Coulomb blockade- and Kondo regime of a SWCNT quantum dot device show systematic gate dependence of the tunneling magnetoresistance (TMR) when the gate voltage is scanned through several Coulomb diamonds.

HL 101.9 Fri 11:45 BH 243

Rotating skyrmion lattices by spin torques and field gradients — •Karin Everschor[1], Markus Garst[1], Benedikt Binz[1], Christian Pfleiderer[2], and Achim Rosch[1] — [1]Institute for Theoretical Physics, University of Cologne, Germany — [2]Physics-Department E21, Technical University Munich, Germany

Chiral magnets like MnSi form lattices of skyrmions, i.e. magnetic whirls, which react sensitively to small electric currents. The interplay of these currents and thermal gradients can induce either a rotation of the magnetic pattern by a finite angle or – for higher current densities or larger gradients – a steady rotation defined by a constant angular velocity. We develop a theory of rotational forces induced by gradients in magnetic field or temperature. Reactive forces (Magnus and Lorentz forces) arise from Berry phases while several mechanisms affect the dynamics of magnets by damping. We use the Landau Lifshitz Gilbert equation extended by extra damping terms in combination with a phenomenological treatment of pinning forces to develop a theory of the relevant rotational torques.

HL 102: Transport: Graphene 2 (jointly with TT, MA, DY, DS, O)

Time: Friday 9:30–12:45 Location: BH 334

HL 102.1 Fri 9:30 BH 334

Transport study of graphene with artificially induced defects — •Verena Martin, Johannes Jobst, Michael Krieger, and Heiko B. Weber — Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg, Staudtstr. 7, 91058 Erlangen

We report on transport properties of ion irradiated graphene which is grown epitaxially on 6H semi-insulating silicon carbide (SiC) substrate. We investigate both monolayer graphene [1] and quasi-free standing epitaxial graphene [2]. Subsequent irradiation steps of argon and carbon ions with different ion energies into the graphene/SiC stack are performed at low temperature (4K) and room temperature. The resistivity of the graphene layer is monitored in situ. After each irradiation step temperature dependent measurements and magnetoresistance measurements are performed to study the effect of the damage. An increase of resistivity with decreasing temperature as well as a broadening of the weak localization peak could be correlated to an increase of the defect amount.

[1] K. Emtsev et al., Nat. Mater. **8**, 203 (2009)
[2] C. Riedl et al., Phys. Rev. Lett. **103**, 246804 (2009)

HL 102.2 Fri 9:45 BH 334

Inelastic Raman scattering on electronic excitations in graphene and carbon nanotubes — •Oleksiy Kashuba[1] and Vladimir Fal'ko[2] — [1]Institut für Theorie der statistischen Physik, RWTH Aachen, 52056 Aachen, Deutschland — [2]Department of Physics, Lancaster University, Lancaster, LA1 4YB, UK

Raman measurements in carbon allotropes are generally associated with the exploration of the vibrational modes. We present a theory of the non-resonant inelastic light scattering accompanied by the excitations of electron-hole pairs and predict the selection rules and polarization properties of the dominant Raman active modes. The prediction of the Raman plot profile for graphene at high magnetic field with pronounced peaks corresponding to the inter-Landau-level transitions [1,2] was confirmed by subsequent experiment [3]. We also provide a theory of Raman scattering on intersubband electron-hole pairs in large diameter carbon nanotubes predicting dominant polarisations and Raman spectra featuring a pattern of van Hove singularities [4].

[1] O. Kashuba and V. I. Fal'ko, Phys. Rev. B 80, 241404(R) (2009).
[2] M. Mucha-Kruczyński, O. Kashuba, and V. I. Fal'ko, Phys. Rev. B 82, 045405 (2010).
[3] C. Faugeras et. al., Phys. Rev. Lett. 107, 036807 (2011).
[4] O. Kashuba and V. I. Fal'ko, submitted to PRL (2011), arXiv:1111.1413

HL 102.3 Fri 10:00 BH 334

Transport in clean side-gated graphene nanoribbons — •Bernat Terrés[1,2], Jan Dauber[1,2], Uwe Wichmann[1], Stefan Trellenkamp[2], and Christoph Stampfer[1,2] — [1]JARA-FIT and II. Institute of Physics B, RWTH Aachen, 52074 Aachen, Germany — [2]Peter Grünberg Institut (PGI-8/9), Forschungszentrum Jülich, 52425 Jülich, Germany

