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Fachverband Halbleiterphysik (HL)

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Overview of Invited Talks and Sessions

(Lecture halls H 31, H 33, H 34, and H 36; Poster E (in front of H 39))

Invited Talks

HL 4.1	Mon	9:30–10:00	H34	**The role of suboxide kinetics and thermodynamics for the catalysis and facet formation during the molecular beam epitaxy of oxides** — •Oliver Bierwagen
HL 4.2	Mon	10:00–10:30	H34	**Is There a Perspective of p-type Doping in Gallium Oxide?** — •David Rogers, Ferechteh Teherani, Philippe Bove, Eric Sandana, Ryan McClintock, Manijeh Razeghi
HL 4.3	Mon	10:30–11:00	H34	**Highly rectifying contacts on Ga_2O_3, In_2O_3 and $(In,Ga)_2O_3$ thin films** — •Daniel Splith
HL 4.4	Mon	11:15–11:45	H34	**Understanding the impact of vibrations and defects on the optical properties of phosphors** — •P. Erhart, C. Linderälv, D Åberg, Y.-C. Lin, M Bettinelli, N. C. George, S. F. Parker, M. Karlsson
HL 4.5	Mon	11:45–12:15	H34	**atomically resolved termination engineering of electronic states at oxide semiconductors** — •Ya-Ping Chiu
HL 4.6	Mon	12:15–12:45	H34	**Nanoscale Control of Native Point Defects and Doping in Oxide Semiconductors** — •Leonard Brillson
HL 6.1	Mon	12:15–12:45	H33	**Advanced nanoscale characterization of structural and optical properties of novel Nanostructures using scanning transmission electron microscopy cathodoluminescence** — •Frank Bertram
HL 13.1	Tue	9:30–10:00	H31	**GaN-based quantum dot single photon sources at room temperature** — •Yasuhiko Arakawa, Mark Holmes, Munetaka Arita
HL 13.2	Tue	10:00–10:30	H31	**Quantum light generation based on group III-nitride semiconductor nanophotonic structures** — •Yong-Hoon Cho
HL 13.3	Tue	10:30–11:00	H31	**Growth of desorption-induced GaN quantum-dots** — •Christoph Berger, Gordon Schmidt, Hannes Schürmann, Sebastian Metzner, Peter Veit, Jürgen Bläsing, Frank Bertram, Armin Dadgar, Jürgen Christen, André Strittmatter, Stefan Kalinoswki, Stefan T. Jagsch, Gordon Callsen, Markus R. Wagner, Axel Hoffmann
HL 13.6	Tue	11:45–12:15	H31	**Nitride single photon sources: quantum dots and defects** — •Rachel Oliver, Tongtong Zhu, Igor Aharonovich, Robert Taylor
HL 13.7	Tue	12:15–12:45	H31	**GaN-based single photon emitters** — •Donat Josef As
HL 26.1	Wed	9:30–10:00	H34	**GaAs quantum dots as tunable sources of entangled and indistinguishable photons** — •Armando Rastelli
HL 26.3	Wed	10:15–10:45	H34	**Phonon-assisted bright and dark exciton preparation in a semiconductor quantum dot** — •Doris Reiter

HL 26.5	Wed	11:15–11:45	H34	**Towards Quantum Communication Networks Exploiting Solid-State Quantum-Light Sources** — •Tobias Heindel
HL 26.6	Wed	11:45–12:15	H34	**Single Organic Molecules for Quantum Optics** — •Ilja Gerhardt, Mohammad Rezai, Jörg Wrachtrup
HL 26.8	Wed	12:30–13:00	H34	**Quantum repeater development based on entangled photons from quantum dots** — •Michael Zopf, Robert Keil, Yan Chen, Jingzhong Yang, Fei Ding, Oliver G. Schmidt
HL 30.1	Wed	12:15–12:45	H33	**Topology−driven excitonic Aharonov−Bohm effect in core−multishell nanowires** — •Vladimir M. Fomin, Pierre Corfdir, Oliver Marquardt, Ryan B. Lewis, Chiara Sinito, Manfred Ramsteiner, Achim Trampert, Uwe Jahn, Lutz Geelhaar, Oliver Brandt

Invited talks of the joint Symposium SKM Dissertation-Prize 2019

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	9:30– 9:50	H2	**Synchronization and Waves in Confined Complex Active Media** — •Jan Frederik Totz
SYSD 1.2	Mon	9:50–10:10	H2	**Spin scattering of topologically protected electrons at defects** — •Philipp Rüssmann
SYSD 1.3	Mon	10:10–10:30	H2	**Beyond the molecular movie: Revealing the microscopic processes behind photo-induced phase transitions** — •Chris W. Nicholson
SYSD 1.4	Mon	10:30–10:50	H2	**Thermodynamic bounds on current fluctuations** — •Patrick Pietzonka
SYSD 1.5	Mon	10:50–11:10	H2	**Lightwave-driven quasiparticle acceleration** — •Fabian Langer
SYSD 1.6	Mon	11:10–11:30	H2	**Ultrafast plasmon-driven point-projection electron microscopy** — •Jan Vogelsang
SYSD 1.7	Mon	11:30–11:50	H2	**Helimagnets, sand patterns and fingerprints linked by topology** — •Peggy Schönherr

Invited talks of the joint Symposium Geometry, Topology, and Condensed Matter

See SYGT for the full program of the symposium.

SYGT 1.1	Tue	9:30–10:00	H1	**Thermal Properties of Vortices on Curved Surfaces** — •José Lorenzana
SYGT 1.2	Tue	10:00–10:30	H1	**Curvature–induced effects in manomagnets** — •Denis Sheka
SYGT 1.3	Tue	10:30–11:00	H1	**Magnetization configurations and reversal of individual ferromagnetic nanotubes** — •Martino Poggio
SYGT 1.4	Tue	11:15–11:45	H1	**An experimental perspective on topology and nanoelectronics in graphene and related 2D materials.** — •Ivan J. Vera-Marun
SYGT 1.5	Tue	11:45–12:15	H1	**Roles of the curvature in two-dimensional nematic films** — •Gaetano Napoli

Invited talks of the joint Symposium Interaction Effects and Correlations in twodimensional Systems - New Challenges for Theory

See SYTS for the full program of the symposium.

SYTS 1.1	Wed	15:00–15:30	H1	**Spectra of layered semiconductors from many-body perturbation theory** — •Michael Rohlfing
SYTS 1.2	Wed	15:30–16:00	H1	**Dark exciton dynamics in 2D materials** — •Ermin Malic
SYTS 1.3	Wed	16:00–16:30	H1	**Excitons versus electron-hole plasma in monolayer transition metal dichalcogenide semiconductors** — •Alexander Steinhoff
SYTS 1.4	Wed	16:45–17:15	H1	**Theory of near K-point optical properties of TMDC multilayers** — •Tineke Stroucken
SYTS 1.5	Wed	17:15–17:45	H1	**High-throughput modeling and discovery of novel 2D materials** — •Kristian Thygesen

Invited talks of the joint Symposium Czech Republic as Guest of Honor

See SYCZ for the full program of the symposium.

SYCZ 1.1	Thu	9:30–10:00	H4	**Crystal symmetries and transport phenomena in antiferromagnets** — •Tomas Jungwirth
SYCZ 1.2	Thu	10:00–10:30	H4	**Terahertz subcycle charge and spin control** — •Rupert Huber
SYCZ 1.3	Thu	10:30–11:00	H4	**1D molecular system on surfaces** — •Pavel Jelinek
SYCZ 1.4	Thu	11:15–11:45	H4	**Tunneling microscopy on insulators provides access to out-of-equilibrium charge states** — •Jascha Repp
SYCZ 1.5	Thu	11:45–12:15	H4	**Occam's razor and complex networks from brain to climate** — •Jaroslav Hlinka
SYCZ 1.6	Thu	12:15–12:45	H4	**Long range temporal correlations in complex systems** — •Holger Kantz

Invited talks of the joint Symposium Interactions and Spin in 2D Heterostructures

See SYIS for the full program of the symposium.

SYIS 1.1	Thu	15:00–15:30	H1	**Magic Angle Graphene: a New Platform for Strongly Correlated Physics** — •Pablo Jarillo-Herrero
SYIS 1.2	Thu	15:30–16:00	H1	**Bilayer Graphene Quantum Devices** — •Klaus Ensslin
SYIS 1.3	Thu	16:00–16:30	H1	**Light-Matter interaction in van der Waals heterostructures** — •Tobias Korn
SYIS 1.4	Thu	16:45–17:15	H1	**Spin transport in Van der Waals materials and heterostructures** — •Bart Van Wees
SYIS 1.5	Thu	17:15–17:45	H1	**Flipping the valley in graphene quantum dots** — •Markus Morgenstern

Invited talks of the joint Symposium Identifying Optimal Physical Implementations for beyond von Neumann Computing Concepts

See SYCC for the full program of the symposium.

SYCC 1.1	Fri	9:30–10:00	H1	**On the Link Between Energy and Information for the Design of Neuromorphic Systems** — •Narayan Srinivasa
SYCC 1.2	Fri	10:00–10:30	H1	**Encoding neural and synaptic functionalities in electron spin: A pathway to efficient neuromorphic computing** — •Kaushik Roy
SYCC 1.3	Fri	10:30–11:00	H1	**Neuromorphic computing with spintronic nano-oscillators** — •Philippe Talatchian
SYCC 1.4	Fri	11:15–11:45	H1	**Artifcial Intelligence and beyond von Neumann architectures, a mutual opportunity** — •Mirko Prezioso
SYCC 1.5	Fri	11:45–12:15	H1	**Brain-inspired approaches in ultrafast magnetism** — •Johan H. Mentink

Sessions

HL 1.1–1.3	Sun	16:00–18:15	H4	**Tutorial: Resistive Switching: From basic physics of memristive devices to neuromorphic systems (joint session HL/TUT)**
HL 2.1–2.14	Mon	9:30–13:15	H31	**Nitrides: Devices**
HL 3.1–3.9	Mon	9:30–12:00	H33	**Semiconductor lasers and Photonic crystals**
HL 4.1–4.6	Mon	9:30–12:45	H34	**Focus Session: Oxide Semiconductors for Novel Devices I (joint session HL/DS)**
HL 5.1–5.15	Mon	9:30–13:30	H36	**Topological insulators**
HL 6.1–6.1	Mon	12:15–12:45	H33	**Invited talk Bertram**
HL 7.1–7.8	Mon	15:00–17:15	H31	**Organic photovoltaics and electronics (joint session HL/CPP)**
HL 8.1–8.10	Mon	15:00–17:30	H33	**Transport and theory of electronic structure**
HL 9.1–9.10	Mon	15:00–17:30	H34	**Focus Session: Oxide Semiconductors for Novel Devices II**
HL 10.1–10.8	Mon	15:00–17:15	H36	**Quantum information systems**
HL 11.1–11.9	Mon	15:00–18:40	PHY 5.0.20	**Focus: Advanced TEM spectroscopy - low energy excitations and chemical composition at high resolution (joint session KFM/HL)**
HL 12.1–12.71	Mon	17:30–20:00	Poster E	**HL Poster I**
HL 13.1–13.7	Tue	9:30–12:45	H31	**Focus Session: GaN-based single photon emitters**

HL 14.1–14.9	Tue	9:30–13:15	H32	**PhD-Symposium: Photoluminescence of halide perovskites: What does it tell us and what not? (joint session DS/AKjDPG/HL)**
HL 15.1–15.7	Tue	9:30–11:15	H33	**Energy materials (other than photovoltaics)**
HL 16.1–16.14	Tue	9:30–13:15	H34	**Focus Session: Oxide Semiconductors for Novel Devices III**
HL 17.1–17.13	Tue	9:30–13:00	H36	**Two-dimensional Materials I (joint session HL/CPP)**
HL 18.1–18.6	Tue	9:30–12:00	PHY 5.0.20	**Diamond I (joint session KFM/HL)**
HL 19.1–19.5	Tue	11:30–12:45	H33	**Thermoelectricity**
HL 20.1–20.5	Tue	14:00–15:15	H31	**Optical Properties**
HL 21.1–21.6	Tue	14:00–15:30	H33	**Quantum Nanophotonics in Solid State Systems**
HL 22.1–22.7	Tue	14:00–15:45	H34	**Quantum dots and wires: Transport properties**
HL 23.1–23.7	Tue	14:00–15:45	H36	**Two-dimensional Materials II: graphene (joint session HL/CPP)**
HL 24.1–24.13	Wed	9:30–13:00	H31	**Nitrides: Preparation and characterization I**
HL 25.1–25.9	Wed	9:30–12:00	H33	**Group IV (other than C): Si/Ge/SiC**
HL 26.1–26.8	Wed	9:30–13:00	H34	**Focus Session: Quantum light sources for applications in quantum communication networks**
HL 27.1–27.13	Wed	9:30–13:00	H36	**Two-dimensional Materials III (joint session HL/CPP)**
HL 28.1–28.5	Wed	9:30–11:30	PHY 5.0.20	**Diamond II (joint session KFM/HL)**
HL 29.1–29.7	Wed	9:30–12:10	H47	**Microscopy, Tomography and Spectroscopy with X-ray Photons, Electrons, Ions and Positrons (joint session KFM/HL)**
HL 30.1–30.1	Wed	12:15–12:45	H33	**Invited talk Fomin**
HL 31.1–31.8	Wed	15:00–17:15	H31	**Nitrides: Preparation and characterization II**
HL 32.1–32.9	Wed	15:00–17:30	H33	**Spintronics**
HL 33.1–33.9	Wed	15:00–17:30	H34	**Quantum light sources**
HL 34.1–34.9	Wed	15:00–17:30	H36	**Photovoltaics (joint session HL/CPP)**
HL 35.1–35.72	Wed	17:30–20:00	Poster E	**HL Poster II**
HL 36.1–36.13	Thu	9:30–13:00	H31	**II-VI- and III-V-semiconductors**
HL 37.1–37.9	Thu	9:30–12:45	H32	**Focus Session: Growth, Properties and Application of Epitaxial Graphene (joint session DS/O/HL)**
HL 38.1–38.7	Thu	9:30–11:15	H33	**Organic semiconductors**
HL 39.1–39.12	Thu	9:30–12:45	H34	**Quantum dots and wires: Optical properties I**
HL 40.1–40.13	Thu	9:30–13:00	H36	**Perovskite and Hybrid Photovolatics I (joint session HL/CPP)**
HL 41.1–41.8	Thu	15:00–17:15	H31	**Heterostructures, interfaces, and surfaces**
HL 42.1–42.8	Thu	15:00–17:15	H34	**Quantum dots and wires: Preparation and characterization**
HL 43.1–43.9	Thu	15:00–17:30	H36	**Perovskite and Hybrid Photovolatics II (joint session HL/CPP)**
HL 44	Thu	17:30–18:30	H34	**Annual General Meeting of the Semiconductor Physics Division**
HL 45.1–45.67	Thu	18:30–21:00	Poster E	**HL Posters III**
HL 46.1–46.12	Fri	9:30–12:45	H31	**Ultra-fast phenomena**
HL 47.1–47.13	Fri	9:30–13:00	H34	**Quantum dots and wires: Optical properties II**
HL 48.1–48.13	Fri	9:30–13:00	H36	**Two-dimensional Materials IV (joint session HL/CPP)**

Annual General Meeting of the Semiconductor Physics Division

Thursday 17:30–18:30 H34

- Bericht
- Wahl
- Verschiedenes

HL 1: Tutorial: Resistive Switching: From basic physics of memristive devices to neuromorphic systems (joint session HL/TUT)

The miniaturization of electronic devices combined with the ongoing digitalization of our live calls for a change in the paradigms of information processing. This goes hand in hand with the discovery of new physical effects that can be harnessed for electronic systems. A most promising candidate for this are resistive switching materials, in which atoms are used instead of electrons for information storage. In the last years, significant progress has been made in understanding the underlying physics and with its transfer into novel electronic devices, often called memristors or memristive devices. This Tutorial starts with an introduction to the physics of resistive switching and aims to explain how to use memristive effects to create new devices and architectures for tomorrows electronics. Furthermore, some concepts for bio-inspired, neuromorphic electronics based on resistive switching are presented.

Organizers: Martin Ziegler and Erich Runge (TU Ilmenau)

Time: Sunday 16:00–18:15 Location: H4

Tutorial HL 1.1 Sun 16:00 H4

Oxide based memristive devices: Current status of understanding and future prospects — •Regina Dittmann — PGI-7, Forschungszentrum Jülich GmbH

Transition metal oxides exhibit a reversible, non-volatile change in electrical resistance upon electrical stimulus, a phenomenon known as resistive switching. In the simplest case resistive switching memory cells, or so called memristive devices, can be switched between a low resistance state (LRS) and a high resistance states (HRS) which can be interpreted as the logical "1" and "0", respectively. Moreover, resistive switching cells often exhibit multiple resistive states rather than only two logical states, which can be highly interesting for neuromorphic applications. Based on the current knowledge, resistive switching in memristive elements based on transition metal oxides can be ascribed to electrically induced redox-processes at the oxide/electrode interface, which occur either in a spatially confined switching filament, multiple filaments or in a spatially homogeneous, area-dependent manner. In most cases, the redox-process in the metal-oxide goes along with a change in the valence state of the metal ion modifying the Schottky barrier at the oxide/electrode interface. Therefore, this type of switching mechanism is also called valence change mechanism (VCM). In this tutorial, we will present the current knowledge about microscopic mechanisms which drive electroforming and resistive switching in different variants of VCM-type memristive elements. Afterwards, a brief overview about the current and future fields of application will be presented.

Tutorial HL 1.2 Sun 16:45 H4

Memristors and memristive devices: theory, physics, criticisms — •Thomas Mussenbrock — Brandenburg University of Technology, Chair of Electrodynamics and Physical Electronics, 03046 Cottbus, Germany

The research in the field of memristive devices dates back to the 1970s when Chua introduced his idea of a missing lumped circuit element, which he named *memristor*. The idea has emerged a considerable interest only after 2008 when researchers at HP Labs linked their resistive switching device to Chuas's theory. Today, memristive (or synonymously resistive switching) devices have been identified as promising candidates for future non-volatile memory applications due to their distinct key features, the most important of which are i) low power consumption, ii) passivity, and iii) scalability into the nanometer scale. Beyond their potential applications as non-volatile memories, memristive devices turned out to be applicable as artificial synapses in neuromorphic circuits. It is interesting to notice that a large number of different devices and concepts turn out to show memristive behavior, while the underlying physics is not completely understood in most of the cases. Furthermore, the scientific dispute is still ongoing, whether the devices which show memristive behavior are in fact memristors in terms of Chua's theory. This contribution is intended to provide an introduction to memristors and memristive devices. Theoretical aspects as well as fundamental physical phenomena are discussed, while the criticism regarding the memristor concept is not concealed.

Tutorial HL 1.3 Sun 17:30 H4

Memristive devices for bio-inspired electronics — •Hermann Kohlstedt — Chair of Nanoelectronics, Faculty for Electrical Engineering and Information Technology, Kiel University, Germany

Information processing in biological nerve system is characterized by highly parallel, energy efficient and adaptive architectures in contrast to clock driven digital Turing machines. Even simple creatures outperform supercomputers when it comes to pattern recognition, failure tolerant systems and cognitive tasks. Fundamental building blocks leading to such remarkable properties are neurons as central processing units, which are (with variable strengths) interconnected by synapses to from a complex dynamical three dimensional network. The field of neuromorphic engineering aims to mimic such biological inspired information pathways by electronic circuitries. The advent of memristive devices opened novel pathways to mimic basal synaptic functionalities as e.g., spike-time-depended plasticity (STDP). In the tutorial I will explain how such local learning mechanisms are mimicked by memristive. In addition I will address the opportunities and challenges to integrate memristive devices as a part of cognitive electronic circuits, in particular for the interesting field of non-linear dynamics in the context with correlation and synchronization phenomena in nerve systems. Acknowledgement: This work is support by the DFG Research Unit 2093 "Memristive devices for neuronal systems.

HL 2: Nitrides: Devices

Time: Monday 9:30–13:15 Location: H31

HL 2.1 Mon 9:30 H31

Performance degradation of AlGaN/GaN (MIS)-HEMTs grown on Silicon substrate under different operational stress-conditions — •Anthony Calzolaro[1], Rico Hentschel[1], Andre Wachowiak[1], and Thomas Mikolajick[1,2] — [1]NaMLab GmbH, Dresden, Germany — [2]TU Dresden IHM, Dresden, Germany

GaN-based high electron mobility transistors (HEMTs) are excellent candidates for next-generation power electronics due to superior material properties, such as large breakdown field, high electron sheet charge density and mobility. In particular, AlGaN/GaN heterostructures grown on large diameter Si-substrates enable delivering high performances at lower cost for component production. For high material quality of the heterostructure and high voltage capability complex GaN buffer layers are grown on Si. Several technology challenges are however still faced mainly related to charge trapping during device operation in the gate and drain regions[1] or in the GaN buffer.

In our study, static and dynamic measurement techniques are applied to Metal-Insulator-Semiconductor (MIS)-HEMT devices to access potential sources of traps and related effects on device performance. MIS-HEMT and HEMT structures are compared in terms of ON-resistance degradation and threshold voltage instability upon different bias stress conditions. The influence of the GaN buffer has been also investigated by substrate back bias methods[2] and focus is given to the kinetics of charge capture and emission processes. Our study enables better understanding of device operation and provides valuable feedback for material and device process technology.

HL 2.2 Mon 9:45 H31

Metastable Negative Differential Capacitances in GaN-based pn- and tunnel-junctions — •Hartmut Witte, Aqdas Fariza, Silvio Neugebauer, Christoph Berger, Armin Dadgar, and Andre Strittmatter — Institute of Physics, Otto-von-Guericke-University Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

GaN-based tunnel junctions grown by MOVPE are actively investigated to improve current spreading on the p-contact region of pn-junction devices. Low or moderate acceptor doping within the p-doped GaN layer leads to anomalous current-voltage characteristics of pn-junction devices displaying a region of negative differential resistance (NDR). The NDR appears within the low forward voltage region and correlates well with an adequate step in capacitance-voltage characteristics. Both in IV- and in CV-characteristics the NDR effect can be changed by applying voltage pulses. An additional space charge region (SPR) is identified from impedance spectroscopy as origin of the NDR. This SCR acts as a rectifying junction in series with the pn-junction with a capacitance between 10 pF and 50 pF. Capacitance transients show temperature dependent recharging effects of defects with time constants in the range of some ms. On the basis of surface potential measurements by kelvin-probe microscopy GaN:Mg defects are discussed as possible candidates for the NDR effect

HL 2.3 Mon 10:00 H31

Vertical field-effect transistors based on regular GaN nanostructure arrays — •Klaas Strempel[1], Feng Yu[1], Friedhard Römer[2], Bernd Witzigmann[2], Andrey Bakin[1], Hergo-Heinrich Wehmann[1], Hutomo Suryo Wasisto[1], and Andreas Waag[1] — [1]Institut für Halbleitertechnik (IHT), TU Braunschweig, Germany — [2]Computational Electronics and Photonics (CEP), Universität Kassel, Germany

A novel vertical field effect transistor (FET) technology based on 3D GaN nanostructures is introduced, combining the superior material properties of GaN for power electronics with a vertical device architecture and the 3D geometry of nanostructures. Previously realized devices based on top-down etched GaN nanowire arrays achieved promising properties such as normally-off operation, high current densities and excellent electrostatic control over the channel. Here, an improved design based on GaN fins is discussed. Regular fin arrays with smooth a-plane sidewalls were fabricated by a combination of ICP-DRIE and wet chemical etching. The fin dimensions could be precisely controlled via etching and small widths down to 60 nm were achieved. Flexible vertical doping profiles allow the modulation of the channel properties. Nevertheless, the three-dimensionality of the nanostructures increases the complexity of the device processing. Several processing steps have been successfully applied to fabricate vertical GaN FinFETs, including Al_2O_3 dielectric atomic layer deposition (ALD), inclined electron beam evaporation of the Cr gate, and planarization techniques. Electrical characterization of the devices will be presented.

HL 2.4 Mon 10:15 H31

Realizing tunnel junctions in semiconductors with bandgap higher than 5 eV for electro-optical applications — •Luca Sulmoni[1], Christian Kuhn[1], Martin Guttmann[1], Johannes Glaab[2], Norman Susilo[1], Tim Wernicke[1], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

A highly conductive UV transparent layer is needed to overcome the poor current spreading of p-electrodes in deep UV LEDs. This is mainly caused by the high sheet and contact resistance of the transparent p-AlGaN layers and results in very large operating voltages. A promising alternative to standard p-electrodes is the injection of holes into the heterostructure by means of efficient tunnel junctions (TJs) allowing for low resistivity n-contacts on both sides of the device. This way, a transparent top n-layer can be used as an excellent native current spreading layer and a metal reflector could be used to enhance the light extraction. We have successfully demonstrated AlGaN-based TJ-LEDs emitting at 271 nm grown entirely by MOVPE. A GaN-based thin interlayer was implemented to facilitate carrier tunneling at the TJ interface. Without interlayer, current injection and light emission was possible but at extremely high operation voltages exceeding 40 V and low current levels. Typically, the operation voltages and the output powers of a 0.35 mm^2 TJ-LED featuring an GaN interlayer of 8 nm are 24 V and 1.3 mW, respectively, measured at 20 mA on wafer in cw operation. A maximum EQE of 1.4% is reached at 40 mA.

HL 2.5 Mon 10:30 H31

Small-area current injection in GaN-based light emitters with tunnel junctions — •Christoph Berger, Silvio Neugebauer, Cleophace Seneza, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Otto-von-Guericke-Universität Magdeburg, Deutschland

MOVPE-grown GaN:Mg/GaN:Ge tunnel junctions enable surface emitting devices such as LEDs and laser diodes with low absorption losses. Efficient activation of hydrogen passivated Mg acceptors requires a combination of in-situ activation directly after the GaN:Mg growth step and ex-situ thermal annealing at 800°C after mesa etching to enable hydrogen out-diffusion from the sidewalls. Excellent lateral current spreading in large area LEDs is confirmed by a homogeneous electroluminescence distribution across the whole mesa area. By optimization of the doping profile, tunnel junction LEDs with negligible increase in bias voltage compared to conventional LEDs with Ni/Au contacts were realized. Light output at 430 nm wavelength through the p-contact region is enhanced by ~70% due to better transparency of the GaN:Ge with regard to the semitransparent Ni/Au contact. Application of these GaN:Mg/GaN:Ge tunnel-junctions in small-area light emitters like μ-LEDs (diameter < 50 μm) or vertical-cavity surface-emitting lasers. A first remarkable result is pulsed operation of such devices at current-densities up to 10 kA/cm^2. We will further report on lateral current confinement to realize injection areas below 10 μm.

HL 2.6 Mon 10:45 H31

Poole-Frenkel-ionization of acceptors in $Al_{0.76}Ga_{0.24}N$:Mg short-period superlattices — •A. Muhin[1], C. Kuhn[1], M. Guttmann[1], J. R. Aparici[1], L. Sulmoni[1], T. Wernicke[1], and M. Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

For efficient light extraction in UVC light emitting diodes (LED), transparent p-doped $Al_xGa_{1-x}N$ layers with $x \geq 0.6$ are needed. AlGaN:Mg with such high Al mole fraction exhibits very high acceptor ionization energies leading to a very poor electrical conductivity. Nevertheless, LEDs with $Al_{0.81}Ga_{0.19}N$ short-period superlattices (SPSL) p-side could be operated at current densities up to

4.7 kAcm^{-2}. This work investigates the vertical resistivity (ρ_V) of $Al_{0.86}Ga_{0.14}N/Al_{0.65}Ga_{0.35}N$:Mg SPSLs. The vertical resistivity of the p-AlGaN-layers was extracted from the IV-characteristics of UVC-LEDs with varied SPSL thickness. The results show that ρ_V is not constant but decreases with the electric field which reaches values up to 10^6 Vcm^{-1}. The influence of such high electric fields on the electrical resistivity can be described by the Poole-Frenkel-effect (PFE), which leads to a field-enhanced dopant ionization. Our investigations of the field dependent ρ_V are in good agreement with the predictions made by PFE theory and provide a deeper understanding of conduction mechanisms in AlGaN:Mg SPSLs with high Al content.

15 min. break

HL 2.7 Mon 11:15 H31

Enhanced light extraction and internal quantum efficiency for fully-transparent AlGaN-based UVC LEDs on patterned-AlN/sapphire substrate — •Martin Guttmann[1], Anna Ghazaryan[1], Luca Sulmoni[1], Norman Susilo[1], Eviathar Ziffer[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Light emitting diodes (LEDs) in the UVC spectral range utilize highly absorbing p-GaN contacts and low aluminum mole fraction p-AlGaN layers to enable low operating voltages. However, to realize high power LEDs a UVC-transparent p-side in combination with a highly reflective p-contact is necessary to increase the light extraction efficiency (LEE). In this paper, we have investigated the effect of the aluminum mole fraction in the $Al_xGa_{1-x}N/Al_yGa_{1-y}N$ p-superlattice (p-SL) ($0.32 < x < 0.65$ and $0.40 < y < 0.71$) and the influence of the p-contact metal reflectivity on the electro-optical properties of LEDs emitting around 265 nm. A five-fold increase of the external quantum efficiency (EQE) with a maximum value of 3.1% was observed for LEDs with UVC-transparent p-SL ($x = 0.65$) and reflective indium contacts. In order to separate this improvement in the EQE into LEE and internal quantum efficiency (IQE), ray-tracing simulations were performed. The increased EQE can be partially ascribed to a 2.5-fold improved LEE in combination with a 2-fold increase of the IQE for the UVC-transparent $Al_{0.65}Ga_{0.35}N/Al_{0.71}Ga_{0.29}N$ p-SL.

HL 2.8 Mon 11:30 H31

Study of heavy-ion irradiation induced degradation on AlInN/GaN on Si High- Electron-Mobility Transistors (HEMTS) — •Seshagiri rao Challa[1], Nahuel Vega[2,3,4], Christian Kristukat[2,3], Nahuel a Müller[2], Mario Debray[2,3], Gordon Schmidt[1], Jürgen Christen[1], Florian Hörich[1], Hartmut Witte[1], Armin Dadgar[1], and André Strittmatter[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Gerencia de Investigación y Aplicaciones, CNEA, Argentina — [3]Escuela de Ciencia y Tecnología, Universidad Nacional de San Martín(UNSAM), Argentina — [4]Consejo Nacional de Investigaciones Científicas y Tecnológicas (CONICET), Argentina

75 MeV sulfur-ion irradiation induced degradation on AlInN/GaN on Si high electron mobility transistor (HEMT) structures are systematically studied for ion fluences ranging from 2.8×10^{12} cm^{-2} to 5.5×10^{13} cm^{-2}. Ion stopping range, ionization vs displacement energy loss profile, and recoil atom distributions were simulated using SRIM software tool (Stopping and range of ions in matter). Transfer curves show a reduction of on-state current, off-state current (buffer leakage), and a positive threshold voltage shift with higher fluences as well as an increase of vertical conductivity by up to eight orders of magnitude. μ-PL measurements show an intensity reduction of the donor bound exciton (D0,X) emission in the GaN buffer layer with increasing fluences. Although performance is degraded, all HEMTs remain fully functional even at highest irradiation levels, which makes them an attractive choice to space applications.

HL 2.9 Mon 11:45 H31

InGaN/GaN microLED arrays as a novel illumination source for imaging and microscopy — •Jan Gülink[1,2], Michael Fahrbach[1,2], Daria Bezshlyakh[1,2], Hutomo Suryo Wasisto[1,2], and Andreas Waag[1,2] — [1]Institute of Semiconductor Technology (IHT), Technische Universität Braunschweig, Hans-Sommer-Str. 66, D-38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Technische Universität Braunschweig, Langer Kamp 6a, D-38106 Braunschweig, Germany

Gallium nitride-based light emitting diodes (LEDs) have developed over the last two decades into highly efficient, cost-effective and compact light sources. While solid state lighting has been the dominant application so far, a number of other applications can take advantage of the LED's benefcial properties, including displays, optical communication, sensing and manipulation in life sciences, and structured illumination.

In this work, we report on a novel light source based on two different top-down fabrication technologies on a planar gallium nitride(GaN)-based LED wafer. We realized highly localized light sources with pitches in the range of 2 microns to 100 microns with individual pixel control, a so-called microLED array. The LED array consists of 64 pixels. The technological details of the 3D processing steps to create the microLED arrays are presented in detail. The microLED arrays were then transferred via flip-chip bonding to PCBs including the driver circuit and their brightness, emission pattern and modulation speed were investigated.

HL 2.10 Mon 12:00 H31

Blue micro-LEDs on Si(111) for optogenetic applications — •Silvio Neugebauer[1], Jürgen Bläsing[1], Armin Dadgar[1], André Strittmatter[1], Martin Deckert[2], Bertram Schmidt[2], Michael Lippert[3], and Frank Ohl[3] — [1]Institute of Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute for Micro and Sensor Systems, Otto-von-Guericke-University Magdeburg, Germany — [3]Department of System Physiology and Learning, Leibniz Institute for Neurobiology Magdeburg, Germany

Optogenetics is a technique that builds on light-sensitive proteins to control neural activity in genetically modified neurons. In order to circumvent problems associated with the use of single optical fibers for excitation, arrays of miniaturized LEDs on a flexible host are a viable solution allowing in addition for a light-patterning approach. In this study we have optimized InGaN/GaN LED heterostructures on Si(111) substrates with low total layer thickness and their processing into micro-sized LEDs for the integration onto flexible polyimide membranes. Special emphasis was put on obtaining stress-free wafers after growth and to keep the thickness of the layer stack below 5 μm. Subsequently, arrays of circular μLEDs with diameters from 60-160 μm were fabricated. Devices exhibit constant J-V characteristics for the range of diameters investigated. We will further report on full-wafer removal of the silicon substrate to obtain freestanding μLEDs that can be transferred one-by-one onto a polyimide optical electrode.

HL 2.11 Mon 12:15 H31

AlGaN-based deep UV LEDs grown on high temperature annealed epitaxially laterally overgrown AlN/sapphire — •Norman Susilo[1], Eviathar Ziffer[1], Sylvia Hagedorn[2], Leonardo Cancellara[3], Sebastian Metzner[4], Bettina Belde[1], Frank Bertram[4], Sebastian Walde[2], Luca Sulmoni[1], Martin Guttmann[1], Tim Wernicke[1], Jürgen Christen[4], Martin Albrecht[3], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Institute of Solid State Physics, Technische Universität Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Germany — [3]Leibniz-Institut für Kristallzüchtung, Germany — [4]Institute of Physics, Otto-von-Guericke-Universität Magdeburg, Germany

The structural and electro-optical properties of AlGaN-based deep ultraviolet light emitting diodes (UV-LEDs) on as grown and on high temperature annealed (HTA) planar AlN/sapphire and epitaxially laterally overgrown (ELO) AlN/sapphire with and without HTA are investigated and compared. After high temperature annealing LED heterostructures on both template types show improved structural and electro-optical properties. The output powers (measured on-wafer) of UV-LEDs emitting at 265 nm were 0.03 mW (planar AlN/sapphire), 0.8 mW (planar HTA AlN/sapphire), 0.9 mW (ELO AlN/sapphire), and 1.1 mW (HTA ELO AlN/sapphire) at 20 mA, respectively. These results show that HTA ELO AlN/sapphire templates provide a viable approach for the fabrication of efficient UV-LEDs, improving both the internal quantum efficiency and the light extraction efficiency.

HL 2.12 Mon 12:30 H31

Influence of the GaN:Mg contact layer on the performance characteristics of AlGaN based UVC LED heterostructures — •Eviathar Ziffer[1], Norman Susilo[1], Luca Sulmoni[1], Martin Guttmann[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchst-

frequenztechnik, Berlin, Germany

AlGaN based UVC LEDs emitting at 265 nm are typically capped with a thick GaN:Mg contact layer in order to achieve low resistivity, ohmic p-contacts. However, the GaN:Mg layer strongly absorbs the UVC light emitted into the p-side of the LED, thereby limiting its light extraction efficiency. In this study, we investigate the performance of UVC LEDs with different GaN:Mg layer thicknesses ranging from 5 nm to 160 nm. The heterostructures were grown by metalorganic vapor phase epitaxy and fabricated into LEDs by standard micro-fabrication techniques with highly reflective p-contacts and vanadium-based n-contacts. For thin GaN:Mg layers, an increasing operation voltage and a reduced yield of working LEDs were observed. At the same time, the on-wafer external quantum efficiency drastically increases with decreasing GaN:Mg cap thickness from 0.6 % to 2.1 %.

HL 2.13 Mon 12:45 H31

Low resistance V/Al/Ni/Au n-contacts on n − $Al_{0.9}Ga_{0.1}N$ for UVC LEDs — •Verena Montag[1], Luca Sulmoni[1], Frank Mehnke[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

Deep UV LEDs emitting below 230nm require high aluminum n − $Al_{0.9}Ga_{0.1}N$ current spreading layers. However, the n-contacts show poor performance as the current-voltage characteristics is not ohmic and high operating voltages are needed even for moderate current densities. This is partly due to the materials lower electron affinity and to the higher activation energies of the Si-donor as the aluminum content in the n-AlGaN layers increases. In this study, the thicknesses of the vanadium and aluminum layers in V/Al/Ni/Au-based n-contacts were varied in order to improve both voltage and contact resistivity. In addition, rapid thermal annealing of the n-contacts was investigated for a wide range of temperatures under N_2 ambient. We were able to achieve contact resistivities of $3.3{\cdot}10^{-3}\Omega$ cm^2 and voltages as low as 2.6V at a current density of 0.1kA/cm^2. Finally, we fabricated UVC LEDs emitting at 229nm with an output power of 10μW and a voltage of 9.8V measured on wafer for a dc current at 20mA.

HL 2.14 Mon 13:00 H31

Field effect transistors with a piezoelectric AlN gate dielectric for force sensing applications — •Henning Winterfeld[1], Lars Thormählen[2], Hanna Lewitz[2], Erdem Yarar[2], Tom Birkoben[1], Nicolai Niethe[1], Nicolas Preinl[1], Henning Hanssen[3], Eckhard Quandt[2], and Hermann Kohlstedt[1] — [1]Nanoelectronics, Faculty of Engineering, Kiel University, Germany — [2]Inorganic Functional Materials, Faculty of Engineering, Kiel University, Germany — [3]Fraunhofer Institute for Silicon Technology, 25524 Itzehoe, Germany

In this work, we present the approach of using low temperature AlN in the gate stack of a MOS transistor. Placing the transistor on a cantilever in combination with the piezoelectric AlN layer allows the use as a force sensor. With this approach the piezoelectric FET was able to detect forces as low as 100 μN. Taking the scaling possibilities into account, the detection of an even wider range of forces is possible with this device. Additionally, we show a performance comparison of our sensors using AlN and AlScN as piezoelectric layers. Furthermore, the placement of the sensing material close to the channel and therefore, the amplifying properties of the transistor reduces noise and possibly allows for higher sensitivity. The CMOS compatibility of AlN would allow the incorporation of this device into standard silicon fabrication without limitations.

HL 3: Semiconductor lasers and Photonic crystals

Time: Monday 9:30–12:00 Location: H33

HL 3.1 Mon 9:30 H33

High-speed InP-based 1.55 μm quantum dot lasers with and without tunnel injection quantum wells — •Sven Bauer[1], Vitalii Sichkovskyi[1], Ori Eyal[2], Gadi Eisenstein[2], and Johann Peter Reithmaier[1] — [1]Technische Physik, Institute of Nanostructure Technologies and Analytics (INA), CINSaT, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Andrew and Erna Viterbi Department of Electrical Engineering, Technion, Haifa 32000, Israel

The performance of directly modulated quantum dot (QD) lasers, used for 1.55 μm telecommunication, is limited by the intraband carrier relaxation time. To improve it, one might use a so-called tunnel injection (TI) scheme. Carriers are captured and relax in a quantum well (QW) and tunnel through a thin barrier for recombination into the QDs. After a careful optimization process, the coupled QW-QD structures, consisting of an InGaAs QW, a thin InAlGaAs barrier, both lattice matched to InP, and InAs QDs, were implemented in a high-speed laser design. A corresponding QD reference laser was grown as well. The structure specific static parameters were extracted from the power current characteristics of the processed broad area lasers. Furthermore, the effect of different rapid thermal annealing temperatures was investigated. The small signal modulation properties of ridge waveguide lasers were measured and significant differences could be evaluated for both laser types. Large signal modulation experiments revealed a high modulation rate for both laser types.