Graphene is a two dimensional form of crystalline carbon with unique electrical properties. However, due to its gap-less nature it is hardly possible to implement concepts of state-of-the-art electronic devices. Recently, it has been shown that by tailoring graphene into narrow ribbons an effective band gap can be induced. Extensive studies have been reported on the transport mechanism in graphene nanoribbons and although being successfully demonstrated as tunneling barriers in quantum dots, graphene nanoribbons show a Coulomb blockade dominated transport behavior. In this work we report on the effects of a symmetrically applied side gate voltage on clean (hydrofluoric acid treated) graphene nanoribbons. In particular we show low-temperature experiments where the overall conductance can be tuned up to a level of about $8e^2/h$. Measurements show evidence that the local resonances in the transport gap can be strongly suppressed by adjusting the side-gate voltages. In summary, the high conductance values together with the observation of onsets of quantized conductance plateaus at integer multiples of $2e^2/h$ indicates that the disorder potential can be dramatically reduced, even though the transport mechanism is still mainly dominated by substrate and rough-edge induced disorder.

HL 102.4 Fri 10:15 BH 334

Coulomb drag in graphene: perturbation theory — •Boris Narozhny[1], Michael Titov[2,3], Igor Gornyi[3,4], and Pavel Ostrovsky[3,5] — [1]Institut für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie, 76128 Karlsruhe, Germany — [2]School of Engineering and Physical Sciences, Heriot-Watt Univer-

sity, Edinburgh EH14 4AS, UK — [3]Institut für Nanotechnologie, Karlsruher Institut für Technologie, 76021 Karlsruhe, Germany — [4]A.F. Ioffe Physico-Technical Institute, 194021 St. Petersburg, Russia — [5]L.D. Landau Institute for Theoretical Physics RAS, 119334 Moscow, Russia

We study the effect of Coulomb drag between two closely positioned graphene monolayers. In the limit of weak electron-electron interaction and small inter-layer spacing d ($\mu_{1(2)}, T \ll v/d$) the drag is described by a universal function of the chemical potentials of the layers $\mu_{1(2)}$ measured in the units of temperature T. When both layers are tuned close to the Dirac point, then the drag coefficient is proportional to the product of the chemical potentials $\rho_D \propto \mu_1\mu_2$ (when any of the layers is precisely at the Dirac point, then the drag vanishes due to electron-hole symmetry). In the opposite limit of low temperature the drag is inversely proportional to both chemical potentials $\rho_D \propto T^2/(\mu_1\mu_2)$. In the mixed case where the chemical potentials of the two layers belong to the opposite limits $\mu_1 \ll T \ll \mu_2$ we find $\rho_D \propto \mu_1/\mu_2$. In the case of strongly doped graphene $\mu_{1(2)} \gg v/d \gg T$ the drag coefficient acquires additional dependence on d and we recover the usual Fermi-liquid result if the screening length is smaller than d.

HL 102.5 Fri 10:30 BH 334

Dirac boundary condition at the reconstructed zigzag edge of graphene — Jan van Ostaa, Anton Akhmerov, Carlo Beenakker, and •Michael Wimmer — Instituut-Lorentz, Universiteit Leiden, The Netherlands

Edge reconstruction modifies the electronic properties of finite graphene samples. We formulate a low-energy theory of the reconstructed zigzag edge by deriving the modified boundary condition to the Dirac equation. If the unit cell size of the reconstructed edge is not a multiple of three with respect to the zigzag unit cell, valleys remain uncoupled and the edge reconstruction is accounted for by a single angular parameter ϑ. Dispersive edge states exist generically, unless $|\vartheta| = \pi/2$. We compute ϑ from a microscopic model for the "reczag" reconstruction (conversion of two hexagons into a pentagon-heptagon pair) and show that it can be measured via the local density of states. In a magnetic field there appear three distinct edge modes in the lowest Landau level, two of which are counterpropagating.

HL 102.6 Fri 10:45 BH 334

Dielectric properties of graphene in the presence of spin-orbit interactions — •Andreas Scholz[1], John Schliemann[1], and Tobias Stauber[2] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Departamento de Fisica de la Materia Condensada and Instituto Nicolas Cabrera, Universidad Autonoma de Madrid. E-28049 Madrid. Spain

We study the dielectric function of graphene in the presence of pseudo-Rashba and intrinsic spin-orbit interactions (SOI) for arbitrary frequency, wave vector, doping, and spin-orbit coupling (SOC) parameters. In the static limit, the asymptotic behavior of the screened potential due to charged and magnetic impurities is derived. Due to the existence of a sharp Fermi surface in doped graphene, the screened potential exhibits characteristic (Friedel) oscillations. These oscillations are absent in the undoped case. An analytical expression for the plasmon dispersion is derived from the long-wavelength limit of the dielectric function and afterwards compared to the numerical result. For finite SOC parameters we find the existence of several new plasmon modes. Several limiting cases, namely the case of pure Rashba or pure intrinsic SOC, the case of equally large Rasbha and intrinsic coupling and of zero SOC are opposed.