HL 3.2 Mon 9:45 H33

Do TMD Nanolasers Benefit From a High β-Factor? — •Frederik Lohof[1], Alexander Steinhoff[1], Matthias Florian[1], Daniel Erben[1], Michael Lorke[1], Roy Barzel[1], Paul Gartner[2], Frank Jahnke[1], and Christopher Gies[1] — [1]Institute for Theoretical Physics, University of Bremen — [2]National Institute of Materials Physics, CIFRA, Bucharest-Măgurele, Romania

The realization of high-β lasers is one of the prime applications of cavity- QED promising ultra-low thresholds, integrability and reduced power consump- tion. Recently also monolayers of transition metal dichalcogenide (TMD) have been reported to be used as gain medium in high-β nanolasers. In my talk I will present first results from material realistic gain calculations of highly excited TMD monolayers and specify requirements to achieve lasing with the four commonly used TMD semiconductors. Combining the results with a rate equation theory I will discuss consequences for experimentally accessible laser characteristics. In cavity-enhanced nanolasers with limited amount of gain, spontaneous emission has been shown to play a central role even above the threshold. In using a simplified approach, I will discuss the prospects of low-threshold high- beta lasing in TMD based nanolasers. Extended rate equations are used to access the photon autocorrelation function, revealing an offset between the laser threshold in the input-output curve and the transition to coherent emission. Furture experimental measurements should provide insight into the validity of our theoretical prediction.

HL 3.3 Mon 10:00 H33

Characterization of the nonlinear optical properties of a semiconductor disk laser — •Christian Kriso[1], Sascha Kress[1], Tasnim Munshi[1], Marius Grossmann[2], Roman Bek[2], Michael Jetter[2], Peter Michler[2], Wolfgang Stolz[1], Martin Koch[1], and Arash Rahimi-Iman[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, D-35032 Marburg, Germany — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, D-70569 Stuttgart, Germany

The quest for pulsed laser sources with steadily higher peak powers and shorter pulse durations is subject of ongoing research efforts. Semiconductor disk lasers or vertical-external-cavity surface-emitting-lasers (VECSELs) are a particularly attractive laser platform for this purpose, since they combine the wavelength flexibility typical for semiconductor lasers, the beam qualities known from solid-state lasers and the desired potential mass producibility for applications like frequency combs or multi-photon imaging.

Besides conventional passive mode-locking of VECSELs with semiconductor-saturable-absorber mirrors (SESAMs), a new mode-locking phenomenon has been observed in these lasers in the absence of such SESAMs. Based on the assumption that Kerr-lensing in the VECSEL chip might explain "self-mode-locked" operation, we systematically characterize the nonlinear refractive index of a gain chip and discuss the impact of the gain chip's microcavity on possible Kerr-lens mode-locking of VECSELs.

HL 3.4 Mon 10:15 H33

A theoretical model for the generation of non-equidistant pulses in passively mode-locked VECSELs — •Jan Hausen[1], Stefan Meinecke[1], Benjamin Lingnau[1,2], and Kathy Lüdge[1] — [1]Institute for theoretical Physics, TU Berlin, Hardenbergstrasse 36, 10623 Berlin — [2]Physics Department, University College Cork, College Rd, Cork, Irland

Embedding the active sections of a passively mode-locked laser, i.e. gain and absorber medium, in an external cavity with a V-shaped geometry can greatly enhance their performance in terms of pulse width and power. However, multi-pulse solutions with non-equidistant interpulse spacing (pulse clusters) emerge in these devices and limit their performance. We derive a system of multi-delay differential equations, which is simple enough to allow for large numeric parameter studies as well as a bifurcation analysis to understand the underlying bifurcation scenarios. We find that by tuning the cavity geometry different mode-locking behaviour can be favoured e.g. fundamental, higher harmonic or pulse cluster mode-locking. Furthermore, our investigations show that by increasing the cavity geometry stable regions of higher order pulse clusters develop from cusps of saddle-node bifurcation and stabilizing torus bifurcations.

HL 3.5 Mon 10:30 H33

Investigation of Red-Emitting Mode-Locked VECSELs — •Philipp Tatar-Mathes, Marius Grossmann, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Since the first realization of mode-locked vertical external-cavity surface-emitting lasers (VECSELs) in 2000, huge development especially in the infrared spectral range was initiated. These systems generate ultrashort pulses with high output powers and a near diffraction-limited beam profile, beneficial properties over a wide wavelength range. Semiconductor structures with an active region containing GaInP/AlGaInP quantum wells, grown on top of AlAs/AlGaAs DBR demonstrate as well excellent performances of VECSELs but in the visible spectral range [1].

We present a VECSEL configuration with emission in the red spectral range from a cavity optimized for high average powers and GHz repetition rates. We interpret the measurements in light of the recently demonstrated self-mode-locking [2] which allows the absence of a SESAM. Therefore, intrinsic nonsaturable losses can be overcome. Our current research focus is capturing the dynamics of pulsed laser emission by investigation of its temporal evolution and frequency spectra with a high bandwidth oscilloscope and performing second harmonic intensity autocorrelations to determine its properties on ultrashort-timescales. [1] Bek et al., Opt. Express 2015; [2] Bek et al., APL. 2017

15 min. break

HL 3.6 Mon 11:00 H33

Dynamics of two coupled semiconductor mode-locked lasers — •Jakob Eberhardt, Stefan Meinecke, and Kathy Lüdge — Institut für Theoretische Physik, TU Berlin, Hardenbergstr 36, 10623 Berlin

Passively mode-locked semiconductor lasers are an inexpensive source of short optical pulses at high repetition rates. Networks of mode-locked lasers have received interest due to applications in data communication and metrology and as a possible implementation of novel analog computing schemes [1]. We numerically investigate the dynamics of the simplest network setup, namely two mutually coupled lasers, using a system of delay differential equations [2]. For two non-identical passively mode-locked lasers, we study the stability and synchronisation behaviour of the two lasers in dependence of the laser and coupling parameters and predict regions of stable synchronised mode locking and regions of leap frogging, where the two lasers alternatingly emit pulses at the fundamental repetition frequency.

[1] Mesaritakis, C. , Kapsalis, A., Bogris, A. and Syvridis, D. , Sci. Rep. 6, 39317 (2016).

[2] Vladimirov, A. G. and Turaev, D. V. , Phys. Rev. A 72, 3, 033808 (2005).

HL 3.7 Mon 11:15 H33

Fabrication of spectrally homogeneous microlaser arrays as a nanophotonic hardware for reservoir computing — •Tobias Heuser[1], Jan Grosse[1], James Lott[1], Daniel Brunner[2], Ingo Fischer[3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universiät Berlin, D-10623 Berlin, Germany — [2]FEMTO-ST, 15B Avenue des Montboucons, 25030 Besançon, France — [3]IFISC (UIB-CSIC), E-07122 Palma de Mallorca, Spain

Reservoir computing is a powerful machine learning concept for a new kind of data processing which is inspired by the neurons in the brain. In this concept an interacting network of nodes is evaluated by a trained readout for applications like fast pattern recognition. To further improve the performance of this concept, a photonic hardware implementation is of particular interest. Here, we report on our new developements in the fabrication process and lasing performance of large 2D arrays of microlasers, namely quantum dot micropillars and VCSELs. These arrays will serve as a nonlinear network via diffractive optical coupling [1]. For this spectral alignment of the involved lasers is crucial. To achieve this with a spectral homogeneity better than 200μeV throughout the array of up to 900 lasers, shifts of the emission energy are compensated by electrical tuning or by precisely adjusting the radius of the fabricated micropillars [2, 3].

References

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[2] S.Reitzenstein, A.Forchel, J.Phys.D.Appl.Phys. 43, 033001 (2010)

[3] T.Heuser et al., APL Photonics 3, 116103 (2018)

HL 3.8 Mon 11:30 H33

Bragg grating cavities embedded into nano-photonic waveguides for Purcell enhanced quantum dot emission — •Stephanie Bauer, Stefan Hepp, Florian Hornung, Mario Schwartz, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, Allmandring 3, Universität Stuttgart, 70569 Stuttgart, Germany

Quantum photonic integrated circuits are a promising platform for quantum information technologies. In contrast to silicon based systems, photonic circuits on a III-V semiconductor platform bear the advantage of the direct implementation of quantum dots with their outstanding properties as single photon sources.

The widely used ridge waveguides offer a scalable and low loss routing of quantum dot light on a photonic chip. However, the coupling efficiency of directly integrated emitters is quite poor.

Here we present a method to increase the coupling efficiency between the quantum dots and waveguides via the utilization of a Bragg grating cavity that can be directly integrated into the waveguide. High Q-factors of fabricated cavities in combination with a stable resonance wavelength of ± 0.11 nm over the full fabricated chip show the potential of this design. Furthermore we show the Purcell enhanced quantum dot emission up to a factor of $F_p = 3.5 \pm 0.5$ which can be increased up to a factor of 20 according to FTDT simulations.

HL 3.9 Mon 11:45 H33

Twisted light - new perspectives for solid state optical spectroscopy — •Florian Büscher[1,2], Dirk Wulferding[1,2], and Peter Lemmens[1,2] — [1]IPKM, TU-BS, Braunschweig, Germany — [2]LENA, TU-BS, Braunschweig, Germany

Conventionally polarized light possesses zero orbital angular momentum. Using spatially modulated filters ("q-plates") [1,2] we probe the response of certain magnetic model systems to a finite orbital angular momentum, so-called twisted light [3]. We search for such effects in electronic and phononic Raman scattering and demonstrate initial results. Work supported by QUANOMET NL-4 and DFG LE967/16-1. [1] Marrucci, et al., PRL 96, 163905 (2006). [2] Slussarenko, et al., Opt. Express 19, 4085 (2011). [3] Schmiegelow, et al., Nat. Commun. 7, 12998 (2016).

HL 4: Focus Session: Oxide Semiconductors for Novel Devices I (joint session HL/DS)

The class of semiconducting oxides materials is currently investigated in terms of promising applications in devices, including low temperature processed amorphous thin films for bendable electronics and display technology as well as highly crystalline materials such as the wide band group-III sesquioxides. Possible devices applications are UV and DUV photo sensors, power electronics and even memristors. This session sets a focus on physical properties of semiconductor oxide materials, their growth methods and heterostructures for demonstrator devices.

Organizers: Holger Eisele (TU Berlin) and Holger von Wenckstern (Uni Leipzig)

Time: Monday 9:30–12:45 Location: H34

Invited Talk HL 4.1 Mon 9:30 H34

The role of suboxide kinetics and thermodynamics for the catalysis and facet formation during the molecular beam epitaxy of oxides — •Oliver Bierwagen — Paul-Drude-Institut für Festkörperelektronik, Leibniz Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5–7, 10117 Berlin, Germany.

Based on its wide band gap of E_g=4.7 eV Ga_2O_3 is a promising oxide semiconductor for novel applications such as power electronics and UV detection. Band-gap engineering by alloying with In_2O_3 (E_g=2.7 eV) allows tuning the detection wavelength and enable heterostructure devices. Thin film growth of these oxides by molecular beam epitaxy (MBE) enables the high material quality (purity and crystallinity) required for novel applications. This contribution shows how the intermediate formation and desorption kinetics of Ga_2O and In_2O limits the MBE growth rate of Ga_2O_3 (and of In_2O_3 to a less extent).[1] Nevertheless, the stronger Ga-O than In-O bonds thermodynamically leads to a favorable incorporation of Ga into the alloy $(In_xGa_{1-x})_2O_3$.[2] The collaborative effect of these kinetics and thermodynamics is shown to lift the growth rate limitation of Ga_2O_3 in the presence of an additional In-flux by metal-exchange catalysis.[3,4] Finally, the impact of the metal-to-oxygen flux ratio on the anisotropy of surface free energy is shown to control the formation of surface facets on both oxides.[4,5] [1] Vogt et al., Phys. Rev. Mater. **2**, 120401(R) (2018). [2] Vogt et al., APL Mater. **4**, 086112 (2016). [3] Vogt et al., Phys. Rev. Lett. **119**, 196001 (2017). [4] Mazzolini et al., APL Mater. **7**, 022511 (2019). [5] Bierwagen et al., J. Phys.: Condens. Matter **28**, 224006 (2016).

Invited Talk HL 4.2 Mon 10:00 H34

Is There a Perspective of p-type Doping in Gallium Oxide? — •David Rogers[1], Ferechteh Teherani[1], Philippe Bove[1], Eric Sandana[1], Ryan McClintock[2], and Manijeh Razeghi[2] — [1]Nanovation, 8 Route de Chevreuse, 78117 Chateaufort, Francenh — [2]Center for Quantum Devices, Department of Electrical Engineering and Computer Science, Northwestern University, Evanston, IL60208, US

Recently, there has been a surge in interest for the ultra wide bandgap semiconductor Ga2O3. Key drivers for this are that bulk β-Ga2O3 wafers have become commercially available and that a variety of film growth methods have been shown to give n-type doping control. A major drawback associated with Ga2O3, however, has been lack of a method for fabricating p-type material. Indeed, it is generally proposed that p-type doping is unlikely to be obtained because of a combination of factors including the relatively low energy level of the valence band, the lack of an identified shallow acceptor, the relatively high effective masses of holes at the top of the valence band, the propensity for self-trapping of holes and the comparatively low formation energy of the oxygen vacancy donor (which favors compensation of acceptors). Recently, however, Chikoidze et al. [1] and Razeghi et al. [2] independently presented direct evidence of majority p-type conduction Ga2O3. The former concerned nominally undoped layers grown by PLD and the latter concerned Si doped layers grown by MOCVD. In this talk we will give an overview of these results. [1] Chikoidze et al. Materials Today Physics 3 (2017) [2] Razeghi et al., Photonics West, Feb (2018)

Invited Talk HL 4.3 Mon 10:30 H34

Highly rectifying contacts on Ga_2O_3, In_2O_3 and $(In,Ga)_2O_3$ thin films — •Daniel Splith — Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig, Germany

Oxide semiconductors like gallium oxide or indium oxide are promising materials for a new generation of transparent electronic devices. Additionally, alloying both materials allows band-gap engineering, enabling e. g. the fabrication of wave-length selective photodetectors. In order to realize devices like diodes, field-effect transistors and photodetectors, the fabrication of rectifying contacts is essential. Further, such contacts also enable the investigation of the materials by means of space charge region based methods like thermal admittance spectroscopy.

In this contribution the properties of Schottky contacts and pn-heterojunctions on heteroepitaxial Ga_2O_3 and In_2O_3 thin films grown by pulsed laser deposition are discussed. Additionally, the properties of such rectifying contacts on $(In,Ga)_2O_3$ thin films having a lateral composition gradient are presented. In order to improve the rectification of the contacts, different vertical layouts were investigated. Further, a comprehensive model, taking into account thermionic emission, thermionic field emission and charging currents as well as non-idealities like barrier height inhomogeneities, current spreading and variations of the net-doping density in growth direction, was employed in order to understand the measured characteristics.

15 min. break

Invited Talk HL 4.4 Mon 11:15 H34

Understanding the impact of vibrations and defects on the optical properties of phosphors — •P. Erhart[1], C. Linderälv[1], D Åberg[2], Y.-C. Lin[1], M Bettinelli[3], N. C. George[4], S. F. Parker[5], and M. Karlsson[1] — [1]Chalmers University of Technology, Sweden — [2]LLNL, USA — [3]University of Verona, Italy — [4]UCSB, USA — [5]ISIS Facility, UK

Activator ions such as Ce are used to control the luminescent properties of phosphors, which are core components in white-light-emitting diodes. Their optical signatures are temperature dependent as they are sensitive to changes in the local environment due to atomic vibrations. Using a combination of experiment and first-principles calculations, we have recently provided a complete phonon assignment for the oxide garnet $Y_3Al_5O_{12}$ (YAG). An increase in temperature causes larger tetragonal distortion of the CeO_8 moieties and an increase of the crystal-field splitting, which gives rise to a redshift of the emitted light. The lattice thermal expansion on the other hand reduces the tetragonality and induces a blue-shift. The non-linear shift of the color of the emitted light with increasing temperature can then be explained as a competition between these two processes. Thermal quenching of the emission due to non-radiative processes limits the efficiency of these devices. In this context, we have investigated the potential contribution of oxygen vacancies. It is found that these defects exhibit very strong and localized electron-phonon coupling, providing an efficient non-radiative recombination channel.

Invited Talk HL 4.5 Mon 11:45 H34

atomically resolved termination engineering of electronic states at oxide semiconductors — •Ya-Ping Chiu — Department of Physics, National Taiwan University, Taipei, Taiwan

Termination engineering at oxide semiconductors has become highly attractive for next-generation electronic and spintronic devices due to a delicate interplay of different correlated processes including orbital, charge, and magnetic ordering as well as lattice degrees of freedom at the interfaces. Therefore, to achieve a detailed physical understanding of such exotic phenomena at oxide interfaces becomes important. Only with such detailed high resolution experimental data, will it be possible to explore the relevance of the different physical models. In our studies, cross-sectional scanning tunneling microscopy and spectroscopy is employed to provide direct experimental insight into the origin and the natural evolution of the electronic properties with atomic precision across the heterointerfaces. In this talk, topics to be discussed include ferromagnetic/superconducting and multiferroic/ferromagnetic heterointerfaces. This study highlights the importance of a direct atomically resolved access to electronic interface states, which is useful

in understanding the intriguing interface properties in oxide semiconductors and providing a lot of insights for these communities. [1-3] Selected references: 1.*ACS nano, 12 (2), 1089 (2018). 2. Phys. Rev. Lett., 109, 246807 (2012). 3. Adv. Mater., 23, 1530 (2011).

Invited Talk HL 4.6 Mon 12:15 H34

Nanoscale Control of Native Point Defects and Doping in Oxide Semiconductors — •Leonard Brillson — The Ohio State University, Columbus, OH, USA

Nanoscale optical and electrostatic techniques can directly measure the movement of native point defects inside oxide semiconductors and how they control space charge regions, tunneling, and contact rectification. Depth-resolved cathodoluminescence spectroscopy (DRCLS) with hyperspectral imaging measures 3-dimensional defect redistribution on a nanoscale for ZnO, Ga2O3, SrTiO3, and BaSrTiO3, revealing how intrinsic and applied electric fields drive defect movement. Defects at metal-ZnO diodes change carrier densities, tunneling, and trap-assisted hopping, altering Zn- vs. O-polar Schottky barriers. Nanoscale 3D measurement and imaging reveal electrically-active defects that extend deep inside wires, altering depletion widths, conducting channel volumes, and metal-ZnO nano-contact rectification. Electron and ion beams alter defect distributions to create rectifying, ohmic, or blocking contacts with the same metal on the same nanowire, demonstrating the interplay between the nature of native point defects, the intrinsic doping, and the physical dimensions of the nanostructure itself in determining the electronic properties of the oxide interface. DRCLS also enabled us to correlate the dominant luminescence features of Ga2O3 with the most thermodynamically stable O vacancy, Ga vacancy, and Ga vacancy-hydrogen defect states in the band gap predicted theoretically. As with ZnO, the combined depth-resolved detection and processing of Ga2O3 suggests new avenues for defect and doping control.

HL 5: Topological insulators

Time: Monday 9:30–13:30 Location: H36

HL 5.1 Mon 9:30 H36

Mirror Chern number in the hybrid Wannier representation — •Tomáš Rauch[1,2], Thomas Olsen[3], David Vanderbilt[4], and Ivo Souza[2,5] — [1]Friedrich-Schiller-University Jena, Germany — [2]Centro de Física de Materiales, San Sebastián — [3]Technical University of Denmark, Kongens Lyngby, Denmark — [4]Rutgers University, Piscataway, New Jersey, USA — [5]Ikerbasque Foundation, Bilbao, Spain

We formulate the mirror Chern number (MCN) of a two-dimensional insulator with reflection symmetry $\hat{M}_z$ in terms of hybrid Wannier functions (the eigenfunctions of $\hat{P}\hat{z}\hat{P}$, the position operator projected onto the valence bands) localized perpendicular to the mirror plane. Because $\hat{P}\hat{z}\hat{P}$ and $\hat{M}_z$ anticommute, the spectrum of "Wannier bands" is symmetric about the mirror plane, and an excess of one mirror eigenvalue over the other in the occupied manifold leads to the appearance of flat bands on the mirror plane. In the absence of flat bands, pairs of dispersive bands may touch at isolated points on the mirror plane. These Dirac nodes are protected by reflection symmetry, and the MCN is given by the sum of their winding numbers. When flat bands are present the Dirac nodes are no longer protected, and the MCN is related instead to the Chern number of the flat bands. In some cases the magnitude of the MCN can be determined without constructing $\hat{M}_z$ explicitly. In three dimensions, the present formalism reveals a simple relation between the MCNs and the quantized axion angle θ, whose expression in the hybrid Wannier representation was previously obtained.

HL 5.2 Mon 9:45 H36

Nanoscale spectroscopy of surface states on a three-dimensional topological insulator — •Fabian Sandner[1], Fabian Mooshammer[1], Markus A. Huber[1], Martin Zizlsperger[1], Helena Weigand[1], Markus Plankl[1], Christian Weyrich[2], Martin Lanius[2], Jörn Kampmeier[2], Gregor Mussler[2], Detlev Grützmacher[2], Jessica L. Boland[1], Tyler L. Cocker[3], and Rupert Huber[1] — [1]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [2]PGI-9, Forschungszentrum Jülich, 52425 Jülich, Germany — [3]Department of Physics and Astronomy, Michigan State University, 48824 Michigan, USA

Massless Dirac fermions in topologically protected surface states (TSSs) make three-dimensional topological insulators (TIs) a promising material class for future high-speed electronics. However, recent reports outline the coexistence of the TSSs and an additional two-dimensional electron gas (2DEG) at TI surfaces due to band bending effects. Here, we use near-field microscopy in the mid-infrared spectral range to probe the local surface properties of $(Bi_{0.5}Sb_{0.5})_2Te_3$ structures with tomographic, three-dimensional precision on the nanoscale. Applying nano-spectroscopy, we retrieve the full complex-valued local dielectric function of the surface states without making *a priori* model assumptions on the spectral response. In this way, we identify a sharp Lorentzian resonance originating from intersubband transitions of the massive 2DEG, and a broadband absorption background in the dielectric function, which we attribute to transitions between the TSSs and the lowest 2DEG subband.

HL 5.3 Mon 10:00 H36

The quantum rectification sum rule in time reversal invariant materials — •Oles Matsyshyn and Inti Sodemann — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We derive a unifying fully quantum mechanical formula for the nonlinear conductivity of metals and insulators. With this formula we establish a new sum rule for the frequency integrated rectified current which is controlled entirely by the non-abelian Berry connection and therefore depends purely on the quantum geometry of the ground state wave-function. For metals the sub-gap spectral weight contributing to this sum rule is exhausted by a sharp peak whose strength is proportional to the Berry curvature dipole introduced in Phys. Rev. Lett. 115, 216806 (2015). This offers a deeper insight into the meaning of the Berry curvature dipole as a kind non-linear analogue of the Drude weight in inversion breaking and time reversal invariant metals, which can be viewed as quantifying an acceleration of the electron liquid which is second order in electric fields. We apply our findings to understand the non-linear opto-electronic properties of Weyl semimetal materials.

HL 5.4 Mon 10:15 H36

Band structure of the 2D HgTe quantum well from the cyclotron resonance — •Jan Gospodaric[1], Alexey Shuvaev[1], Vlad Dziom[1], Andrei Pimenov[1], Alena Dobretsova[2], Elena Novik[3], Nikolay Nikolaevich Mikhailov[2], and Ze Don Kvon[2] — [1]Institute of Solid State Physics, Vienna University of Technology, 1040 Vienna, Austria — [2]Rzhanov Institute of Semiconductor Physics and Novosibirsk State University, Novosibirsk 630090, Russia — [3]Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany

One of the most standardised and prominent methods to acquire the band structure of solids is provided by angle-resolved photoemission spectroscopy (ARPES). However, access to the electronic structure of thin film materials with a surrounding layered structure by ARPES is limited since the technique only allows investigation of the area close to the surface of the sample (typical depths in Ångström range). Here we present one the alternative method to obtain insight into the band dispersion of such samples by probing the cyclotron resonance of the free carriers in a thin film of three-dimensional topological insulator HgTe. Specifically, we applied our measuring procedure to a strained 80 nm thick HgTe quantum well, which is insulating in the bulk and is characterised by a 2D surface electron gas with a Dirac-like dispersion. With present technique we can map both the electron as well as the hole part of the band structure. The resulting band picture agrees reasonably well with theoretical predictions.

HL 5.5 Mon 10:30 H36

Topological crystalline insulators from stacked graphene layers — •Sanjib Kumar Das[1], Binghai Yan[2], Jeroen van den Brink[1,3], and Ion Cosma Fulga[1] — [1]Institute for Theoretical Solid State Physics, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot, 7610001, Israel — [3]Department of Physics,

Technical University Dresden, 01062 Dresden, Germany

In principle the stacking of different two-dimensional (2D) materials allows the construction of 3D systems with entirely new electronic properties. Here we propose to realize topological crystalline insulators (TCI) protected by mirror symmetry in heterostructures consisting of graphene monolayers separated by two-dimensional polar spacers. The polar spacers are arranged such that they can induce an alternating doping and/or spin-orbit coupling in the adjacent graphene sheets. When spin-orbit coupling dominates, the non-trivial phase arises due to the fact that each graphene sheet enters a quantum spin-Hall phase. Instead, when the graphene layers are electron and hole doped in an alternating fashion, a uniform magnetic field leads to the formation of quantum Hall phases with opposite Chern numbers. It thus has the remarkable property that unlike previously proposed and observed TCIs, the non-trivial topology is generated by an external time-reversal breaking perturbation.

HL 5.6 Mon 10:45 H36

Superconductivity in MBE grown $In_xSn_{1-x}Te/Bi_2Te_3$ films — •Andrea Bliesener, Junya Feng, Alexey Taskin, and Yoichi Ando — Institute of Physics II, University of Cologne, Germany

$In_xSn_{1-x}Te$ is derived from the topological crystalline insulator SnTe which becomes superconducting when doped with Indium and it is one of the top candidates for topological superconductivity [1].

$In_xSn_{1-x}Te$ thin films have been grown by molecular beam epitaxy (MBE) on a Bi_2Te_3 buffer layer, which has a good lattice matching for the growth in the (111) direction [2]. Using in situ post-annealing procedures, we achieve robust superconductivity in the grown $In_xSn_{1-x}Te$ films.

To look for possible signatures of topological superconductivity in the grown films, we fabricated tunnelling junctions on the surface of the superconducting $In_xSn_{1-x}Te$ films. The tunnelling spectroscopy data shows a clear two-gap structure in the measured conductance spectra which points to the coexistence of bulk and surface superconductivity in the studied $In_xSn_{1-x}Te$ thin films.

References

[1] S. Sasaki et al; Physical Review Letters 109, 217004 (2012)

[2] A. A. Taskin et al; Physical Review B 89, 121302(R) (2014)

HL 5.7 Mon 11:00 H36

Topological band structures in electrical circuits — •Tobias Hofmann[1], Tobias Helbig[1], Ching Hua Lee[2,3], Martin Greiter[1], and Ronny Thomale[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute of High Performance Computing, A*STAR, Singapore, 138632 — [3]Department of Physics, National University of Singapore, Singapore, 117542

Topolectrical circuits present themselves as a platform to investigate fundamental topological states of matter realized in classical synthetic crystals. The manifold degrees of freedom unfolding as lattice connectivity and parameter choice in electric networks enable the implementation of arbitrary tight-binding models. We report on the design, measurement and engineering of admittance band structures in periodic circuits providing an extensive symmetry classification. We employ our approach on explicating several examples reaching from the Su-Schrieffer-Heeger and the graphene model over the implementation of the Chern state up to the realization of non-Hermitian physics in this classical environment.

HL 5.8 Mon 11:15 H36

Haldane circuit — •Tobias Helbig[1], Tobias Hofmann[1], Ching Hua Lee[2,3], Martin Greiter[1], and Ronny Thomale[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institute of High Performance Computing, A*STAR, Singapore, 138632 — [3]Department of Physics, National University of Singapore, Singapore, 117542

We propose an implementation of the Chern state in a topolectrical circuit network, featuring topologically protected, unidirectional propagation of voltage packages at its boundary. Recently, electrical circuit arrays have been established as an easily accessible and tunable environment to host synthetic topological states of matter. The breaking of reciprocity and time-reversal symmetry as well as minimizing dissipation effects constitute the central challenges arising in a circuit realization of the Chern state. In this talk, we present operational amplifiers in a negative-impedance converter configuration as the key component to master these challenges. We report on our results of a dissipation-corrected circuit implementation of the Haldane model.

15 min. break

HL 5.9 Mon 11:45 H36

Quantum oscillations of the Hall resistance in bulk Bi_2Se_3 at high temperatures — •Olivio Chiatti[1], Marco Busch[1], Sergio Pezzini[2], Steffen Wiedmann[2], Oliver Rader[3], Lada V. Yashina[4], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]High Field Magnet Laboratory, Radboud University Nijmegen, 6525ED Nijmegen, The Netherlands — [3]Helmholtz-Zentrum-Berlin für Materialien und Energie, 12489 Berlin, Germany — [4]Department of Chemistry, Moscow State University, 119991 Moscow, Russia

Bi_2Se_3 is one of the prototype three-dimensional (3D) topological insulators, where investigating transport by the two-dimensional (2D) topological surface states (TSS) has been hampered by residual bulk charge carriers. In recent work, the high-field Hall resistance and low-field magnetoresistance indicate that the TSS may coexist with a layered 2D electronic system [1]. We have investigated nominally undoped, bulk Bi_2Se_3 with a high electron density $n \approx 2{\cdot}10^{19}$ cm^{-3} and show quantum oscillations of the Hall resistance for temperatures up to 50 K. The angular and temperature dependence of the Hall resistance and the Shubnikov-de Haas oscillations show 3D and 2D contributions to transport. Angular-resolved photoemission spectroscopy proves the existence of TSS. We present a model for Bi_2Se_3 and suggest a coexistence of TSS and 2D layered transport stabilizing the quantum oscillations of the Hall resistance [2].

[1] Chiatti *et al.*, Sci. Rep. **6**, 27483 (2016).

[2] Busch *et al.*, Sci. Rep. **8**, 485 (2017).

HL 5.10 Mon 12:00 H36

Early onset of a '−1' quantized Hall plateau in HgMnTe / HgCdTe quantum wells close to charge neutrality — Saquib Shamim, •Wouter Beugeling, Andreas Budewitz, Pragya Shekhar, Philipp Leubner, Hartmut Buhmann, and Laurens W. Molenkamp — Physikalisches Institut (EP3), Würzburg University, Würzburg, Germany

Transport measurements of HgCdTe/HgMnTe/HgCdTe quantum wells indicate that the Hall conductivity quantizes at $-e^2/h$ already for remarkably small magnetic fields of $\sim$ 100 mT and remains quantized up to a few tesla. This phenomenology is reminiscent of a suggestion [1] that the quantum anomalous Hall effect could occur in this material. However, the suggested mechanism of closing the bulk gap for one spin component does not apply to our setup due to insufficient magnetization at small magnetic fields.

Comparing our data to predictions obtained from $k{\cdot}p$ theory, we find that the particle-hole asymmetric dispersion gives rise to a Landau-level fan with a $-e^2/h$ plateau that spans a large range of magnetic field values. The Mn doping favours the onset at small magnetic fields due to the effect of the exchange coupling. We confirm our theory by showing that it remains consistent with experiments performed in a tilted magnetic field and at different temperatures.

[1] C.-X. Liu *et al.*, Phys. Rev. Lett. 101, 146802 (2008).

HL 5.11 Mon 12:15 H36

Top-down fabrication of gate-tuneable bulk-insulating TI nanowires and their quantum transport — •Matthias Rössler, Dingxun Fan, Oliver Breunig, Andrea Bliesener, Gertjan Lippertz, Alexey Taskin, and Yoichi Ando — II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany

With proximity-induced superconductivity, bulk-insulating topological insulator nanowires (TI NWs) are expected to serve as a robust platform for realizing Majorana bound states. When exploiting their non-Abelian exchange statistics, these could enable realizations of topological quantum computation schemes. In previous reports, however, manipulation of naturally- or MBE-grown TI NWs limited possible device layouts and finite bulk transport contribution yet showed potential for improvements.

We have been performing fabrication and optimization of bulk-insulating TI NWs based on a scalable approach, namely etching of MBE-grown high quality $(Bi_{1-x}Sb_x)_2Te_3$ thin films. Magneto-transport measurements have been carried out to characterize the NWs properties, showing that the quality of the pristine material can be maintained during fabrication. Using this technique, highly gate-tuneable bulk insulating TI NWs with a diameter of less than 100 nm

can be prepared to form arbitrary networks, which will be utilized to study proximity-induced superconductivity in more complex devices layouts.

HL 5.12 Mon 12:30 H36

Higher-order topology in two-dimensional crystals — Frank Schindler[1], Wladimir A. Benalcazar[2,3], Marta Brzezinska[1,4], Mikel Iraola[5,6], Adrien Bouhon[7,8], •Stepan S. Tsirkin[1], Maia G. Vergniory[5,9], and Titus Neupert[1] — [1]University of Zürich, Switzerland — [2]Pennsylvania State University, USA — [3]University of Illinois at Urbana-Champaign, USA — [4]Wroclaw University of Science and Technology, Poland — [5]Donostia International Physics Center, Donostia - San Sebastian, Spain — [6]University of the Basque Country UPV/EHU, Bilbao, Spain — [7]Uppsala University, Sweden — [8]NORDITA, Stockholm, Sweden — [9]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

We study two-dimensional spinful topological phases of matter protected by time-reversal and crystalline symmetries. To define the topology we employ the concept of corner charge fractionalization: We show that corners in a higher-order topological phase can carry charges that are fractions of even multiples of the electric charge. These charges are quantized and topologically stable as long as all symmetries are preserved. We classify the topologies corresponding to different corner charge configurations for all 80 layer groups, and present their bulk topological indices. These can be calculated from the symmetry data and Brillouin zone Wilson loops. To corroborate our findings, we present tight-binding models and density functional theory calculations for various material realizations.

HL 5.13 Mon 12:45 H36

Topological Crystalline Protection in the BHZ and Kane-Mele models — •Fernando Dominguez, Benedikt Scharf, and Ewelina M. Hanckiewicz — Wuerzburg University, Wuerzburg, Germany

We investigate the topological crystalline protection against in-plane magnetic fields that naturally appears in two general quantum spin Hall models: the BHZ and and the Kane-Mele models [1]. This protection avoids the mixing of counter propagating modes and arises through the combination of particle-hole and reflection symmetries. Indeed, a gap can be opened in the presence of terms that break one of the mentioned symmetries. Therefore, we explore the impact on the gap opening of different coupling terms that break particle-hole symmetry, such as, Rashba spin-orbit coupling, a staggered potential, next-nearest neighbor hopings, anisotropic g-factor and lattice strain.

[1] F. Dominguez, B. Scharf, G. Li, J. Schäfer, R. Claessen, W. Hanke, R. Thomale, and E. M. Hankiewicz, Phys. Rev. B 98 , 161407 (2018).

HL 5.14 Mon 13:00 H36

Interplay of disorder and interactions in 3d tilted Weyl cones — •Tycho Sikkenk[1] and Lars Fritz[2] — [1]Utrecht University, Utrecht, The Netherlands — [2]Utrecht University, Utrecht, The Netherlands

"Weyl semi-metals (WSMs) are characterised by a non-degenerate touching point in a linear dispersion where the density of states vanishes. This cone-like behaviour strongly affects the reaction of these materials to disorder and interactions, which we investigate within an RG framework.*In a less idealised case the cones in the dispersion can be tilted, which destabilises the fixed points of the upright model in favour of others that are associated with potentially different critical exponents."

HL 5.15 Mon 13:15 H36

Majorana bound states in Phase-Controlled Josephson Junctions with Strong Spin-Orbit Coupling — •Benedikt Scharf[1], Falko Pientka[2], Hechen Ren[3], Amir Yacoby[4], Bertrand I. Halperin[4], and Ewelina M. Hankiewicz[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Würzburg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]California Institute of Technology, Pasadena, California 91125, USA — [4]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Topological superconductors based on Josephson junctions in two-dimensional electron gases (2DEGs) with strong Rashba spin-orbit coupling (SOC) offer an attractive alternative to wire-based setups [1,2]. Here, we elucidate how phase-controlled Josephson junctions with an arbitrary combination of Rashba and Dresselhaus SOC can also host Majorana bound states (MBS) for a wide range of parameters as long as the magnetic field is oriented appropriately. Hence, MBS based on Josephson junctions can appear in a wide class of 2DEGs. We study the effect of SOC, the Zeeman energies, the superconducting phase difference and normal reflection to create a full topological phase diagram and find the optimal stability region to observe MBS. Finally, we study the role of the Doppler effect that can arise due to the magnetic-field-induced local gradient of the superconducting phase in these junctions. [1] F. Pientka, et al. Phys Rev X 7, 021032 (2017). [2] H. Ren, et al. arXiv:1809.03076.

HL 6: Invited talk Bertram

Time: Monday 12:15–12:45 Location: H33

Invited Talk HL 6.1 Mon 12:15 H33

Advanced nanoscale characterization of structural and optical properties of novel Nanostructures using scanning transmission electron microscopy cathodoluminescence — •Frank Bertram — Institut für Physik, Otto-von-Guericke-Universität Magdeburg

For a detailed understanding of complex semiconductor heterostructures and the physics of devices based on them, a systematic determination and correlation of the structural, chemical, electronic, and optical properties on a nanometer scale is essential. Luminescence techniques belong to the most sensitive, non-destructive methods of semiconductor research. The combination of luminescence spectroscopy,in particular at liquid He temperatures - with the high spatial resolution of a scanning transmission electron microscope (STEM) (dx $<$ 1 nm at RT, dx $<$ 5 nm at 10 K), as realized by the technique of low temperature scanning transmission electron microscopy cathodoluminescence microscopy (STEM-CL), provides a unique, extremely powerful tool for the optical nano-characterization of semiconductors, their heterostructures as well as their interfaces.

HL 7: Organic photovoltaics and electronics (joint session HL/CPP)

Time: Monday 15:00–17:15 Location: H31

HL 7.1 Mon 15:00 H31

Spectroscopy of Oligoacene molecules attached to Argon clusters — •Matthias Bohlen[1], Corey A. Rice[1], Aaron LaForge[1,2], and Frank Stienkemeier[1] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg — [2]University of Connecticut, Department of Physics, 2152 Hillside Rd, Storrs, CT, USA

Energy conversion efficiency for solar cells is generally limited by the Shockley-Queisser limit [1]. One way to circumvent this limit is through the use of organic photovoltaics (OPV), where specific charge and energy transfer processes can lead to higher conversion efficiencies. Polyaromatic hydrocarbons such as oligoacene molecules exhibit interesting quantum effects such as singlet fission, triplet-triplet annihilation, or superradiance and make promising candidates for OPV applications. Recently anthracene, tetracene and pentacene molecules adhered to the surface of neon clusters have been shown to provide interesting model systems for detailed studies of such effects [2]. We want to extend these measurements by spectroscopy of oligoacenes deposited to the surface of argon clusters.

[1] W. Shockley and H. J. Queisser, J Appl Phys 32, 510 (1961)
[2] S. Izadnia et al., J. Phys. Chem. Lett.*8,*2068 (2017)

HL 7.2 Mon 15:15 H31

When the model description hampers the parameter extraction for organic thin-film transistors — Markus Krammer[1], James Borchert[2], Andreas Petritz[3], Gerburg Schider[3], Esther Karner-Petritz[3], Barbara Stadlober[3], Hagen Klauk[2], and •Karin Zojer[1] — [1]Institute of Solid State Physics, NAWI Graz, Graz University of Technology, Graz, Austria — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany — [3]Joanneum Research Materials, Weiz, Austria

When transistor parameters, like charge mobility or contact resistances, are determined from the electrical characteristics, their values are not unambiguous, but rather depend on the extraction technique and on the underlying transistor model. We propose a technique to establish whether the ambiguity arises already from the chosen transitor model. This two-step technique analyzes the electrical measurements of a series of TFTs with different channel lengths. The first step extracts the parameters for each individual transistor. The second step checks whether the channel length-dependence of the extracted parameters is consistent with the model. We demonstrate the technique for a range of organic TFTs that differ in the semiconductor, the injecting contacts, and the geometry. Independent of the transistor set, state-of-the-art transistor models fail to reproduce the correct channel length-dependence. Our technique suggests that transistor models require improvements in terms of carrier density dependence of the mobility and the consideration of uncompensated charges in the transistor channel.

HL 7.3 Mon 15:30 H31

Vibronic coupling governs ultrafast intermolecular energy transfer in an oligomer thin film — Ephraim Sommer[1], Xuan Trung Nguyen[1], Lynn Gross[2], Thomas Frauenheim[2], Elena Mena-Osteritz[3], Peter Bäuerle[3], •Antonietta De Sio[1], and Christoph Lienau[1] — [1]Institut für Physik, Universität Oldenburg — [2]BCCMS, Universität Bremen — [3]Institut für organische Chemie II und neue Materialien, Universität Ulm

Organic photovoltaic(OPV) materials are complex molecular systems with many vibrational degrees of freedom. In such large molecules, vibronic coupling may result in conical intersections(CIs) of potential energy surfaces. Close to CIs, large vibronic couplings induce efficient ultrafast transition between electronic states. Hence CIs may profoundly influence the dynamics and yield of energy and charge transfer processes. So far, however, the importance of CIs for OPV materials has not yet been discussed. Here we use ultrafast two-dimensional electronic spectroscopy to study the light-induced dynamics in an oligomer thin film for OPV. Upon impulsive excitation, we detect a grid-like peak pattern suggesting coherent wavepacket motion in the excited state. After <50fs, the pattern transforms into a broad, featureless single peak. We observe an increase of oscillation period with an abrupt vanishing of the optically excited wavepacket, followed by the emergence of a new wavepacket with different oscillation. These results, together with ab-initio molecular dynamics calculations, show that intermolecular energy transfer in stacked dimers of this oligomer involves passage of the optically excited wavepacket through a CI within <50fs.

HL 7.4 Mon 15:45 H31

Influence of thermal transport parameters on operation temperature of OLEDs — •Georgii Krikun and Karin Zojer — Institute of Solid State Physics, NAWI Graz, Graz University of Technology, Graz, Austria

Utilizing organic light emitting diodes (OLEDs) for lighting requires a homogeneous operation across large surface areas. This poses the challenge to suppress local variations in temperature and current density. While OLED research mostly focuses on electric and optical properties, thermal properties are highly relevant, as charge transport in organics is thermally activated. Due to the peculiar coupling between thermal and charge transport, related properties cannot be decoupled from each other.

We investigate how thermal conductivity and heat transfer between OLED surface and environment impact current voltage relations and device temperature for a given ambient temperature. By using self-consistent drift-diffusion based simulations, that simultaneously account for thermal and charge transport and their coupling, we establish how excess heating can be effectively counteracted. Despite a strong coupling between charge and heat transport, heat transport is essentially governed by layers that not participate in charge transport. Hence, electrical and thermal properties can be tuned with separate layers.

15 min. break

HL 7.5 Mon 16:15 H31

Barrier Heights in Contacts to Electroluminescent Thin Films of 1-(pyridin-2-yl)-3-(quinolin-2-yl)imidazo[1,5-a]quinoline Determined by Kelvin Probe Force Microscopy — •Clemens Geis[1], Georg Albrecht[1], Julia Ruhl[2], Jasmin Martha Herr[2], Richard Göttlich[2], and Derck Schlettwein[1] — [1]Justus-Liebig-Universität Gießen, Institut für Angewandte Physik — [2]Justus-Liebig-Universität Gießen, Institut für Organische Chemie

Thin films of 1-(pyridin-2-yl)-3-(quinolin-2-yl)imidazo[1,5-a]quinoline (*PCIC*) were prepared by physical vapor deposition and analyzed in situ by Kelvin probe force microscopy (KPFM). As contact phases, poly(3,4-ethylenedioxythiophene) polystyrene sulfonate (*PEDOT* : *PSS*) and poly(9-vinylcarbazole) (*PVK*) were used as hole conductors and bathocuproine (*BCP*) as electron conductor. Charge carrier injection barriers were identified, electroluminescent layer structures were prepared and effects of contact formation on radiative recombination were studied. Aside from the expected blue emission, a significantly red-shifted emission was found and assigned to electroplex formation with *BCP*. Using *PCIC* in a host-guest system within a matrix of *PVK* led to blue emission at improved luminescence. The studied interactions of *PCIC* with typical contact materials reveal the potential and limitations of *PCIC* as an electroluminescent material.

HL 7.6 Mon 16:30 H31

Rubrene based diodes for rectification applications — •Michael Sawatzki[1], Bahman Kheradmand Boroujeni[2], Hans Klemann[1], Frank Ellinger[2], and Karl Leo[1,3] — [1]Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and Institute for Applied Physics, Technische Universität Dresden, 01187 Dresden, Germany — [2]Chair for Circuit Design and Network Theory (CCN), Technische Universität Dresden, 01069 Dresden, Germany — [3]Center for Advancing Electronics Dresden (cfaed), 01187 Dresden, Germany

The developement of organic electronics is usually focused on a small set of electronic components, mainly OLEDs, solar cells, and various types of OFETs. To realize circuits, additional devices are required. One such device type are high-speed diodes, in the role of rectifiers, voltage stabilizers or analog signal processing. In particular for high-frequency RFID-applications it is essential to provide fast-switching diodes. The performance of such devices is closely related to the mobility of the semiconductor materials in use. Due to the anisotropy of charge carrier transport in most high-mobility organic semiconductors,

it is necessary to find material systems that offer high vertical mobilities. We present organic diodes, optimized for transition-frequency and high driving current, utilizing highly crystalline layers of Rubrene. These diodes show record values for the transition frequency, both in open circuit and under load. The values rached are higher than for inorganic diodes based on amorphous silicon and therefore allow for a low-cost realization of medium to long range RFID-systems.

HL 7.7 Mon 16:45 H31

Non-fullerene acceptors with tailored properties for organic solar cells — •Anastasia Markina[1], Frederic Laquai[2], and Denis Andrienko[1,2] — [1]Max Planck Institute for Polymer Research, Mainz 55128, Germany — [2]King Abdullah University of Science and Technology (KAUST), KAUST Solar Center (KSC), Thuwal 23955-6900, Kingdom of Saudi Arabia

One promising method to achieve higher solar cell efficiencies is to replace fullerenes with strongly-absorbing dye molecules, namely, non-fullerene acceptors (NFAs). However, the systematic design of acceptor molecules with tailored properties has yet to be demonstrated. The main difficulty here is that, while fullerenes are electrostatically inert, new acceptor molecules typically have strong static quadrupole moments.

By exploring the long-range electrostatic interaction at the interface, we demonstrate that, for a set of recently developed NFAs, the electrostatic bias potential can be directly related to the stabilization (or destabilization) of charge-transfer (CT) states as well as changes of the photovoltaic gap.

We find that the correlation between quadrupole moments, charge separation efficiency, and CT-state energy predicted by our model, is experimentally reproduced for several different donor /acceptor combinations. This allows us to predict new NFA structures using combinations of readily available molecular building blocks that can potentially reach even higher performances than those currently achieved in state-of-the-art NFA devices.

HL 7.8 Mon 17:00 H31

The three optical signatures of p-doping in poly(3-hexylthiophene) — Malavika Arvind[1], •Claudia Tait[2], Jan Behrends[2], and Dieter Neher[1] — [1]Universität Potsdam, Potsdam, Germany — [2]Freie Universität Berlin, Berlin, Germany

Doping is an important process in the realization of electronic devices. Here we investigate the mechanism of p-doping of regioregular- and regiorandom- poly(3-hexylthiophene) (P3HT) using two dopants - F4TCNQ and tris(pentafluorophenyl)borane (BCF). Although both dopants exhibit Integer Charge Transfer (ICT) with rreP3HT in solution, the sub-band gap features in the UV-Vis-NIR spectra of F4TCNQ- and BCF-doped rraP3HT differ significantly.[1] The concentration and nature of paramagnetic states generated in the different systems was investigated using EPR spectroscopy. The results reveal significantly reduced spin concentrations in the doped rraP3HT solutions, in particular with F4TCNQ as dopant, supporting the existence of EPR-silent bound charge pairs. Additionally, the hole delocalization was shown to be reduced in regiorandom- compared to regioregular-P3HT. We conclude that CTC and ITC formation is not specific for thiophene-based polymers and oligomers, respectively, as suggested by earlier results. [2] Instead, the nature of the doping-induced state correlates strongly with the ability of the conjugated backbone to planarize and to delocalize the polaron along the conjugated system.

[1] Pingel P., Arvind M. et al. (2016). Adv. Electron. Mater.,2:1600204 [2] H. Méndez, I. Salzmann, et al., Nat. Commun. 6, 8560 (2015).

HL 8: Transport and theory of electronic structure

Time: Monday 15:00–17:30 Location: H33

HL 8.1 Mon 15:00 H33

Anomalous microwave-induced resistance oscillations in double quantum well hetero-structures — •Jana Meyer[1], Jan Scharnetzky[2], Maik Hauser[3], Werner Dietsche[3], Werner Wegscheider[2], Lars Tiemann[1], and Robert H. Blick[1] — [1]Center for Hybrid Nanostructures, Hamburg University, 22761 Hamburg, Germany — [2]ETH Zürich, 8092 Zürich, Switzerland — [3]Max-Planck-Institute for Solid State Research, 70569 Stuttgart, Germany

Gallium arsenide double quantum well systems with various barrier thicknesses were exposed to microwave radiation at low temperatures and large magnetic fields. The double quantum well Hall bar samples employ structured top and back gates to control the electron densities and to electrically separate the two quantum wells.[1] At specific microwave frequencies and carrier densities, pronounced anharmonic oscillations in the longitudinal resistance emerge, which exhibit nodes at certain Landau level filling factors. The amplitude of these oscillations is very sensitive to the microwave power and variations of the carrier density. We propose this phenomenon to originate from plasmonic excitations.

[1] J. P. Eisenstein et al., Appl. Phys. Lett. 57, 2324 (1990).

HL 8.2 Mon 15:15 H33

Is the multifractal spectrum at the spin quantum Hall transition exactly parabolic? — •Daniel Hernangómez-Pérez[1], Soumya Bera[2], Ilya Gruzberg[3], and Ferdinand Evers[1] — [1]Institute of Theoretical Physics, University of Regensburg, Germany — [2]Department of Physics, Indian Institute of Technology Bombay, India — [3]Department of Physics, Ohio State University, USA

The integer quantum Hall effect (IQHE) has recently been proposed to have an exactly parabolic multifractality spectrum [1, 2]. Due to strong corrections to scaling, however the corresponding exponents are very difficult to access numerically. A close relative of the IQHE (class A) is the spin quantum Hall effect (SQHE, class C). In contrast to IQHE, for SQHE analytical results for certain anomalous exponents are available [3]. Correspondingly, corrections to scaling are under better control. Thus motivated, we here present a numerical study of multifractality at the SQHE using the corresponding network model. Our results: The multifractal spectrum of SQHE obeys the expected symmetry relation [4]; the analytically known exponents for the LDoS moments, $x_2 = 1/4, x_3 = 0$, are reproduced with good precision: 0.2504 ± 0.008 and 0.000 ± 0.002. The spectrum exhibits significant deviations from parabolicity, i.e. $x_q/q(3-q)$ shows linear term $a_1 = 0.0021 \pm 0.0002$. We see our results as providing constraints for future analytical theories of the SQHE. [1] R. Bondesan, et al., Nucl. Phys. B **918**, 52 (2017). [2] M. Zirnbauer, arXiv:1805.12555 (2018). [3] F. Evers et al., Phys. Rev. B **67**, 041303(R) (2003). [4] A. Gruzberg, et al., Phys. Rev. Lett. **107**, 086403 (2011).

HL 8.3 Mon 15:30 H33

Magnetotunneling Spectroscopy of Imbalanced Double Quantum Wells — •Gunnar Lasse Schneider[1], Werner Dietsche[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Uni Hannover, Deutschland — [2]MPI for Solid State Research, Stuttgart, Germany

Since several years bilayer phenomena such as 2D-2D Tunneling [1], Coulomb drag [2] and excitonic Bose-Einstein condensates (BEC) [3] are observable within double quantum wells in the Quantum Hall regime. Most studies were focused on balanced systems (i.e. the BEC was first found to arise at balanced layer densities with the filling factor combination of 1/2 and 1/2). In our work we are investigating imbalanced layers, allowing a mapping of the magnetotunneling characteristics at various filling factor combinations and the evolution of the excitonic condensate in the charge carrier density space.

All measurements were performed on a MBE grown GaAs double quantum well separated by a 10 nm AlAs/GaAs barrier. Each layer is individually contacted using field gates for a local depletion [4]. Additional gates allow tuning the charge carrier densities between 1E10 and 4E10 per square centimeter. Our measurements show Quantum Hall selection rules in the magnetotunneling characteristics (Quantum Hall spin diode) and the transition towards excitonic condensation.

[1]N. Turner et al., Phys. Rev. B 54, 10614 (1996)
[2]C. Jörger et al., Physica E 6, 586 (2000)
[3]J.P. Eisenstein and A.H. MacDonald, Nature 432, 691 (2004)
[4]J.P. Eisenstein et al., Appl. Phys. Lett. 57, 2324 (1990)

HL 8.4 Mon 15:45 H33

Suppression of magnetic-field-induced electronic transi-

tions in graphite microflakes — •Jose Luis Barzola Quiquia[1], Christian Precker[1], Markus Stiller[1], Mahsa Zoragui[1], Pablo Esquinazi[1], Tobias Foerster[2], and Thomas Herrmannsdoerfer[2] — [1]Felix-Bloch Institute for Solid State Physics, University of Leipzig, 04103 Leipzig, Germany — [2]Hochfeld-Magnetlabor Dresden (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

In this contribution we report a detailed study of the magnetoresistance of bulk and microflakes of different thickness prepared from a highly oriented pyrolytic graphite sample. Measurements have been done at different temperatures with pulsed magnetic fields up to 62 T applied parallel to the c-axis. The bulk and thicker samples show the well-known sudden jumps in the magnetoresistance in a restricted field region that were interpreted in the past as field-induced electronic phase transitions in graphite associated with, e.g., charge density waves. In the case of the thin graphite flakes the jumps in the magnetoresistance nearly vanish. In general, this suppression agrees very well with other thickness dependent results, such as the temperature dependence of the resistance, the absolute resistivity, the relative change in the magnetoresistance and the Shubnikov-de-Haas oscillations amplitude. Our results indicate that the electronic transport properties of bulk graphite are dominated by the two-dimensional electron gas formed at the interfaces between crystalline regions with the same or different stacking orders present in graphite.

HL 8.5 Mon 16:00 H33

Surface acoustic wave induced electrical current in graphene — •Pai Zhao, Lars Tiemann, and Robert H. Blick — Center for Hybrid Nanostructures, Hamburg University, 22761 Hamburg, Germany

Surface acoustic waves (SAWs) generated on a piezoelectric substrate are able to induce an acoustoelectric current that sweeps electrons along with the propagating waves.[1,2] Here, we show how to apply this acoustoelectric current as an alternative to a conventional current to study magnetotransport in monolayer graphene. We fabricated a pair of interdigitated transducers (IDTs) on a semi-insulating GaAs substrate, separated by 1,800 μm. A large CVD graphene sheet was transferred from a copper substrate onto the GaAs sample. In a photolithographic process we patterned a Hall bar structure centered between the two IDTs. Regular magnetotransport characterization of the graphene sample shows an intrinsic carrier concentration of $5.5\times10^{11}\mathrm{cm}^{-2}$ and a mobility of $600\mathrm{cm}^2/\mathrm{Vs}$. When the IDTs on the GaAs are excited at one of their harmonic resonance frequencies, we detect an acoustoelectric current passing through the graphene Hall bar, which follows the longitudinal resistance oscillations with magnetic fields up to 8 Tesla at 4.2 Kelvin.

[1] A. Wixforth et al., Phys. Rev. Lett 56, 2104 (1986).
[2] D. Kreft et al., Phys. Rev. B 94, 235305 (2016).

HL 8.6 Mon 16:15 H33

Explaining Charge Mobility Regimes in Amorphous Materials — •Markus Krammer[1], Chris Groves[2], and Karin Zojer[1] — [1]Institute of Solid State Physics, NAWI Graz, Graz University of Technology, Austria — [2]Department of Engineering, Durham University, United Kingdom

Charge mobility in amorphous materials like disordered organic semiconductors is commonly evaluated assuming hopping transport, where charges are viewed to migrate via hopping between localised states. The charge motion is governed by a complex interplay of energetic disorder, electric field, interactions, temperature, and other parameters. While state-of-the-art simulation techniques like kinetic Monte Carlo or Master equation (ME) account well for this complex interplay, it is desirable to distinguish between field- and charge density related mobility regimes and transitions between them from a more fundamental point of view. We developed a new simulation technique providing this fundamental view. The technique is reminiscent of ME with the benefit that it can directly incorporate correlations and interactions. The separation of field- and charge density related effects included in our new technique allows to interpret the corresponding evolution of the mobility. We will explore the mobility regimes from the perspective of steady state charge densities and occupation statistics. With simulations containing one charge carrier, we will explain the ideas behind our technique and discuss the reasons for the field dependence of the mobility. By increasing the number of charge carriers, the charge density dependence of the mobility will be elucidated.

HL 8.7 Mon 16:30 H33

Tunable disorder and localization in the rare-earth nickelates — •Changan Wang[1], Ching-Hao Chang[2], Angus Huang[3], Lin Yang[5], Roman Böttger[1], Manfred Helm[1], Ying-Hao Chu[4], Ramachandran Ganesh[6], and Shengqiang Zhou[1] — [1]Helmholtz-Zentrum-Dresden-Rossendorf, Dresden, Germany — [2]Leibniz-Institute for Solid State and Materials Research, Dresden, Germany — [3]National Tsing Hua University, Taiwan — [4]National Chiao Tung University, Taiwan — [5]South China Normal University, Guangzhou, China — [6]The Institute of Mathematical Sciences, Chennai, India

The rare-earth nickelates are a rich playground for transport properties, known to host non-Fermi liquid character, resistance saturation and metal-insulator transitions. We report a disorder engineering in LaNiO3 by ion-irradiation generated scattering centres in a tunable fashion to induce localization. While pristine LaNiO3 samples are metallic, highly irradiated samples show insulating behaviour at all temperatures. Using irradiation fluence as a tuning handle, we uncover an intermediate region hosting a metal-insulator transition. In the high temperature metallic regime, we find a transition from non-Fermi liquid to a Fermi-liquid-like character. On the insulating side of the metal-insulator transition, we find behaviour that is consistent with weak localization. In the highly irradiated insulating samples, we find good agreement with variable range hopping, consistent with Anderson localization. Our results demonstrate that ion irradiation can be used to tailor transport and study the physics of localization.

HL 8.8 Mon 16:45 H33

Analytically tractable model for chirality-induced spin selectivity — •Areg Ghazaryan[1], Yossi Paltiel[2], and Mikhail Lemeshko[1] — [1]IST Austria (Institute of Science and Technology Austria), Am Campus 1, 3400 Klosterneuburg, Austria — [2]Department of Applied Physics, Hebrew University, Jerusalem 91904, Israel

It is well established experimentally that electron transmission and tunneling through chiral molecules is spin selective. This phenomenon is termed as chirality-induced spin selectivity (CISS). Despite substantial advances on the experimental investigation of CISS, a theoretical understanding of the microscopic origin of the effect is still lacking. Previous theoretical efforts usually employed helical structure of the molecule for constructing the scattering or transport theories of CISS. The complicated geometry of the helix makes these theories intractable analytically. Here we develop a scattering theory for the CISS effect, by modelling the molecule as a combination of dipoles. These allows us to develop an analytically tractable model for analyzing the microscopic origin of the CISS effect. Different enantiomers are distinguished with different directions of the dipoles and the dipole moments can be directly measured using Stark effect measurements of the microwave spectrum of the molecules. Therefore, the parameters of our model can be directly obtained from the experimental results.

HL 8.9 Mon 17:00 H33

Ab-initio electronic structure calculations for random alloys: Accurate SiGe composition-dependent band gap at reduced computational cost — •Petr A. Khomyakov, Daniele Stradi, Ulrik G. Vej-Hansen, Maeng-Eun Lee, Jess Wellendorff, Søren Smidstrup, and Kurt Stokbro — Synopsys QuantumATK, Fruebjergvej 3, 2100 Copenhagen, Denmark

Semiconductor random alloys are commonly used in microelectronics, so first-principles calculations for the physical properties of random alloys are of great interest. This kind of calculations allow for obtaining the physical parameters for any alloy composition. However, configuration sampling of results for alloy supercells, which is the standard approach to capturing the effect of alloy disorder on the physical properties, can be computationally demanding.

In this study, we use the special quasi-random structures (SQS) approach for modeling SiGe random alloys over the entire range of alloy compositions. The SQS method alleviates the need for configuration sampling, reducing the computational cost considerably. At each alloy composition, we apply our recently-developed pseudopotential projector-shift (PPS) method for obtaining accurate band energies for silicon and germanium within the framework of the DFT-PBE functional approach. Using the SQS + PPS-PBE combination allowed us to obtain accurate SiGe band gaps across the entire range of alloy compositions, as compared to room-temperature measured gaps. Applying the HSE06 hybrid functional yields the composition-dependent SiGe band gaps in good agreement with low-temperature measured gaps.

HL 8.10 Mon 17:15 H33

Robust automatic Wannierisation — •Giovanni Pizzi[1], Valerio Vitale[2,3], Antimo Marrazzo[1], Nicola Marzari[1], Jonathan R. Yates[4], and Arash A. Mostofi[3] — [1]NCCR MARVEL and EPFL, CH — [2]Cavendish Laboratory, University of Cambridge, UK — [3]Department of Materials and Physics and Thomas Young Centre, Imperial College London, UK — [4]Department of Materials, University of Oxford, UK

In a recent work [1], the SCDM-k method has been successfully extended to obtain a set of localised Wannier functions in the case of entangled bands. The method relies on numerical parameters that need to be identified. Here, we first present the implementation of the method in Quantum ESPRESSO. Then, we provide a validation on ∼200 chemically different structures (including also lower-dimensional structures), discussing the robustness for the choice of the parameters with respect to the quality of the band interpolation and final spread of the localized orbitals. Thanks to this, we are able to provide a physical understanding of the parameters and present an automated protocol to select them, making use of the projectability of the states onto atomic-like orbitals. Finally, we present the implementation of this fully automated method into AiiDA workflows for Quantum ESPRESSO and Wannier90, that makes it possible to obtain automatically maximally-localised Wannier functions for any material without supervision.

[1] A. Damle, L. Lin, Disentanglement via entanglement: A unified method for Wannier localization, arXiv:1703.06958v1 (2017).

HL 9: Focus Session: Oxide Semiconductors for Novel Devices II

Organizers: Holger Eisele (TU Berlin) and Holger von Wenckstern (Uni Leipzig)

Time: Monday 15:00–17:30 Location: H34

HL 9.1 Mon 15:00 H34

Tin-assisted PLD-growth of epitaxial κ-Ga_2O_3 thin films — •M. Kneiss[1], A. Hassa[1], D. Splith[1], C. Sturm[1], H. von Wenckstern[1], M. Lorenz[1], T. Schultz[2], N. Koch[2], and M. Grundmann[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik — [2]Humboldt Universität zu Berlin, Institut für Physik

Among the polymorphs of Ga_2O_3, the orthorhombic κ-phase features some outstanding properties. In contrast to the monoclinic β-modification, it is expected to possess a large spontaneous electrical polarization of 23 μC/cm^2 [1], while still exhibiting a high E_g of $\approx$ 5 eV [2]. Alloying with Al_2O_3 or In_2O_3 further enables band gap as well as polarization engineering, such that heterointerfaces can be utilized to localize high electron densities in a 2DEG. To create high quality heterostructures, epitaxial growth of κ-Ga_2O_3 with high crystalline quality and smooth surfaces is necessary. We show the growth of κ-Ga_2O_3 (001) with well-defined in-plane epitaxial relationships on Al_2O_3 (00.1), STO (111), YSZ (111) and MgO (111) substrates by pulsed laser deposition (PLD). A Sn-doped Ga_2O_3 PLD-target was used to catalyze the κ-phase [3]. The growth in this phase, epitaxial relationships and a high crystalline quality were verified by XRD, while AFM measurements reveal smooth surface morphology. We propose surfactant-mediated epitaxy as possible growth mechanism [4].

[1] M. B. Maccioni *et al.*, Appl. Phys. Expr. **9**, 041102 (2016)
[2] J. Furthmüller *et al.*, Phys. Rev. B **93**, 115204 (2016)
[3] M. Orita *et al.*, Thin Solid Films **411**, 134 (2017)
[4] M. Kneiß *et al.*, APL Materials, Accepted (2018)

HL 9.2 Mon 15:15 H34

Effective electron mass anisotropy in α-Ga_2O_3 — •Martin Feneberg[1], Jürgen Bläsing[1], Rüdiger Goldhahn[1], and Kazuaki Akaiwa[2] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg — [2]Department of Information and Electronics, Tottori University, Tottori 680-8552, Japan

Metastable α-Ga_2O_3 is a currently discussed candidate material system for future electronic devices. It is alloyable with corundum α-Al_2O_3 (sapphire) and α-In_2O_3. While p-type doping proves to be problematic, n-type doping by the substitutional donor tin is successful up to $n > 10^{19}$ cm^{-3}.

Here, we investigate the infrared optical properties of m-plane $(1\bar{1}00)$ α-Ga_2O_3 thin films grown on sapphire by mist chemical vapour epitaxy. Spectroscopic ellipsometry and Raman spectroscopy yields a full picture of the anisotropic phonon modes. A free-carrier contribution in degenerately highly doped material is found in the dielectric functions and yields anisotropic plasma frequencies.

By taking the Hall-effect free-electron concentration into account, effective electron masses of $m^*_\perp = 0.297m_0$ and $m^*_{||} = 0.316m_0$ are obtained at $n = 1.1 \times 10^{19}$ cm^{-3}. We finally discuss the nonparabolic dispersion relation of the conduction band rendering these values to be upper limits for the effective masses at the Γ-point of the Brillouin zone.

HL 9.3 Mon 15:30 H34

Transport Properties and Finite Size Effects in β-Ga_2O_3 Thin Films — •Robin Ahrling[1], Johannes Boy[1], Martin Handwerg[1], Olivio Chiatti[1], Rüdiger Mitdank[1], Zbigniew Galazka[2], Günter Wagner[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Leibniz Institute for Crystal Growth, 12489 Germany

As a wide-band gap semiconductor with a high breakthrough field, gallium oxide (Ga_2O_3) has shown to be a promising material for applications in high power electronics. Here, we investigate the electrical properties of thin films and their dependence on film thickness. The scattering processes in the films may changes drastically with decreasing film thickness. [1]

Homoepitaxially MOVPE-grown monocrystalline Si-doped β-Ga_2O_3 films (28 - 225 nm thickness) were electrically characterized in a temperature range from 300 K down to 10 K. Van-der-Pauw and Hall-measurements were performed to determine conductivity, Hall density and carrier mobility. Thicker films (>150 nm) show a behavior similar to the bulk. Below 100 nm, a drastic drop of the mobility with decreasing thickness was observed, pointing to an additional surface scattering effect. We find that the commonly applied classical Fuchs-Sondheimer model does not explain the contribution of electron scattering at the film surfaces sufficiently. Instead, by applying an electron wave model by Bergmann, a mobility suppression due to the large de Broglie wavelength in β-Ga_2O_3 is proposed as a limiting quantum mechanical size effect. [1] R. Ahrling *et al.*, https://arxiv.org/abs/1808.00308

HL 9.4 Mon 15:45 H34

Properties of the β-Ga_2O_3(1 0 0) surface — •Jonathan K. Hofmann[1], Celina S. Schulze[1], Wjatscheslav Martyanov[1], Martin Franz[1], Zbigniew Galazka[2], and Holger Eisele[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Germany — [2]Leibniz-Institut für Kristallzüchtung, Germany

β-Ga_2O_3 is a wide band gap material showing n-type conductivity. The electrical conductivity of β-Ga_2O_3 can be controlled by growth environment, intentional doping, or post-growth heat treatment. Due to its large band gap of 4.85 eV, β-Ga_2O_3 is a promising material for high power electronics and UV optoelectronics.

The β-Ga_2O_3 single crystals were grown from the melt by the Czochralski method [1] and show good conductivity. For the present study, a sample was cleaved in UHV and the (1 0 0) surface was investigated with low energy electron diffraction (LEED) and scanning tunnelling microscopy/spectroscopy (STM/STS). The LEED-patterns show the unreconstructed (1 0 0) surface. STM images with atomic resolution display an atomically flat surface with dark contrasts. These dark contrasts are likely induced by oxygen vacancies below the surface. STS reveals an electronic state 1.5 eV below the conduction band minimum. This state is probably induced by the (+2/0) transition level of the oxygen vacancies.

The project was supported by the Leibniz Association, Leibniz Science Campus GraFOX, project C2-3.

[1] Z. Galazka et al., ECS J. Solid State Sci. Technol. **6**, Q3007 (2017).

HL 9.5 Mon 16:00 H34

Low-frequency noise characterization of MOCVD-grown β-Gallium Oxide — •Christian Golz[1], Günther Wagner[2], Andreas Popp[2], Fariba Hatami[1], and W. Ted Masselink[1] — [1]Department of Physics, Humboldt-Universität zu Berlin, Newton-Str. 15, D-12489 Berlin, Germany — [2]Leibniz Institute for Crystal Growth,

Max-Born-Str. 2, 12489 Berlin, Germany

Low-frequency noise spectroscopy was used to characterize β-Ga_2O_3 epilayers. These high-quality Si-doped layers were homoepitaxially grown by metal-organic chemical vapour deposition (MOCVD) on insulating Mg-doped β-Ga_2O_3 substrates. For noise measurements, Greek cross structures were processed using optical lithography. Hot H_3PO_4 etch was applied to process the mesa structures. Ohmic Cr/Au contacts were processed by thermal evaporation. Low-frequency noise is produced by the fluctuations in conductivity in a material. The 1/f noise intensity was used to determine a room temperature Hooge factor below 10^{-4}. This value indicates a high structural quality of the epilayer. Generation-recombination noise was analyzed between 80 K and 400 K. Several trap levels were found with characteristic time constants depending exponentially on temperature. Activation energies for these levels were determined to be in the range from 30 meV to 300 meV.

HL 9.6 Mon 16:15 H34

Ion beam Doped Transparent Conductive Oxides for Metasurfaces — •Alexander Koch, Jura Rensberg, Martin Hafermann, and Carsten Ronning — Institute of Solid State Physics, Friedrich Schiller University Jena, Germany

Transparent conductive oxides have recently gained a lot of attention for applications in plasmonics and nanophotonics due to their low optical loss, metal-like behavior, tailorable optical properties, and well established fabrication procedures. In particular, n-type doped zinc oxide (ZnO), such as aluminum doped ZnO (AZO), is very attractive because its dielectric permittivity can be precisely engineered over a broad range in the near-IR and IR regime via its doping level. Here, we show that a very high doping concentration in ZnO can be achieved by ion implantation and post implantation annealing treatments. Furthermore, ion implantation offers the great opportunity of area selective doping using either focused ion beams or appropriate lithography techniques in combination with ion implantation. By this means, metasurfaces can be fabricated, which are composed of subwavelength sized structure elements possessing high optical contrast.

HL 9.7 Mon 16:30 H34

Phase transitions in Zn_2GeO_4: Insights from first-principles calculations — •Daniel Fritsch[1], Joachim Breternitz[1], and Susan Schorr[1,2] — [1]Department Structure and Dynamics of Energy Materials, Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [2]Department of Geosciences, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany

At ambient conditions, Zn_2GeO_4 crystallises in the thermodynamically stable willemite-type structure. However, under high-pressure, it is known to undergo a phase transition into a spinel-type phase. Given the plethora of possible applications for Zn_2GeO_4, ranging from cathode material in Li-ion batteries to photocatalyst system, requires a deeper understanding of the material properties in consideration of possible phase transitions.

Here, we will show results on the structural and electronic properties of Zn_2GeO_4 based on density functional theory calculations. Structural properties have been calculated using the PBEsol and the hybrid HSE06 functionals, and will be compared to results from a combined X-ray and neutron powder diffraction study. The electronic properties, e.g. band structure and effective masses, will be discussed as well.

This work made use of computational resources provided by the North-German Supercomputing Alliance (HLRN), and the Soroban and Dirac HPC facilities of the Freie Universität Berlin and the Helmholtz-Zentrum Berlin, respectively.

HL 9.8 Mon 16:45 H34

A theoretical study of Electronic and Optical Properties of Mercaptocarboxylic Acids on ZnO Surfaces — •Michael Lorke[1], Dennis Franke[1], Andreia daRosa[1,2], and Thomas Frauenheim[1] — [1]University of Bremen, Germany — [2]Institute of Physics, Federal University of Goiás,Brazil

In this work we investigate the electronic properties of mercaptocarboxylic acids with several carbon chain lengths adsorbed on ZnO-(10-10) surfaces via density functional theory calculations using semi-local and hybrid exchange-correlation functionals. Amongst the investigated structures, we identify the monodentate adsorption mode to be stable. Moreover, this mode introduces optically active states in the ZnO gap, is further confirmed by the calculation of the dielectric function at PBE0 and TD-PBE0 levels. One interesting finding is that adsorption mode and the dielectric properties of the hybrid system are both rather insensitive to the chain length, since the acceptor molecular state is very localized on the sulphur atom. This indicates that even small molecules can be used to stabilize ZnO surface and to enhance its functionality for opto-electronic applications.

HL 9.9 Mon 17:00 H34

Thermodynamics and electronic structure of low-index β-Ga_2O_3 surfaces — •Konstantin Lion[1,2], Sergey V. Levchenko[3,2,4], Matthias Scheffler[2], and Claudia Draxl[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, DE — [2]Fritz-Haber-Institut der MPG, Berlin, DE — [3]Skolkovo Innovation Center, Moscow, RU — [4]NUST MISIS, Moscow, RU

The surface properties of β-Ga_2O_3 play a vital role in epitaxial growth, electrical contacts, and gas sensors, but are still not well understood. In this work, we study the stability and electronic structure of several non-polar low-index surfaces of β-Ga_2O_3 using *ab initio* atomistic thermodynamics. Employing the efficient high-precision all-electron code FHI-aims, we perform density-functional-theory calculations with the HSE06 hybrid exchange-correlation functional. Numerous surface free energies are calculated, also including vibrational contributions. We find that the (100) surface is the most stable one, in agreement with previous reports [1], but, quite suprisingly, it is followed closely by the $(\bar{2}01)$ surface. Here, the topmost surface layers are significantly flattened upon relaxation, reducing the surface energy to 40 % of the value of the unrelaxed surface. This result explains recent experimental findings where $(\bar{2}01)$ facets were found to form during homoepitaxial growth on off-oriented β-Ga_2O_3 (100) substrates [2]. For this surface the electronic structure also reveals a strong surface resonance at the top of the valence band.

[1] V.M. Bermudez, Chem. Phys. **323**, 193 (2006).
[2] R. Schewski *et al.*, APL Materials **7** (2019), in print.

HL 9.10 Mon 17:15 H34

Nanostructured Metal-Oxides as Chemiresistive Gas Sensors for Breath Analysis — •Zafer Ziya Öztürk, Onur Alev, Neslihan Sarica, Alp Kiliç, and Serkan Büyükköse — Gebze Technical University, Çayirova Campus, 41400 Gebze/KOCAELI TURKEY

Recently, breath analysis has attracted much attention for disease monitoring and clinical diagnostics due to its non-invasive and therapeutic features. A number of breath markers or tracer compounds are summarized and related to different diseases, such as ammonia (kidney disease), HCN (bacterial infection), CO (lung inflammation), NO (asthma) and acetone (diabetes).

For point-of-care diagnosis, a portable, low cost and user-friendly sensors are desirable. To meet these requirements, emphasis is placed on metal-oxide (MOX) based chemiresistive gas sensors. Chemiresistive type sensors using various semiconducting MOXs, such as SnO2, ZnO and NiO have been considered for use as exhaled breath sensors due to their adequate reaction with volatile organic compounds. One dimensional nanostructures have attracted considerable interest due to their high surface-to-volume ratio and unique electrical properties. These features make them promising candidates for highly sensitive and selective breath analysis. In this work, nanostructured MOXs; ZnO, TiO2, CuO and WO3 sensors were fabricated by different techniques such as hydrothermal, electrochemical deposition and anodization. Fabricated sensor devices were tested towards some breath markers such as acetone, ammonia, HCN and ethanol in the range of ppb and sub-ppm.

HL 10: Quantum information systems

Time: Monday 15:00–17:15 Location: H36

HL 10.1 Mon 15:00 H36

Stimulated Microwave Emission from Opticaly Pumped Vacancy Defects in 4H Silicon Carbide for Maser Applications — •Andreas Gottscholl[1], Andreas Sperlich[1], Georgy V. Astakhov[2], Moritz Fischer[1], and Vladimir Dyakonov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden

Masers are already well known for decades, nevertheless their application as telecomunications amplifier is highly limited due to their operating conditions requiring vacuum techniques and cryogenic temperatures. Just recently a new generation of room-temperature masers was invented based on spin-properties of pentacene and diamond, respectively. In this study, we pave the way for a silicon carbide based maser to overcome the maser-threshold and which may potentially offer some advantages over the other approaches. In order to get a population inversion, we use opticaly pumped silicon vacancies and by applying an external magnetic field we tune the microwave transition into the range of 10 GHz [1]. Using magnetic resonance techniques, we characterize the system including population inversion, pumping efficiency and ultimately stimulated microwave emission [2]. In combination with a high-Q resonator ($Q_L \approx 50000$) our material is well on its way to become a suitable maser system with a wide-ranging applicability.

[1] Kraus et al., Nat. Phys. **10**, 152 (2014)
[2] Fischer et al., Phys. Rev. Applied. **9**, 054006 (2018)

HL 10.2 Mon 15:15 H36

Optimization of the Dispersive Readout of a Spin Qubit — •Benjamin D'Anjou and Guido Burkard — Universitätstr. 10, D-78464 Konstanz, Deutschland

Recently, strong coherent coupling of semiconductor spin qubits with a superconducting microwave resonator was demonstrated in several settings [1-3]. These breakthroughs pave the way for quantum information processing platforms that combine the long coherence times characteristic of solid-state spin qubits with the long-distance connectivity, fast control, and fast high-fidelity non-demolition readout that have so far been the hallmark of superconducting qubit implementations. Here, we analyze the dispersive readout of a single spin in a double quantum dot coupled to a microwave cavity via its dipole moment. The strong spin-photon coupling arises from the admixture of electronic charge and spin induced by a strong local magnetic field gradient. We estimate the expected signal-to-noise ratio of the readout accounting for both Purcell spin relaxation and spin relaxation arising from sources of electric noise. In particular, we analyze the tradeoff between maximizing the spin-photon coupling strength and minimizing spin relaxation. We give expressions for the values of the experimentally tunable parameters that maximize the signal-to-noise ratio.

[1] Mi et al., Nature 555, p. 599 (2018)
[2] Landig et al., Nature 560, p. 179 (2018)
[3] Samkharadze et al., Science 359, p. 1123 (2018)

HL 10.3 Mon 15:30 H36

Entangling distant single electron spin qubits via circuit quantum electrodynamics — •Mónica Benito and Guido Burkard — Department of Physics, University of Konstanz, Konstanz, Germany

The recent realization of a coherent interface between electron spin qubits fabricated in quantum dots and superconducting transmission line resonators [1,2,3] opens the way for implementing resonator-mediated two-qubit entangling gates. In order to couple a spin to the resonator electric field, some type of spin-charge hybridization is needed, which deteriorates the coherence properties of the spin qubit. In this work we focus on single electron spin qubits placed in double quantum dots and hybridized to the charge degree of freedom via an externally applied magnetic field gradient [4]. We calculate entangling gate fidelities both in the dispersive and resonant regime accounting for errors due to the spin-charge hybridization.

[1] X. Mi et al., Nature 555, 599 (2018).
[2] N. Samkharadze et al., Science 359, 1123 (2018).
[3] A. J. Landig et al., Nature 560, 179 (2018).
[4] M. Benito et al., Phys. Rev. B 96, 235434 (2017).

HL 10.4 Mon 15:45 H36

Polytypism induced sign reversal in zero-field splitting of silicon vacancies in 6H-SiC — •Victor Soltamov[1], Vladimir Dyakonov[1], Timur Biktagirov[2], Wolf Gero Schmidt[2], Uwe Gerstmann[2], Boris Yavkin[3], Sergei Orlinskii[4], and Pavel Baranov[5] — [1]Experimental Physics VI, Julius-Maximilian University of Würzburg, 97074 Würzburg, Germany — [2]Lehrstuhl für Theoretische Materialphysik, Universität Paderborn, 33098 Paderborn, Germany — [3]3rd Institute of Physics, University of Stuttgart, 70569 Stuttgart, Germany — [4]Kazan Federal University, 420008 Kazan, Russia — [5]Ioffe Institute, 194021 St. Petersburg, Russia

Negatively charged S = 3/2 silicon vacancy centers in Silicon Carbide (SiC) are one of the candidates featuring unique functionality for quantum sensing [1, 2], as well as for quantum communication [3]. The polytypism of SiC, i.e., the ability to form many different crystal structures, appears as an additional lever to reach the ideal combination of magnetic and optical characteristics. Here the properties of the zero-field splitting (ZFS) of these centers in 6H-SiC are uncovered by means of EPR and ENDOR techniques, combined with first-principles calculation. We show that the centers possess not only significantly different absolute values of ZFS, but also differ in their sign. This diversity is rationalized by a flattened/elongated character of their spin density distribution.

[1] D. Simin et al., Phys. Rev. B 95, 161201(R) (2017).
[2] S.-Y. Lee et al., Phys. Rev. B 92, 115201 (2015).
[3] S. E. Economou and P. Dev, Nanotechnology 27, 504001 (2016).

15 min. break

HL 10.5 Mon 16:15 H36

Cavity quantum electrodynamics with spin and valley — •Christoph Adelsberger, Monica Benito, and Guido Burkard — Department of Physics, University of Konstanz, D-78464 Konstanz, Germany

The energy level structure of a double quantum dot fabricated in Si/SiGe combines orbital, spin and valley degrees of freedom [1]. Although it has been demonstrated that in some cases the orbital and spin degrees of freedom can be isolated from the valley in order to engineer a strong interaction between the electronic spin and a photon in a coupled superconducting microwave resonator [2,3,4], it is desirable to understand the general role of the valley in this kind of cavity quantum electrodynamics setup. First, we analyze the possibility for a strong interaction between the valley degree of freedom and a microwave photon, which could benefit from protection against charge noise [5]. Then we incorporate the spin degree of freedom and investigate the possible hybrid qubits that provide a useful relation between coupling strength to the photons in the resonator and decoherence due to typical noise sources. We expect that these results contribute to the future performance of long-distance coupling between qubits in this potentially scalable semiconductor quantum dot systems.