15 min. break.

HL 102.7 Fri 11:15 BH 334

Monolithic Epitaxial Graphene Electronics — •Stefan Hertel[1], Daniel Waldmann[1], Johannes Jobst[1], Sergey Reshanov[2], Adolf Schöner[2], Michael Krieger[1], and Heiko B. Weber[1] — [1]Chair of Applied Physics, Erlangen, Germany — [2]ACREO AB, Kista, Sweden

We developed a scheme to fabricate transistors with high switching performance by employing the whole system epitaxial graphene consisting of the graphene itself, but also include the semiconducting silicon carbide substrate and their common interface.

We used n-type SiC as conducting channel and tailored two different interfaces to the graphene: (a) monolayer epitaxial graphene [1] to provide ohmic contacts and (b) quasi-freestanding bilayer graphene [2](as achieved by hydrogen intercalation of MLG) to get Schottky-like contacts. We developed a method to produce both species side-by-side on the same chip. The resulting transistor works similar to a MeSFET with graphene as source and drain material but also as gate metal. In principal one single lithography step is sufficient to fabricate a transistor.

We demonstrate an epitaxial graphene transistor with on/off ratios exceeding 4 orders of magnitude at room temperature which can operate in both normally-on and normally-off operation mode, adjustable using a parametric backgate voltage. No damping was observed up to MHz frequencies.

[1] Emtsev et al., Nature Material **8**, 203-207 (2009).
[2] Speck et al., Applied Physics Letters **99**, 122106 (2011).

HL 102.8 Fri 11:30 BH 334

Field Effect Superconductivity in Multigraphene — •Ana Ballestar[1], Srujana Dusari[1], Jose Barzola-Quiquia[1], Pablo Esquinazi[1], Robson da Silva[2], and Yakov Kopelevich[2] — [1]Division of Superconductivity and Magnetism, Institut für Experimentelle Physik II, Universität Leipzig, Linnéstraße 5, D-04103 Leipzig, Germany — [2]Instituto de Fisica, Unicamp, 13083-970 Campinas, Sao Paulo, Brasil

We have studied the temperature and magnetic field dependence of the electrical resistivity of mesoscopic tens of nanometers thick multigraphene samples as a function of bias voltage applied perpendicular to the graphene planes. We found that the resistivity changes asymmetrically with the bias voltage. For large and negative bias voltages the resistivity shows non-percolative superconducting-like transitions at $T \sim 15 \ldots 20$ K . The transition can be suppressed at high enough magnetic fields applied normal or parallel to the main plain of the samples. We discuss the obtained results in terms of electric field induced superconductivity at localized near surface regions of the graphite sample.

HL 102.9 Fri 11:45 BH 334

Graph theory meets ab-initio molecular dynamics: atomic structures and transformations at the nanoscale — •Fabio Pietrucci[1] and Wanda Andreoni[1,2] — [1]CECAM - EPFL Lausanne, Switzerland — [2]Institute of Theoretical Physics - EPFL Lausanne, Switzerland

We introduce a set of Social PeRmutation INvarianT (SPRINT) coordinates which describe the topology of the network of bonds among atoms [1]. These coordinates are obtained from the contact matrix, they are invariant under permutation of identical atoms, and provide a clear signature of the transition between ordered and disordered structures. In combination with first-principles molecular dynamics and metadynamics, the topological coordinates are employed to explore low-energy structures of silicon clusters and organic molecules, demonstrating the possibility of automatically simulating isomerization, association, and decomposition reactions without prior knowledge of the products or mechanisms involved.

Finally we discuss the application of this new approach to the simulation of carbon nanostructures: we obtain transformation pathways for the reconstruction of zig-zag edges of graphene ribbons to 5-7 rings, as well as the folding of graphene into fullerene-like cages. Our results show that it is now feasible the blind exploration of complex structural rearrangements of nanostructures at finite temperature and at density-functional theory level of accuracy.

[1] F. Pietrucci and W. Andreoni, Phys. Rev. Lett. 107 (2011) 085504.

HL 102.10 Fri 12:00 BH 334

Localization behavior of Dirac particles in disordered graphene superlattices — Qifang Zhao[1], Jiangbin Gong[1], and •Cord Müller[2] — [1]Department of Physics and Centre for Computational Science and Engineering, National University of Singapore — [2]Centre for Quantum Technologies, National University of Singapore

Graphene superlattices (GSLs) can be used to engineer band structures and, from there, charge transport properties, but these are sensitive to the presence of disorder. We study the localization behavior of massless 2D Dirac particles induced by weak disorder for both scalar-potential and vector-potential GSLs. By an analytical weak-disorder expansion, we investigate how the localization length depends on the incidence angle to a 1D GSL. Delocalization resonances are found for both scalar and vector GSLs. The sharp angular dependence of the Lyapunov exponent may be exploited to realize disorder-induced filtering devices [1].