[1] G. Burkard and J. R. Petta, PRB **94**, 195305 (2016).
[2] X. Mi et al., Nature **555**, 599 (2018).
[3] N. Samkharadze et al., Science **359**, 1123 (2018).
[4] M. Benito et al., PRB **96**, 235434 (2017).
[5] X. Mi, S. Kohler, and J. R. Petta, PRB **98**, 161404(R) (2018).

HL 10.6 Mon 16:30 H36

Ultrafast electric phase control of a quantum dot exciton — •Alex Widhalm[1], Amlan Mukherjee[1,2], Sebastian Krehs[1], Björn Jonas[1], Nandlal Sharma[1], Peter Kölling[1,2], Andreas Thiede[2], Jens Förstner[1,2], Dirk Reuter[1], and Artur Zrenner[1] — [1]Physics Department, University of Paderborn — [2]Department of Electrical Engineering, University of Paderborn, Paderborn 33098, Germany

In our experiment we created a superposition state of a quantum dot exciton, whose quantum phase is subsequently manipulated by ultrafast Stark tuning. The resulting phase shift is measured by Ramsey interference. Previously we have already shown, that the coherent phase of a QD exciton can be manipulated electrically by phase-locked RF signals [1]. Here we have designed ultrafast BiCMOS chips for

the generation of electric pulses (rise times <20 ps @ cryogenic operationality) and RF-photodiodes with embedded high quality InGaAs QDs. Electric connections have been established by short distance wire bonding. This hybrid approach enables us to perform electric phase control synchroneous to double pulse ps laser excitation. We are able to demonstrate electrically controlled phase manipulations with magnitudes up to 3π and the electric control of the QD occupancy on time scales below the dephasing time of QD exciton [2].

Ref: [1] S. de Vasconcellos et al., Nature Photonics 4, 545 (2010).
Ref: [2] A. Widhalm et al., Applied Physics Letters 112(11):111105 (2018).

HL 10.7 Mon 16:45 H36

Optimal choice of state tomography quorum formed by projection operators — Violeta N. Ivanova-Rohling[1] and •Niklas Rohling[2] — [1]Department of Mathematical Foundations of Computer Science, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Akad.G.Bonchev, block 8, 1113 Sofia, Bulgaria — [2]Center for Quantum Spintronics, Department of Physics, Norwegian University of Science and Technology, NO-7491 Trondheim, Norway

The density matrix of a n-dimensional quantum system, can be estimated by repeatedly performing projections on $n+1$ measurement operators. Ideally, the eigenbases of these operators form a set of mutually unbiased bases [1]. However, the situation is different if, due to restrictions in the experimental setup, only certain measurments are available. One example for this is the restriction to single-shot spin-to-charge conversion measurements for two spin qubits ($n=4$) in a double quantum dot where measuring the charge state is equivalent to projections on individual quantum states. In order to perform state tomography under this restriction for n dimensions, n^2-1 different quantum states need to be selected. While it is possible to use states from a set of mutually unbiased bases [2], we present here numerically optimized sets of quantum states which perform significantly better regarding the expected precision of the tomography scheme [3].

[1] W. K. Wootters and B. D. Fields, Ann. Phys. **191**, 363 (1989)
[2] N. Rohling and G. Burkard, Phys. Rev. B **88**, 085402 (2013)
[3] V. N. Ivanova-Rohling and N. Rohling, arXiv:1810.09484

HL 10.8 Mon 17:00 H36

Spin exchange in quantum dot arrays — •Ferdinand Kuemmeth — Niels Bohr Institute, University of Copenhagen

Using an array of quantum dots in a GaAs heterostructure, defined and controlled by top gates, we explore the properties of a multielectron dot for inducing coherent spin exchange processes between neighboring and non-nearest-neighbor one-electron dots.

Our measurements indicate that a multielectron quantum dot with 50-100 electrons serves as an excellent mediator, preserving speed and coherence of the resulting spin-spin coupling while providing functionalities that may be of practical importance. These include speed (mediated two-qubit rates up to several gigahertz), distance (of order of a micrometer), voltage control, possibility of sweet spot operation (reducing susceptibility to charge noise), and reversal of the interaction sign [1] (useful for dynamical decoupling from noise). By detuning two one-electron dots with respect to the multielectron dot, we map out different configurations useful for long-distance spin exchange, including indirect, direct, and on-site exchange mediated by the multielectron dot [2].

Our results show a pathway to implementing fast, non-nearest neighbor two-qubit gates in semiconducting spin qubits. I will show our recent efforts into extending the mediated spin coupling into two dimensions.

[1] F. K. Malinowski, F. Martins, et al, Phys. Rev. X 8, 011045 (2018) [2] F. K. Malinowski, F. Martins, et al, arXiv:1808.09736

HL 11: Focus: Advanced TEM spectroscopy - low energy excitations and chemical composition at high resolution (joint session KFM/HL)

The recent progress in transmission electron microscope (TEM) based spectroscopies in terms of spatial, temporal and spectral resolution allows to address new regimes of electronic and vibrational excitations and therefore widened our understanding of condensed matter. This session focuses on recent developments and applications of spectroscopy techniques in the TEM, in particular electron energy loss spectroscopy in the low-loss regime for optical properties and core-loss regime for chemical analysis, at both atomic and medium resolution. Moreover, contributions on ultrafast techniques as well as energy dispersive X-ray spectroscopy, hardware and technique developments, theory and simulation and data processing will be discussed.

Organizer and Chair: Axel Lubk (IFW Dresden)

Time: Monday 15:00–18:40 Location: PHY 5.0.20

Invited Talk HL 11.1 Mon 15:00 PHY 5.0.20

Fifteen years of electron magnetic circular dichroism — •Ján Rusz — Department of Physics and Astronomy, Uppsala University, Uppsala, Sweden

Electron magnetic circular dichroism (EMCD; [1]) has been proposed in 2003 and for the first time experimentally realized in 2006. Since then the method went through a rapid development at both fronts - experimental and theoretical. Dynamical diffraction effects severely complicate EMCD detection and often reduce the its strength. To circumvent this, numerous ways of acquiring EMCD have been proposed and many of them were experimentally tested. Recently, EMCD was detected using astigmatic electron beams on antiferromagnets, or with convergent probes, resolving magnetic signals from areas smaller than a square nanometer. In high-resolution TEM setting, EMCD signal from individual atomic planes was detected using the PICO instrument, where a crucial role was played by chromatic aberration corrector. Theory predicts that electron vortex beams should be efficient probes of EMCD at atomic resolution. Successful realization of this experiment could be extended further to probe the third dimension by means of magnetic depth sectioning. We will review the recent history of EMCD, its present state-of-art and discuss some of its challenges for the near future.

[1] P. Schattschneider et al., Nature **441**, 486 (2006).

HL 11.2 Mon 15:30 PHY 5.0.20

Spectral Field Mapping of Surface Plasmon Resonances using High Energy Electrons — •Jonas Krehl[1], Giulio Guzzinati[2], Johannes Schultz[1], Pavel Potapov[1], Jerome Martin[3], Jo Verbeeck[2], Bernd Büchner[1], and Axel Lubk[1] — [1]IFW Dresden, Dresden, Deutschland — [2]EMAT, Antwerpen, Belgien — [3]Institute Charles Delaunay, Troyes, Frankreich

Surface plasmons resonances (SPR) are discrete modes in the response of the electron gas near the surface of a metallic nanoparticle. They contain very strong and localized electric and magnetic fields which enables interesting nanophotonic applications. Conventional electron energy-loss spectroscopy (EELS) is readily used for mapping the loss probablity of these modes with high energy and high spatial resolution.

The energy-loss signal only entails the longitudinal inelastic momentum transfer (IMT), so for a more comprehensive study of the fields of plasmon modes the lateral IMT components are crucial. The associated beam deflection is only a few μrad so we needed to develop a especially low-angle TEM setup for energy-filtered diffraction. With the energy slit set to a particular mode, the full IMT corresponds to a spectral component of the projected (along the beam trajectory) fields.

We demonstrated this technique in mapping the electric field at the dipole mode of an aluminium nanorod and compared the results with boundary-element-method simulations where we reached reasonable quantitative agreement. We are developing several extensions to this

technique which e.g. tackle methodic problems or enable the mapping of magnetic fields.

HL 11.3 Mon 15:50 PHY 5.0.20

Automatic Truncation of Principal Components in the PCA Analysis of EELS and EDX Spectrum-Images — •Pavel Potapov[1], Paolo Longo[2], and Axel Lubk[1] — [1]Leibniz Institute for Solid State and Materials Research (IFW), Dresden, Germany — [2]Gatan Inc, Pleasanton, CA, USA

The Principal Component Analysis (PCA) allows to denoise drastically STEM EELS and EDX spectrum-images by extracting the meaningful fraction of data while cutting off the irrelevant noise. The number of meaningful PCA components is usually estimated through the evaluation of a scree plot - a dependence of the log eigenvalues (variances) on the component index. This strategy however introduces some subjectivity in the treatment. A novel promising method for the truncation of principal components is the analysis of bivariate scatter plots. This method can be easily implemented in automatic algorithms promoting a smooth, unsupervised data treatment flow.

HL 11.4 Mon 16:10 PHY 5.0.20

Synthesis and high-resolution structural and chemical analysis of iron-manganese-oxide core-shell nanoparticles — •Aladin Ullrich, Mohammad Mostafizar Rahman, and Siegfried Horn — Universität Augsburg, Universitätsstr. 1, 86159 Augsburg

Nanoparticles were synthesized by thermal decomposition of a mixture of iron oleate and manganese oleate precursors in high-boiling solvents in the presence of Na-oleate and oleic acid as surfactants. The structural and chemical composition of the nanoparticles was investigated by high-resolution analytical transmission electron microscopy (TEM). The particles appear core-shell like in bright field TEM images. High-resolution TEM (HRTEM) analysis reveals a FeO/MnO like structure in the core and a spinel like structure in the shell. With high-resolution analytical methods like energy dispersive x-ray spectroscopy and electron energy loss spectroscopy, the distribution of the metals Mn and Fe, respectively, was investigated. Furthermore, differences in the oxidation state of these metals were found between the core and the shell region. The presence of sodium from the used surfactant (Na-oleate) on the surface of the particles has been proved.

HL 11.5 Mon 16:30 PHY 5.0.20

How sharp are atomically sharp interfaces in complex functional oxide heterostructures? — •Peter A. van Aken — Max Planck Institute for Solid State Research, Stuttgart Center for Electron Microscopy, Stuttgart, Germany

Complex functional oxide heterostructures have been serving as a multi-directional platform for engineering novel interface functionalities. Recent technical improvements of the epitaxial growth techniques enable fabricating high-quality thin films and heterostructures. The phenomena occurring at their interfaces can be tailored depending on the choice of the constituents. The key factor dominating the interface functionalities is the control of interface sharpness. Therefore, examining the interfacial structure and chemistry is vital for correlating with the underlying physical properties.

High-resolution analytical STEM investigations on various complex functional oxide heterostructures exhibiting different interface sharpness and different functionalities will be presented yielding that i) the growth technique has a direct impact on the structural and chemical sharpness of the interfaces, ii) two-dimensional doping of La2CuO4-based multilayers results in different dopant distribution at both sides of the interfaces which induces different superconducting mechanisms, iii) the choice of the dopant directly affects the interface sharpness. The effect of dopant distribution at interfaces on physical properties will be discussed.

Break 20 min

Invited Talk HL 11.6 Mon 17:10 PHY 5.0.20

Advanced Imaging and Spectroscopy in an Ultrafast Transmission Electron Microscope — •Armin Feist — IV. Physical Institute, University of Göttingen, 37077 Göttingen, Germany

Electron microscopy is tremendously successful in studying complex nanostructured systems, with a temporal resolution governed by typical detector response times. Overcoming these time-domain limitations, ultrafast transmission electron microscopy (UTEM) combines the versatile imaging, diffraction and spectroscopy capabilities of state-of-the-art TEM with femtosecond temporal resolution achieved by a laser pump/electron probe scheme [1,2].

Here, I will briefly introduce the UTEM methodology and show recent results of the Göttingen UTEM instrument, which features high coherence electron pulses generated from nanoscale field emitter tips [2]. The novel applications of UTEM include the study of coherent inelastic electron-light scattering (IELS) at laser-excited nanostructures [3,4]. Besides nanometer mapping of optical near-fields and plasmonic modes, IELS enables the transverse and longitudinal phase control of the free-electron wavefunction [4,5], as evident from characteristic multiphoton gain and loss spectra. In particular, this new concept now allows us to generate attosecond electron pulse trains with applications for optically phase-resolved electron microscopy [5].

[1] A. H. Zewail, Science **328**, 187 (2010). [2] A. Feist *et al.*, Ultramicroscopy **176**, 63 (2017). [3] Barwick *et al.*, Nature **462**, 902 (2009). [4] A. Feist *et al.*, Nature **521**, 200 (2015). [5] K. E. Priebe *et al.*, Nat. Photonics **11**, 793 (2017).

HL 11.7 Mon 17:40 PHY 5.0.20

Spectroscopic coincidence experiments in Transmission Electron Microscopy — •Daen Jannis[1], Knut Müller-Caspary[1], Armand Béché[1], Andreas Oelsner[2], and Jo Verbeeck[1] — [1]EMAT, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerpen, Belgium — [2]Surface Concept GmbH, Am Sägewerk 23a, 55124 Mainz, Germany

Modern transmission electron microscopes are often equipped with EELS and EDX spectrometers. Both measurement techniques share the fact that excitations of atomic states are involved. Indeed, there is for every emitted X-ray photon at least one electron that transfers a part of its energy to excite the atom in the first place, and therefore one could imagine that they convey very similar information. Since the two signals originate from the same process, the temporal correlation between these signals can be measured. Our current setup consists of a novel delay line detector setup for EELS and a Super-X EDX detector. These allow to detect the energy and arrival time (time resolution 270 ns) of every incoming electron and X-ray. This setup keeps all detected events and allows for extensive post processing. By the measurement of every event, it is possible to disentangle the background from the coincidence signal opening up the possibility of background free EELS and EDX with EELS resolution.

[1] D. Jannis, K. Müller-Caspary, A. Béché A. Oelsner and J. Verbeeck. Unpublished Paper, 2018.

[2] D.J., A.B. and J.V. acknowledge funding from the Flemish Research Fund FWO under projectno. G093417N

HL 11.8 Mon 18:00 PHY 5.0.20

High-resolution EFTEM at very low accelerating voltages — •Martin Linck[1], Michael Mohn[2], Johannes Biskupek[2], Heiko Müller[1], Stephan Uhlemann[1], and Max Haider[1] — [1]CEOS GmbH, Englerstr. 28, D-69126 Heidelberg, Germany — [2]Central facility of electron microscopy, Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany

Simultaneous correction of both, spherical and chromatic aberration in a dedicated low-voltage transmission electron microscope (TEM) has enabled atomic resolution TEM observations on beam sensitive materials at beam energies from 20 to 80 keV (SALVE project). The reduction of focus spread due to chromatic aberration correction, however, not only allows for highest resolution atomic phase contrast (elastic zero-loss imaging) but also enables high-resolution imaging capabilities over significant energy windows in energy-filtered (EF)TEM. In order to provide a significant field of view on the energy filter's camera device, it is essential that the corrector is free of chromatic distortions, i.e. image distortions which change with electron energy. It has been shown that the SALVE corrector is well-suited for such ambitious investigations. First experimental results, in fact, show that high-resolution EFTEM is feasible in the SALVE microscope. The subsequent interpretation of such data, however, is very challenging due to the multiple scattering, i.e. mixture of elastic and inelastic scattering.

HL 11.9 Mon 18:20 PHY 5.0.20

Plasmonics in topological insulators — •Johannes Schultz[1], Axel Lubk[1], Flavio Nogueira[2], Darius Pohl[3], and Bernd Büchner[1] — [1]IFF, IFW Dresden, Helmholtzstraße 20, 01069 Dresden — [2]ITF, IFW Dresden, Helmholtzstraße 20, 01069 Dresden — [3]Dresden Center for Nanoanalysis, TU Dresden, 01062 Dresden

Surface plasmons are self-sustaining resonances occuring at interfaces

between media whose permittivities have a different sign. They are associated with strongly enhanced, localized electrical fields, which may be coupled to external optical excitations. Surface plasmons can be used for the sub-wavelength control of electromagnetic fields. Based on this, novel electronic devices can be realized, for instance on-chip light spectrometers and linear accelerators, plasmonic rectennas for the harvesting of light or LEDs and photovoltaics with a higher efficiency. We study the properties of these surface plasmons when they are localized on a surface of a topological insulator like Bismuth selenide.

Surfaces of topological insulators contain conducting states which leads to negative permittivity on the surface and positive permittivity in the bulk. Consequently topological insulators can in principle sustain surface plasmons if they are embedded in a dielectric environment with positive permittivity. To characterize this localized surface plasmon-modes on the surfaces of topological insulators we use low loss spectroscopy techniques in the TEM.

HL 12: HL Poster I

Time: Monday 17:30–20:00 Location: Poster E

HL 12.1 Mon 17:30 Poster E

Charge transport in bottom-up synthesized graphene nanoribbon networks — Alexander Tries[1,2,3], •Leo Schnitzspan[1], Nils Richter[1], Zongping Chen[2], Kamal Asadi[3], Akimitsu Narita[3], Klaus Müllen[3,4], and Mathias Kläui[1,2] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz — [2]Graduate School of Excellence Materials Science in Mainz — [3]Max Planck Institute for Polymer Research — [4]Institut für Physikalische Chemie, Johannes Gutenberg-Universität Mainz

Graphene nanoribbons (GNRs) attract attention due to particular physical properties resulting from the geometrical confinement, and these also depend crucially on both width and edge morphology [1]. Using GNR field-effect transistors, we perform a systematic study on the electronic properties of chemically synthesized and atomically perfect armchair GNRs with a width of 5 and 9 carbon atoms (5-AGNR and 9-AGNR)[2]. Our measurements reveal nuclear tunneling-assisted charge carrier hopping [3] as the dominant charge transport mechanism allowing us to apply a universal scaling law valid for charge transport in networks of both GNR structures over a large range of driving voltages and temperatures. Gate-dependent measurements show a pronounced hysteretic effect and we identify the origin of this hysteresis by temperature dependent measurements[4,5].

[1] Son et al., Phys.Rev.Lett.97, 216803 (2006). [2] Z. Chen et al., J.Am.Chem.Soc., 139, 9483-9486 (2017). [3] K. Asadi et al., Nat.Commun. 4:1710 (2013). [4] N. Richter et al., arXiv:1806.00962 [5] A.Tries et al., submitted (2018)

HL 12.2 Mon 17:30 Poster E

Defect-induced photoluminescence of WS_2 monolayers — •Aswin Asaithambi[1], Roland Kozubek[1], Guenther Prinz[1], Francesso Reale[2], Cecelia Mattevi[2], Marika Schleberger[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Duisburg, Germany — [2]Department of Materials, Imperial College London, London, UK

The transition metal dichalcogenide tungsten di-sulphide (WS_2) has a layered structure with an indirect band gap, which becomes direct at the K point in momentum space if only a monolayer is present. This leads to strongly enhanced photoluminescence (PL), compared to the bulk. However, WS_2 monolayers are not defect free and the defects present in the material affect their emission properties drastically, which makes it necessary to study and characterize their influence.

In this contribution, we present highly sensitive, non-destructive, temperature- and power- dependent PL measurements to study defects in WS_2 monolayers. WS_2 monolayers were irradiated with different fluences of Xe^{30+} ions to create defects (presumably S and W vacancies) with different densities. Room temperature (RT) PL shows no defect-bound emission. Low temperature (LT) PL spectra of irradiated samples show new defect-related emission lines. Interestingly, those new defect-related peaks were annealed when subjected to higher laser power at both RT and LT. These results will be discussed in the frame of excitons, vacancy defect states and possible adsorbates, and compared with literature.

HL 12.3 Mon 17:30 Poster E

Probing long-lived spin polarization in n-doped $MoSe_2$ monolayers. — •Michael Kempf[1], Markus Schwemmer[1], Philipp Nagler[1], Andreas Hanninger[1], Christian Schüller[1], and Tobias Korn[2] — [1]University Regensburg, 93053 Regensburg Germany — [2]University Rostock, 18051 Rostock Germany

With the coupling of spin and valley degree of freedom in transition metal dichalcogenides, these materials are very well suited for valleytronics. Yet due to ultrafast exciton recombination times on the order of picoseconds, strongly limiting possible applications and other processes, it is highly advantageous to transfer the polarization to resident carriers. Utilizing time-resolved Kerr rotation we study the spin-valley dynamics in undoped and n-doped $MoSe_2$ monolayers. In contrast to undoped samples we observe a long-lived polarization of several nanoseconds in the n-doped $MoSe_2$, which can be explained by a polarization of resident carriers. M. Schwemmer et al., Appl. Phys. Lett. **111** (2017)

HL 12.4 Mon 17:30 Poster E

Edge currents driven by terahertz radiation in graphene in the quantum Hall regime — •Susanne Candussio[1], Helene Plank[1], Mikhail Durnev[2], Johanna Pernul[1], Kathrin-Maria Dantscher[1], Erwin Mönch[1], Andreas Sandner[1], Jonathan Eroms[1], Dieter Weiss[1], Vasily V. Belkov[2], Sergey A. Tarasenko[2], and Sergey Ganichev[1] — [1]Terahertz Center, University of Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia

We observe that the illumination of unbiased graphene in the quantum Hall regime with polarized terahertz laser radiation results in a direct edge current. This photocurrent is caused by an imbalance of persistent edge currents, which are driven out of thermal equilibrium by indirect transitions within the chiral edge channel. The direction of the edge photocurrent is determined by the polarity of the external magnetic field, while its magnitude depends on the radiation polarization. The microscopic theory developed in this paper describes well the experimental data.

HL 12.5 Mon 17:30 Poster E

Optical Contrast Analysis and Electrical Properties of Thin $ZrSe_3$-Films — •Lars Thole[1], Christopher Belke[1], Sonja Locmelis[2], Johannes C. Rode[1], Peter Behrens[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Institut für Anorganische Chemie, Leibniz Universität Hannover, 30167 Hannover, Germany

In recent years interest in two-dimensional materials has been strong. They have a layered structure with unique properties. One type of layered materials are Transition Metal Trichalcogenides of the form MX_3, where M is a transition metal and X is a chalcogenide [1, 2]. We concentrate on the semiconductor $ZrSe_3$ [2, 3]. It was exfoliated to get thin flakes with only a few layers. The flakes were characterized with atomic force microscopy and optical microscopy to determine a contrast relation for the height. Through electrical measurements on contacted flakes the mean free path for the material was determined. Further measurements to determine the mobilities of the flakes were conducted.

[1] J. O. Island et al., 2D Materials, 4, 0220033 (2017).
[2] J. Dai et al., WIREs Comput. Mol. Sci., 6, 211-222 (2016).
[3] Y. Jin et al., Phys. Chem. Chem. Phys., 17, 18665 (2015).

HL 12.6 Mon 17:30 Poster E

Magnetotransport properties of weakly coupled double trilayer graphene — •Xiao Xiao, Sung Ju Hong, Christopher Belke, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany

We have investigated magnetotransport properties of double trilayer graphene (DTLG). The DTLG was fabricated by stacking two trilayer graphene (TLG) flakes. Analyzing the edges of the two flakes in the optical microscope, we identified a large twist angle around 24°. This is consistent with the electrical measurements which show the superpo-

sition of two independent magnetotransport properties. As in twisted bilayer graphene, the large twist angle seems to result in a weak coupling between the two layers. In the observed Landau fan diagram, one of the DTLG turns out to be ABA-stacked TLG with broken symmetry states. Furthermore, we found an additional high carrier density which comes from the other TLG.

HL 12.7 Mon 17:30 Poster E

Fabrication of twisted graphene heterostructures: Different layer sequences and novel device configurations — •Benjamin Gajeufsky, Xiao Xiao, Sung Ju Hong, Christopher Belke, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany

Twisted bilayer graphene (tBLG) is a representative van der Waals heterostructure, which shows various electronic properties depending on the twist angle. To date, the heterostructures have been constructed using monolayer graphene. Therefore, heterostructures which consist of different ingredients such as bilayer or trilayer graphene remain elusive. Furthermore, since the observable quantities are also limited to conventional transport properties, distinct measurement configurations may reveal novel kind of electronic properties. Here we expand the twisted graphene heterostructure in terms of different layer sequences or device configurations.

HL 12.8 Mon 17:30 Poster E

From multi- to monolayer: monitoring the time-evolution of laser-induced thinning of MoS_2 layers by Raman and photoluminescence spectroscopy — •Christian Tessarek, Oleg Gridenco, Jan Müssener, Stephan Figge, Kathrin Sebald, Jürgen Gutowski, and Martin Eickhoff — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, D-28359 Bremen, Germany

Exfoliation of MoS_2 crystals is a simple method to obtain multi- and monolayer material. However, size and number of monolayers produced by this technique are usually small and not well controllable. Laser-thinning is an established method to produce MoS_2 monolayers from multilayers [1]. For a better control of a homogeneous monolayer generation, monitoring of the thinning process is required.

Multi- and monolayers show different distinct properties in Raman and photoluminescence spectroscopy and thus these spectroscopic techniques are suitable to monitor the transition from multi- to monolayer. A laser emitting at 325 or 406 nm is used simultaneously for both thinning and spectroscopy. The time-evolution of the Raman and photoluminescence peaks will show a layer-by-layer etching of MoS_2 and a transformation into amorphous MoO_x in an oxygen containing atmosphere during the thinning process. Microstructuring of multilayers into monolayers such as writing of single points, lines and areas will be demonstrated.

[1] A. Castellanos-Gomez et al., Nano Lett. **12**, 3187 (2012).

HL 12.9 Mon 17:30 Poster E

Strain induced optical effects of WS_2 monolayers — •Marcel Ney, Aswin Asaithambi, Lukas Madauss, Günther Prinz, Marika Schleberger, and Axel Lorke — Faculty of Physics and CENIDE, University Duisburg-Essen, Germany

Two-dimensional transition metal dichalcogenide (TMD) monolayers interact efficiently with visible light due to the direct bandgap nature at K-point in momentum space. The result of the quantum confinement effects in two dimensions is a strong electron-hole Coulomb interaction, leading to a large exciton binding energy, which makes this material very promising for optoelectronic device fabrication.

We will present photoluminescence- (PL) and Raman spectroscopy results of WS_2 monolayers grown on a standard Si/SiO_2 substrate via a chemical vapor deposition (CVD) process.

In PL investigations, we observed a redshift of the excitonic wavelength between the center and the edge of a triangular WS_2 monolayer. These redshifting recombination energies could indicate strain within the monolayer. Therefore complementary Raman spectroscopy measurements were performed, which results support the assumption of a strain induced excitonic redshift. The maximum relative tensile strain was calculated to 1.2%, applying a relation between strain and Raman shift [1].

The influence of strain on the optical properties of WS_2 monolayers at temperatures ranging from 295K to 77K and for different excitation powers will be discussed and compared with results from literature.

[1] F. Wang et al., 2D Mater. 4, 015007 (2016)

HL 12.10 Mon 17:30 Poster E

Induced defect states in supported and freestanding MoS_2 monolayers — •Sven Mehrkens, Oleg Gridenco, Kathrin Sebald, Christian Tessarek, Martin Eickhoff, and Jürgen Gutowski — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Alle 1, D-28359 Bremen, Germany

Single-layer molybdenum disulfide (MoS_2) photoluminescence emission is strongly affected by the dielectric environment, i.e., of the supporting substrate. To avoid this, it is highly preferable to study the optical properties of freestanding monolayers. In this contribution an etching-free transfer method using polymethyl-methacrylate (PMMA) will be demonstrated, for the transfer of mechanically exfoliated MoS_2 flakes from SiO_2 substrates to a TEM grid. Localized excitons, trapped at vacancies are of considerable importance for the characteristics of optoelectronic devices. In MoS_2, vacancies can be introduced via Ga^+ ion irradiation using a focused ion beam (FIB). A variation of the ion dose results in different densities of defect states, emitting at 1.75 eV for flakes on SiO_2 at 4 K. We compare the optical properties of freestanding and supported monolayers in order to investigate the influence of the dielectric environment on the introduced defect states.

HL 12.11 Mon 17:30 Poster E

Raman spectra vs. transport properties in graphene field-effect transistors suitable for applications in ultrasensitive biodetection — •Daniel Hüger[1], David Kaiser[1], Christof Neumann[1], Thomas Weimann[2], and Andrey Turchanin[1] — [1]Institute of Physical Chemistry, Friedrich-Schiller-University Jena, 07743 Jena, Germany — [2]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

For applications of graphene field-effect transistors (GFETs) in ultrasensitive biodetection the devices must have a high charge carrier mobility, a low doping level as well as an absence of the transfer curves hysteresis. To study these properties, extensive and time-consuming transport measurements in vacuum are typically required. Here, in order to find a faster and non-invasive method for this assessment, we use Raman spectroscopy to characterize GFETs fabricated on Si/SiO_2 wafers and correlate the spectroscopy and transport data. We present an analysis of over 600 FET devices made by electron-beam lithography from single-layer graphene produced via chemical vapor deposition (CVD) by three different manufacturers. Employing a spectral resolution of $\sim$10 cm^{-1}, we acquire the Raman data within only 3 minutes per sample. We analyze the relationships between hysteresis in the transfer curves, position of the Dirac-point and charge carrier mobility in the GFETs with position of the 2D-, D- and G-peak, their full width half maximum (FWHM) and intensity ratios.

HL 12.12 Mon 17:30 Poster E

Enhanced Photoluminescence from Monolayer WS2 Excitons with a 2D-material-air-GaP in-plane Microcavity — Oliver Mey[1], Franziska Wall[1], •Lorenz Maximilian Schneider[1], Frederik Walla[2], Amin Soltani[2], Hartmut G. Roskos[2], Ni Yao[3], Peng Quing[3], Wei Fang[3], and Arash Rahimi-Iman[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, D-35032 Marburg, Germany — [2]Physikalisches Institut, Goethe-Universität, D-60438 Frankfurt am Main, Germany — [3]State Key Laboratory of Modern Optical Instrumentation, College of Optical Science and Engineering, Zhejiang University, Hangzhou 310027, China

To improve light-matter interaction with two-dimensional semiconductors for future applications involving monolayer materials in waveguide-coupled on-chip integrated circuitry and valleytronic nanophotonics, we study the effects of tailoring the landscape on which the monolayers are placed. In this context, photoluminescence enhancement from monolayer WS2 on GaP substrates patterned by focused-ion-beam etching was investigated. Here, we present a unique optical microcavity approach, which results in a WS2 photoluminescence enhancement by a factor of 10 at room temperature compared to the unstructured substrate. Here, we combine a bulls-eye-shaped circular Bragg grating, for interference effects in the horizontal direction, and an optimized etching depth of circular air-GaP structures, for maximum constructive interference effects of the applied pump and expected emission light in the vertical direction.

HL 12.13 Mon 17:30 Poster E

Band Gap Determination and Induced Conductivity in Thin Films of ZrS_3 — •Christopher Belke[1], Sonja Locmelis[2], Johannes C. Rode[1], Hennrik Schmidt[1], Bastian Hoppe[2], Peter Behrens[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik,

Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Institut für Anorganische Chemie, Leibniz Universität Hannover, 30167 Hannover, Germany

New varieties of two-dimensional crystals [1] are currently getting into focus of the material sciences. An example for such layered materials are Transition Metal Trichalcogenides. Here we study the compound ZrS_3: Bulk crystals were synthesized by chemical gas transport; stoichiometry and structure were verified by powder X-ray diffractometry and energy-dispersive X-ray spectroscopy (EDX) and it was analyzed by absorption measurements. The latter indicate an indirect bandgap of about 1.8 eV and a direct bandgap of 2.3 eV, which differ slightly from literature values [2, 3]. Thin flakes are exfoliated and contacted. Conductivity measurements are investigated in response to illumination with LEDs of different wavelengths. We observe a pronounced rise in conductivity between 2.1 eV and 2.4 eV which is in good agreement with the direct bandgap found in the absorptions measurements. Also with field effect measurements charge carriers could be induced in thin flakes.

[1] A. K. Geim, I. V. Grigorieva, Nature 499, 419-425 (2013).
[2] M. Abdulsalam, D. Joubert, Eur. Phys. J. B. 88, 177 (2015).
[3] Y. Jin, X. Li, J. Yang, Phys. Chem. Chem. Phys. 17, 18665 (2015).

HL 12.14 Mon 17:30 Poster E

Structural Dynamics of Rhenium Disulphide Studied by Ultrafast Electron Diffraction — Arne Ungeheuer, •Ahmed Hassanien, Marlene Adrian, Arne Senftleben, and Thomas Baumert — Institute of Physics and CINSaT, University of Kassel, Heinrich-Plett-Strasse 40, D-34132 Kassel, Germany

Unlike most two-dimensional transition metal dichalcogenides (MoS_2, WSe_2, etc...), rhenium disulphide (ReS_2) shows minor dependence of its electronic and vibrational properties on the number of stacked atomic layers [1]. Its distorted triclinic crystal structure due to in-plane dimerization of Re atoms results in a weak binding energy between its layers and consequently weak coupling. On the other hand, due to this so-called Peierls distortion, ReS_2 shows significant polarization-dependent optical properties which hold promise for such applications as valleytronics [2].

Ultrafast electron diffraction is a continuously developing technique for providing direct insights into photo-induced primary dynamics at the atomic level in molecules and solids. Using a highly compact femtosecond electron diffractometer developed in our group [3], we show our first measurements of the structural dynamics of mechanically-exfoliated few-layer ReS_2 revealed on a picosecond timescale, following the photoexcitation with a femtosecond laser pulse.

References:
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[2] Cui, Yudong, et al. Scientific Reports 7 (2017): 40080.
[3] Gerbig, C., et al. New J. Phys. 17.4 (2015):043050.

HL 12.15 Mon 17:30 Poster E

Charge transport in graphene and graphene nanoribbons on hexagonal boron nitride as field effect transistor devices — •Leo Schnitzspan[1], Alexander Tries[1,2,3], Marie-Luise Braatz[1], and Mathias Kläui[1,2] — [1]Institut für Physik, Johannes Gutenberg Universität Mainz — [2]Graduate School of Excellence Materials Science in Mainz — [3]Max Planck Institute for Polymer Research

Graphene nanoribbons (GNRs) have attracted attention due to particular physical properties resulting from the geometrical confinement, and these also depend crucially on both width and edge morphology [1]. Hexagonal boron nitride (hBN) has turned out as ideal substrate for graphene due to its flat and similarly lattice structure, which results in charge mobilities up to 275 000 $cm^2V^{-1}s^{-1}$ [2]. Using a field-effect transistor layout with a hBN underlayer, we study the electronic properties of graphene and GNRs and analyze the underlying mechanisms. Different wet and dry graphene transfer methods are tested and developed. Magnetotransport as well as gate-dependent measurements are investigated to understand the impact of hBN on the transport properties.

[1] Son et al., Phys. Rev. Lett. 97, 216803 (2006). [2] Zomer, P. J., et al., App. Phys. Lett. Bd. 99.23 (2011)

HL 12.16 Mon 17:30 Poster E

Metal gate vs graphene gate in two-dimensional (2D) MoS2 FET — •Vaishnavi Kateel[1,2], Zahra Fekri[1,2], Phanish Chava[1,2], Himani Arora[1,2], Kenji Wanatnabe[3], Takashi Taniguchi[3], and Artur Erbe[1] — [1]Helmholtz-Zentrum Dresden Rossendorf,Bautzner Landstraße 400, 01328 Dresden — [2]Technische Universität Dresden, 01062 Dresden Germany — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

The extensive scaling of semiconducting devices caused the search for alternative materials as the conventional semiconductor reached the edge of their physical limits. Huge research in 2D material was driven by their wide range of electrical properties from metallic to insulating. The interlayer van der Waals interaction allowed 2D materials to be exfoliated and stacked in order to form heterostructure with little lattice mismatch. Layer dependent electronic band structure and the absence of surface dangling bond made semiconducting MoS2 as a good channel material in our 2d transistor. Graphene(Gr) source/drain contacts were used as transport across the schottky barrier of Gr/MoS2 interface can be altered by gate voltage and current bias. Excellent properties like wide bandgap, atomic flatness and absence of charge traps makes hexagonal Boron Nitride (hBN) a better dielectric layer for our 2D FET compared to SiO2 which shows large hysteresis and low mobility. Furthermore, hBN can be used as protection by encapsulating 2D semiconductors. We demonstrate a 2D heterostructure MoS2 transistor with graphene gate electrode and compare its electrical characteristics with metal top-gate electrode MoS2 transistor.

HL 12.17 Mon 17:30 Poster E

Three-dimensional electronic band dispersion in bulk black phosphorus — •Charlotte Sanders[1], Klara Volckaert[2], Deepnarayan Biswas[2], Marco Bianchi[2], Jill Miwa[2], Søren Ulstrup[2], and Philip Hofmann[2] — [1]Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, U.K. — [2]Department of Physics and Astronomy, Interdisciplinary Nanoscience Center (iNANO), Aarhus University, Aarhus, Denmark

Bulk black phosphorus has a layered structure similar to that of pseudo-two-dimensional materials like graphite and bulk MoS2. However, to a greater extent than in some other layered materials, interlayer interaction plays an important role in determining the electronic properties of black phosphorus, leading to a distinctive kz-dispersing band and a direct band gap of 0.3 eV at the Z point of the Brillouin zone. Investigations by angle-resolved photoemission spectroscopy (ARPES) of the three-dimensional dispersion of nominally undoped black phosphorus have been reported (e.g., [1,2]), but several questions remain unanswered. For example, a surface resonance state has been reported [2]; but whether such a state in fact exists, and what its origin might be, remain in doubt. Furthermore, ARPES measurements have yielded results that differ rather widely from predictions from theory. Here I will present ARPES measurements–spanning the photon energy range hv=15-135 eV–of the three-dimensional band structure of bulk black phosphorus, and I will suggest how our results can address some of the questions which have remained unresolved in the literature so far. [1] PRB 33 (1986) 4324. [2] PRB 90 (2014) 085101.

HL 12.18 Mon 17:30 Poster E

Manipulating transition-metal dichalcogenide monolayers with proximity effects — •Lanqing Zhou, Sven Borghardt, and Beata Kardynal — Forschungszentrum Jülich PGI-9,Jülich, Germany

Transition-Metal Dichalcogenides (TMDs) monolayers have been shown to exhibit many interesting physical properties related to their crystal structure and strong spin-orbit interactions. In addition, being only three atomic planes thin, their properties can be manipulated using proximity fields generated when they are placed in contact with functional molecules or films. Here we interface tungsten diselenide monolayers with thin films of chromium trichlotride and chromium tribromide. Both chromium trihalides are layered materials which are electronic insulators that are also ferromagnetic at low temperatures. As such, they can be used as functional substrates for the monolayer WSe2 to introduce energy splitting of the spin states in K and K* valleys of the monolayer. In this contribution, we study different sample preparation methods to maximize the stability of the chromium trihalide films. We use hexagonal boron nitride to protect the ferromagnetic films from the ambient humidity and thin graphite films to protect the TMD monolayers from the effects of charge fluctuations in the substrate that can cause inhomogeous broadening of the photoluminescence spectra. Effects of the ferromagnetic layers on the monolayers in the devices are investigated using optical spectroscopy at different temperatures.

HL 12.19 Mon 17:30 Poster E

Highly sensitive micro-cavity based absorption spectroscopy

of low dimensional materials — •Thomas Hümmer[1,2], Jonathan Noé[3], Alexander Högele[3], Theodor W. Hänsch[1,2], and David Hunger[4] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck Institut für Quantenoptik, Garching, Deutschland — [3]Fakultät für Physik and Center for NanoScience (CeNS), Ludwig-Maximilians-Universität München, D-80539 München — [4]Karlsruher Institut für Technologie, Karlsruhe, Deutschland

We use a tunable high-finesse optical micro-cavity [1] to measure absorption in carbon nanotubes (CNTs) and transition metal dichalcogenides (TMDs) down to the parts-per-million level. Our scanning-cavity imaging technique[2,3], where a microscopic mirror is scanned across a larger mirror that hosts the sample, allows to collect absorption images of individual nano-structures with unprecedented sensitivity, spatially resolved with 1*m resolution and in real time. First spectroscopic measurements are performed on these samples. We present our progress to extend this technology to measurements in cryogenic environments. [1] Hunger et al., NJP 12, 065038 (2010) [2] Mader et al., Nat Commun 6, 7249 (2015) [3] Hümmer et al Nat Commun 7, 12155 (2016)

HL 12.20 Mon 17:30 Poster E

First principles study of Ta_2NiSe_5, a possible candidate excitonic insulator, using GW and hybrid functional approaches — •Lukas Windgätter, Simone Latini, Hannes Hübener, and Angel Rubio — Max Planck Institut für die Struktur und Dynamik von Materie

The idea of the excitonic insulator scenario, which describes the electron-hole condensation in thermal equilibrium, was originally proposed by X. Jerome et al. in 1967. It is expected to occur in semiconducting materials with a very small bandgap of a few milli electron volt. Recently it has attracted renewed interest with the discovery of several materials with experimental signature of equilibrium exciton condensation. In this context we are investigating Ta_2NiSe_5, which has shown to be a promising candidate in recent publications, using ab-initio methods. We present results using DFT hybrid functionals as well as ab-initio GW calculations.

HL 12.21 Mon 17:30 Poster E

Optical characterization of implanted transition metal dichalcogenides monolayers — •Minh Bui[1], Jhih-Sian Tu[1], Manuel Auge[2], Sven Borghardt[1], Eoghan O'Connell[3], Ursel Bangert[3], Hans Hofsäss[2], and Beata Kardynał[1] — [1]Peter Grünberg Institut 9, Forschungszentrum Jülich, Jülich, Germany — [2]II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany — [3]Department of Physics, School of Sciences and Bernal Institute, University of Limerick, Limerick, Ireland

Two dimensional semiconductors, such as monolayers (MLs) of transition metal dichalcogenides, possess some unique properties due to their band structure and geometry. In analogy to classic bulk semiconductors, it is desirable to introduce stable dopant atoms into their lattice in a controlled way for exploiting these properties. In this contribution, we investigate low energy ion implantation as a method to introduce foreign atoms into MoS_2 and $MoSe_2$ MLs. Raman, reflectance and photoluminescence spectroscopies, supported by transmission electron microscopy, are used to characterize the resulting semiconductors. Implantation of Se ions with energies below 50 eV into exfoliated MoS_2 MLs is studied as a prototypical system. Substitution of S with Se atoms should convert MoS_2 into $MoSe_{2x}S_{2(1-x)}$ without generating free charge carriers. Implantation levels of up to few percent, much larger than needed for doping, are shown. We find that implanted ion energy is a compromise between implantation success rate and defect formation rate, and we identify the most likely defects. Similarly, results of $MoSe_2$ implanted with P as an n-type dopant are discussed.

HL 12.22 Mon 17:30 Poster E

Investigation of mechanical properties of Carbon Nanomembrane using wrinkling based metrology — •Himanshu P. Patel[1], Bernhard Alexander Glatz[1], Maria Kuellmer[2], Zian Tang[2], Andreas Winter[2], Andrey Turchanin[2], and Andreas Fery[1,3] — [1]Leibniz-Institut für Polymerforschung Dresden e. V., Dresden, Germany — [2]Friedrich Schiller University Jena, Institute of Physical Chemistry, Jena, Germany — [3]Cluster of Excellence Center for Advancing Electronics Dresden (cfaed), Technische Universität Dresden, Germany

We demonstrate further development in application of wrinkling-based metrology (SIEBIMM) to evaluate the Young's modulus and mechanical properties for 2D materials. In this case we have used Carbon Nanomembranes (CNMs), a 1nm thin 2D molecular material with known mechanical properties. This work addresses critical issues in the sample preparation for this method related to the adhesion of 2D films on the substrate and volumetric swelling of the substrate during removal of the protective PMMA layer used for transfer of various 2D materials. The optimized procedure results subsequently in an easy to apply system for deriving immediate first results on the mechanical properties of 2D materials produced and transferred using a similar technique. We show the improved transfer of 2D materials to PDMS and further formation of wrinkle by application of strain. The wrinkle pattern is studied in situ using atomic force microscopy (AFM). Calculations using the SIEBIMM formula confirm the values reported in literature before.

HL 12.23 Mon 17:30 Poster E

Quantum Spin Hall Insulator Phase in Graphene/Bismuthene Quantum Well Heterostructure — Hamoon Fahrvandi[1], •Ebrahim Nadimi[1,2], and Michael Schreiber[2] — [1]Faculty of Electrical Engineering, Center for Computational Micro and Nanoelectronics, K. N. Toosi University of Technology, Tehran, Iran. — [2]Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany.

Quantum spin Hall insulators (QSHI) have attracted much research interest due to their unique electronic properties. Time-reversal-symmetry-protected helical edge states provide dissipationless conductance at the boundaries of these two-dimensional (2D) systems. On the other hand, graphene another prominent 2D material, possesses just an ignorable QSHI phase with a small gap of about 1 meV. This is due to the weak spin-orbit coupling (SOC) in C atoms. In order to combine superior properties of graphene with unique electronic properties of novel QSHI, the idea of increasing SOC in graphene by proximity effect of a strong topological insulator has been proposed. This motivated us to investigate a vertical quantum well heterostructure of bismuthene-graphene-bismuthene (B-G-B) employing first-principles density-functional theory. We found that the proximity-enhanced SOC effect originating from bismuthene, leads to an enhancement in nontrivial topological nature of graphene. A weak van-der-Waals interaction in B-G-B heterostructure protects QSHI states with a sizable nontrivial gap. This structure can be a suitable candidate for realizing room temperature spintronic applications.

HL 12.24 Mon 17:30 Poster E

Coupled Organic Microcavities with Balanced Gain and Loss for Experimental Studies on Non-Hermitian Physics — •Karla Roszeitis[1], Markas Sudzius[1], Hartmut Fröb[1], Jan Carl Budich[2], and Karl Leo[1] — [1]Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP), TU Dresden, Germany — [2]Institute for Theoretical Physics, TU Dresden, Germany

Photonic systems are perfect model systems to experimentally investigate topological effects. One way to achieve topological non-trivial phases is to construct a parity-time symmetric system, comprising gain and loss, leading to non-hermitian terms in the corresponding Hamiltonian. In our experiments we realize a parity-time symmetric setup, consisting of two coupled organic microcavities. While one cavity contains an absorbing dye (loss cavity), the other can be pumped with a 532-nm laser (gain cavity). By thoroughly tuning the pump power as well as other parameters (e.g. coupling strength between the cavities) we achieve a parity-time symmetric system with pronounced modes in the visible regime.

We model the above mentioned system by a non-hermitian Hamiltonian $\mathcal{H}$ of the form $\mathcal{H} = \mathbf{d}(k) \cdot \sigma$. Here, $\mathbf{d} \in \mathbb{C}$ is a vector with complex components, k denotes the wave vector, and σ the vector of Pauli matrices. By the interplay between theoretical analysis of the Hamiltonian and recording of spectra we predict and explain the non-hermitian behaviour of the spectrum, in particular the mode splitting. Further research will address the ability of the gain cavity to exceed lasing threshold, steering the system into non-linear regime.

HL 12.25 Mon 17:30 Poster E

High frequency impact ionization and nonlinearity of photocurrent induced by intense terahertz radiation in HgTe-based quantum well structures — •Stefan Hubmann[1], Sebastian Gebert[1], Grigory Budkin[2], Vasily Belkov[2], Eugenius Ivchenko[2], Alexandr Dmitriev[2], Susanne Baumann[1], Maximilian Otteneder[1], Dimitry Kozlov[3], Nikolay Mikhailov[3], Sergey Dvoretsky[3], Ze-Don Kvon[3], and Sergey Ganichev[1] —

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We report on a strong nonlinear behavior of photogalvanics and photoconductivity under excitation of HgTe quantum wells by intense terahertz radiation. The increasing radiation intensity causes an inversion of sign of the photocurrent and transition to its superlinear dependence on the intensity. The photoconductivity also shows a superlinear raise with the intensity. We show that the observed nonlinearities are caused by *light* impact ionization with a photon energy less than the band gap. The signature of this kind of impact ionization is that the angular radiation frequency $\omega = 2\pi f$ is much higher than the reciprocal momentum relaxation time. Thus, the impact ionization takes place solely because of collisions in the presence of a high-frequency electric field. The effect has been measured applying polarized radiation with f from 0.6 to 1.07 THz and intensities up to hundreds of kW/cm^2. We demonstrate that the impact ionization probability $W \propto \exp(-E_0^2/E^2)$, with the radiation electric field amplitude E and the field parameter E_0.

HL 12.26 Mon 17:30 Poster E

Phase-coherent transport and gating of top-down etched bulk-insulating topological insulator nanowires — •Dingxun Fan, Matthias Rössler, Oliver Breunig, Andrea Bliesener, Gertjan Lippertz, Alexey Taskin, and Yoichi Ando — II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany

A solid understanding of the phase-coherent transport properties of the surface states in quantum devices based on topological insulator (TI) nanowires is of fundamental importance for the exploration of various applicational concepts, e.g. Majorana-fermion-based topological quantum computing and spintronic devices. In general, a TI nanowire can be realized by natural growth, mechanical exfoliation or top-down etching from thin films. Despite the significant progress that has been achieved in the magnetotransport properties of the first two cases, which highlights the topological nature of quantized surface states, the investigation of thin-film-based nanowire devices is far from complete in revealing the role of topological surface states in transport.

Here we study the transport properties of top-gated $(Bi_{1-x}Sb_x)_2Te_3$ nanowires with width down to 100 nm realized by etching MBE-grown bulk-insulating thin films. Low temperature transport measurements show full gate tunability of both top and bottom surfaces. Mesoscopic transport phenomena including weak anti-localization, universal conductance fluctuations and Aharonov-Bohm oscillations are measured and compared both at and away from the Dirac point. The effect of local gating is also discussed.

HL 12.27 Mon 17:30 Poster E

Plasmonic modes in micro-ribbon arrays of topological insulators — •Philipp Warzanowski, Muhamad Saleh, Andrea Bliesener, Gertjan Lippertz, Yoichi Ando, and Markus Grüninger — Institute of Physics II, University of Cologne, Germany

The electronic surface states of topological insulators offer a rich playground to study unconventional plasmonic excitations in 2D by optical spectroscopy [1,2]. Spin-momentum locking leads to the emergence of the spin plasmon, a novel collective excitation carrying both spin and charge character. In thin films, spin plasmons on opposite surfaces interact via Coulomb interactions, yielding coupled modes which are either pure spin or pure charge modes [3]. The momentum q of the optically excited plasmon can be tuned by varying the periodicity of the micro-ribbon array. This work presents far-infrared measurements of micro-ribbon arrays of thin films of the topological insulator $Bi_{2-x}Sb_xTe_3$ grown on Al_2O_3. Plasmons hybridize with longitudinal phonons, resulting in excitations with a Fano lineshape [4]. By analysing the energy and lineshape as a function of the ribbon period, we study the character of the observed plasmonic excitations.

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[3] T. Stauber, J. Phys.: Condens. Matter 26, 123201 (2014).
[4] V. Giannini et al., Nano Lett. 11, 2835 (2011).

HL 12.28 Mon 17:30 Poster E

Exciton-polariton topological insulator — Sebastian Klembt[1], •Tristan H. Harder[1], Oleg A. Egorov[1], Karol Winkler[1], Rongchun Ge[2], Miguel A. Bandres[3], Monika Emmerling[1], Lukas Worschech[1], Timothy C. H. Liew[2], Moti Segev[3], Christian Schneider[1], and Sven Höfling[1,4] — [1]Technische Physik, Universität Würzburg, Germany — [2]School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore — [3]Physics Department and Solid State Institute, Technion, Israel — [4]School of Physics and Astronomy, University of St Andrews, UK

Topological insulators constitute a striking example of materials in which topological invariants are manifested in robustness against perturbations. Here, we demonstrate experimentally the first exciton-polariton topological insulator and as such the first symbiotic light-matter topological insulators. Exciton-polaritons arise from the strong coupling of quantum well excitons to microcavity photons. In polaritonic honeycomb lattices, we show the existence of a C = 2 Chern topological insulator, manifesting in a chiral, topologically protected edge mode.

HL 12.29 Mon 17:30 Poster E

Topological Hall effect in magnetically doped topological insulator thin films — •Gertjan Lippertz[1,2], Andrea Bliesener[1], Alexey Taskin[1], Lino Pereira[2], and Yoichi Ando[1] — [1]Institute of Physics II, University of Cologne, Germany — [2]Instituut voor Kernen Stralingsfysica, KU Leuven, Belgium

Topological insulators (TIs) belong to a new class of quantum materials in which a strong spin-orbit coupling leads to a band inversion. Time-reversal symmetry (TRS), in turn, prevents the band gap from opening at the surface of the TI, leading to a protected metallic surface state.

Breaking TRS by magnetic doping opens an energy gap at the Dirac point on the top and bottom surface of the TI. Thin films of this kind of gapped topological insulator exhibit new quantum phenomena, including the quantum anomalous Hall effect (QAHE), where spontaneous magnetization leads to a dissipationless spin-polarised edge channel and a quantized Hall resistance of h/e^2.

Here we report on the observation of the topological Hall effect in V-doped $(Bi_xSb_{1-x})_2Te_3$ films grown by MBE and the possible existence of Skymions.

References:
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HL 12.30 Mon 17:30 Poster E

Topological surface states in α-Sn: from 3D Dirac semimetal to quasi-2D few-layer stanene — •Victor A. Rogalev[1], Johannes Jehn[1], Felix Reis[1], Florian Adler[1], Maximilian Bauernfeind[1], Jonas Erhardt[1], Liam B. Duffy[2], Thorsten Hesjedal[2], Moritz Hoesch[3], Gustav Bihlmayer[4], Jörg Schäfer[1], and Ralph Claessen[1] — [1]Physikalisches Institut und Röntgen Center for Complex Materials Systems, Universität Würzburg, 97074 Würzburg, Germany — [2]Clarendon Laboratory, Physics Department, Oxford University, OX1 3PU, United Kingdom — [3]Diamond Light Source, Didcot, OX11 0DE, United Kingdom — [4]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich,52428 Jülich, Germany

We report on the TSS evolution in α-Sn films with different thickness and surface orientation, studied by angle-resolved photoemission. α-Sn films were grown epitaxially on InSb substrates (0.14% biaxial compressive strain) with (001)- and (111)-surface orientations, which renders a Dirac semimetal phase. For the (001)-oriented α-Sn films we observe quantum well effects in the electronic structure, while the Dirac point (DP) remains mainly unchanged down to ∼2.5 nm. The DP in (111)-oriented α-Sn was found to be 200 meV below the Fermi level for 10-nm-thick α-Sn film, which enabled us to observe the hybridization gap opening in TSS for lower α-Sn film thicknesses. The crossover to a quasi-2D few-layer stanene electronic structure is accompanied by a disappearance of the TSS spectral weight and a gap opening, in agreement with our DFT calculations of the electronic bandstructure.

HL 12.31 Mon 17:30 Poster E

Native point and layer defect in magnetically doped topological insulator multilayers — •Jakub Šebesta, Pavel Baláž, and Karel Carva — Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 5 121 16 Praha 2, Czech Republic

The effect of magnetic doping on surface states of topological insulators represents an interesting and highly debated problem, since magnetic field breaks the time-reversal symmetry guaranteeing surface band crossing. In reality several kinds of native defect could appear in

these systems as well. Their inclusion allows to obtain a more realistic behavior as compared to the ideal one. Their presence could influence the size of a bulk and surface gap or the presence of ungapped surface states. The mutual interplay between defects is also important. In this work we focus on physical properties of magnetically doped well-know Bi_2Se_3 3D topological insulator [1] under the presence of native point and layer defects [2] treated by TB-LMTO+CPA within the surface Green's function approach. We show the impact of the mentioned defects on its bulk and surface band structure, especially on its gap size and magnetism related properties in the case of magnetic doping. The relations between occuring defects are discussed as well. Finally we try to compare exchange interactions leading to magnetic ordering as a function of composition.

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HL 12.32 Mon 17:30 Poster E

Boosting the Sensitivity and Selectivity of a Nanotube-Based NO_2 Gas Sensor: A First-Principles Investigation — Seyed Shahim Vedaei[1], •Ebrahim Nadimi[1,2], and Michael Schreiber[2] — [1]Faculty of Electrical Engineering, Center for Computational Micro and Nanoelectronics, K. N. Toosi University of Technology, Tehran, Iran. — [2]Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany.

The sensing properties of carbon-nanotube (CNT) boron-nitride-nanotube (BNNT) heterostructures toward NO_2, O_2 and H_2O have been theoretically investigated applying first-principles density-function theory in combination with non-equilibrium Green's function formalism. The core idea is to change the current-flow mechanism in CNT to a quantum-mechanical tunneling process by introducing BNNT insulating layers within the CNT. Due to the strong sensitivity of the tunneling current to the barrier height and the influence of adsorbed agent on the position of the band edges in the BNNT layer a very high level of sensitivity is expected for the proposed device. The binding energies and current as well as the device sensitivity have been calculated for energetically favorable adsorption geometries of NO_2, O_2 and H_2O molecules. In general NO_2 and O_2 show higher sensitivity compared to H_2O molecule. In order to increase the selectivity, the application of a vertical electric field on the BNNT part of the device is suggested. It is shown that by collecting the signals at different vertical electric fields a very good selectivity can be expected toward NO_2, O_2 and H_2O gases.

HL 12.33 Mon 17:30 Poster E

Fabrication and properties of carbon-nanodot-based planar microcavities — •Lukas Trefflich[1], Frank Dissinger[2], Chris Sturm[1], Siegfried R. Waldvogel[2], Marius Grundmann[1], and Rüdiger Schmidt-Grund[1] — [1]Felix-Bloch-Institute for Solid State Physics, Universität Leipzig, 04103 Leipzig — [2]Institute for Organic Chemistry, Johannes Gutenberg Universität Mainz, 55128 Mainz

We report about the growth and structural as well as optical properties of carbon-nanodot-based planar microcavities. The carbon nanodots made from citric acid emit bright light in the spectral range between 450 nm and 500 nm. By incorporating them in a microcavity and varying the cavitylayer thickness, it is possible to tune the emission wavelength of the device. We present the angularly and temporally resolved emission characteristic of the microcavity, as well as the dielectric function of the carbon-nanodot-containing cavity layer from the NIR to the UV spectral range. Furthermore, we explore their usage for possible laser and white light LEDs. White light LEDs usually contain rare-earth elements [1], which are less abundant and expensive. Carbon nanodots can be synthesized from environment-friendly substances like coffee, tea, grass and candle soot. [2] They are biocompatible [3] and photo-stable [4] and therefore promising alternatives for conventional LED designs. [1] H. Höppe, Angew. Chem., Int. Ed. 2009, 48 [2] Roy et al., Mater. Today, 2015, 18 [3] da Silva et al., Trends Anal. Chem., 2011, 30 [4] Sun et al., J. Am. Chem. Soc., 2006, 128

HL 12.34 Mon 17:30 Poster E

Redox and electrochemical doping of nanoscale semiconductors — •Klaus Eckstein, Florian Oberndorfer, and Tobias Hertel — Institute of Physical and Theoretical Chemistry, Am Hubland, Julius-Maximilians-University Würzburg, 97074 Würzburg

We report on recent advances with the spectroscopic characterization of doped semiconducting carbon nanotubes (SWNTs) using photoluminescence- and femtosecond time-resolved spectroscopies as well as IR-VIS absorption spectroscopy [1-2]. Our primary objective is to obtain an understanding of charge-induced modifications of exciton- and trion- photo- physics, that may eventually provide the basis for a quantitative spectroscopic assessment of carrier concentrations in doped nanotubes or other low-dimensional semiconductors.

Our investigations of electrochemically and redox-chemically doped SWNTs suggest that surplus carriers tend to be localized by their interaction with poorly screened counterions in the nanotube environment. These findings have important implications for several aspects related to the performance of doped nanoscale semiconductors in functional materials, specifically when it comes to charge and energy transport properties of these systems.

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HL 12.35 Mon 17:30 Poster E

Improving the spin coherence of shallow nitrogen-vacancy centers (NVs) by CVD-diamond overgrowth — •Christoph Findler[1,2], Christian Osterkamp[1], Johannes Lang[1], Josef Souček[3], Milos Nesladek[3], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany. — [2]Daimler AG, RD/EBT, HPC U028, Wilhelm-Runge-Str. 11, D-89081 Ulm, Germany. — [3]Institute for Materials Research (IMO), Hasselt University, Wetenschapspark 1, B-3590 Diepenbeek, Belgium.

The negatively charged nitrogen-vacancy center (NV) is a paramagnetic defect in diamond with long spin coherence times at room temperature. The spin-dependent fluorescence of the NV enables optical polarization, read-out and manipulation of single or ensembles of spins. For quantum technology applications like magnetic resonance imaging [1] and magnetic field sensing on the nanoscale [2] the NVs have to be close to the diamond's surface. To minimize the influence of near-surface noise and defects we combine two state-of-the-art NV production methods, namely plasma enhanced chemical vapor deposition (PECVD) [3] and nitrogen ion implantation with precise depth control [4]. We produce shallow NV centers by implantation into ^{12}C-enriched (100) diamond and overgrow then the NVs with a thin ^{12}C-enriched diamond capping layer using PECVD [4]. [1] T. Staudacher et al., Science 339, 561-563 (2013). [2] S. Schmitt et al., Science 356, 832-837 (2017). [3] C. Osterkamp et al., Appl. Phys. Lett. 106, 113109 (2015) [4] T. Staudacher et. al., Appl. Phys. Lett. 101, 212401 (2012)

HL 12.36 Mon 17:30 Poster E

Magnetic resonance of electrochemically fabricated carbon quantum dots — •Theresa Grünleitner[1], Jonathan Zerhoch[1], Martin Stutzmann[1], Martin S. Brandt[1], and Zhenhui Kang[2] — [1]Walter Schottky Institut and Physik-Department, Technische Universität München, Garching, Germany — [2]Functional Nano & Soft Materials Laboratory (FUNSOM), Soochow University, Suzhou, China

Optically detected magnetic resonance is a unique technique to identify the microstructure of excited states leading to fluorescence. In this contribution, we apply this technique to investigate the origin of the luminescence in carbon-based nanoparticles synthesised via alkali-assisted electrochemical fabrication. ODMR measurements show broad structures up to about 600 G, which we assign to Pake doublets caused by triplet excitons. The assignment is corroborated by the observation of the corresponding half-field transitions. We discuss the correlation of this fine structure to the photoluminescence energy of the quantum dots and to the diameter of the particles.

HL 12.37 Mon 17:30 Poster E

Rydberg-like states in organic semiconductor rods — •Aswin Asaithambi[1], Daichi Okada[2], Guenther Prinz[1], Yohei Yamamoto[2], and Axel Lorke[1] — [1]Lotharstrasse 1, Faculty of Physics, CENIDE, University of Duisburg-Essen, 47057 Duisburg, Germany — [2]Division of Material Science, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan

The Organic semiconductor Borondipyrromethene (BODIPY) drawn much attention in recent years due to their advantageous photophysical properties. BODIPY molecules, under certain conditions, can be grown into crystalline rods [1]. Different growth methods result in BODIPY rods with different photo-emission wavelengths, for example green, orange or red [1].

In this contribution we show photo-luminescence (PL) spectra of green rods under 405nm laser excitation. The PL spectrum shows, besides a broad luminescence band, a set of peaks with energies that

follows E(n)=E_g-E_0/n^2. E_g is the band gap and E_0 is the effective Rydberg constant that varies between different rods. Interestingly, PL line scans reveal that E_0 is constant within a single green rod and even in a serendipitously grown striped rods containing both red and green emitting regions.A slight decrease in the line width without a change in peak position was observed when lowering the temperature to 83K. The findings will be discussed using different models such as Rydberg excitons or charge complexes in the crystal.

[1] A. Asaithambi et al., JPC C DOI: 10.1021/acs.jpcc.8b09202

HL 12.38 Mon 17:30 Poster E

C8-BTBT air gap field-effect transistors — •Michael Bretschneider, Bernd Büchner, and Yulia Krupskaya — IFW Dresden, Germany

Despite the fact that organic semiconductors are already used to produce large scalable electronic devices, basic mechanisms of charge transport in these materials are not fully understood. The field-effect transistor is a common device to study charge transport in semiconductors by creating a conductive channel at the semiconductor/insulator interface. C8-BTBT is the workhorse of a new type of high hole mobility organic semiconductors. As a matter of fact there are several different mobilities reported in literature for comparable device structures of a C8-BTBT transistor. Electrical and mechanical distortion of the interface region caused by the solid dielectric cannot be excluded in these measurements, so that it remains unclear what the intrinsic mobility value of C8-BTBT is. With the help of an air gap field effect transistor we get rid of these distortions by using air/vacuum as an insulating layer between gate electrode and organic semiconductor. We investigate highly ordered films of C8-BTBT, grown by vapor phase transport. After the growth these films are flipped around and laminated with the upper surface on top of the air/vacuum gap stamp. In such a configuration it is possible to measure the current in the organic semiconductor which is not influenced by a gate dielectric. These measurements allow to get a closer look into the intrinsic transport behaviors of C8-BTBT.

HL 12.39 Mon 17:30 Poster E

Rubrene single-crystal based charge-transfer interfaces — •Bipasha Debnath[1], Eter Mgeladze[1], Alexey Popov[1], Yevhen Karpov[2], Anton Kiriy[2], Bernd Büchner[1], and Yulia Krupskaya[1] — [1]Leibniz Institute for Solid State and Materials Research Dresden, 01069 Dresden — [2]Leibniz Institute of Polymer Research Dresden, 01069 Dresden

Organic materials based on small conjugated molecules are typically large gap semiconductors. However, it has been observed that if two of these materials are in direct contact, they can exhibit enhanced electrical conductivity at the interface. The conductivity is originated from the charge transfer between two constituent materials. Therefore, this conductivity can be used to study the charge transfer effects. One of the very good tools to investigate such phenomena is single-crystal charge-transfer interfaces. In this research work, we build and investigate Rubrene single-crystal based charge-transfer interface devices with new interesting acceptor materials such as fullerenes and hexacyano-[3]-radialene anion-radical material family. Here, we present different ways of fabricating these interface devices, i.e., thermal evaporation, drop-casting, spin coating, and shear coating as well as discuss the electrical properties of these interfaces. This work is financially supported by DFG KR 4364/4-1.

HL 12.40 Mon 17:30 Poster E

Comparing thickness dependence and transport properties of the organic semiconductors F_{16}CoPc and F_{16}CuPc — •Mareike Dunz, Karsten Rott, Jan Schmalhorst, and Günter Reiss — Center for Spinelectronic Materials and Devices, Physics Department, Bielefeld University, Germany

Nowadays, organic semiconductors are widely used in OLED and organic photovoltaic systems. However, organic field effect transistors cannot yet compete with silicon based technology as the search for high-mobility and air stable n-channel organic semiconductors goes on. Fluorinated metal phthalocyanines (F_{16}MPc) are considered to be promising candidates due to their high stability and easy synthesis but their carrier mobilities are insufficiently small. Understanding, how different metal center atoms influence the molecules' properties is a crucial step towards their applicability.

Hence, we prepared organic field effect transistors via thermal evaporation of F_{16}CuPc as well as F_{16}CoPc and investigated their thickness dependencies and transport properties at various temperatures. In situ measurements of the resistance allow for the detection of a thickness dependent source-drain current during the evaporation of the molecules and suggest a thinner conduction channel width for the F_{16}CoPc transistors. Furthermore, we show that oxygen dosing only worsens the performance of transistors with phthalocyanine thicknesses in the regime of the associated channel width, independent of the metal atom. Finally, as F_{16}CoPc features a magnetic center atom, first results of magnetic field dependent measurements are presented.

HL 12.41 Mon 17:30 Poster E

New insight into electronic excitations of metal phthalocyanines — •Louis Philip Doctor, Marco Naumann, Lukas Graf, Nikolay Kovbasa, and Martin Knupfer — IFW Dresden, Helmholtzstr. 20, D-01069 Dresden, Germany

We deposited thin films with a thickness of 120 nm, of copper-, zinc- and nickel-phthalocyanine on a KBr substrate in ultra-high vacuum, respectively. Afterwards these thin films underwent a phase transition to the β-phase. Furthermore the optical absorption spectra were measured at different temperatures down to 77 K. They show a drastic difference in the absorption of the initially evaporated α-phase compared to the β-phase in all optical regimes. The four peaks in the visible regime can be each assigned to a dipole transition element, which can be modelled by the extended double dipole approach. This model calculates the interaction between the two molecules in a metal-phthalocyanine dimer from crystallographic data. We added a distortion angle to model a momentum dependent dipole interaction. With electron-energy-loss-spectroscopy we are able to measure a momentum dependent excitation. Here again we see a different behaviour of the excitons in the α- and β-phase. The first excitation peak underwent a redshift for higher momentum transfer, whereas the second excitation peak virtually vanishes at the same time. This behaviour can be seen until a momentum transfer of 0.7 $Å^{-1}$. For higher momentum transfer this process seems to revert to the initial spectrum. This leads to the conclusion that excitons in metal-phthalocyanines have a negative dispersion with a minimum around 0.7 $Å^{-1}$.

HL 12.42 Mon 17:30 Poster E

Concept of multi-stage ballistic rectifiers — •Nina Niedworok and Ulrich Kunze — Electronic Materials and Nanoelectronics, Ruhr-Universität Bochum, 44780 Bochum, Germany

We analyze the behavior of input-current addition in a multi-stage ballistic rectifier implemented on Si/SiGe heterostructures. In a preceding work [1] we demonstrated a fundamental difference between two-stage ballistic rectifiers with large (740 nm) and small (340 nm) center-to-center separation between the current-injector pairs. While for large separation the output voltage V_{out} of both stages add up as $V_{out} = \alpha_1^2 I_{in1}^2 + \alpha_2^2 I_{in2}^2$ (where I_{in1}, I_{in2} are the input currents and α_1, α_2 denote the curvature coefficients) in closely-spaced stages the input currents are added leading to a characteristic which is accurately described by $V_{out} = (\alpha_1 I_{in1} + \alpha_2 I_{in2})^2$. More generally, this results in an excess voltage $V_{out}^{exc} = 2\beta\alpha_1\alpha_2 I_{in1} I_{in2}$, where β descibes the degree of overlap between the injected charge clouds of both stages, $0 \leq \beta \leq 1$. In the present work we present nanoscale geometries of multi-stage ballistic rectifiers which promise maximum excess voltage due to current addition. For n-stage rectifiers we present a model which describes the synergetic behavior. The aim of the work is to implement multi-stage ballistic rectifiers which show output voltages of technical relevance for high frequency applications with the smallest possible numbers of injectors on Si/SiGe heterostructures.

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HL 12.43 Mon 17:30 Poster E

Sign-alternating photoconductivity and magnetoresistance oscillations induced by terahertz radiation in HgTe quantum wells — •Maximilian Otteneder[1], Ivan Dmitriev[1,2], Susanne Candussio[1], Maxim Savchenko[3], Dmitry Kozlov[3], Vasily Bel'kov[2], Ze-Don Kvon[3], Nikolay Mikhailov[3], Sergey Dvoretsky[3], and Sergey Ganichev[1] — [1]University of Regensburg, Regensburg, Germany — [2]Ioffe Institute, St. Petersburg, Russia — [3]Rzhanov Institute of Semiconductor Physics, Novosibirsk, Russia

We report on the observation of terahertz radiation induced photoconductivity and of terahertz analog of the microwave-induced resistance oscillations (MIRO) in HgTe quantum wells (QWs). The MIRO-like effect has been detected in 20 nm QWs with a mobility of 3×10^5 $cm^2/V\,s$. In other structures with QW widths ranging from 5 to 20 nm and lower mobility we observed an unconventional non-oscillatory photoconduc-

tivity signal which changes its sign upon magnetic field increase. In samples having Hall bar and Corbino geometries this results in a single and double change of the photoresponse sign, respectively. We show that within the bolometric mechanism these unusual features imply a non-monotonic behavior of the transport scattering rate, which should decrease (increase) with temperature for magnetic fields below (above) a certain value. This behavior is consistent with the results of dark magnetoresistivity measurements at different temperatures. Our experiments demonstrate that photoconductivity is a very sensitive probe of the temperature variations of the transport properties, even those that are hardly detectable using standard transport measurements.

HL 12.44 Mon 17:30 Poster E

Probing energy transfer in TMDC/organic heterostructures using Femtosecond Electron Diffraction — •Helene Seiler[1], Daniela Zahn[1], Soohyung Park[2], Thomas Vasileiadis[1], Ying-Peng Qi[1], Norbert Koch[2], and Ralph Ernstorfer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Department of Physics, Humboldt-Universität zu Berlin, Brook-Taylor-Straße 6, 12489 Berlin, Germany

Transition metal dichalcogenide (TMDC)/organic heterostructures have recently gained attention for their potential in opto-electronic applications. While first devices have been demonstrated, a microscopic understanding of the couplings within the sub-systems as well as between the sub-systems in the heterostructure is still lacking. Here we show how femtosecond electron diffraction can provide direct insights into these couplings using a MoS2/pentacene heterostructure as an example. Our measurements complement optical studies by revealing the energy relaxation pathways dominated by the participation of dark states and incoherent phonons, both not directly accessible with optics. The presented method is general and we expect that it can be applied to a wide range of heterostructures.

HL 12.45 Mon 17:30 Poster E

***In situ* study of the surface preparation of metamorphic GaAsP buffers for III-V-on-Si integration** — •Ammar Tummalieh, Agnieszka Paszuk, Oliver Supplie, Alexander Heinisch, Peter Kleinschmidt, and Thomas Hannappel — Institute for Physics, University of Technology, Ilmenau, Germany

Low defect $GaAs_{1-x}P_x$ graded buffers grown on Si enable highly efficient III-V-on-Si multi-junction solar cells. Here, $GaAs_{1-x}P_x$ graded buffers were grown by metalorganic chemical vapor phase deposition on GaP substrates to explore the possibility of *in situ* growth control. To this end, the GaAsP growth was monitored with reflection anisotropy spectroscopy (RAS). Ultra-high vacuum surface-sensitive methods were used to identify the surface reconstruction and chemical composition in dependence on the GaAsP stoichiometry and post-growth surface preparation routes. The strain relaxation of each layer was measured by high-resolution x-ray diffraction. We show that the As content of individual GaAsP layers can be quantified *in situ* during the growth by RAS: With increasing As supply, a peak close to the GaP E_1 critical point energy shifts towards GaAs E_1 at lower energy. The atomic structure of the GaAsP surfaces depends on the processing routes. GaAsP surfaces annealed at 500°C are V-rich whereas annealing at 700°C leads to Ga-rich surfaces. The preparation of the surfaces can be optimized *in situ* via their RAS fingerprints.

HL 12.46 Mon 17:30 Poster E

Heterostructures of 2D Materials and Organic Semiconductors for Ambipolar Field Effect Transistors — •Sirri Batuhan Kalkan[1], Henrik Hecht[1], Antony George[2], Andrey Turchanin[2,3], and Bert Nickel[1] — [1]Faculty of Physics and CeNS, Ludwig-Maximilians-Universität München, 80539 Munich, Germany — [2]Institute of Physical Chemistry, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany — [3]Jena Center for Soft Matter (JCSM), 07737 Jena, Germany

We investigated the electronic and optoelectronic properties of a MoS2 field effect transistor (FET) and a pentacene/MoS2 heterostructure as an ambipolar FET. Heterostructures are constituted by transferring a pentacene sheet on top of the MoS2 layer. This transfer is enabled by using low energy electron beams to crosslink the first couple of layers of pentacene increasing mechanical stability. Therefore, less defective surfaces are achievable in compared to photoresist or PMMA assisted transfer. In previous work, we introduced the technique of scanning photocurrent microscopy (SPCM) for spatially identifying defect sites within an OFET channel, as well as regions of low contacts. Now we employ this technique to the pentacene/MoS2 heterojunction. Here, pentacene serves as p-type and MoS2 as n-type semiconductor. Tuning the excitation wavelength allows to separate the contributions of the two semiconductor layers. Furthermore, the effect of surface adsorbates at ambient condition in comparison to N2 atmosphere is studied. Understanding how to operate at ambient conditions will be valuable for design of transistors and photodetectors.

HL 12.47 Mon 17:30 Poster E

Luminescence of indium residues after local droplet etching and thermal annealing on GaAs (111)A substrates — •Julian Ritzmann[1], Nandlal Sharma[2], Dirk Reuter[1,2], Henning Moldenhauer[3], Jörg Debus[3], Marc Portail[4], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Ruhr-Universität Bochum, D-44780 Bochum — [2]Universität Paderborn, D-33098 Paderborn — [3]Technische Universität Dortmund, D-44227 Dortmund — [4]CNRS-CRHEA, 06560 Valbonne, France

(111)A-oriented GaAs has proved as interesting substrate for the growth of nanostructures of high symmetry. GaAs quantum dots on (111)A-oriented substrates produced by droplet epitaxy, for example, exhibit reduced fine-structure splitting. However, these QDs are strongly distributed in size resulting in rather broad photoluminescence (PL) spectra. More uniform quantum dot ensembles are achieved by filling up nanoholes on (001)-oriented Al(Ga)As with GaAs. Ensemble PL inhomogeneous broadenings of less than 10 meV are realized. Nanoholes are generated via local droplet etching (LDE), a technique which is capable of alternating the substrate surface in various ways and to produce a wide spectrum of nanostructures. Our approach is to establish the LDE technique on (111)A-oriented substrates. Therefore, we present a study on different parameters for the LDE with indium droplets using atomic force microscopy, PL, micro-PL and cathodoluminescence. We discuss luminescent characteristics of indium residues which form InGaAs/GaAs heterostructures with the substrate material.

HL 12.48 Mon 17:30 Poster E

Ab-initio dynamics of highly excited amorphous graphene — Sergej Krylow, Othmane Benhayoun, •Lukas Nöding, Marie Kempkes, Tobias Zier, and Martin E. Garcia — Theoretische Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Amorphous materials are ubiquitous in todays society. However, many properties of amorphous media are still not understood, and pose a challenge to theoretical and experimental methods. Here, we analyze the response of amorphous carbon to an intense ultrafast laser pulse using ab-initio molecular dynamics simulations and compare our results to recent XAS experiments performed at the EIS-TIMEX and Fermi beamlines. In particular, we observe in our simulations s ignificant changes in the electronic density of states upon laser excitation. These changes are consistent with the time-evolution of the absoprtion spectrum in experiments. We demonstrate that the changes of the electronic density of states are caused by a non-thermal melting of the system. This can be particularly observed in the time-evolution of the radial distribution function and the mean square displacements.

HL 12.49 Mon 17:30 Poster E

Time-dependent photo-conductivity in DCNQI radical ion salts — •Lisa Schraut-May[1], Sebastian Hammer[1], Florian Hüwe[1], and Jens Pflaum[1,2] — [1]Experimental Physics VI, Julius Maximilian University, 97074 Würzburg — [2]ZAE Bayern, 97074 Würzburg

The material class of organic radical anion salts offers a wide range of attractive electronic and photo-physical properties. For instance, dicyanochinondiimine (DCNQI) coordinated by metal atoms is characterized by a low-dimensional metallic ground state at high temperatures which is transferred to an insulating state upon cooling to cryogenic temperatures. The corresponding metal-insulator Peierls transition is tunable by the chemical composition of the $Me(DCNQI)_2$ sidegroups and the choosen metal as well as by external parameters, e.g. the hydrostatic pressure. Moreover, it has been demonstrated that the Peierls transition can be initiated by photon absorption on picosecond time scales [1] which renders $Me(DCNQI)_2$ a model system for studying the time-dependent photo-switching between metallic and insulating ground state. We present studies on the transient photo-conductivity in $Cu(DCNQI)_2$ and $Li(DCNQI)_2$ single crystals. We characterize the photo-induced Peierls transition as function of sample temperature, incident light intensity as well as excitation wavelength. The variation of these parameters provides detailed insights in the mechanisms gov-

erning the phase transition and allows for evaluation of this material class for application as ultra-fast photo-switches.

[1] F. Karutz et al., Phys. Rev. Lett. 81 (1998) 143

HL 12.50 Mon 17:30 Poster E

Ab-Initio Electronic Structure Parameters of Thermoelectric Mg2X-Mg2Y (X,Y=Si,Ge,Sn) Substitutional Alloys — •Juan Guerra, Marcel Giar, Carsten Mahr, Michael Czerner, and Christian Heiliger — Justus Liebig University Giessen, Institut für Theoretische Physik, Giessen, Germany

There has been a wide interest in the Mg2X-Mg2Y substitutional alloys, between the isoelectronic X,Y=Si,Ge,Sn, for technological applications and fundamental research. We use the Bloch spectral density function, defined within the coherent potential approximation in the KKR method, to map an electronic band structure, to explore the electronic nature, and to extract parameters relevant for transport such as energy gaps and effective masses. We compute formation energy using total energy calculations, and we report deviations from Vegard's laws stronger when Y=Sn. General non-linear trends are reported in the measured quantitites, anisotropies in the effective masses, and the well-know convergence of the conduction bands at intermediate compositions of Mg2X_{1-x}Sn_x. We discuss the trends of our calculations, and compare them with available experimental data.