[1] Q. Zhao, J. Gong, and C. A. Müller, `arXiv:1111.3436`

HL 102.11 Fri 12:15 BH 334

Thermal Transport in Graphene: a Large-scale Molecular Dynamics Study — •Luiz Felipe C Pereira and Davide Donadio — Max Planck Insitute for Polymer Research, Mainz, Germany.

Carbon-based materials show exceptional thermal properties. The thermal conductivity of carbon allotropes can range five orders of magnitude. In the bulk, amorphous carbon is a very poor heat conductor, with $\kappa \approx 0.01$ W/m/K, whereas diamond has the highest thermal conductivity among elemental solids, $\kappa \approx 2000$ W/m/K at room temperature. Carbon nanostructures extend the range even further. Thermal conductivities as large as 5000 W/m/K have been measured for suspended graphene and carbon nanotubes. Nonetheless, there is still much controversy over the thermal transport properties of graphene, both experimentally and theoretically. We have performed extensive equilibrium and non-equilibrium molecular dynamics simulations aimed at understanding the mechanism of heat transport in graphene. In order to address the influence of system size on the simulation results, an aspect frequently overlooked in similar computational studies, we perform large scale molecular dynamics simulations of micrometer-size models containing more than 10^6 atoms. Furthermore, we investigate the influence of uniaxial strain on the thermal conductivity of graphene, and show that the resulting strain-induced anysotropy has a profound influence on its thermal conductivity.

HL 102.12 Fri 12:30 BH 334

Effect of short-range interactions on the phase diagram of graphene — •David Mesterhazy[1], Jürgen Berges[1], and Lorenz von Smekal[2] — [1]Institut für Theoretische Physik, Universität Heidelberg — [2]Institut für Kernphysik, Technische Universität Darmstadt

We study low-energy theories of suspended monolayer graphene at the charge neutral point by means of functional renormalization group methods. In particular, the role of residual short-range interactions for the expected chiral phase transition is investigated. The resulting effective low-energy description can provide a firm basis for a study of the universal properties of the quantum phase transition. Furthermore, first results for the phase diagram at finite temperature are presented.

HL 103: Resistive Switching II (jointly with DS, DF, KR)

Time: Friday 11:00–12:30 Location: H 0111

HL 103.1 Fri 11:00 H 0111

Resistive switching mechanism of Ti/HfO_2/TiN RRAM cells studied by nondestructive hard x-ray photoelectron spectroscopy — •Małgorzata Sowińska[1], Thomas Bertaud[1], Damian Walczyk[1], Christian Walczyk[1], Sebastian Thiess[2], Wolfgang Drube[2], and Thomas Schroeder[1] — [1]IHP, Im Technologiepark 25, 15236 Frankfurt/Oder, Germany — [2]DESY, Notkestrasse 85, 22607 Hamburg, Germany

A variety of different metal-insulator-metal (MIM) multilayered structures reveal reversible changes in resistance upon applying bias voltages across the layers. The physical mechanism of this resistive switching effect in such MIM cells is mostly unknown up to nowadays, although different models depending on the switching behaviour (unipolar or bipolar) and the conducting path type (filamentary or interface) have been proposed. In order to identify whether the resistance variation in the Ti/HfO_2/TiN system is related to local changes in the chemistry or to charge distribution we performed ex-situ and in-situ hard x-ray photoelectron spectroscopy (HAXPES) studies. This technique is well suited for investigating the buried interface of our resistive random access memory (RRAM) cell in a nondestructive way. In result, spectral differences observed between as-deposited and electrically switched devices lead us to the conclusion that the Ti/HfO_2 interface was modified, which can be associated with an interface-type model. Furthermore, we have also better revealed the impact of the current compliance on the HAXPES spectra of our device.

HL 103.2 Fri 11:15 H 0111

Pulse-induced resistive switching of CMOS embedded HfO_2-based 1T1R cells — •damian walczyk, christian walczyk, thomas bertaud, małgorzata sowińska, mindaugas lukosius, steffen kubotsch, thomas schroeder, and christian wenger — IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany.