HL 12.51 Mon 17:30 Poster E

DFT calculation of zero-field splitting for high-spin defects in solids — •Timur Biktagirov, Wolf Gero Schmidt, and Uwe Gerstmann — Universität Paderborn, Warburger str. 100, 33098 Paderborn, Germany

For high-spin point defects, the zero-field splitting (ZFS, also known as magnetic anisotropy) is one of the key spectroscopic signatures addressable by electron paramagnetic resonance (EPR). Due to the complex nature of the ZFS, its comprehensive interpretation often has to rely on a combination of the experiment and the first-principles theory [1,2]. We report on the recent progress in developing a general and efficient framework for density functional theory (DFT) based calculation of the ZFS in extended periodic systems implemented in the Quantum ESPRESSO software [3].

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[3] P. Giannozzi, et al., J. Phys Cond. Matter 29, 465901 (2017).

HL 12.52 Mon 17:30 Poster E

Phonon-mediated optical absorption of BAs using first principles simulation methods — •Ivona Bravić and Bartomeu Monserrat — TCM Group, Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom

Recently the semiconductor boron arsenide (BAs) was experimentally found to exhibit ultrahigh lattice thermal conductivity at room temperature. Its capability to dissipate heat has emerged much interest in the optoelectronics community, since the discovery of highly thermal conductive semiconductors is imperative to facilitate the performance of optoelectronic devices. Considering the design of materials for that application field, not only the thermal conductivity but also the interplay between optical properties and temperature needs to be studied rigorously.

Hence, we report a detailed first principles analysis of the phonon-assisted optical properties of BAs using semilocal and hybrid DFT methods. We combine the electronic structure simulation with phonon-calculations using finite differences and thermal lines for the study of temperature effects on the electronic bandstructure and optical absorption. We will present the underlying computational techniques and we will demonstrate how the electron-phonon interaction influences indirect absorption in BAs, and inherently defines the temperature dependence of the absorption spectrum. This case study will also serve as an example of how considering phonons proves invaluable to the design of novel conductor materials operating under realistic conditions.

HL 12.53 Mon 17:30 Poster E

Theoretical Description of Two-Dimensional Spectroscopy in a CdTe Quantum Dot doped with a Single Mn Ion — •Magnus Molitor, Tilmann Kuhn, and Doris Reiter — Institut für Festkörpertheorie, Wilhelm-Klemm-Straße 10, 48149 Münster

Quantum dots (QDs) doped with single Mn ions offer new opportunities in the field of spintronics. In these QDs the Mn ion behaves as a spin $M = \frac{5}{2}$ with six eigenstates $M_z = \pm\frac{5}{2}, \pm\frac{3}{2}, \pm\frac{1}{2}$ resulting in a photoluminescence (PL) spectrum consisting of six equally spaced lines even in the absence of a magnetic field. By increasing the magnetic field, states which are coupled by the exchange interaction are brought into resonance and multiple anticrossings are observed in the PL spectrum. However, using PL alone one cannot unambiguously distinguish if these resonances arise from different non-interacting states or from a coupled system. In contrast, two-dimensional (2D) four-wave mixing (FWM) spectroscopy allows us to disentangle involved spectra.

In this contribution we study two- and three-pulse excitations to probe the coherence and population dynamics of a QD doped with a single Mn ion. We model the system as an ensemble of QDs in different Mn spin states, whereby each member is comprised of a few-level system. Our study shows that 2D FWM is able to identify and investigate coherent coupling mechanisms between the excitonic excitations and the magnetic dopant in the QD.

HL 12.54 Mon 17:30 Poster E

OAM spectroscopy of fractional exciton polariton vortices — •Bernd Berger, Marius Kahlert, Daniel Schmidt, and Marc Assmann — Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany

Vortices are elementary excitations of exciton polariton condensates that receive significant attention. Their characteristic feature is a helical phase gradient $l \cdot 2\pi$ which translates into the orbital angular momentum (OAM) state of the emitted light field. We demonstrate a spectroscopic method which utilizes the technique of OAM sorting to transform the helical phase gradient of OAM states to a linear phase gradient. This enables the detection of the topological charge of exciton polartion vortices without an interferometric setup. We demonstrate that this method is not limited to integer topological charges, but also works for arbitrary fractional OAM states with phase rotations different from multiples of 2π, which is comparatively hard to do using interferometric techniques. In summary the method we present opens new ways in researching vortices in exciton polaritons especially tailored towards non-integer OAM states. We discuss the possibility of exciting fractional vortices in exciton polariton condensates and probing the time dynamics of complex polariton processes such as vortex decays or vortex switching.

HL 12.55 Mon 17:30 Poster E

PbWO4 ground- and excited-state properties from first-principles calculations — •Johannes Bilk, Kris Holtgrewe, Christof Dues, and Simone Sanna — Justus-Liebig-Universität Gießen, Institut für theoretische Physik, Heinrich-Buff-Ring 16, 35392 Gießen

The scheelite tungstate crystals such as PbWO4 feature peculiar optical properties, including the excitonic luminescence, which is based on the radiative transition within tetrahedral (WO4)2- group, where the exciton becomes autolocalised. In particular, lead tungstate is a dense, fast scintillator material, which is often employed in high end calorimetric detectors in high energy physics accelerators [1]. Unfortunately, our theoretical knowledge of the models is still poor if compared to its technological relevance. In order to fill this gap, we present a comprehensive theoretical investigation of the scheelite phase of PbWO4. The atomic and electronic structure as well as the optical absorption are calculated for from first principles. The structural and optical properties predicted from local and hybrid density functional theory are in good agreement with experiment and earlier theoretical work [2]. The electronic structure and optical response are found to be very sensitive to the computational approach. Exact-exchange calculations are found to open the band gap substantially by 1.07 eV. In contrast to earlier calculations, good agreement with the measured optical data is achieved.

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HL 12.56 Mon 17:30 Poster E

Linear and non-linear optical properties of adamantane-derived molecular clusters — •Christof Dues[1,2] and Simone Sanna[1,2] — [1]Institut für Theoretische Physik, Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, 35392 Gießen, Germany — [2]Zentrum für Materialforschung (ZfM/LaMa), Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, 35392 Gießen, Germany

A new class of molecular materials based on adamantane-type organotetrel chalcogenide clusters has recently attracted the attention of the scientific community due to its outstanding optical properties [1]. De-

pending on the composition (organic substiuents and tetrel atoms in the cluster core), these materials show either white-light generation or strong non-linear response upon IR radiation [2]. In order to determine the prerequisites for white light generation, different related clusters have been synthesized, which posses an additional ligand based on a coinage-metal atom [3]. To explore the optical response, we perform first-principles calculations within the density functional theory. Linear optical properties such as absorption and transmission are calculated basing on the electronic structure for both single molecules and molecular crystals. Furthermore, the frequency dependent non-linear optical response is estimated calculating the second harmonic coefficients $\chi^{(2)}_{\mathrm{SHG}}$ and the photoluminescence is modeled by constrained total energy calculations.

[1] N. W. Rosemann et al., Science **352**, 1301 (2016).
[2] N. W. Rosemann et al., J. Am. Chem. Soc. **138**, 16224 (2016).
[3] E. Dornsiepen et al., submitted (2018).

HL 12.57 Mon 17:30 Poster E

Voigt exceptional-points in anisotropic ZnO-based photonic structures — •Evgeny Krüger[1], Steffen Richter[1,2], Sebastian Henn[1], Heinrich-Gregor Zirnstein[3], Jesús Zúñiga-Pérez[4], Christiane Deparis[4], Lukas Trefflich[2], Chris Sturm[2], Bernd Rosenow[3], Marius Grundmann[1], and Rüdiger Schmidt-Grund[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstr. 5, Leipzig — [2]ELI Beamlines/Fyzikální Ústav AV ČR, v.v.i., Za Radnicí 835, 25241 Dolní Břežany, Czech Republic — [3]Universität Leipzig, Institut für Theoretische Physik, Brüderstr. 16, 04103 Leipzig — [4]Université Côte d'Azur, CRHEA-CNRS, rue Bernard Gregóry, Valbonne, France

We report on exceptional points (EP) in planar ZnO-based microcavities with broken cylindrical symmetry, realized by inclining the optical axis of the uniaxial cavity layer to the mirror direction [1]. Such EPs represent non-Hermitian degeneracies in momentum space, related to a local complex-square-root topology of the resonator eigenenergies. The eigenmodes coalesce along these directions, yielding degeneracy in energy, broadening and polarization, the latter being either left or right circular. We prove the exceptional point nature experimentally and theoretically by monitoring the square-root topology around the EP and show how the occurrence and direction of EP can be controlled by the geometrical microcavity design.

[1] S. Richter et al., Phys. Rev. A 95, 023836 (2017)

HL 12.58 Mon 17:30 Poster E

Template-Assisted Fabrication of Spectrum-Programmable Superlattice Photonic Crystals for Efficient Solar Energy Harvesting — •Zhiqiang Zeng, Rui Xu, and Yong Lei — Institut für Physik & IMN MacroNano* (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, Germany

Superlattice photonic crystals (SPhCs) possess tremendous potentials as building blocks for high-performance solar thermal conversion systems because of their great flexibility in optical manipulation. To be as solar absorbers, the key points are to fabricate highly-ordered SPhCs in large scale and to realize spectrally-programmable selective light absorption spectra for different operational temperatures. In this work, wafer-scale nickel (Ni) SPhCs with excellent structural uniformity are fabricated by structurally replicating nanoporous alumina templates comprising two sets of nanopores (NPs) and nanoconcaves (NCs). Both self-aligned sets of NPs and NCs are simultaneously formed during the anodization of surface-patterned aluminum foils. The Ni SPhCs demonstrate omnidirectional polarization-independent selective light absorption spectra whose cutoff wavelength can be precisely programmed in the spectral range of 600 to 1500 nm. Below the cutoff wavelength all absorption efficiencies are enhanced to over 90% due to surface plasmon resonance and cavity resonance stemming from both NCs and NPs. All these advantages in optics and fabrication qualify Ni SPhCs as excellent candidates of solar absorbers for practical utilization.

HL 12.59 Mon 17:30 Poster E

A high power (11 W), tunable (1.45 - 1.65 μm) OPCPA for THz generation in organic crystals — •Ivanka Grguras, Torsten Golz, Michael Schulz, Jan Heye Buss, Robert Riedel, and Mark James Prandolini — Class 5 Photonics GmbH, Notkestraße 85, 22607 Hamburg, Germany

Owing to their high second-order nonlinear susceptibility, organic crystals have gained tremendous interest as THz generators. Recently high field THz generation in several organic crystal have been demonstrated [1-3]. Here we demonstrate a high power, tunable (1.45 - 1.65 μm) OPCPA with pulse duration of $<$ 36 fs and a repetition rate of 350 kHz for THz generation using organic crystals. To enhance the flexibility of this system, a second synchronized probe channel is available, delivering compressed pulses at 850 nm with $<$15 fs.

[1] M. Savoini *et al.*, THz Generation and Detection by Fluorenone Based Organic Crystals, ACS Photonics **5**, 671-677 (2018)
[2] A. Curcio *et. al.*, Terahertz-based retrieval of the spectral phase and amplitude of ultrashort laser pulses, Opt. Lett. **43**, 783 (2018)
[3] C. Vicario *et. al.*, Generation of 1.5-octave intense infrared pulses by nonlinear interactions in DAST crystal, J. Opt. **17**, 094005 (2015)

HL 12.60 Mon 17:30 Poster E

Structural, Energetic and Electronic Properties of Lanthanum and Fluorine Doped HfO_2/SiO_2 Gate Stack of MOSFETs — Arash Rahimi[1], •Ebrahim Nadimi[1,2], and Michael Schreiber[2] — [1]Faculty of Electrical Engineering, Center for Computational Micro and Nanoelectronics, K. N. Toosi University of Technology, Tehran, Iran. — [2]Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany.

Aggressive down scaling of the dimensions of metal-oxide-semiconductor field-effect transistors requires the application of high-k gate dielectrics in order to keep the gate leakage current at an acceptable level. Among several candidates HfO_2-based high-k gate stacks have been shown to be the most promising solution. However, the high-k gate stacks suffer from high density of trap levels as well as difficulties in threshold voltage adjustment. Doping of the gate stack with different atoms such as La and F has been shown to improve the gate stack quality. We employed first-principles calculations to investigate different atomic structures for La and F doping agents and their interactions with oxygen vacancies in a SiO_2/HfO_2 gate dielectric stack. The formation energies are calculated for different configurations and the results show that the F atoms prefer to occupy the position of an oxygen vacancy, particularly at the SiO_2/HfO_2 interface. The energetically favored configuration for a La defect complex is also located at the HfO_2 layer close to the interface. F and La doping is shown to be applicable for the passivation of trap levels as well as for the adjustment of the threshold voltage.

HL 12.61 Mon 17:30 Poster E

From Hybrid Si Nanowire Transistors to Artificial Neurons — •Khrystyna Nych[1], Eunhye Baek[1,2], Taiuk Rim[3], Larysa Baraban[1,2], and Gianaurelio Cuniberti[1,2] — [1]Institute for Materials Science and Max Bergmann Center of Biomaterials, TU Dresden — [2]Center for Advancing Electronics Dresden — [3]Department of Electrical Engineering, Pohang University of Science and Technology

The rampant development of neuromorphic computing technologies inspired multiple alternatives to be presented - from complex CMOS circuits to novel circuit elements with external post-processing. Presently, both extensive training iterations and a large number of devices is necessary to enable error-free low pixel quantity image recognition tasks. We are striving to combine both strategies by proposing an electrically-controlled n-doped Si nanowire transistor on a silicon on insulator wafer as the computational means combined with an ionic silicate film spin-coated on top to emulate the biological function of the cell body. This cell body, also known as the soma, is responsible for processing multiple dendrite inputs and generating an electric signal, the action potential, which is sent through the axon to the next neuron. An electrical bias at the gate stimulates a polarization in the silicate film which modulates the nanowire current, depending on the voltage polarity. The time constants for charging and discharging the film depend on the concentration of ions in the sol-gel matrix, the intensity of the voltage applied, the frequency of the input pulses and the integration time.

HL 12.62 Mon 17:30 Poster E

Towards Dopant-free MOSFETs by Silicon Nitride Interface Engineering — •Lena Hellmich, Benjamin Richstein, and Joachim Knoch — Institut für Halbleitertechnik, RWTH Aachen University, Germany

Though doping enables conductivity in silicon and low contact resistances, and degenerate doping avoids carrier freeze out in low temperature applications. However, in deep nanoscale MOSFETs even at very high dopant concentrations only a few dopants reside in typical device volumes resulting in strong variability. Furthermore, the nanoscale

size leads to deactivation of dopants increasing parasitic source/drain resistances. Thus, the replacement of dopants in nanoscale MOSFETs becomes more and more important. Our approach to replace the degenerate doping in source/drain (S/D)-contacts is a thin Fermi-Level-Depinning layer in the contact area between metal and silicon. In order to suppress the penetration of the metal wave function of S/D-contacts into the bandgap of silicon, very thin silicon nitride layers in sub-nm regime are fabricated. This thin insulating layer results in a Fermi-Level-Depinning; thus, the Schottky-barrier decreases, resulting in a lower contact resistance and suppression of ambipolar behavior. The metal work function, however, can be utilized to obtain N- or PMOS-like behavior. We fabricated dopant-free ohmic contacts are realized and characterized at room temperature and low temperatures. Besides, S/D-contacts with different metals and a thin silicon nitride layer to demonstrate unipolar behavior.

HL 12.63 Mon 17:30 Poster E

Temperature dependent electrical characteristics of a junction field effect transistor for cryogenic sub-attoampere charge detection — •Hüseyin Azazoglu, Paul Graf, Anahita Kavangary, Meike Flebbe, Kornelia Huba, Hermann Nienhaus, and Rolf Möller — Fakultät für Physik/Cenide, Universität Duisburg-Essen, Germany

The electrical input and output characteristics of a commercial n-channel junction field effect transistor (JFET) is studied as a function of temperature in the range between 30 and 300K. As long as the charge carrier concentration is constant an increasing drain current is observed for reduced temperatures and low gate voltages. Using a constant mobility model for the device this behaviour can be explained with the higher electron mobility in the source-drain channel. For larger negative gate voltages a source-drain voltage is found at which the drain current is almost temperature independent. As soon as the charge carriers freeze out the input characteristics changes significantly due to the exponential decrease of the carrier concentration. The source-gate leakage current is measured through the entire temperature range in an open gate configuration. It decreases exponentially with lower temperatures by more than six orders of magnitude and reaches values of 0.01 attoampere below 160K. The result can be explained by the generation of electron-hole pairs in the depletion layer in agreement with the Shockley-Read-Hall model. As a consequence, JFETs at cryogenic temperatures can be employed as almost perfect charge detectors. Applications, e.g. in scanning probe potentiometry, are discussed.

HL 12.64 Mon 17:30 Poster E

Magnetotransport in nanostructured narrow-gap semiconductors — •Olivio Chiatti[1], Christian Riha[1], Johannes Boy[1], Aron Castro Martinez[1], Sergio Pezzini[2], Steffen Wiedmann[2], Christian Heyn[3], Wolfgang Hansen[3], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]High Field Magnet Laboratory, Radboud University Nijmegen, 6525ED Nijmegen, The Netherlands — [3]Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

Transport properties of low-dimensional electron systems can be effectively investigated by measurements in magnetic fields. We investigate the magnetotransport of semiconductor heterostructures and nanostructures with spin-orbit interaction (SOI), under the influence of in-plane and out-of-plane electric fields. We fabricated etched quantum point contacts (QPCs) embedded in Hall-bars with in-plane gates. The Hall-bars and the constrictions were defined by micro-laser photolithography and wet-chemical etching from an InGaAs/InAlAs quantum well with an InAs-inserted channel [1]. We have performed transport measurements at low temperatures in the combined QPC and Hall-bar structures in magnetic fields. We show that the gate-voltages can tune the filling-factor mismatch between bulk Hall-bar and QPC. We observe the crossover from reflection to transmission of the quantum Hall edge channels at the QPC and tunneling across the QPC between reflected edge states, which depends on the magnitude and direction of the in-plane electric field.

[1] Chiatti *et al.*, Appl. Phys. Lett. **106**, 052102 (2015).

HL 12.65 Mon 17:30 Poster E

1-D and 2-D Multi-Gate Devices: Tailoring the Potential Landscape on the Nanoscale — •Thomas Grap[1,2] and Joachim Knoch[1] — [1]Institute of Semiconductor Electronics, RWTH Aachen, Germany — [2]Peter Grünberg Institute 11, FZ Jülich, Germany

One-dimensional (1-D) materials such as nanowires (NW) and carbon nanotubes (CNT) as well as two-dimensional (2-D) materials like graphene and MoS_2 have attracted a great deal of attention as buildings blocks of future nanoelectronics systems. NWs and CNTs enable 1-D electronic transport. Considering sufficient gate control, devices based on quantum effects (e.g. quantum dots) can be formed within these nanostructures. Furthermore 2-D materials exhibit excellent electronic transport due to a very high electron mobility. In this study we examined the electronic transport properties of 1-D and 2-D nanostructures by utilizing a buried multi-gate architecture where a large number of gates are used (order of 10 and more). The multi-gate substrate allows to tailor the potential landscape of the nanostructures on the nanoscale. The influence of gate length and inter-gate distances as well as different top-dielectrics such as SiO_2 or Al_2O_3 are investigated. Various device configurations (e.g. RTD, superlattice-FET) are realized for different materials by applying appropriate voltages to the multi-gates. Measurements of field effect transistors at room temperature as well as low temperatures are shown.

HL 12.66 Mon 17:30 Poster E

Temperature-robust terahertz quantum cascade lasers using Ge/SiGe — Thomas Grange[1], •Stefan Birner[1], Giacomo Scalari[2], Giovanni Capellini[3], Douglas Paul[4], Monica De Seta[5], and Michele Virgilio[6] — [1]nextnano GmbH, 85748 Garching b. München, Germany — [2]Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland — [3]IHP GmbH, 15236 Frankfurt (Oder), Germany — [4]School of Engineering, University of Glasgow, G12 8LT Glasgow, UK — [5]Dipartimento di Scienze, Università di Roma Tre, 00146 Roma, Italy — [6]Dipartimento di Fisica "E. Fermi" Università di Pisa, 56127 Pisa, Italy

In the past 15 years, terahertz (THz) quantum cascade lasers have been developed using III-V materials. High output power has been demonstrated but the maximum temperature operation reported remains limited to 200 K. To achieve higher temperature operation, group IV semiconductors, thanks to their non-polar lattice, offer an interesting alternative. Nevertheless, group IV QCLs have not been demonstrated yet. Furthermore, an accurate theoretical prediction of their performance, in comparison with III-V systems is still lacking. In this work, we theoretically investigate transport and gain in n-type Ge/SiGe THz QCLs that leverage on L valley electrons using a nonequilibrium Green's functions (NEGF) model. The calculated maximum operation temperature in the Ge/SiGe QCL is found above room temperature. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 766719 - FLASH project.

HL 12.67 Mon 17:30 Poster E

Statistical studies of random silicon-germanium alloys using electronic structure calculations — •Willi Roscher[1,2,3], Florian Fuchs[1,2,3], Christian Wagner[1,2], Jörg Schuster[1,3], and Sibylle Gemming[1,2] — [1]Institute of Physics, Technische Universität Chemnitz, Chemnitz, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany — [3]Fraunhofer Institute for Electronic Nano Systems (ENAS), Chemnitz, Germany

Random alloys are relevant for many applications. One example is silicon-germanium which is used for high frequency devices like heterojunction-bipolar transistors. We therefore investigate the electronic structure of $Si_{1-x}Ge_x$ alloys in the entire composition range $0 \leq x \leq 1$. For our study we use density functional theory in combination with bulk models of the alloys. To describe the band gap precisely we use the pseudopotential projector shift method as implemented in QuantumATK 18.06.

We perform a random generation of $Si_{1-x}Ge_x$ structures to get statistical distributions of the electronic properties. After optimizing the structure we evaluate the band structure by averaging equivalent directions in the Brillouin zone.

The mean of the band gap is in good agreement with experimental reference data. We also demonstrate wide variations of the band gap, which are in the range of about 10 %. Further properties, such as the lattice constant and the formation energy are studied as well. Finally, we investigated also the impact of additional carbon dopants in the silicon-germanium alloy.

HL 12.68 Mon 17:30 Poster E

Highly doped silicon for photonic and plasmonic applications — •Jura Rensberg, Kevin Wolf, Martin Hafermann, and Carsten Ronning — Institute of Solid State Physics, Friedrich Schiller University Jena, Germany

For some time now, laser processing is a key technology in basic solid-state and material science research with a manifold of industrial applications, such as recrystallization and dopant activation in semiconductor industries. The basis of laser annealing is the deposition of large amounts of energy (a few J/cm^2) over very short time scales, which leads to surface layer melting followed by rapid resolidification. Pulsed laser annealing of ion-implanted silicon leads to the formation of supersaturated alloys with maximum substitutional dopant concentrations far greater than equilibrium solubility limits. Here, we show the optoelectronical properties of silicon doped to the laser-annealing-induced solubility limit with respect to photonic and plasmonic applications.

HL 12.69 Mon 17:30 Poster E

Phosphorous doped Germanium nanowires — •Ahmad Echresh, Shima Jazavandi Ghamsari, Yordan M. Georgiev, and Lars Rebohle — Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden Rossendorf, Bautzner Landstraße 400, D-01328 Dresden, Germany

Germanium (Ge) is a promising high mobility channel material for future nanoelectronic devices with a lower effective charge carrier mass than Silicon (Si) and higher electron and hole mobility. Materials with high carrier mobility can enable increased integrated circuit functionality. Hence, Ge based nanoelectronic devices could offer improved performance at reduced power consumption compared to Si electronics. In this work, Ge nanowires were fabricated using electron beam lithography (EBL) and inductively coupled plasma (ICP) etching. Then ion beam implantation was used to introduce phosphorous (P) dopant atoms into the Ge nanowires. Afterwards, flash lamp annealing (FLA) was applied to recover the crystal structure of the Ge nanowires and activate the dopant atoms. Micro-Raman spectroscopy spectra showed that by increasing the fluence of ion implantation, the peak of optical phonon mode in Ge was broadened asymmetrically which shows that dopant atoms are electrically activated. Moreover, we are designing Hall Effect measurement configurations for single Ge nanowires to determine their mobility and carrier concentrations.

HL 12.70 Mon 17:30 Poster E

Control of the photoluminescence of the silicon vacancy color center in 4H-silicon carbide by electric fields — •Lena Bergmann, Maximilian Rühl, Christian Ott, Michael Krieger, and Heiko B. Weber — Lehrstuhl für Angewandte Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Color centers in Silicon carbide (SiC) are promising candidates for novel quantum technology based on single photon sources [1]. In this study we report on the control of the photoluminescence (PL) of the silicon vacancy (V_{Si}) color center in 4H-SiC by electric fields at low temperatures. In particular, we monitored the ensemble PL depending on electric field strength and field direction. Structured epitaxial graphene is used as transparent electrodes at the surface to drive a static electric field. The V_{Si} color centers under investigation are created by proton implantation [2]. We observe a Stark splitting of the V_1' line of about 2.4 meV at a field strength of about 0.7 $\frac{V}{cm}$. In addition, the PL intensity of V_1' and V_1 changes in the presence of the field. In contrast, the V_1 line does not display any splitting.

[1] S. Castelletto *et. al.* Nature Materials 13, 151-156 (2013)
[2] M. Rühl *et. al.* Appl. Phys. Lett. 113, 122102 (2018)

HL 12.71 Mon 17:30 Poster E

Optical Spin Injection in Silicon — •Eduard Sauter — Abt. Nanostrukturen Leibniz Universitaet Hannover

Silicon is a promising candidate for electron spin manipulation due to lack of nuclear spin of the 28 isotope and low spin orbit coupling due to inversion symmetry of the unit cell. I would like to present results of electron spin manipulation by circularly polarized light with energy close to the band gap in the NIR region. The observed decay of spin orientation with increasing magnetic field is an indicator for the spin lifetime of electrons.

HL 13: Focus Session: GaN-based single photon emitters

Sources of single photons will be of use for future quantum technologies. Although there are several technologies that can be used for the emission of single photons, in recent years III-nitride based quantum dots (QDs) have been the subject of increased attention due to their possible operation over a wide range of wavelengths from the ultraviolet to the red end of the visible spectrum. Furthermore, III-nitride QD-based single photon sources have also been shown to operate at room temperature and even at elevated temperatures.

Organizers: Frank Bertram, Jürgen Christen (OvGU Magdeburg), and Markus Wagner (TU Berlin)

Time: Tuesday 9:30–12:45 Location: H31

Invited Talk HL 13.1 Tue 9:30 H31

GaN-based quantum dot single photon sources at room temperature — •Yasuhiko Arakawa[1], Mark Holmes[1,2], and Munetaka Arita[1] — [1]Institute for Nano Quantum Information Electronics, The University of Tokyo, Tokyo, Japan — [2]Institute of Industrial Science, The University of Tokyo

III-Nitride quantum dots, with their large band offsets and wide range of bandgaps, are promising nanostructures for room temperature quantum information technologies. Growth of high-quality GaN/AlN quantum dots was reported by metal organic C chemical vapor deposition (MOCVD) with Stanski-Krastnanov growth mode in 2002. The quantum dots exhibited a large biexciton binding-energy and a strong phonon interaction, leading to observation of a single photon at 200 K in 2006. However, the magnitude of the binding energy of biexciton was not large enough to realize single photon emission at room temperature.

In this presentation, we discuss our recent progress in GaN-based single photon emitters operating at/above room temperature. A position controlled GaN/AlGaN nanowire quantum dot, with a typical lateral dimension of 10 nm and a vertical dimension of 1 nm, was grown by selective area MOCVD. A large binding energy of biexciton (> 60meV) in the quantum dot was realized, which enabled single photon emission at 350 K (77C). In addition, we also discuss interface-fluctuation GaN/AlN quantum dots for realizing high quality single photon emission. We obtained a measured raw g(2)(0) value smaller than 0.1 at 10 K, demonstrating the remarkable nature of these quantum dots.

Invited Talk HL 13.2 Tue 10:00 H31

Quantum light generation based on group III-nitride semiconductor nanophotonic structures — •Yong-Hoon Cho — Department of Physics and KI for the NanoCentury, Korea Advanced Institute of Science and Technology (KAIST), Daejeon 34141, Korea

We present quantum light generation and control with various group III-nitride semiconductor nanophotonc structures. We fabricated three-dimensional GaN-based semiconductor nano- and microstructures, which was followed by the growth of quantum structures by metal-organic chemical vapor deposition. We demonstrated ultrafast and highly directional single photon generation from a quantum dot formed at the apex of pyramid structures, the self-aligned deterministic coupling of single quantum dot (QD) to nanofocused plasmonic modes, and exciton-polariton formation and condensation at room-temperature using GaN-based rod structures. Our approaches overcome the major hurdles in implementing practical solid-state quantum devices operating at room temperature and also show great promise for versatile quantum photonic applications.

Invited Talk HL 13.3 Tue 10:30 H31

Growth of desorption-induced GaN quantum-dots — •Christoph Berger[1], Gordon Schmidt[1], Hannes Schürmann[1], Sebastian Metzner[1], Peter Veit[1], Jürgen Bläsing[1], Frank Bertram[1], Armin Dadgar[1], Jürgen Christen[1], André

Strittmatter[1], Stefan Kalinoswki[2], Stefan T. Jagsch[2], Gordon Callsen[2], Markus R. Wagner[2], and Axel Hoffmann[2] — [1]Institute of Physics, Otto-von-Guericke-University Magdeburg — [2]Institute of Solid State Physics, Technical University Berlin

We studied the MOVPE-growth of thin GaN films on top of AlN/sapphire-templates. After the deposition of a few monolayers GaN at 960°C, a growth interruption (GRI) with durations between 0 s and 60 s without ammonia supply was applied to allow for quantum dot formation. Each quantum dot (QD) structure was capped with AlN grown at 1195°C. Without a GRI, a continuous GaN layer with additional hexagonally-shaped truncated pyramids forms. On the other hand growth interruptions lead to desorption of GaN resulting in smaller islands without definite form located in close vicinity to threading dislocations. Ultra narrow line widths in the spectral range from 220 nm to 310 nm are observed from these islands and single photon emission is verified by Hanbury Brown-Twiss experiments. Aiming for efficient single photon sources realized as resonant cavity structures, such quantum dots were also grown on deep-UV AlGaN/AlN distributed Bragg reflectors with maximum reflectivities of 98 %.

15 min. break

HL 13.4 Tue 11:15 H31

Self-organized GaN quantum dots grown on a wavelength-matched deep UV AlN/AlGaN distributed Bragg reflector — •Hannes Schürmann[1], Gordon Schmidt[1], Christoph Berger[1], Sebastian Metzner[1], Peter Veit[1], Jürgen Bläsing[1], Frank Bertram[1], Armin Dadgar[1], André Strittmatter[1], Jürgen Christen[1], Stefan Kalinowski[2], Stefan T. Jagsch[2], Gordon Callsen[2], Markus R. Wagner[2], and Axel Hoffmann[2] — [1]Institute of Physics, Otto-von-Guericke-University Magdeburg — [2]Intitute of Solid-State Physics, Technical University Berlin

We present emission properties of self-assembled GaN quantum dots (QDs) in an AlGaN cavity on top of a wavelength-matched deep UV AlN/AlGaN distributed Bragg reflector using cathodoluminescence (CL) experiments directly performed in a scanning transmission (STEM) and a scanning electron microscope (SEM). GaN QD growth results from metalorganic vapor phase epitaxy of a nominally 2 nm thick GaN layer (V/III = 30) directly followed by a growth interruption for 30 s. To avoid a degraded DBR, an Al-concentration of 70 % in the AlGaN layers was chosen regarding the trade-off between the lattice-mismatch of AlN and GaN and its high difference in refractive indices. The obtained sample has the highest reflectivity of 88 % at 272 nm with a stopband width of 9.2 nm. SEM-CL measurements at LHe temperatures demonstrate emission from GaN QDs with an intensity increase at the stopband position of the DBR at 271 nm, thus confirming the successful MOVPE growth of self-organized GaN QDs on top of a highly reflective deep UV DBR.

HL 13.5 Tue 11:30 H31

Pyramids on N-face GaN for the aim of light emitting quantum dot structures — •Uwe Rossow[1], Fedor Ketzer[1], Angelina Jaros[2], Tobias Voss[2], Hendrik Spende[2], Andreas Waag[2], Philipp Henning[1], Philipp Horenburg[1], Heiko Bremers[1], and Andreas Hangleiter[1] — [1]Technische Universität Braunschweig, Institut f. Angewandte Physik, 38106 Braunschweig — [2]Technische Universität Braunschweig, Institut f. Halbleitertechnik, 38106 Braunschweig

Semiconductor nanostructures are very promising for single photon emitters near or at room temperature. The group-III nitrides are especially interesting in this respect since the bandgap of $In_xGa_{1-x}N$ can in principle be tuned over the whole wavelength range from the near IR to the near UV. Quantum dots based on self-organized growth, in the top of pyramids, and embedded in nanorods have been investigated. The latter two cases are better suited if individual single photon emitters need to be addressed. Unfortunately, if such nanostructures are formed during growth, indium incorporation on side facets, edges, and tip varies and it is difficult to maintain a homogeneous composition.

Here we report on a new process to produce pyramids on the basis of GaN. First we grow InGaN/GaN (single or multi) quantum well structures on N-face GaN by MOVPE. In a second step pyramids are formed by KOH etching. We demonstrate that pyramids with sharp tips can be achieved which show blue-shifted photoluminescence. We aim to optimize the efficiency to allow the realization of arrays of single photon emitters with similar emission properties.

Invited Talk HL 13.6 Tue 11:45 H31

Nitride single photon sources: quantum dots and defects — •Rachel Oliver[1], Tongtong Zhu[1], Igor Aharonovich[2], and Robert Taylor[3] — [1]Dept. of Materials Science, University of Cambridge, U.K. — [2]Faculty of Science, University of Technology Sydney, Australia — [3]Dept. of Physics, University of Oxford, U.K.

Single photon sources are a key enabling technology for quantum communications, and in the future more advanced quantum light sources may underpin other quantum information processing paradigms such as linear optical quantum computation. In considering practical implementations of quantum technologies, the nitride materials system is attractive since it allows single photon emission at accessible temperatures, potentially enabling the implementation of quantum key distribution in contexts where cryogenic cooling is impracticable. The wide variation in bandgap across the nitride semiconductors allows access to a vast range of wavelengths from the infra-red to the ultra-violet spanning the visible spectrum.

In the visible region, both epitaxial InGaN quantum dots (QDs) and defects in GaN have been demonstrated as single photon emitters. QDs currently are easier to engineer and to incorporate into device structures. Non-polar QDs in particular offer attractive advantages in terms of short radiative lifetimes and deterministically polarised emission. Whilst single photon emission from non-polar InGaN QDs has been demonstrated at temperatures up to 220 K, defects in GaN allow room temperature single photon emission and present an exciting option for the development of for integrated quantum photonic circuitry.

Invited Talk HL 13.7 Tue 12:15 H31

GaN-based single photon emitters — •Donat Josef As — University of Paderborn, Department of Physics, Warburger Str. 100, 33098 Paderborn

Single-photon emission from cubic GaN/AlN quantum dots grown by molecular beam epitaxy is shown. Two different growth methods: the droplet epitaxy technique and the Stranski-Krastanov growth mode were used to fabricate single zinc-blende GaN/AlN quantum dots. By micro-photoluminescence we observed spectrally clean and isolated emission peaks from both kind of quantum dots. Clear single-photon emission was detected by analyzing one such peak at 4K and a $g^{(2)}[0]$ value of 0.25 was estimated, which becomes 0.05 by correcting the background and detector dark counts. Both excitonic and multi-excitonic recombinations in individual quantum dots with radiative lifetimes shorter than 287 ± 68 ps are demonstrated. Due to the large band offsets and a large exciton binding energy, the excitonic recombinations of single zinc-blende GaN/AlN quantum dots can be observed up to 300 K. These results indicate that cubic GaN quantum dots are possible candidates for high-temperature operating UV single-photon sources with the possibility of integration into photonic nanostructures.

HL 14: PhD-Symposium: Photoluminescence of halide perovskites: What does it tell us and what not? (joint session DS/AKjDPG/HL)

Perovskite Solar Cells (PSCs) have recently emerged as a new research field due to their rapid increase in power conversion efficiency. Many research groups formerly working in other fields such as in DSSC, organic solar cells and thin film solar cells, quantum dots, single molecules have jointly created a new research field. Photoluminescence spectroscopy is a technique used rather widely in all of these fields as a simple standard method. Applying specific models and theory, photoluminescence can however be converted into an advanced characterization technique. The models and analysis tools used for this have been unique to the specific fields so far and now tend to collide when PSCs are measured and analysed.
This symposium therefore aims to give a brief overview of advanced models and analysis tools which allow a more nuanced interpretation of photoluminescence emission of perovskite solar cell materials. In a mix of introductory talks, invited expert talks and contributed talks we will explore how certain models have been used to analyse PSCs and argue why and under what conditions a certain model can or cannot be applied to perovskite solar cells.

Organizers:

• Juliane Borchert, Clarendon Laboratory, Department of Physics, University of Oxford, Parks Road, Oxford OX1 3PU, United Kingdom
• Klara Suchan, Lund University, Kemicentrum, Naturvetarvägen 16, 22362 Lund, Sweden
• Tobias Seewald, Department of Physics, University of Konstanz, Universitätsstr. 10, 78457 Konstanz, Germany

Time: Tuesday 9:30–13:15 Location: H32

Invited Talk HL 14.1 Tue 9:30 H32

Photoluminescence Analysis of Thin Films: What can it tell us about (Perovskite) Solar Cells? — •Thomas Unold — Helmholtz-Zentrum Berlin für Materialien und Energy

Photoluminescence analysis has been an important analytical tool in semiconductor characterization, and depending on the experimental conditions can reveal detailed information about various optical and electronic properties such as radiative recombination, non-radiative recombination, defects, carrier trapping and the quasi-Fermi level splitting[1-4]. The technique can be applied to thin films as well as to complete solar cell devices, but may require additional analysis to consider the presence of either free surfaces or built-in electrical fields, additional recombination processes as well as partial charge extraction. In the ideal case different types of luminescence measurements yield a consistent picture of the material properties and the limitations of device performance. Different aspects of such photoluminescence analyses will discused with a special focus on how results obtained on (hybrid) perosvkites comply with the state-of-the-art knowledge on more common inorganic semiconductor materials. [1] T. Unold, L. Gütay, in Advanced Characterization Techniques for Thin Film Solar Cells, Wiley VCH (2011) 151-175. doi.org/10.1002/9783527636280.ch7 [2] F. Staub et al., Phys. Review Applied 6 (2016) 044017 [3] C. Hages et al., Adv. Energy Mater. 7(2017) 1700167 [4] M. Stolterfoht et al., Nature Energy 3 (2018) 847.

HL 14.2 Tue 10:00 H32

In-situ film formation studies of metal-halide perovskite layers — •Katrin Hirselandt[1,2], Rahim Munir[1], Florian Mathies[1], Aboma Merdasa[1], Emil J. W. List-Kratochvil[2], and Eva Unger[1,2] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, Kekuléstraße 5, 12489 Berlin, Germany — [2]Institut für Physik, Institut für Chemie & IRIS Adlershof, Humboldt-Universität zu Berlin, Brook-Taylor-Str. 6, 12489 Berlin, Germany

By optimizing the perovskite fabrication process during spin-coating by introduction of complex solvent blends and quenching steps, solar cells with power conversion efficiencies above 22% have been realized on small active areas. Reproducing published fabrication procedures is not trivial as process conditions vary from place to place and adapting methodologies developed for small-area devices based on spin-coating to larger area devices even less so. Understanding the film formation during different stages of processing allows for a more rational approach to translate deposition strategies to scalable processing methods.

In this study we compared the temporal evolution of MAPbI3 and Cs0.05(FA0.83MA0.17)0.95Pb(I0.83Br0.17)3 (3CAT) covered substrates during spin-coating using a fibre-optic based photoluminescence and reflection spectroscopy setup. Varying the time of a crystallization-inducing anti-solvent drip, we identified a much narrower process window for MAPbI3, compared to 3CAT corroborated with scanning electron microscope images of annealed samples. We here present insight into the difference in crystallization kinetics of these different standard formulations for perovskite processing.

Invited Talk HL 14.3 Tue 10:15 H32

Defect activity in lead halide perovskite semiconductors — •Silvia Motti — Clarendon Laboratory, Department of Physics, University of Oxford, Parks Road, OX1 3PU, Oxford, United Kingdom

Perovskite semiconductors have recently emerged as promising materials for optoelectronic applications, with photovoltaic efficiencies that have now reached over 23%. Great research effort has been employed towards understanding how the perovskite crystalline and electronic structure relates to their remarkable defect tolerance and surprisingly long carrier lifetimes and high open circuit voltages. At the same time, the material instability often interferes with experimental observations, besides posing a major challenge for commercial application. A comprehensive investigation of defect activity in lead halide semiconductors was conducted by combining computational studies with experimental evidences from optical spectroscopy. It was possible to identify the most predominant charge-trapping point defects in MAPbBr3 and MAPbI3 and their role in recombination dynamics, explaining the defect tolerance in these semiconductors. Moreover, the reactivity of such defects under external stimuli could be associated with the photoinstabilities observed in these materials, allowing for the development of successful strategies to control them. This understanding opens the possibility of developing intelligent fabrication methods and further optimizing performance and stability of perovskite optoelectronic devices.