Low-cost embedded nonvolatile memories (eNVMs) with high-density, high-speed, and low-power are of interest for many different system applications in Si-based CMOS technologies, including consumer electronics, high-end and mobile computing, various sensor and medical health care devices. The rising importance of embedded NVM technologies in recent years has pushed Resistance change Random Access Memory (RRAM) into the spotlight. However, despite numerous integration efforts, the driving mechanism for the resistive switching effect of HfO_2-based RRAM is still under debate [1]. Progress in the development has mainly been delayed due to the lack of control over the switching parameters. To achieve an application relevant endurance, the capability to control the resistance by an access device is addressed in this talk. Moreover, this work considers the pulse-induced resistive switching of memory cells with an area down to $1 \times 1\ \mu m^2$. It is observed that the pulse width range for the set process is between 60 ns and 80 ns while the reset encompasses a pulse width range of 10-30 μs. Due to the intrinsic current compliance of the access transistor, low set currents of 10 μA and reset currents of 1 μA are obtained.

[1] C. Walczyk et al., IEEE Trans. Electron. Devices, vol. 58, no. 9, pp. 3124-3131 (2011).

HL 103.3 Fri 11:30 H 0111

Resistive switching on HfO_2-based metal-insulator-metal structures: effects of the top metal electrode and the oxygen partial pressure — •Thomas Bertaud[1], Damian Walczyk[1], Christian Walczyk[1], Steffen Kubotsch[1], Malgorzata Sowinska[1], Thomas Schroeder[1], Christophe Vallée[2], Vincent Jousseaume[3], and Christian Wenger[1] — [1]IHP, Im Technologiepark 25, 15236 Frankfurt Oder, Germany — [2]LTM Université Joseph Fourier, 17 Rue des Martyrs 38054 Grenoble, France — [3]CEA-LETI Minatec, 17 Rue des Martyrs 38054 Grenoble, France

Embedded nonvolatile memories (eNVM) are attractive for a growing number of applications. One promising candidate for next-generation eNVM is based on the electrically switchable resistance change between a high and a low resistive state of a metal-insulator-metal (MIM) structure, called resistance random access memory (RRAM). Due to the cost effectivity and BEOL compatibility with (Bi)CMOS technologies, this approach is highly attractive. In this talk, the resistive switching on HfO_2/bottom TiN based devices will be demonstrated. The work is focused on the impact of the top metal electrode on the switching behavior of the RRAM devices: Al, Hf and Ti (reactive non-blocking), and Cu, Pt and Au (non-reactive blocking) are used and lead to bipolar or unipolar switching, respectively [1]. The current and capacitance characteristics of the MIM diodes are studied by voltage sweeps and retention measurements under different gas ambient in order to highlight the effect of the oxygen partial pressure for a better understanding of the mechanism. [1] T. Bertaud et al., Thin Solid Films (2011).

HL 103.4 Fri 11:45 H 0111

A model for a non-volatile memory material: First principles study of Cu diffusion in α-cristobalite and α-quartz — •Martin Zelený[1], Jozsef Hegedüs[1], Adam. S. Foster[2], David. A. Drabold[3], Stephen. R. Elliott[4], and Risto. M. Nieminen[1] — [1]COMP/Dept. of Applied Physics, Aalto University School of Science, Espoo, Finland — [2]Dept. of Physics, Tampere University of Technology, Tampere, Finland — [3]Dept. of Physics and Astronomy, Ohio University, Athens, USA — [4]Dept. of Chemistry, University of Cambridge, Cambridge, UK

The switching mechanism of a new type of non-volatile memories can be based on electrochemical metallization occurring due to the migration of Ag or Cu ions in oxide glasses as for example SiO_2. In order to clarify this mechanism, we have performed simulations of Cu diffusion in the different modifications of SiO_2. All calculations in our study were carried out based on first-principles density-functional theory using the Vienna Ab initio Simulation Package (VASP).

We present a total-energy calculation of the barrier along a diffusion path of Cu between two equivalent interstitial positions in α-cristobalite and α-quartz. Our results for α-cristobalite show that the shape of the path strongly depends on the charge of the system, but the height of the migration barrier stays between 0.15-0.2 eV. On the

other hand, the height of the barrier in α-quartz varies between 0.1 and 0.6 eV and depends on the directions of Cu motion. We also present results of molecular dynamics simulations of the drift of a Cu atom driven by an external electric field.

HL 103.5 Fri 12:00 H 0111

Transient Processes in Response to Electronic Excitation of Phase Change Materials — •Martin Salinga and Martin Wimmer — 1. Institut of Physics, RWTH Aachen University, Germany

In recent years a strong interest in phase change materials has been aroused by their potential for being utilized as the core element of a promising novel electronic memory technology. For such an application it is crucial to understand the characteristic switching mechanisms. Especially the electronic properties of the amorphous phase are of paramount importance. Thus, the strong non-linearity in the current-voltage-dependence of the amorphous phase, often referred to as threshold-switching, has drawn much attention.

In this work the transient current response of vertical Ge2Sb2Te5 devices to controlled voltage excitations is experimentally studied down to a time-scale of a few nanoseconds and analyzed with a particular focus on the delay-time before threshold switching and its dependence on the applied voltage. The results are compared to both experimental and theoretical studies in the literature and their implications for this field of research are discussed.

HL 103.6 Fri 12:15 H 0111

Nonvolatile resistive switching in Au/BiFeO3 rectifying junction — •Yao Shuai[1,2], Chuangui Wu[2], Wanli Zhang[2], Shengqiang Zhou[1], Danilo Bürger[1], Stefan Slesazeck[3], Thomas Mikolajick[3], Manfred Helm[1], and Heidemarie Schmidt[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, P. O. Box 510119, Dresden 01314, Germany — [2]State Key Laboratory of Electronic Thin Films and Integrated Devices, Chengdu, China — [3]Namlab gGmbH, Nöthnitzer Strasse 64, 01187 Dresden, Germany

BiFeO3 thin films have been grown on Pt/Ti/SiO2/Si substrates with pulsed laser deposition. RF sputtered Au has been used for the top electrode. The transport properties of the BiFeO3 thin films have been previously demonstrated to be sensitive to the interface [1]. In the present work, an interface-related resistive switching behavior with large switching ratio up to 4500 has been observed in the Au/BiFeO3/Pt structure [2]. The different polarities of the external voltage induce an electron trapping or detrapping process, and consequently change the depletion layer width below the Au Schottky contact, which is revealed by capacitance-voltage measurements and by long-term low/high resistance state capacitance transient measurements at zero bias [3]. [1] Y. Shuai et al., Appl. Phys. Lett., 98, 232901 (2011). [2] Y. Shuai et al., Appl. Phys. Express. 4, 095802 (2011). [3] Y. Shuai et al., J. Appl. Phys. 109, 124117 (2011).

HL 104: Quantum Dots and Wires: Optical Properties V (mainly Indiviual Photons)

Time: Friday 11:45–14:00 Location: EW 201

HL 104.1 Fri 11:45 EW 201

Contactless carrier transport and photon anti-bunching emission in GaAs-based nanowires using surface acoustic waves — •Alberto Hernández-Mínguez[1], Michael Möller[2], Steffen Breuer[1], Carsten Pfüller[1], Claudio Somaschini[1], Snežana Lazić[1], Oliver Brandt[1], Alberto García-Cristóbal[2], Mauricio M. de Lima Jr.[2], Andrés Cantarero[2], Lutz Geelhaar[1], Henning Riechert[1], and Paulo V. Santos[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — [2]Materials Science Institute, University of Valencia, Valencia, Spain

The oscillating piezoelectric field of a surface acoustic wave (SAW) has proven to be very useful in capturing and transporting photogenerated charges as well as spin ensembles in 2-D semiconductor heterostructures. In this contribution we demonstrate that the piezoelectric potential generated by a SAW propagating on a $LiNbO_3$ substrate can transport photoexcited carriers in GaAs-based nanowires (NWs) deposited on it, leading to remote exciton recombination in the form of sub-ns light pulses synchronized with the SAW frequency. This contactless manipulation of carriers by SAWs opens interesting perspectives for NW applications in opto-electronic devices operating at GHz frequencies. As an example, we demonstrate a high-frequency source of anti-bunched photons based on the acoustic transport of electrons and holes photoexcited on one end of the NW and their recombination in quantum-dot-like centers created by the introduction of In at the opposite end.

HL 104.2 Fri 12:00 EW 201

Photons on demand from an electrically driven single quantum dot under pulsed excitation — •Matthias Florian[1], Paul Gartner[1], Christopher Gies[1], Christian Kessler[2], Fabian Hargart[2], Matthias Reischle[2], Wolfgang-Michael Schulz[2], Marcus Eichfelder[2], Robert Rossbach[2], Michael Jetter[2], Peter Michler[2], and Frank Jahnke[1] — [1]Institut für Theoretische Physik, Universität Bremen — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart

Electrically driven, integrated single-photon sources are key components for applications in quantum information. Cavity-enhanced quantum dots (QDs) offer fast relaxation and recombination times, enabling high repetition rates. Short electrical excitation pulses, on the other hand, are a challenge. In a collaboration between theory and experiment, we study the influence of electrical excitation-pulse parameters on the single photon emission from a single QD. On the basis of the time-integrated photon autocorrelation function, the anti-bunching is determined. The theoretical description is based on a solution of the von-Neumann equation, where we consider the single-particle states of the QD, together with many-body effects introduced by the Coulomb and light-matter interaction. The electrical pump pulse creates carriers in the delocalized barrier or WL states, from which we model the capture into the localized QD states, as well as intraband scattering and dephasing, via Lindblad terms. The reduction of the anti-bunching with increasing pulse width is in quantitative agreement with our experiments and defines the operational regime for practical applications.