HL 14.4 Tue 10:45 H32

The impact of lead iodide on the recombination kinetics in metal halide perovskites — •Aboma Merdasa[1], Alexandros Kiligaridis[2], Carolin Rehermann[1], Mojtaba Abdi-Jalebi[3], Jonas Stöber[2], Boris Louis[2], Marina Gerhard[2], Samuel D. Stranks[3], Eva L. Unger[1,2], and Ivan G. Scheblykin[2] — [1]Young Investigator Group Hybrid Materials Formation and Scaling, Helmholtz-Zentrum Berlin für Materialen und Energie, Berlin, Germany — [2]Chemical Physics and NanoLund, Lund University, Lund, Sweden. — [3]Cavendish Laboratory, Department of Physics, University of Cambridge, Cambridge, United Kingdom.

Metal halide perovskites are promising semiconductor materials for photovoltaic devices with solar cell efficiencies soaring over 20%, but

understanding the fundamental operational principles are lagging behind. One example is the role and influence of lead iodide (PbI2) reportedly being both beneficial and detrimental for a device. Herein, we present a study on the impact of lead iodide on the charge-carrier recombination kinetics in methylammonium lead triiodide (MAPbI3) thin films. We simultaneously acquire spectrally-resolved photoluminescence quantum yield and time-resolved photoluminescence lifetime at excitation wavelengths ranging from 450 nm to 780 nm during hours of light-soaking, and identify a unique radiative recombination mechanism occurring at the PbI2/MAPbI3 interface when charge carriers are generated in PbI2. We thereby provide important insight into the long-debated question of whether excess PbI2 is beneficial or detrimental for charge carrier dynamics in perovskite solar absorber materials.

15 min. break

Invited Talk HL 14.5 Tue 11:15 H32

Beyond traditional use of photoluminescence: Assessing halide perovskites quantitatively and qualitatively — •Carolin Sutter-Fella — Lawrence Berkeley National Laboratory, Berkeley, California, US

Hybrid metal halide perovskites have recently transformed the landscape of light harvesting solar energy materials while showing promise in a range of other optoelectronic applications. These materials do not only show exceptional optoelectronic properties and apparent defect tolerance but are also easy to synthesize via solution processing. Nevertheless, there are non-radiative recombination losses which have to be characterized and ideally tied back to synthesis conditions.

In the first part of this talk I will cover our work on quantitative photoluminescence quantum yield measurements under variation of the halide as well as cation. This quantity will be related to the device relevant open circuit voltage (Voc) by comparing the electrically measured Voc to the optically implied Voc. In the second part I will show how in situ photoluminescence spectroscopy can be used to monitor perovskite film and nanoparticle formation. I will reveal the onset of semiconducting properties during synthesis and the correlation to other material characteristics such as morphology and crystal phase. The work provides guidance to a fast screening of the synthetic parameter space and ultimately controlled experimental procedures that yield high device efficiencies.

HL 14.6 Tue 11:45 H32

Temperature dependent charge carrier transport in MAPI single crystal thin films — •Alexander Biewald[1], Richard Ciesielski[1], Nadja Giesbrecht[1], Kathrin Handloser[1], Pablo Docampo[2], Thomas Bein[1], and Achim Hartschuh[1] — [1]Department Chemie und (CeNS), LMU München, Deutschland — [2]School of Electrical and Electronic Engineering, Newcastle, UK

Methylammonium lead iodide (MAPI)-based thin-film solar cells today reach power conversion efficiencies of more than 20 % [1]. The material is prototypical for the large class of perovskite semiconductor materials for photovoltaic applications and is therefore at the focal point of research interest to a global community. Here, we present an all-optical study of the charge carrier diffusion properties in large-crystal MAPI thin films using photoluminescence microscopy [2]. We vary the temperature between 170 K and room temperature, thus remaining in the tetragonal crystal phase [2]. We probe the local material properties of individual crystal grains within a PMMA-coated MAPI thin film and find a steady increase of the diffusion constant towards lower temperatures. In a previous paper we found that grain boundaries in such thin films act as solid walls for diffusing charge carriers [2], which we also see at low temperatures.

[1] M. A. Green, et al., Solar cell efficiency tables (version 52), 2018.
[2] R. Ciesielski, et al., ACS Appl. Mat. & Interfaces. 10 (9), 7974-7981 (2018).
[3] N.O. Yamamuro, et al., J. Phys. Chem. Solids 53 (7), 935-939 (1992).

Invited Talk HL 14.7 Tue 12:00 H32

Photophysics of Sn-based hybrid perovskites — •Maria Antonietta Loi — Zernike Institute for Advanced Materials, University of Groningen, Groningen, The Netherlands

Thanks to the intensive research efforts of a large scientific community over the past years, lead (Pb)-based hybrid perovskite solar cells have reached impressive (>23%) power conversion efficiency. Against the initial criticism about their instability, also large improvements in the thermal and photo stability of this kind of solar cells were obtained in the last years. Despite these outstanding accomplishments, the toxicity of lead causes concerns about the possible large-scale utilization of this new type of solar cell. Among the various alternatives to lead, Sn has been recognized to have a great potential, as the Sn-based hybrid perovskites display excellent optical and electrical properties such as high absorption coefficients, very small exciton binding energies and high charge carrier mobilities. Recently solar cells with efficiencies approaching 10% have been reported. In my presentation I will report about important features of the photophysical properties of formamidinium tin triiodide. Photoluminescence spectra are highly assimetric at the high-energy edge. This is accompanied by the unusually large blue shift of the time-integrated photoluminescence with increasing of the excitation power. These phenomena are associated with very slow hot carrier relaxation and state-filling of band edge states. Most importantly, the hot carrier photoluminescence is evident not only upon pulsed excitation but also with continuous wave one.

HL 14.8 Tue 12:30 H32

Metastable defects in perovskite semiconductors reveal microscopic insight into non-radiative processes — •Marina Gerhard[1], Boris Louis[1,2], Rafael Camacho[2], Aboma Merdasa[3], Alexander Kiligaridis[1], Jun Li[1], Alexander Dobrovolsky[1], Johan Hofkens[2], and Ivan G. Scheblykin[1] — [1]Division of Chemical Physics and NanoLund, Lund University, Box 124, 22100 Lund, Sweden — [2]KU Leuven, Molecular Imaging and Photonics, Celestijnenlaan 200f, Box 2404, 3001 Leuven, Belgium — [3]Helmholtz-Zentrum für Materialien und Energie GmbH, Kekulestraße 5, 12489 Berlin, Germany

Metal halide perovskites are an interesting model system for fundamental studies of non-radiative processes due to their photoluminescence (PL) fluctuations on a timescale of milliseconds to seconds, also referred to as 'blinking'. This phenomenon is attributed to the presence of metastable defects, able to switch between a passive (not quenching) and an active (quenching) configuration. Here, we study temperature dependent blinking of methylammonium lead iodide nanocrystals using PL microscopy. Monitoring the behavior of individual defects allows us to understand their concerted contribution to macroscopic quantities, such as the temperature dependent PL quantum yield. We find that both the quenching efficiency and the switching rate of the metastable defects decrease with decreasing temperature. Based on a simple mechanistic picture, we estimate activation barriers for the switching on the order of 200-800 meV. This energy range suggests that the switching mechanism could be related to ion migration.

HL 14.9 Tue 12:45 H32

Panel Discussion (with invited speakers) — •Thomas Unold[1], Silvia Motti[2], Carolin Sutter-Fella[3], and Maria Antonietta Loi[4] — [1]Helmholtz-Zentrum Berlin für Materialien und Energy — [2]Clarendon Laboratory, Department of Physics, University of Oxford, Parks Road, OX1 3PU, Oxford, United Kingdom — [3]Lawrence Berkeley National Laboratory, Berkeley, California, US — [4]Zernike Institute for Advanced Materials, University of Groningen, Groningen, The Netherlands

Do pre-existing models hold? Or do we need novel approaches to fully understand perovskite photoluminescence?

HL 15: Energy materials (other than photovoltaics)

Time: Tuesday 9:30–11:15 Location: H33

HL 15.1 Tue 9:30 H33

Ab-initio study of the electronic structure of Na2KSb and NaK2Sb for photocathode applications — •Raymond Amador and Caterina Cocchi — Institut für Physik und IRIS Adlershof, Humboldt-Universität zu Berlin, Deutschland

In the search for novel materials for electron sources with enhanced quantum efficiency and minimised intrinsic emittance, multi-alkali antimonides are particularly promising in light of their relatively low band gap and electron affinity giving rise to emission in the near-infrared and visible region [1]. To fully exploit their potential, it is essential to reliably understand the electronic structure of these materials. First-principles methods such as density-functional theory (DFT) and many-body perturbation theory are suited for this purpose, as recently demonstrated in the case of CsK2Sb [2]. Here, we employ DFT to investigate the electronic structure of two Na-based alkali antimonides, namely Na2KSb and NaK2Sb. From the analysis of the band structure and the density of states, computed with exciting [3], we clarify the character of the electronic states in the gap region and rationalise their behaviour in comparison with previously investigated Cs-based compounds [2]. Our results represent the first step towards an in-depth characterisation of the photoemission processes in Na-based alkali antimonides.

[1] Musumeci et. al., Nucl. Instrum. Methods Physics 907, 209 (2018) [2] Cocchi, et. al. J. Phys.: Condens. Matter https://doi.org/10.1088/1361-648X/aaedee (2018) [3] Gulans et. al., J. Phys.: Condens. Matter 26, 363202 (2014)

HL 15.2 Tue 9:45 H33

The roles of polarons and defects in charge carrier transport in $BiVO_4$ photoanodes for solar water splitting — •Viktoria Kunzelmann, Irina Ilicheva, Alex Henning, and Ian Sharp — Walter Schottky Institute and Physics Department, Technical University of Munich, Garching, Germany

Hydrogen generation by solar water splitting provides a promising route towards the sustainable storage of solar energy. Bismuth vanadate ($BiVO_4$) has a favorable band gap (2.5 eV) for solar light absorption and it has been demonstrated as a photoanode in photoelectrochemical cells (PEC) with one of the highest solar-to-hydrogen conversion efficiencies using metal oxide electrodes. While it is known that polarons and defects in $BiVO_4$ limit electron and hole mobilities, and thereby the PEC efficiency, their energetics and influence on macroscopic cell parameters have not yet been determined. This work aims to identify the energy levels of polarons and defects and to understand their effects on the surface photovoltage. Temperature-dependent photocurrent spectroscopy and photothermal deflection spectroscopy are used to investigate interband absorption, self-trapping and localization of carriers as well as their escape mechanisms in polycrystalline $BiVO_4$ thin films. These measurements yield key ensemble-averaged physical insights that are complemented with the nanoscale spatial characterization of surface photovoltage and charge transport by Kelvin probe force microscopy and conductive AFM, respectively.

HL 15.3 Tue 10:00 H33

Increasing the Spectroelectrochemical Performance of WO_3 Films Prepared by Spin-Coating with Additives — •Thi Hai Quyen Nguyen and Derck Schlettwein — Justus-Liebig-Universität Gießen, Institut für Angewandte Physik

Tungsten oxide (WO_3) can be widely used as an electrochromic material in smart windows. In the presence of an electrolyte containing small cations such as Li^+ ions the application of a negative voltage leads to reversible coloration of WO_3 thin films. The electrochromic properties of WO_3 including the charge transfer strongly depend on the internal structure of the films. In this work, thin films of WO_3 were prepared by spin-coating followed by heat-treatment using a precursor solution based on peroxotungstic acid with optional addition of poly(ethyleneglykol) of different molecular weight and similar components. The influence of the additives on the morphology and film structure was examined by SEM and XRD. The electrochromic properties of the films were studied by cyclic voltammetry and chronoamperometry with spectroscopic monitoring in a three-electrode-setup with $LiClO_4$ in propylencarbonate as electrolyte. The films prepared with additives clearly showed an improvement in the rate and in the extent of optical switching between the coloring and bleached state with a clearer color impression. The diffusion coefficient of the Li^+ ions in WO_3 could be increased confirming a facilitated diffusion of the ions through the film network. Hence, the presence of additives created an improved film structure of WO_3 which can be promising for smart windows with high efficiency.

HL 15.4 Tue 10:15 H33

Pre-activating CO2 for Photocatalytic Reduction at the Semiconductor Surface — Hongting Wu, Veronika König, Peter Budweiser, •Jacek Stolarczyk, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Department of Physics, Ludwig-Maximilians-Universität, Munich, Germany

Photocatalytic properties of semiconductor nanostructures are drawing much attention in recent researches because it provides possibilities to harvest solar energy and change it directly into chemical energy. Among all the possible photocatalytic reactions, CO2 reduction remains to be much more challenging than others due to its stable C-O double bonds and its linear molecular structure. This makes it especially energetically costly to bring a single electron onto the molecule, which is the first step for most CO2 photo-reduction reaction-chains. Recently Copper (I) compounds have been proved to be promising in forming simple, yet efficient photocatalytic nanostructures for CO2 reductions. We use Cu2O nanoparticles with the aim to improve the overall efficiency of CO2 reduction by exploring ways to pre-activate CO2 molecules and hence lowering the potential barrier for the initial one electron transfer in the CO2 reduction reaction-chain.

HL 15.5 Tue 10:30 H33

Photochemical stability of $BiVO_4$ photoanodes for solar water splitting — •Irina Ilicheva, Viktoria Kunzelmann, and Ian Sharp — Walter Schottky Institute and Physics Department, Technical University of Munich, Garching, Germany

Artificial photosynthesis, the conversion of solar energy into chemical fuels, could be a promising alternative to fossil fuels. One way of realizing this is by photoelectrochemical water splitting. Here, the main challenge is to identify a semiconductor that is simultaneously stable, scalable and efficient. One of the materials showing a suitable electronic structure is the transition metal oxide bismuth vanadate ($BiVO_4$), which has a band gap of 2.5 eV in the visible range. Metal oxide semiconductors are often studied for their superior chemical stability. However, they can suffer from photochemical instability. Recent studies have shown the dissolution of $BiVO_4$ thin films under water splitting conditions, even though thermodynamic considerations predict the formation of a self-passivating, stable bismuth oxide surface layer. In this work, we analyze the photochemical stability of polycrystalline $BiVO_4$ photoanodes by photoelectrochemical methods to gain better insights into the corrosion mechanisms under operating conditions. We intentionally alter the $BiVO_4$ surface state by different surface pre-treatments in order to favor the formation of a stable bismuth oxide phase and to identify possible chemical and electronic passivation schemes. Changes in the morphology are monitored by scanning electron and atomic force microscopy.

HL 15.6 Tue 10:45 H33

Impact of surface adsorbates on charge carrier transport in metal oxide semiconductors for solar water splitting — •Johanna Eichhorn[1], Christoph Kastl[2], Adam Schwartzberg[2], Ian Sharp[3], and Francesca Toma[1] — [1]Lawrence Berkeley National Laboratory, Chemical Sciences Division, Berkeley, United States — [2]Lawrence Berkeley National Laboratory, The Molecular Foundry, Berkeley, United States — [3]Technische Universität München, Walter Schottky Institute and Physics Department, Garching, Germany

Photoelectrochemical (PEC) water splitting is a promising route for efficient conversion of solar energy to chemical fuels. In this context, bismuth vanadate (BiVO4) is one of the most investigated photoanode materials. Here, we employ in-situ photoconductive atomic force microscopy to elucidate the interplay of surface interactions and interfacial charge transport in polycrystalline BiVO4 films. We demonstrate that the low intrinsic bulk conductivity limits interfacial charge transport. The transport mechanism is attributed to space charge limited current (SCLC) with shallow trap states.[1] By analyzing the SCLC

in selective gas environments, we are able to quantify the impact of surface adsorbates on bulk transport. Surface adsorbed oxygen acts as a shallow trap state and accounts for 40% of the effective trap density in BiVO4 films.[2] Understanding such limitations of charge transport and transfer in photoelectrodes at the nanoscale and under in-situ conditions will enable the design of next generation PEC materials.

[1] Eichhorn et al., Nat. Commun. 9, 2597 (2018).
[2] Eichhorn et al., ACS Appl. Mater. Interfaces 10, 35129 (2018).

HL 15.7 Tue 11:00 H33

Sn nanoparticles@nitrogen-doped carbon nanofiber composites as high-performance anodes for sodium-ion batteries — •Mo Sha — Max-Planck-Ring 16/02-03-21 98693 ilmenau

Recently, sodium-ion batteries (SIBs) have attracted increasing attention as an important supplement and/or alternative to lithium ion batteries due to the abundance of sodium resources and its much lower cost. A critical issue in current research is the development of earth-abundant and high-performance electrode materials for the extensive applications of SIBs. Sn-based nanocomposites have been identified as one of the promising anodes for SIBs. In this study, the composites of Sn nanoparticles anchored on nitrogen-doped carbon nanofiber (Sn@NCNFs) have been synthesized by an electrostatic spinning technique and used as anodes for SIBs. Morphological and structural characterizations indicate that the Sn nanoparticles anchored uniformly on the surface of NCNFs. The corresponding specific capacity can reach over 600 mA h/g at 0.1 C after 200 cycles. Additionally, these Sn@NCNFs also show excellent high-rate cycling performance and maintain a capacity of up to 390 mA h/g even at an extremely high rate of 1 C for over 1000 cycles. The results demonstrate that this Sn@NCNFs composite is a promising anode material with good reversible capacity and cycling performance for SIBs.

HL 16: Focus Session: Oxide Semiconductors for Novel Devices III

Organizers: Holger Eisele (TU Berlin) and Holger von Wenckstern (Uni Leipzig)

Time: Tuesday 9:30–13:15 Location: H34

HL 16.1 Tue 9:30 H34

Mechanical properties of HfO_{2-x} and ZrO_{2-x} suboxides — •Konstantin Z. Rushchanskii, Stefan Blügel, and Marjana Ležaić — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Hafnia is a well-known high-k material that is compatible with silicon technology. Both hafnia and its crystallographic sibling, zirconia, are intensively investigated as resistive switching materials for the next generation non-volatile memory and potential neuromorphic computing applications. Zirconia-based ceramics are widely employed in industry and medicine because of their high strength and fracture toughness. Observed shape-memory effect is related to the martensitic transition from tetragonal to monoclinic phase in zirconia. A fundamental understanding of the mechanical properties and stability of these materials is, therefore, very important for their practical applications.

Recently [1,2], we reported the new suboxide phases in Hf-O and Zr-O systems, which contain ordered vacancy chains, a desired property for the resistive switching devices. Here we focus on the mechanical properties of these phases. We will report a prediction of superelastic behavior of these phases and discuss the role of ordered oxygen vacancies in the mechanical properties of hafnia and zirconia. We acknowledge the support by DFG via SFB 917 "Nanoswitches".
[1] K.Z. Rushchanskii, S. Blügel, M. Ležaić, Phys. Rev. Materials **2**, 115002 (2018); [2] K.Z. Rushchanskii, S. Blügel, M. Ležaić, Faraday Discussions (2019).

HL 16.2 Tue 9:45 H34

Protective coatings for photoelectrochemical applications — •David Silva, Oliver Bienek, and Ian Sharp — Technische Universität München, Walter Schottky Institut, Munich, Germany

Several photoactive semiconductor materials have been reported to yield promising energy conversion efficiencies in photocatalytic applications. However, the harsh chemical environments in which photoelectrochemical conversion (PEC) systems operate causes accelerated (photo) corrosion of many semiconductor light absorbers. In recent years, this issue has been mitigated via the application of conformal thin film protection layers, such as TiO_2, deposited via atomic layer deposition (ALD). However, interfacial charge transfer pathways, as well as the nature and impact of electronically active defects in highly disordered protection layers, remain poorly understood. Here, we report on optical characterization of these films using photothermal deflection spectroscopy (PDS), combined with complementary photocurrent measurements and surface photovoltage spectroscopy (SPS). Together, these measurements provide a deeper understanding of defect properties of these materials and their roles in photoelectrochemical energy conversion. Impacts of heterojunction energetics are analyzed by extending these approaches to model systems comprising TiO_2 on GaN substrates.

HL 16.3 Tue 10:00 H34

Theoretical and experimental investigation of optoelectronic properties of Ti:Nb3O7(OH) photoelectrodes — •Haseen Ullah Jan[1], Walayat Khan[1], Christina Scheu[2], and Jan Minar[1] — [1]University of West Bohemia (UWB), Pilsen, Czech Republic — [2]Max Planck Institute, Germany

Global warming and CO2 resulting from the combustion of fossil fuels adds the largest mass to the scales caused by continuous emission of greenhouse gases. Therefore, new technologies for power generation and energy storage are required. Our study focuses on the design[1], development[2], synthesis[3] and characterization[3] of novel materials for solar cells as photo-catalyst for water-splitting. Water photolysis is a renewable source for hydrogen fuel and is therefore considered as a solution for the energy crises. Recently, Nb3O7(OH) has been proposed as a promising material for this propose due to stability and suitable band gap. Our main goal to achieve is to find the possible stable position for the hydrogen atom by modifications of the structure and electronic properties of Nb3O7(OH) due to the Ti doping. Our theoretical study is based on the density functional theory using full potential linearized augmented plane wave (FP-LAPW) method. Structural properties reveals that the surface of the host material was enhanced at the loading of Ti. In addition, the optical spectra of Nb3O7(OH) and Ti:Nb3O7(OH) systems revealed that the optical band gap energy was not changed upon the addition of Ti, but the amount of photoabsorption drastically increased with increased contents of Ti.

HL 16.4 Tue 10:15 H34

Simulation of retention and endurance in memristive devices — •Max Huber[1,2], Jörg Schuster[2], and Michael Schreiber[1] — [1]Institute of Physics, Technische Universität Chemnitz, Chemnitz, Germany — [2]Fraunhofer Institute for Electronic Nano Systems, Chemnitz, Germany

Memristors are promising candidates for next generation memory. For practical purposes nonvolatility and reliability of the switching process are crucial to build high performance memristive devices. These properties can be checked with retention and endurance tests.

In our contribution we demonstrate, how such tests can be performed based on state-of-the-art physical device models [1]. For this purpose, Poisson's equation as well as drift-diffusion equation and continuity equation for electrons are solved selfconsistently for a one-dimensional device model. The movement of mobile donors and Joule heating of the device are considered as well. For the retention test, the device is switched from high resistance state (HRS) to low resistance state (LRS). In the following the device is read out for many times in order to check that this procedure does not change the topical state of the device. In contrast, the endurance test is performed by repeating the cycle *HRS → read out → LRS → read out* many times. We show how retention and endurance depend on device parameters like Schottky barriers, average donor concentration and mobility of charges.

[1] A. Marchewka, R. Waser, and S. Menzel: Proc. of 2015 International Conference on Simulation of Semiconductor Processes and Devices (SISPAD), pp. 297-300, IEEE, 2015.

HL 16.5 Tue 10:30 H34

Investigating the Memristive Behavior of Hydrothermally Grown TiO2 Nanorod Arrays — •Carola Ebenhoch[1], Julian Kalb[1], Joohyun Lim[2], Christina Scheu[2], and Lukas Schmidt-Mende[1] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]Max-Planck-Institut für Eisenforschung GmbH, Max-Planck-Straße 1, 40237 Düsseldorf, Germany

Metal oxide memristors gained great attention during the last decade in using them for nonvolatile data storage, as well as for artificial synapses. The key reason for changing the resistance state of a metal oxide material is the possibility to form conductive filaments due to oxygen vacancies. The known mechanisms for building such filaments are unipolar, bipolar and complementary switiching, which are based on the electromigration of oxygen ions by applying an electric field and thermophoresis caused by Joule heating. The investigated hydrothermally grown TiO2 nanorod arrays (NRAs) show a combination of these effects, whereas dependence of the growth temperature on the memrisitive behavior of the NRAs will be demonstrated.

HL 16.6 Tue 10:45 H34

Structural, electronic and magnetic properties of Iron doped hexagonal $BaTiO_3$: First principles investigation — •Waheed A. Adeagbo[1], Sanjeev K. Nayak[2], Hichem B. Hamed[1], Hans T. Langhammer[3], Rolf Böttcher[4], and Wolfram Hergert[1] — [1]Institute of Physics, Martin Luther University Halle-Wittenberg, 06120 Halle, Germany — [2]Department of Materials Science and Engineering, University of Connecticut, USA — [3]Institute of Chemistry, Martin Luther University Halle-Wittenberg, 06120 Halle, Germany — [4]Faculty of Physics and Earth Sciences, Leipzig University, Germany

DFT calculations of Fe-doped hexagonal $BaTiO_3$ resulted in three different Fe^{3+} defects incorporated at Ti sites: Two isolated defects and one associate of Fe^{3+} with a neighbouring oxygen vacancy. Substitution of Fe at Ti sites leads to a distortion of the surrounding oxygen octahedron. Fe is considered in different charge states. These charge states affect the Fe-O bonds and overall geometry near the defect and also influence the stability. The calculated formation energies, which are measure of the relative stability are in agreement with EPR experiment and demonstrate that Fe in BTO must exist in oxidation state of 3+ and has to occupy a face-sharing Ti(2) site while compensated by V_O located in its first coordination sphere. Magnetic configurations of Fe pairs for all possible crystallographic nearest neighbor sites are also studied by calculations of the exchange interactions. A ferromagnetic coupling for the closest Fe pair is predicted and their formation is stabilized by V_O. Achieving ferromagnetism in this material through impurity doping is a promising direction for further research.

15 min. break

HL 16.7 Tue 11:15 H34

Molecular beam epitaxy of SnO: Investigation of growth parameters including the comparison of a Sn and a SnO source — •Melanie Budde, Georg Hoffmann, and Oliver Bierwagen — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, 10117 Berlin, Germany

Tin monoxide (SnO) is a p-type transparent semiconducting oxide (TSO) with a relatively high mobility for this class of materials. However, the SnO phase is instable and easily oxidized to SnO2 or reduced into metallic Sn.[1] On the other hand, SnO2 is a n-type TSO allowing a change in the carrier type only by controlling the oxygen stoichiometry x of SnOx. The investigations of Vogt[2] on the sub-oxide formation during the SnO2 growth also shows additional formation of SnO under metal-rich conditions. However, SnO was volatile at the growth temperature of 600 °C and desorbed from the substrate, thus not contributing to the film growth.

In this work, the desorption of SnO for growth temperatures below 600 °C are investigated using a line-of-sight quadrupole mass spectrometer to find a growth window for the formation of SnO. First, the SnO layers are grown and characterized using a SnO source. Secondly, different fluxes from a Sn cell in combination with an oxygen plasma are used. The grown layers are investigated using X-ray diffraction and energy dispersive x-ray spectroscopy.

[1] Zhang et al., J. Phys.: Condens. Matter 28 (2016). [2] Vogt and Bierwagen, Appl. Phys. Lett. 106 (2015).

HL 16.8 Tue 11:30 H34

Structural, optical and electrical properties of orthorhombic $(In_xGa_{1-x})_2O_3$ thin films — •A. Hassa, H. von Wenckstern, D. Splith, C. Sturm, M. Kneiss, C. Krömmelbein, and M. Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstraße 5, 04103 Leipzig, Germany

Gallium oxide is a wide bandgap semiconductor appearing in various polymorphs. The orthorhombic κ-phase is of increasing interest because of its predicted large polarization of $23\,\mu C/cm^2$ [1] rendering it well suited for usage e.g. in high electron mobility transistors. We present material properties of a κ-$(In_xGa_{1-x})_2O_3$ thin film grown with continuous composition spread [2] by pulsed laser deposition on (00.1) Al_2O_3. As target segments we used Ga_2O_3/In_2O_3 doped with tin to facilitate formation of the orthorhombic phase [3], which was observed for an indium content up to $x \sim 0.35$ enabling band gap engineering between 4.3 and 4.9 eV. In order to induce n-type conductivity we doped a sample consisting of $(In_{0.01}Ga_{0.99})_2O_3$ with 1.3 at.% zirconium and achieved electrically conducting thin films with room temperature conductivity of up to 0.1 S/cm. Resulting samples were investigated by means of X-ray diffraction, transmission, energy-dispersive X-ray spectroscopy, atomic force microscopy, and electrical transport measurements. Further, properties of Schottky barrier diodes are presented in dependence on the temperature.

[1] M. B. Maccioni *et al.*, Appl. Phys. Express 9, 04102 (2016).
[2] H. v. Wenckstern *et al.*, CrystEngComm 15, 10020 (2013).
[3] M. Kneiß *et al.*, APL Materials, Accepted (2018).

HL 16.9 Tue 11:45 H34

Temperature dependence of the Seebeck coefficient of epitaxial β-Ga_2O_3 thin films — •Johannes Boy[1], Martin Handwerg[1], Robin Ahrling[1], Rüdiger Mitdank[1], Günter Wagner[2], Zbigniew Galazka[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany — [2]Leibniz Institute for Crystal Growth, Max-Born-Strasse 2, 12489 Berlin, Germany

In the past years, β-Ga_2O_3 crystals and thin films have proved to be promising materials for high power devices. However, one drawback is the low thermal conductivity[1,2], which enhances the energy-dissipation by Joule heating. One approach could be a direct cooling using the Peltier effect. For this purpose values of the Seebeck coefficient of β-Ga_2O_3 need to be known.

In this work, the temperature dependence of the Seebeck coefficient of homoepitaxial metal organic vapor phase grown, silicon doped β-Ga_2O_3 thin films was measured relative to aluminum. For room temperature we found the relative Seebeck coefficient of $S_{\beta\text{-}Ga_2O_3\text{-}Al} = (-300 \pm 20)\ \mu V/K$. At high bath temperatures $T > 240$ K, the scattering is determined by electron-phonon-interaction. For lower bath temperatures between $T = 100$ K and $T = 300$ K, an increase in the magnitude of the Seebeck coefficient is explained in the frame of Stratton's formula.

[1] M. Handwerg, *et al.*, Semicond. Sci. Technol. **30**, 024006 (2015).
[2] M. Handwerg, *et al.*, Semicond. Sci. Technol. **31**, 125006 (2016).

HL 16.10 Tue 12:00 H34

Realization of MESFET and inverter devices based on Mg-doped In_2O_3 — •Fabian Schöppach, Robert Karsthof, Daniel Splith, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix Bloch Institute for Solid State Physics, Linnéstraße 5, 04103 Leipzig, Germany

Indium oxide (In_2O_3) has promising physical properties such as high conductivity and transparency in the visible. However In_2O_3 is not used in active devices such as diodes or transistors yet. This is due to its tendency to form an electron accumulation layer on its surface preventing the formation of a significant depletion layer.

In this work, metal-semiconductor field-effect transistors (MESFETs) and inverters are presented for the first time. These are based on thin In_2O_3 films with various Mg doping concentrations. These films are grown via high-temperature pulsed laser deposition in oxygen atmosphere. For source and drain contacts gold is deposited via inert ambient sputtering. Schottky gate diodes are fabricated in a reactive sputter process which is a requirement for obtaining rectifying contacts to In_2O_3 [1,2]. Transistors with on-off ratios of over 5 orders of magnitude are reported.

[1] H. v. Wenckstern, et al. APL Mater. 2, 046104 (2014)
[2] Th. Schultz, et al. Phys. Rev. Appl. 9, 064001 (2018)

HL 16.11 Tue 12:15 H34

Integrated Logic Circuits Based on Amorphous Zinc-Tin-Oxide Thin Films Processed at Room Temperature —

•Oliver Lahr, Sofie Vogt, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Semiconductor Physics Group, Leipzig, Germany

Currently there exists an increasing demand for low cost electronics and novel devices based on sustainable materials. Amorphous zinc-tin-oxide (ZTO) is a promising candidate for such technology since it consists of abundant, non-toxic elements and can be deposited at room temperature. Recently, the first metal field-effect transistors (MESFETs) as well as inverters based on amorphous ZTO channels have been reported [1,2].
We present Schottky diode FET logic (SDFL) inverters and SDFL ring oscillators based on MESFETs and junction field-effect transistors using amorphous n-type ZTO as channel material. The channels were deposited at room temperature by radio frequency long throw magnetron sputtering using a target with a 67 % SnO_2 and 33 % ZnO composition. MESFET-based inverters show high peak gain magnitudes up to 330 at an operation voltage of 3 V with uncertainty levels below 113 mV. Single stage delay times down to 1.9 μs at $V_{DD} = 10$ V are observed for ring oscillators based on our ZTO-MESFETs.

[1] Dang *et al.*, Appl. Phys. Lett., **110**, 7, 2017.
[2] Vogt *et al.*, Appl. Phys. Lett., **113**, 13, 2018.

HL 16.12 Tue 12:30 H34

IR-Vis-UV optical properties of α-Ga_2O_3 films grown by halide vapor phase epitaxy — •Pingfan Ning[1], Martin Feneberg[1], Jürgen Bläsing[1], Hoki Son[2], Dae-Woo Jeon[2], and Rüdiger Goldhahn[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg — [2]Korea Institute of Ceramic Engineering & Technology, 15-5, Chungmugong-dong, Jinju-si, Gyeongsangnam-do

Ultra wide band gap semiconductor α-Ga_2O_3 has been attracting increasing interest due to their potential advantages in UV optoelectronics, power devices, RF electronics as well as transparent electronics. However, many basic physical properties are still unclear, including optical properties, which must be investigated in detail to fully exploit their functions. We investigated the linear optical response of metastable α-Ga_2O_3 epitaxial layers by spectroscopic ellipsometry. The α-Ga_2O_3 films are grown on (0001) α-Al_2O_3 substrates by halide vapor phase epitaxy method while the precursors GaCl and O_2 are controlled in different ways. The ordinary dielectric function has been determined by point-by-point fitting of the ellipsometry data from the infrared (300 cm^{-1}) to the ultraviolet (6.5 eV). Effects of GaCl and O_2 gas controlling on the infrared-active phonon modes, dielectric limits, and interband transitions are discussed. The infrared dielectric function is accurately described with a sum of Lorentzian oscillators and the dielectric limit. Characteristic energies, broadening factors, and amplitudes of three out of the four expected E_u infrared-active modes are determined.

HL 16.13 Tue 12:45 H34

Influence of strain on yellow excitons in cuprous oxide with different principle quantum numbers — •Patric Rommel[1], Christoph Uihlein[2], and Jörg Main[1] — [1]Institut für Theoretische Physik 1, Universität Stuttgart, Germany — [2]Experimentelle Physik 2, TU Dortmund, Germany

Recently J. Mund et al. demonstrated Second Harmonic Generation (SHG) for the yellow series in cuprous oxide [1]. Assuming perfect O_h symmetry, SHG is forbidden along certain high-symmetry axes. Perturbations can break this symmetry and forbidden transitions may become allowed. We investigate the effect of strain in the crystal structure on the yellow exciton lines of cuprous oxide. Strain in a high-symmetry direction of the crystal leads to a splitting of the exciton lines according to the related symmetry reduction [2]. For the S states of symmetry Γ_5^+, this splitting can be described using a simple 3×3 matrix model. We derive the strengths of the splitting in dependence on the main quantum number n by numerically diagonalizing the exciton Hamiltonian including an appropriate strain term.

[1] J. Mund et al., Phys. Rev. B 98, 085203 (2018)
[2] H.-R. Trebin et al., Phys. Rev. B. 23, 597 (1981)

HL 16.14 Tue 13:00 H34

Tuning functionality at the nanoscale — •Donald M. Evans[1], Theodor. S. Holstad[1], Aleksander. B. Mosberg[2], Per-Erik Vullum[2], Didirik Småbråten[1], Zewu Yan[3], Sverre Selbach[1], Antonius Van Helvoort[2], and Dennis Meier[1] — [1]Department of Materials Science and Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway. — [2]Department of Physics, Norwegian University of Science and Technology (NTNU), Trondheim, Norway. — [3]Department of Physics, ETH Zurich, 8093 Zürich, Switzerland

One of the stand out scientific achievements of the twenty first century is the ability to tune a material*s functional properties, e.g. doping silicon to become either p- or n-type. As we reach the limits of silicon technology other options to tune functional properties become interesting, particularly local changes rather than bulk changes. In this work we use an atomic force microscope (AFM) to locally apply an electric field that changes the conductive properties of a hexagonal manganite (ErMnO3). This has all the control and resolution of an AFM giving us the freedom to write any combination of shapes and sizes for nano-circuitry. We analyse these areas of enhanced conductivity with a transmission electron microscope (TEM) to find changes in crystal structure and do electron energy loss spectroscopy (EELS) to look for changes in chemical composition. These are combined with Density Functional Theory (DFT) work to establish the likely mechanism of enhanced conductivity.

HL 17: Two-dimensional Materials I (joint session HL/CPP)

Time: Tuesday 9:30–13:00 Location: H36

HL 17.1 Tue 9:30 H36

Electronic Dipole Spin Resonance of 2D Semiconductor Spin Qubits — •Matthew Brooks and Guido Burkard — Universität Konstanz, Konstanz, Deutschland

Monolayer transition metal dichalcogenides (TMDs) offer a novel two-dimensional platform for semiconductor devices. One such application, whereby the added low dimensional crystal physics (i.e. optical spin selection rules) may prove TMDs a competitive candidate, is quantum dots as qubits. The band structure of TMD monolayers offers a number of different degrees of freedom and combinations thereof as potential qubit basis, primarily electron spin, valley isospin and the combination of the two due to the strong spin orbit coulping known as a Kramers qubit. Pure spin qubits in monolayer MoX_2 (where X = S or Se) have been shown to be achievable by energetically isolating a single valley and tuning to a spin degenerate regime within that valley by a combination of a sufficiently small quantum dot radius and large perpendicular magnetic field. Within such a TMD spin qubit, we theoretically induce and analyse single qubit rotations with an electric dipole spin resonance. We employ a rotating wave approximation within a time dependant Schrieffer-Wolf approximation to derive analytic expressions for the Rabi frequency of single qubit oscilations, and compare this result to more exact numerics, as to find optimal operational regimes.

HL 17.2 Tue 9:45 H36

Metalorganic Vapour Phase Epitaxy (MOVPE) Technology for 2D Transition Metal Dichalcogenides (TMDC) — •Michael Heuken[1,2], Annika Grundmann[2], Dominik Andrzejewski[3], Tilmar Kümmell[3], Gerd Bacher[3], Holger Kalisch[2], and Andrei Vescan[2] — [1]AIXTRON SE, Dornkaulstr. 2, 52134 Herzogenrath, Germany — [2]Compound Semiconductor Technology, RWTH Aachen University, Sommerfeldstr. 18, 52074 Aachen, Germany — [3]Werkstoffe der Elektrotechnik and CENIDE, University Duisburg-Essen, Bismarckstr. 81, 47057 Duisburg, Germany

The 2D TMDC MoS_2 and WS_2 have raised strong interest due to their exceptional properties and prospects for micro- and optoelectronics. For fundamental material physics and the development of (opto)electronic devices, a reproducible deposition technology providing uniform layers of controlled thickness and purity is indispensable. MOVPE is perfectly suited for this task and can furthermore be scaled up to production with high volume and yield. Here, we report on the systematic investigation of 2D MoS_2 and WS_2 growth on sapphire us-

ing a hydride-free MOVPE process in a commercial AIXTRON multi-wafer MOVPE reactor. Metal hexacarbonyls (WCO and MCO) as well as DTBS are used as high-purity MO sources. The impact of the fundamental growth parameters is discussed, shedding light on nucleation and lateral 2D growth until full layer coalescence. Samples are characterized using Raman spectroscopy, SEM, AFM, PL, and reflectometry. Finally, a WS_2-based LED will be presented to demonstrate the applicability of 2D TMDC for optoelectronic devices.

HL 17.3 Tue 10:00 H36

Interplay of bright and dark excitons in transition metal dichalcogenides — •Malte Selig[1], Dominik Christiansen[1], Florian Katsch[1], Ermin Malic[2], and Andreas Knorr[1] — [1]Nichtlineare Optik und Quantenelektronik, Institut für Theoretische Physik, Technische Universität Berlin, Deutschland — [2]Chalmers University of Technology, Department of Physics, Göteborg, Sweden

The extraordinarily strong Coulomb interaction in monolayers of transition metal dichalcogenides (TMDs) gives rise to the formation of tightly bound electron hole pairs, excitons, which dominate the optical and electronic properties of these ultrathin materials. In particular, a variety of dark exciton states occurs, including excitons with opposite spins of the constituent carriers [1] and excitons with momenta well above the radiative cone [2]. In this talk, we will address the impact of such dark exciton states to the optical properties of TMDs, including optical lineshape [2,3], luminescence properties [4] and intervalley relaxation. Additionally, we compare the influence of these states on the excitonic linewidth between mono- and bilayer samples [5].