HL 104.3 Fri 12:15 EW 201

Influence of the excitation pulse width on the purity of single-photon emission from light emitting diodes — •Fabian Hargart[1], Christian Kessler[1], Matthias Reischle[1], Wolfgang-Michael Schulz[1], Marcus Eichfelder[1], Robert Rossbach[1], Michael Jetter[1], Paul Gartner[2], Matthias Florian[2], Christopher Gies[2], Frank Jahnke[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart — [2]Institut für Theoretische Physik, Universität Bremen, Postfach 330 440, 28334 Bremen

For many applications in quantum computing and quantum cryptography single-photons on demand are desirable. Electrically driven semiconductor quantum dots are a promising solution due to their tailorable emission energy and the possible integration in well-known semiconductor devices.

Present-day pulse generators feature pulse widths only down to several 10 ps which is comparatively long to ordinary laser pulses. Therefore we determine the influence of the electrical excitation pulses on the purity of single-photon emission from InP/GaInP quantum dots. For rising widths we observe an increasing $g^{(2)}(0)$ - value and on account of this we assume an increasing probability of further excitations during one single cycle. Using autocorrelation measurements with high temporal resolution we can distinguish the background contribution from re-excitation processes on the non-vanishing $g^{(2)}(0)$-value. Theoretical investigations are in a good agreement with the experimental results.

HL 104.4 Fri 12:30 EW 201

Triggered indistinguishable photons from site-controlled In(Ga)As quantum dots — •Markus Müller[1], Klaus D. Jöns[1], Paola Atkinson[2,3], Matthias Heldmaier[1], Sven M. Ulrich[1], Oliver G. Schmidt[3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Center SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Institut des Nanosciences de Paris, UPMC, CNRS UMR 7588, 4 Place Jussieu, 75252 Paris Cedex 05, France — [3]Institute for Integrative Nanosciences, IWF Dresden, Helmholtzstraße 20, 01069 Dresden, Germany

Self-assembled quantum dots (QDs) as solid-state single-photon sources are promising candidates for quantum information applications with particular respect to the generation of indistinguishable photons. For integration into emitter devices, individual control of the QD position is desirable. We investigate samples which consist of two vertically stacked layers of In(Ga)As QDs, where the local strain fields of the lower "seed" dot layers (SQDs) act as nucleation sites for QDs on top. The SQDs are grown on a pre-patterned GaAs substrate with a 12.5 x 12.5 μm^2 grid of small pits. Micro-photoluminescence maps of QD and SQD layers verify their mutual correlation of position. High-resolution photoluminescence reveals ultra-narrow single QD emission linewidths of ~ 10 μeV. Under quasi-resonant p-shell excitation we observe nearly background-free single-photon emission with $g^{(2)}(0) = 0.02$ and demonstrate the generation of triggered indistinguishable photon pairs with a high visibility up to 61%.

HL 104.5 Fri 12:45 EW 201

Two-photon emission from single GaN quantum dots — •Gordon Callsen[1], Juri Brunnmeier[1], Andrei Schliwa[1], Johannes Settke[1], Christian Kindel[1], Erik Stock[1], Alexander Dreismann[1], Satoshi Kako[2], Yasuhiko Arakawa[2], and Axel Hoffmann[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institute of Industrial Science, University of Tokyo, Japan

Recent reports on single photon emission of MOCVD grown GaN quantum dots embedded in an AlN matrix at elevated temperatures (> 200 K) resulted rising interest in such quantum dots with large exciton binding energy, oscillator strength and band-offset. Simultaneous observation of excitonic and biexcitonic emission in μPL-spectra allows direct determination of the strain state and size of the quantum dot. As characteristic for wurzite GaN/AlN quantum dots the biexciton binding energy varies between +3 meV and -11 meV. This transition of the biexciton binding energy from the binding to the antibinding case facilitates a spectral window in which the technologically desirable colour-coincidence of the exciton and the biexciton can be observed. We analyse the exciton-biexciton cascade in single GaN quantum dots which yields the observation of the emission of a photon couple in a narrow (< 2 ns) time interval as demonstrated by photon-correlation measurements based on a Hanbury-Brown & Twiss setup. In detail analysis of the bunching signal of the autocorrelation experiments allows us to deduce the temporal evolution of the cascade process depending on temperature and excitation density variation.

HL 104.6 Fri 13:00 EW 201

Single photon emission from site-controlled InP quantum dots — Vasilij Baumann, •Christian Schneider, Florian Stumpf, Stefan Kremling, Lukas Worschech, Alfred Forchel, Sven Höfling, and Martin Kamp — Wilhelm Conrad Röntgen Center for Complex Material Systems, Technische Physik, Universität Würzburg

Single semiconductor quantum dots (QDs) turned out to be promising candidates to realize building blocks in the prospering research field of quantum information. Pronounced effects of light matter interaction between a single QD and an optical microcavity mode have been demonstrated and already exploited to fabricate single photon sources of high efficiency. A main obstacle towards the scalable fabrication of such devices is the self assembled growth method commonly applied to grow high quality quantum dots on GaAs substrates. Here, we discuss recent progress in the realization of well ordered arrays of InP quantum dots emitting in the visible spectral range. The QDs are ordered on nanohole lattices with pitches up to 1.25 μm. The large periods allow us to address overgrown single QDs via spatially resolved microphotoluminescence. While the average single QD emission linewidth amounts to 550 μeV, their bright emission features close to the detection maximum of highly efficient single photon detectors allows to carry out photon correlation measurments in an Hanbury Brown and Twiss configuration. We could extract a $g^{(2)}(\tau{=}0)$ value as small as 0.13, clearly demonstrating the single photon emission from such a QD.

HL 104.7 Fri 13:15 EW 201

Growth and Analysis of Quantum Dots with highly reduced Fine Structure Splitting — •Julian Treu, Alexander Huggenberger, Christian Schneider, Alfred Forchel, Sven Höfling, and Martin Kamp — Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Quantum key distribution for secure communication requires efficient sources of single or entangled photons. A possible source for entangled photons is the biexciton-exciton cascade in semiconductor quantum dots (QDs). In this case, the fine structure splitting (FSS) has to be less than the homogenous linewidth. For InGaAs/GaAs QDs grown on common (100) substrates it can be shown that piezoelectric fields reduce the symmetry and often a reduction of the FSS by post-growth annealing or the application of an electric/magnetic field is required. Therefore, QDs with an inherently vanishing FSS are highly desirable.

We have investigated the growth of self organized, low density quantum dots (QDs) on high index substrates like (111) GaAs where such a reduction of symmetry is not existent. Microphotoluminescence spectroscopy (μPL) measurements reveal single QD lines in the range 850-900nm and linewidths below $100\mu eV$. The measured FSS $<10\mu eV$ is limited by the resolution of our setup.

HL 104.8 Fri 13:30 EW 201

Quantum key distribution using electrically triggered quantum dot - micropillar single photon sources — •Tobias Heindel[1], Markus Rau[2], Christian Schneider[1], Martin Fürst[2,3], Sebastian Nauerth[2,3], Matthias Lermer[1], Henning Weier[2,3], Stephan Reitzenstein[1,5], Alfred Forchel[1], Sven Höfling[1], Harald Weinfurter[2,4], and Martin Kamp[1] — [1]Technische Physik and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany — [3]qutools GmbH, 80539 Munich, Germany — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [5]Present address: Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

In 1984, Bennett and Brassard proposed a secret key-distribution protocol (BB84) that uses the quantum mechanical properties of single photons to avoid the possibility of eavesdropping on an encoded message. So far, most quantum key distribution (QKD) experiments have been performed with strongly attenuated lasers due to the lack of efficient single photon sources. First experiments utilizing optically pumped solid state based single photon sources affirmed the great potential of QKD but still suffered from the drawbacks of this excitation scheme. In this work we report on a QKD experiment using electrically triggered quantum dot - micropillar single photon sources. These optimized devices generate sifted key rates of up to 35.4 kBits/s at a quantum bit error rate of 3.8 % and $g^{(2)}(0)$-values down to 0.148.

HL 104.9 Fri 13:45 EW 201

Semiconductor theory for higher order photon autocorrelation functions of quantum dot microcavity lasers — •Heinrich A. M. Leymann, Alexander Foerster, and Jan Wiersig — Otto-von-Guericke-Universität Magdeburg

Semiconductor quantum dots (QDs) are of considerable interest due to their potential for device applications such as lasers [1] and nonclassical light sources, as well as fundamental studies. We present a theory for the higher order photon auto-correlation functions $g^{(3)}(0)$, $g^{(4)}(0)$ based on an equation of motion technique. Starting from the semiconductor model described in [2] we present a general method to expand this theory to higher orders. The coherence properties of light emitted by QD based microcavity lasers are discussed. Also the convergence of the cluster expansion technique is investigated. Furthermore, photon anti-bunching for high fidelity cavity lasers near the threshold is discussed.

[1] J. Wiersig et al. , Nature (London) 460 245 (2009)
[2] C. Gies et al., Phys. Rew A 75 013803 (2007).