[1] X.-X. Zhang et al., Nature Nanotechnology 12, 883 (2017)
[2] M. Selig et al., Nature Communications 13279 (2016)
[3] D. Christiansen et al., Physical Review Letters 119, 187402 (2017)
[4] M. Selig et al., 2D Materials 5 035017 (2018)
[5] A. Raja et al., Nano Letters, 18 (10), 6135 (2018)

HL 17.4 Tue 10:15 H36

Many-body quantum Monte Carlo study of 2D materials: cohesion and band gap in single-layer phosphorene — •Tobias Frank[1], Rene Derian[2], Kamil Tokar[2], Lubos Mitas[3], Jaroslav Fabian[1], and Ivan Stich[2,4] — [1]University of Regensburg, Regensburg, Germany — [2]Slovak Academy of Sciences, Bratislava, Slovakia — [3]North Carolina State University, Raleigh, NC — [4]University of Ss. Cyril and Methodius, Trnava, Slovakia

Quantum Monte Carlo (QMC) is applied to obtain the fundamental (quasiparticle) electronic band gap, Δ_f, of a semiconducting 2D phosphorene. Similarly to other 2D materials, the electronic structure of phosphorene is strongly influenced by reduced screening, making it challenging to obtain reliable predictions by conventional methods. Using the recently uncovered universal scaling between the exciton binding energy and Δ_f, we predict the optical gap of about 1.7 eV that can be directly related to experiments. The QMC gaps agree with recent optical absorption and photoluminescence measurements. We also predict the cohesion of phosphorene to be only slightly smaller than that of the bulk crystal. Our investigations not only benchmark GW methods and experiments, but also open the field of 2D electronic structure to computationally intensive but highly predictive QMC methods which include many-body effects such as electronic correlations. We were supported by GRK Grant No. 1570, the International Doctorate Program Topological Insulators of the Elite Network of Bavaria, and DFG SFB 1277 (B07). We acknowledge the Gauss Centre for Supercomputing (www.gauss-centre.eu) for funding.

HL 17.5 Tue 10:30 H36

Interlayer band-to-band tunneling in h-BN encapsulated MoS2-WSe2 heterojunction — •Phanish Chava[1,2], Vivek Mootheri[1], Himani Arora[1,2], Kenji Wantanbe[3], Takashi Taniguchi[3], Manfred Helm[1], and Artur Erbe[1] — [1]Helmholtz Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]TU Dresden, 01062 Dresden, Germany — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

Quantum mechanical band-to-band tunneling (BTBT) is a particular type of carrier injection mechanism which is responsible for the electronic transport in tunneling based devices like Esaki diode and Tunnel Field Effect Transistor (TFET). Atomically thin layers of transition metal dichalcogenides (TMDCs) are promising semiconducting materials for realizing such devices owing to their sharp interfaces. In this work, we demonstrate BTBT between the layers of molybdenum disulfide (MoS2) and tungsten diselenide (WSe2) in a MoS2-WSe2 heterojunction which is encapsulated with hexagonal boron nitride (h-BN) on the top and bottom. Also, we employ few-layer graphene as the contact material to the heterojunction thereby forming a 2D-2D van der Waals contact. We find that the device works as a p-TFET for for negative top gate voltages and an n-MOSFET for positive top gate voltages. The device exhibits Negative Transconductance (NTC) in the positive gate voltage regime, a minimum sub-threshold swing of about 170 mV / dec at 125 K and an ON-OFF ratio of about 10^6.

HL 17.6 Tue 10:45 H36

Effects of the Fermi Level Energy on the Adsorption of O2 to Monolayer MoS2 — •Philip Klement[1], Christina Steinke[3], Sangam Chatterjee[1], Tim Wehling[3], and Martin Eickhoff[2] — [1]Institute of Experimental Physics I and Center for Materials Research, Justus Liebig University Giessen, D-35392 Giessen, Germany — [2]Institute of Solid State Physics, University of Bremen, D-28359 Bremen, Germany — [3]Institute for Theoretical Physics and Bremen Center for Computational Material Sciences, University of Bremen, D-28359 Bremen, Germany

Two-dimensional transition metal dichalcogenides possess large surface-to-volume ratios that make them ideal candidates for sensing applications such as detecting the surface adsorption of specific gas molecules. The resulting changes of the electrical and optical properties allow for detection and analysis of interaction mechanisms at the sensing interface. Specifically, we investigate the influence of O2 adsorption on monolayer MoS2 and the role of the Fermi level energy in this process. We record the response in photoluminescence and transport properties of monolayer MoS2 upon O2 adsorption and the impact of external electric gating. We find an increase of the photoluminescence intensity and a reduction of the conductivity upon O2 adsorption, and show that the adsorption can be enhanced by an increase of the Fermi level energy. These results demonstrate that ionosorption of O2 on MoS2 by charge transfer only occurs if free carriers are available in the conduction band of MoS2. Furthermore, photoluminescence recording is rendered advantageous for sensing.

15 min. break

HL 17.7 Tue 11:15 H36

Zeeman splitting and inverted polarization of biexciton emission in monolayer WS_2 — •Philipp Nagler[1], Mariana V. Ballottin[2], Anatolie A. Mitioglu[2], Mikhail V. Durnev[3], Takashi Taniguchi[4], Kenji Watanabe[4], Alexey Chernikov[1], Christian Schüller[1], Mikhail Glazov[3], Peter C. M. Christianen[2], and Tobias Korn[1] — [1]University of Regensburg — [2]High Field Magnet Laboratory, Nijmegen — [3]Ioffe Institute, St. Petersburg, Russia — [4]NIMS, Tsukuba, Japan

Monolayer TMDCs are an ideal testbed to study the physics of quasiparticles in the two-dimensional limit. Besides excitons, more complex many-body states such as trions and biexcitons can emerge due to the strong Coulomb interaction in these materials. Here, we shed light on the intricate many-body physics of biexcitons in monolayer WS_2 [1]. The encapsulation of the monolayer between two sheets of hBN significantly reduces the overall spectral broadening and allows us to observe biexciton emission with linewidths below 5 meV at 4 K. In magneto-PL experiments, we observe an inverted field-induced polarization, implying a preferential population of the high-energy peak in emission. We explain this unusual phenomenon by considering the evolution of the total energy of the biexciton complex in a magnetic field. Based on the experimental results and the developed model we are able to identify the momentum-space configuration of the optically dominant biexciton state of monolayer WS_2.

[1] P. Nagler et al., *Phys. Rev. Lett.* **121**, 057402 (2018)

HL 17.8 Tue 11:30 H36

Electromagnetically induced transparency in second-harmonic generation from monolayer WSe2 — •Kai-Qiang Lin, Robert Martin, Sebastian Bange, and John Lupton — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, 93053 Regensburg, Germany

Electromagnetically induced transparency (EIT) occurs in atomic systems and shows versatile applications in slow-light generation, gain without inversion and optical quantum-information processing. We demonstrate a cavity-free, atomic-like EIT effect in single-layer crystals of WSe2, probed by exploiting the intrinsic second-harmonic generation (SHG) arising from the breaking of inversion symmetry.[1] Under conditions of double resonance of the driving and radiated field with

the fundamental transitions, the SHG spectrum bifurcates. The feature follows a pump-wavelength-dependent spectral anticrossing, accurately described by a ladder-type three-level model. Crucially, the SHG power-law exponent diverges from the canonical value of 2 to follow a Fano-like dispersion with wavelength. This dispersion is retained at room temperature, implying persistence of quantum interference. Our work opens up opportunities to exploit quantum nonlinear optics such as inversionless gain in the solid state.

[1]. K.-Q. Lin, S. Bange and J. M. Lupton, Nature Physics, in press. (preprint: https://arxiv.org/abs/1811.09479)

HL 17.9 Tue 11:45 H36

Studying exciton-phonon interaction in a $MoSe_2$ monolayer by fluorescence-detected 2D electronic micro-spectroscopy — •Donghai Li[1], Chiara Trovatello[2], Stefano Dal Conte[2], Matthias Nuss[1], Giancarlo Soavi[3], Andrea Ferrari[3], Giulio Cerullo[2,4], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Dipartimento di Fisica, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy — [3]Cambridge Graphene Centre, University of Cambridge, Cambridge, UK. — [4]Istituto di Fotonica e Nanotecnologie, CNR, Piazza Leonardo da Vinci 32, 20133 Milano, Italy

Monolayer transition metal dichalcogenides (TMDs) received extensive attention as they have extraordinary opto-electronic characteristic. Exciton-phonon interaction in TMD monolayers can result in sidebands in their absorption spectra, for some dark states are activated by exciton-phonon scattering [1]. However, in the absorption spectra, the phonon-induced sidebands are obscured by inhomogeneous broadening. Here, we study the excitonic physics of a $MoSe_2$ monolayer using fluorescence-based two-dimensional (2D) electronic spectroscopy. We confirm and extend the theoretical prediction [1] by our observations of sidebands and their quantum beating behavior within the 2D spectra. The analysis indicates a four-level energy structure with one dark state near the excited state and an additional, unpredicted, one near the ground state activated by exciton-phonon scattering.

[1] D. Christiansen et al., Phys. Rev. Lett. **119**, 187402 (2017)

HL 17.10 Tue 12:00 H36

Transport and photoelectron spectroscopy of few-layer epitaxial WSe_2 — •Hiro Nakamura[1], Avaise Mohammed[1], Philipp Rosenzweig[1], Kathrin Müller[1], Peter Wochner[1], Armin Schulz[1], Mona Stadler[2], Michael Jetter[2], Peter Michler[2], Ulrich Starke[1], and Hidenori Takagi[1,3,4] — [1]Max Planck Institute for Solid State Research — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, University of Stuttgart — [3]Department of Physics, University of Tokyo — [4]Institute for Functional Matter and Quantum Technologies, University of Stuttgart

Giant spin splitting of monolayer WSe_2 is an interesting element both for spintronics and topological phenomena. Here, we present electronic and structural properties of few-layer WSe_2 grown by hybrid pulsed-laser deposition. Angle-resolved, ultraviolet and X-ray photoelectron spectroscopy reveal the band structure of monolayer WSe_2 including strong spin-orbit splitting, as well as clarify the band alignment between WSe_2 and the underlying graphene/SiC substrate, indicating electron transfer from graphene to WSe_2. To access the valence bands in transport, hole-doping of few-layer WSe_2 has been performed using Nb as a dopant. The Hall effect and transport measurements confirmed the expected density of hole carriers, and associated metallic conduction down to low temperatures for optimal films. Synchrotron X-ray diffraction sheds further light on structure-property relationships, in particular strain effects in the WSe_2 layer.

HL 17.11 Tue 12:15 H36

Excitation-Induced Transition from Direct to Indirect Band Gaps in Monolayer TMDs — •Daniel Erben[1], Alexander Steinhoff[1], Michael Lorke[1,2], Tim Wehling[1,2], Christopher Gies[1], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen — [2]Bremen Center for Computational Materials Science, University of Bremen

Monolayers of transition metal dichalcogenides (TMDs) show exceptionally strong Coulomb interaction between charge carriers due to the small thickness and weak dielectric screening. Many-body interactions induced by excited charge carriers directly influence the electronic and optical properties in these materials. Strong many-particle renormalizations caused by the Coulomb interaction of the excited carriers will be discussed for MoS_2, $MoSe_2$, WS_2 and WSe_2. We solve the semiconductor Bloch equations on the full Brillouin zone using ab-initio band structures and interaction matrix elements.

Large excitation-dependent band-gap renormalizations are found. In all four materials, the conduction band Σ-valley exhibits a stronger shift to lower energies than the K-valley. As a result, all four TMDs show a tendency to become more indirect or even undergo a transition from a direct to indirect band gap with increasing excited carrier density.

For optical excitation of monolayer TMDs, we also study the connection between pump fluence and excited carrier density. The contributions of various many-body effects to a strong non-linearity are identified.

HL 17.12 Tue 12:30 H36

Theory of Exciton-Exciton Coupling in Atomically Thin Transition Metal Dichalcogenides — •Florian Katsch, Malte Selig, and Andreas Knorr — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, 10623 Berlin, Germany

The valley-selective circular dichroism in monolayer transition metal dichalcogenides (TMDCs) and the subsequent fast valley depolarization due to intervalley Coulomb interactions enables the study of new many-body physics in these atomically thin materials. Here, a microscopic approach is presented to describe the optical response of monolayer TMDCs dominated by strongly correlated, bound electron-hole pairs [1, 2]. The approach includes Hartree–Fock and correlation effects up to two excitonic excitations [3], as well as TMDC typical Coulomb intra- and intervalley coupling and exciton-phonon interactions [4]. The developed theory is applied to access the exciton dynamics in the coherent limit and contributes to the understanding of valley-selective pump-probe experiments [5, 6].

[1] A. L. Ivanov and H. Haug, *Phys. Rev. B* **48**, 1490 (1993).
[2] F. Katsch et. al., *Phys. Status Solidi B*, 1800185 (2018).
[3] V. M. Axt and A. Stahl, *Z. Phys. B* **93**, 2 (1994).
[4] M. Selig et. al., *2D Mater.* **5**, 035017 (2018).
[5] C. Mai et. al., *Nano Lett.* **14**, 202 (2013).
[6] R. Schmidt et. at., *Nano Lett.* **16**, 2945 (2016).

HL 17.13 Tue 12:45 H36

Creation and optical spectroscopy of localized excitons in 2D MoS_2 — •Oleg Gridenco, Sven Mehrkens, Kathrin Sebald, Christian Tessarek, Martin Eickhoff, and Jürgen Gutowski — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, D-28359 Bremen, Germany

It is known that missing atoms in a semiconductor are exciton trapping sites, moreover, excitons can bind to impurity atoms or can be trapped in a potential well created by local strain or structural defects. In this context, structuring with a focused ion beam gives the opportunity for manipulation of 2D materials on the nanometer scale. In this study, we explore how focused gallium ion irradiation affects the intrinsic luminescence and vibrational properties of atomically thin MoS_2. Defects were introduced by scanning the Ga^+ ion probe over a certain area of the flake using a focused ion beam (FIB). The amount of defects was controlled by varying the Ga^+ ion dose starting from 2 x 10^{12} ions/cm^2 until the PL signal was completely vanished (2 x 10^{13} ions/cm^2). After Ga^+ ion irradiation, micro-photoluminescence measurements at T=4K show that the A exciton emission is suppressed and a new peak, a bound exciton (D) located at 1.75 eV, emerges. This broad peak is redshifted by ΔE∼170 meV with respect to the neutral exciton X emission. Encapsulating monolayer MoS_2 into hBN drastically reduces the inhomogeneous contributions to the exciton linewidth [1]. The possibilities of tailoring optically active defect centers in 2D MoS_2 to even host single-photon emitters will be discussed.

[1] E. Courtade et al., Appl. Phys. Lett. **113**, 032106 (2018).

HL 18: Diamond I (joint session KFM/HL)

This session represents the physics, the production and applications of diamond and diamond related materials in the fields of dielectrics, electronics, high frequency techniques, GHz * THz * applications, mechanics and optics and biological applications as well. Defects in diamond have a large influence to the physical properties (e. g. NV-centers). Applications of diamond (single, poly-crystalline, UNCD, etc.) or related materials in technical systems are part of this session (Nuclear fusion applications, high frequency heating systems and material processing).

Chair: Dirk Strauss (KIT)

Time: Tuesday 9:30–12:00 Location: PHY 5.0.20

HL 18.1 Tue 9:30 PHY 5.0.20

The ITER Diamond Window - Qualification Program Development of a Safety Important Component — •Sabine Schreck, Gaetano Aiello, Andreas Meier, Theo Scherer, and Dirk Strauss — Karlsruhe Institute of Technology, Institute for Applied Materials, Hermann-von-Helmholtz-Platz 1,

An important component of the ITER ECRH Upper Launcher system is the torus diamond window, which serves as primary vacuum and tritium boundary of the ITER vacuum vessel and allows the transmission of high power mm-waves coming from the gyrotrons into the plasma. The window consists of an ultra-low loss CVD diamond disk mounted in a system of metallic parts and is integrated into the transmission line system. Because of its confinement function the window is classified as Protection Important Component (PIC) and high requirements for quality and safety apply. An ad-hoc qualification program is required for this specific component because it cannot be entirely covered by codes and standards.

Diamond disks with a diameter of about 70 mm and a thickness of 1.11 mm (resonance thickness for 170 GHz) will be used and need to be qualified with respect to their mm-wave transmission capability and mechanical stability. Qualification procedures are also to be established for the joining of the disk to the metallic structure, which is performed by brazing and finally for the qualification of the complete housing made of metallic parts, that are welded together.

The status of the window qualification program will be given together with results of already performed prototype tests.

HL 18.2 Tue 9:50 PHY 5.0.20

Development of Diamond Windows Diagnostics for fusion applications — •Theo Scherer, Aurelian Tesniere, Gaetano Aiello, Francesco Mazzocchi, Andreas Meier, Sabine Schreck, and Dirk Strauss — Karlsruhe Institut für Technologie KIT, IAM-AWP, D-76344 Eggenstein-Leopoldshafen, Hermann-von-Helmholtz-Platz 1, Germany

The future nuclear fusion power plants will require Electron Cyclotron Heating and Current Drive (ECH&CD) systems to heat up and stabilize the plasma inside the vacuum vessel. One of the key components of such systems is the Chemical Vapor Deposition (CVD) diamond window. The purpose of this device is to act as vacuum and tritium boundary while providing a high microwave transparency with minimal reflectivity. Although suited for high power microwave operation, the windows shall be internally monitored in order to properly ensure the ECH system efficiency and safety. In this paper, the latest assessment study on a set of diagnostics to be part of the window assembly is shown. The required diagnostics include arc and tritium detection, microwave stray radiation (perpendicular to the main beam and generated by cracks in the windows), pressure and disk temperature measurements. To accommodate the diagnostics previously mentioned, a new design for the window housing was developed.

HL 18.3 Tue 10:10 PHY 5.0.20

Brewster-angle diamond window for microwave application — •Gaetano Aiello[1], Theo Scherer[1], Thomas Franke[2], John Jelonnek[1], Andreas Meier[1], Dirk Strauss[1], Quang Tran[3], Christoph Wild[4], and Eckhard Woerner[4] — [1]KIT, Hermann-von-Helmholtz-Platz 1, Eggenstein-Leopoldshafen, Germany, 76344 — [2]EUROfusion Consortium, Boltzmannstrasse 2, Garching, Germany, 85748 — [3]Swiss Plasma Center (SPC), EPFL, Lausanne, Switzerland, 1015 — [4]Diamond Materials GmbH, Hans-Bunte-Strasse 19, Freiburg, Germany, 79108

The Brewster-angle diamond window is a broadband window solution for the frequency step-tunable gyrotrons in the context of the DEMO EC H&CD system. It consists of an elliptical CVD diamond disk brazed to two copper WGs at the Brewster angle of 67.2° for diamond. This window concept is being investigated for long pulse gyrotron operation at 2 MW power. Main challenges along this path are the production of very large area optical grade diamond disks suited for a 63.5 mm WG aperture, the proper joining of the disks to the WGs and the design of an effective cooling layout. A 63.5 mm WG requires a minimum disk diameter of 180 mm and 2 mm thickness. Available state of the art microwave plasma reactors are not able of growing diamond disks of such size. In collaboration with Diamond Materials GmbH, tests aiming to obtain large disks were thus investigated by different methods and experiments are still ongoing. In this work, the results of these experiments shall be reported, also together with the results of the FEM analyses aiming to investigate different window cooling layouts.

Break 20 min

HL 18.4 Tue 10:50 PHY 5.0.20

ECRH system development for nuclear fusion reactors: Antenna design and diamond window implementation — •Dirk Strauss, Theo Scherer, Sabine Schreck, Peter Spaeh, Gaetano Aiello, Andreas Meier, and Francesco Mazzocchi — KIT Karlsruhe, Deutschland

The ITER ECRH system consists of 24 gyrotrons with up to 24 MW millimeter wave heating power at 170 GHz, power supplies, control system, transmission lines, one Equatorial and the four Upper Launchers. With its high frequency and small beam focus the ECRH has the unique capability of driving locally current. While the Equatorial Launcher mainly acts for central heating and current profile shaping, the Upper Launchers aim on suppressing MHD instabilities, especially neoclassical tearing modes triggering plasma disruptions. The Upper Launchers inject millimeter waves through a quasi-optical section. The eight overlapping beams have focal points optimized for suppression of NTMs. Changes in the design include new ex-vessel waveguide components with a reduced aperture and redesigned ultra low-loss CVD diamond windows.

Invited Talk HL 18.5 Tue 11:10 PHY 5.0.20

Development of Kinetic Inductance Detectors for polarimetric applications in plasma diagnostics — •Francesco Mazzocchi[1], Eduard Driessen[2], Shibo Shu[2], Giovanni Grossetti[1], Dirk Strauss[1], and Theo Scherer[1] — [1]Karlsruhe Institute of Technology, Eggenstein Loepoldshafen, Germany — [2]Institute de RadioAstronomie Millimetrique, Grenoble, France

Polarimetry is a technique that measures the Faraday rotation in a magnetized medium, such as a fusion plasma. It allows to determine various fundamental plasma parameters, such as current density when used independently from other diagnostics and like poloidal field and electron density when coupled to specific systems (i.e. interferometry). To mitigate these issues of current systems, we have considered to use in our device a Quantum Cascade Laser (QCL). The lack of power of such source requires the use of extremely sensitive detectors, hence the development of custom superconducting Kinetic Inductance Detector (KID) presented in this work. The whole system will be composed of a cryostat containing the source and the detector (both of which require cryogenic temperatures to operate optimally) and a beam delivery system, consisting of suitable waveguides and a diamond window on the reactor side, to have a very strong pressure barrier between the tritium rich atmosphere of the fusion reactor and the vacuum of the polarimeter side waveguides. The dielectric and mechanical properties of the synthetic diamond allow us to have such barrier without compromising the beam transmission factor.

HL 18.6 Tue 11:40 PHY 5.0.20

Diamant und die Knickpyramide in Ägypten: Eine überraschende Gemeinsamkeit — •Peter-Michael Wilde — 15711 Königs Wusterhausen, Deutschland

Der Habitus und die Zusammensetzung von kristallinen Mikroobjekten auf Silicium (111)- Substraten wurden mit SEM und EDX aufgeklärt. Mittels des LPE Verfahrens waren Felder von Mikropyramiden erzeugt worden, deren Böschungswinkel typisch sind für die kubische Struktur von Diamant. Mikroanalysen ergaben die Zusammensetzung C - Si - Ge, wobei die Verhältnisse dieser drei Elemente bei konstantem Böschungswinkel gezielt variiert werden können. Die aus Kalkstein errichtete Kickpyramide von Dahschur mit über 105 m Höhe weist fast bis zur Hälfte den gleichen Böschungswinkel von 54,5 Grad auf, wie er für die Diamantstruktur typisch ist. Über die geometrische Tangens-Funktion ergibt sich ein Zahlenwert von 1,41 in sehr guter Übereinstimmung mit dem Wert Quadratwurzel aus 2. Auch bei der Realisierung des oberen Teils der Knickpyramide kommt eine Wurzelfunktion von 2 zum Tragen. Das sind überraschende Befunde, da die Mathematik der alten Ägypter die Operation des Radizierens nicht kannte. Es wird eine Erklärung hierzu vorgestellt.

HL 19: Thermoelectricity

Time: Tuesday 11:30–12:45 Location: H33

HL 19.1 Tue 11:30 H33

Simulating time dependent thermoelectric transport with t-Kwant — •Phillipp Reck, Adel Kara Slimane, and Geneviève Fleury — SPEC, CEA, CNRS, Université Paris-Saclay, CEA Saclay, 91191 Gif sur Yvette Cedex, France

Recent theoretical works suggest that the thermoelectric efficiency of a nanodevice could be greatly enhanced if it is suddenly pushed out of equilibrium with the use of an external time-dependent parameter [1-3]. In those studies, quantum dot models were considered and the thermoelectric properties were calculated analytically with a non equilibrium Green's function (NEGF) approach. Instead, we are developing an extension to the t-Kwant library [4] which will enable us to study numerically time-dependent thermoelectric transport in arbitrary (non-interacting) tight-binding models. It is based on a wave function approach, equivalent to the NEGF approach but drastically more efficient from a numerical point of view.

In this talk I will briefly introduce t-Kwant and discuss how to generalize it to thermoelectric transport. I will show that we reproduce previous results in the literature within derived the NEGF formalism for the resonant level model [1,5] and discuss first results for the dynamic thermoelectric transport in more complicated nanodevices.

[1] A. Crépieux et al., Phys. Rev. B 83, 153417 (2014)
[2] H. Zhou et al., Scientific Reports 5, 14870 (2015)
[3] A.-M. Daré and P. Lombardo, Phys. Rev. B 93, 035303 (2016)
[4] B. Gaury et al., Physics Reports 534, 1 (2014)
[5] F. Covito et al., J. Chem. Theory Comput. 14, 2495 (2018)

HL 19.2 Tue 11:45 H33

Synthesis of organic-inorganic hybrids based on mesoporous silicon and PEDOT:PSS — •Haider Haseeb, Klaus Habicht, and Tommy Hofmann — Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Berlin, Germany

This contribution thoroughly discusses synthesis routes to combine mesoporous silicon and the conductive polymer blend, polyethylendioxythiophene:polystyrenesulfonate (PEDOT:PSS) in novel organic-inorganic hybrid materials. The synthesis of self-supporting, mesoporous silicon membranes by means of electrochemical etching is described in detail. Post treatment in hydrogen peroxide and hydrofluoric acid subsequently proves to be a versatile approach to widen the average pore size from 8 nm in as-etched samples to 25 nm in post-treated samples. The increased pore size and fine-tuned wetting properties of diluted PEDOT:PSS solutions are crucial for liquid imbibition into the pore space and thus for the synthesis of the hybrids. Microscopic SEM studies and gas adsorption isotherms are invaluable tools to reveal morphological properties of the synthesized samples. They readily show changes in pore size distributions, specific surfaces and porosities upon chemical treatment. They also provide stringent proof for successful incorporation of PEDOT:PSS into mesoporous silicon. Our contribution discusses in an outlook - the synthesized samples in the context of novel organic-inorganic thermoelectric hybrids.

HL 19.3 Tue 12:00 H33

Phonons in mesoporous silicon: the influence of nanostructuring on the dispersion in the Debye regime — •Tommy Hofmann and Klaus Habicht — Helmholtz Zentrum Berlin für Materialien und Energie, Berlin, Deutschland

This contribution presents a comprehensive scattering study of nanostructured silicon [1]. Neutron and x-ray scattering experiments elucidate structural and dynamical properties of electrochemically etched, porous silicon membranes with pores roughly 8 nm across. In particular, inelastic cold neutron scattering techniques reveal the phonon dispersion of the nanostructured, single crystalline samples in the linear Debye regime for energy transfers up to 4 meV whereas inelastic thermal neutron scattering experiments provide access to the dispersion closer to the zone boundary. A modified dispersion relation characterized by systematically reduced sound velocities manifests itself in altered elastic properties of porous silicon when compared to bulk silicon. Its relevance for nanostructured silicon as thermoelectric material of interest is discussed. In this context, we give an outlook on phonon lifetime measurements to ascertain directly phonon scattering rates in nanostructured silicon by means of neutron spin-echo studies.

[1] T. Hofmann, D. Wallacher, R. Toft-Petersen, B. Ryll, M. Reehuis, and K. Habicht. Phonons in mesoporous silicon: the influence of nanostructuring on the dispersion in the Debye regime. Microporous and Mesoporous Materials, 243:263*270, 5 2017.

HL 19.4 Tue 12:15 H33

Structure and Thermoelectric Characterization of Li-substituted Bismuth Palladium Oxide — •Hong Hai Nguyen, Jan-Ekkehard Hoffmann, Klaus Habicht, and Katharina Fritsch — Helmholtz-Zentrum Berlin für Materialien und Energie , Hahn-Meitner-Platz 1, 14109 Berlin

Bismuth palladium oxide (Bi_2PdO_4) has recently been theoretically proposed as a promising thermoelectric oxide. The material is predicted to display an intrinsically low thermal conductivity κ related to Bi anharmonicity and good electrical properties due to the presence of PdO_4 square planar motifs, and a high power factor $PF=\sigma S^2$ upon hole doping. In this talk, we present experimental work on the synthesis of polycrystalline and bulk samples of Bi_2PdO_4 and Li-substituted $Bi_2Pd_{1-x}Li_xO_4$ and report on their structural characterization by means of powder diffraction measurements. We confirm the incorporation of Li at the Pd site from Rietveld refinements of our neutron diffraction data. Measurements of the TE properties reveal a very low κ close to the amorphous limit for all studied samples, in excellent agreement with theory. Moreover, we find that Bi_2PdO_4 is electrically insulating, leading to a rather low PF over the whole temperature range studied, while the Seebeck coefficient is high - in disagreement with theory. Surprisingly, incorporation of tiny amounts of Li (x=0.02) leads to an increase in electrical conductivity by two orders of magnitude. Overall, the measured PF is found to be considerably smaller than theoretically predicted which we attribute to the theoretical assumption of a much larger intrinsic charge carrier density and mobility.

HL 19.5 Tue 12:30 H33

Silicon Nitride Interface Engineering for the Realization of Dopant-free MOSFETs — •Benjamin Richstein[1,2], Thomas Grap[1,2], Lena Hellmich[1], and Joachim Knoch[1] — [1]Institute of Semiconductor Electronics, RWTH Aachen, Germany — [2]Peter Grünberg Institute 11, FZ Jülich, Germany

Dopants are necessary in standard CMOS-technology as they enable conductivity in silicon and provide low contact resistances. Moreover, degenerate doping avoids carrier freeze out in low temperature applications. However, in deep nanoscale MOSFETs even at very high dopant concentrations only a few dopants reside in typical device volumes resulting in strong variability. Furthermore, the nanoscale size leads to deactivation of dopants increasing parasitic source/drain resistances. Thus, new concepts are required to avoid the problems with dopants in small MOSFETs. Therefore we show a study on silicon

nitride interface engineering. Very thin silicon nitride layers in the sub-nm regime are fabricated to suppress the penetration of the metal wave function of S/D-contacts into the bandgap of silicon. This leads to a Fermi-Level-Depinning and a decrease of the Schottky-barrier in Schottky-MOSFETs. As a result, the contact resistivity decreases and the ambipolar behavior can be suppressed. The metal work functions of S/D-contact metals are utilized to obtain N-, or PMOS-like behavior. Dopant-free ohmic contacts were fabricated and characterized at room and very low temperatures. Additionally, Schottky-MOSFETs with S/D-contacts consisting of a thin silicon nitride layer and different contact metals are fabricated to demonstrate unipolar behavior.

HL 20: Optical Properties

Time: Tuesday 14:00–15:15 Location: H31

HL 20.1 Tue 14:00 H31

Second-Order Nonlinear Susceptibility of $KNbO_3$ — •Nils Mengel[1], Florian Dobener[1], Simone Sanna[2], and Sangam Chatterjee[1] — [1]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-Universität Giessen, D-35392 Giessen — [2]Institute of Theoretical Physics and Center for Materials Research, Justus-Liebig-Universität Giessen, D-35392 Giessen

Nonlinear effects offer numerous scientific and economic usability. From low-cost applications, e. g., laser pointers, to complex systems, such as optical parametric amplifiers, nonlinear materials play an important role in almost any spectroscopy related field. Some materials are able to convert the photon energies of available laser sources to photons of higher energy, thus making them key to extend laser excitation to the blue, UV and X-ray regions. The second-order ($\chi^{(2)}$) is the first and, generally, strongest nonlinear term emerging from the Taylor extension of the susceptibility, describing the doubling of the incident frequency. However, its wavelength dependency is somewhat unclear, since most of the materials are only characterized at standard wavelengths such as 532, 1064 or 808nm, as corresponding laser sources were early available.

Here, $\chi^{(2)}$ of potassium niobate ($KNbO_3$) is measured in a relative setup, corrected by the well-characterized nonlinear effects of alpha-quartz. $KNbO_3$ is an interesting material showing high second-order susceptibilities and resonances in the spectral excitation range of a Ti:sapphire laser. The measured spectra are in agreement with corresponding DFT calculations.

HL 20.2 Tue 14:15 H31

THz nonlinear optics in graphene ribbons — M. Mehdi Jadidi[1,2], Kevin M. Daniels[1], Rachel Myers-Ward[3], D. Kurt Gaskill[3], Jacob König-Otto[4,5], •Stephan Winnerl[4], Andrei Shushkov[1], H. Dennis Drew[1], Thomas E. Murphy[1], and Martin Mittendorff[1,6] — [1]University of Maryland, College Park, USA — [2]Columbia University, New York, USA — [3]U. S. Naval Research Laboratory, Washington DC, USA — [4]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [5]Technische Universität Dresden, Dresden, Germany — [6]Universität Duisburg-Essen, Duisburg, Germany

Graphene plasmonics is an emerging field due the unique combination of spectral tunability, strong plasmonic resonance and low losses. Here we study the nonlinear optical properties of graphene bilayer ribbons, featuring a plasmonic resonance at 3.9 THz, in time resolved experiments. A redshift of the plasmonic resonance is observed upon excitation with picosecond THz pulses. The unconventional nonlinear effect is explained by the optical response of hot carriers. Already at fairly low fluences in the $\mu J/cm^2$ range strong changes in transmission in the 10 % range can be induced. This strong response, together with the fast recovery determined by the electron cooling time (∼10 ps), makes the system promising for optical switching applications.

HL 20.3 Tue 14:30 H31

Nonlinear Optical Properties of Group-IV-Tetraphenyls — •Marius Müller, Florian Dobener, and Sangam Chatterjee — Institute of Experimental Physics I and Center for Materials Research, Heinrich-Buff-Ring 16, Justus-Liebig-University Giessen, D-35392 Giessen, Germany

Tetraphenyl compounds of adamantane-like organic and inorganic clusters show strong nonlinear optical properties. For some habitus, they generate a supercontinuum by infrared cw-laser pumping. However, the underlying mechanism for the nonlinear optical effect is not completely understood. Tentatively, delocalized π-electron systems promote the white light generation. Also, amorphous habitus exhibit supercontinuum generation, while crystalline habitus feature second harmonic generation.

Group-IV-tetraphenyls (Ph_4X) are an alternative group of compounds to examine the influence of the crystallinity on the nonlinear optical properties. These compounds were prepared as single crystals and microcrystalline powders and their nonlinear optical properties are investigated. The compounds are known to show second-harmonic generation, but white-light generation is also observed. We investigated the cause for the change of behavior. The molecules show photo degradation at higher excitation power, which was analyzed using Raman spectroscopy.

HL 20.4 Tue 14:45 H31

Nonlinear white-light generation driven by far infrared light in the broad region from 20 μm to 240 μm — •Nils W. Rosemann[1,2], Florian Dobener[2], Robin C. Döring[2], Eike Dornsiepen[3], Stefanie Dehnen[3], and Sangam Chatterjee[2] — [1]Division of Chemical Physics, Department of Chemistry, Lund University, Sweden — [2]Institute of Experimental Physics I, Justus-Liebig-Universität Giessen, D-35392 Giessen, Germany — [3]Faculty of Chemistry and Materials Sciences Center, Philipps-Universität Marburg, D-35043 Marburg, Germany

The far infrared response of an amorphous cluster compound which exhibits highly nonlinear optical properties is presented. The extreme nonlinearity enables white-light generation using excitation wavelengths in the range from 20 μm to 240 μm. The emitted light is found to cover a range from the visible to mid-infrared region. Additionally, changes of the emission characteristics for pump energies close to vibrational resonance of the cluster compound are explored. The results support prior developed model that assigns the white-light generation to the anharmonic movement of electrons in the clusters ground state potential and excludes simple photon upconversion.

HL 20.5 Tue 15:00 H31

Tunable optical resonance effects from a tailored hyperbolic metamaterial based on an oxide semiconductor — •Evgenij Travkin[1], Thomas Kiel[1], Sergey Sadofev[1], Kurt Busch[1,2], Oliver Benson[1], and Sascha Kalusniak[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Max-Born-Institut, 12489 Berlin, Germany

The versatile hyperbolic metamaterials (HMMs) can be utilzed for e.g. negative refraction, spontaneous emission enhancement and thermal heat control. Recently, we have studied also the impact of the HMM on optical resonances by embedding an HMM based on stacked layer pairs of dielectric ZnO and metallic highly doped ZnO:Ga into a planar optical microcavity. In this configuration, we have observed anomalous resonance effects, some of which demonstrated strong potential for the realization of subwavelength cavity resonances (Travkin et al., Phys. Rev. B 97, 195133, 2018). We explore this potential by experimentally realizing cavities in which the HMM core is tailored to support the anomalous modes spectrally below any permitted conventional cavity mode. Subsequently, we experimentally confirm the existence of subwavelength resonances in the near infrared spectral range. The experimental and numerical study of different-sized HMM-cavities reveals a surprising behavior of the individual mode dispersion with decreasing cavity length, showing among other mode separation and a reversal in dispersion monotony. Further, we compare the results between cavities with different metal fill factors of the HMM core and study the plasmonic nature of the observed effects in detail.

HL 21: Quantum Nanophotonics in Solid State Systems

Time: Tuesday 14:00–15:30 Location: H33

HL 21.1 Tue 14:00 H33

Single-spin-readout via spin-selective tunnelling aided by a microwave resonator — •Florian Ginzel, Maximilian Russ, and Guido Burkard — Department of Physics, University of Konstanz, D-78457 Konstanz, Germany

Recent implementations of the energy-selective schemes for single-spin-readout encountered limitations for its use in quantum information processing or sensing [1]. In this theoretical work an alternative detection method is proposed where a microwave resonator is used to read out the spin state through the state-dependent dispersive shift of the cavity frequency [2,3]. Using input-output-theory the expectation value and variance of the output field of the cavity are calculated from an idealised model. The cavity response to spin-dependent charge transitions distinguishes the initial spin-states of the electron with high fidelity. The feasibility of the cavity mediated spin-readout is discussed and the optimal operating regime is indicated.

[1] D.M. Zajac *et al.*, Science **359**, 439 (2018)
[2] K.D. Petersson *et al.*, Nature **490**, 380 (2012)
[3] G. Burkard, J.R. Petta, Phys. Rev. B **94**, 195305 (2016)

HL 21.2 Tue 14:15 H33

Quantum dot rapid adiabatic passage by ultrafast Stark tuning — Amlan Mukherjee[1], Alex Widhalm[1], •Björn Jonas[1], Sebastian Krehs[1], Nand Lal Sharma[1], Peter Kölling[2], Andreas Thiede[2], Jens Förstner[2], Dirk Reuter[1], and Artur Zrenner[1] — [1]Physics Department, University of Paderborn, Warburger Straße 100, Paderborn 33098, Germany — [2]Department of Electrical Engineering, University of Paderborn, Warburger Straße 100, Paderborn 33098, Germany

An exciton in a single quantum dot is an attractive implementation of a qubit, since it can be Rabi-flopped or coherently manipulated with pulsed laser fields. Robust methods of preparation have been demonstrated by the application of polarization tailored pulses [1] or chirped laser pulses, resulting in rapid adiabatic passage (RAP) [2,3]. Here we use unchirped laser pulses and an ultrafast transient Stark shift of the exciton energy to prepare an inversion via RAP. We use self-assembled InGaAs QDs embedded in a low capacitance Schottky-photodiode. An ultrafast BiCMOS chip that is closely connected to the photodiode generates transient Stark shifts as fast as 3.6 μeV/ps. It operates at low temperature and is synchronized to the laser excitation. By detecting the occupancy of the QD via photocurrent detection, we are able to observe the transition from the unchirped Rabi scenario to a RAP when the electric chirp is applied.

[1] D. Mantei et al., Sci. Rep. 5, S. 10313 (2015)
[2] Yanwen Wu et al., PRL 106, 067401 (2011)
[3] C.M. Simon et al., PRL 106, 166801 (2011)

HL 21.3 Tue 14:30 H33

Giant Rydberg excitons in the presence of an ultralow-density electron-hole plasma — Julian Heckötter[1], Martin Bergen[1], Marcel Freitag[1], Dietmar Fröhlich[1], Manfred Bayer[1], Peter Grünwald[2], Florian Schöne[2], Dirk Semkat[3], Heinrich Stolz[2], Stefan Scheel[2], and •Marc Assmann[1] — [1]Experimentelle Physik 2, TU Dortmund, 44221 Dortmund — [2]Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23-24, 18059 Rostock — [3]Institut für Physik, Ernst-Moritz-Arndt-Universität Greifswald, Felix-Hausdorff-Straße 6, 17489 Greifswald

Giant Rydberg excitons in Cu_2O show a spatial extension up the micrometer range and huge interactions, which may result in intriguing blockade effects similar to the Rydberg blockade known from cold atom physics. We study the Rydberg exciton absorption spectrum in the presence of free carriers injected by above-bandgap illumination. Already at plasma densities below one hundredth electron-hole pair per μm^3, exciton lines are bleached, starting from the highest observed principal quantum number, while their energies remain constant. Also, the band gap decreases due to correlation effects with the plasma. An exciton line loses oscillator strength when the band gap approaches its energy, vanishing completely at the crossing point. Adapting a plasma-physics approach, we describe the observations by an effective Bohr radius that increases with plasma density, reflecting Coulomb interaction screening by the plasma. We distinguish plasma-induced bleaching from genuine Rydberg blockade and discuss the interplay between time-resolved blockade and Rydberg exciton population dynamics.

HL 21.4 Tue 14:45 H33

Coupling of Quantum Emitter Near-Infrared Radiation to Dielectric Mie Resonators — •Viktoriia Rutckaia[1], Joerg Schilling[1], Dominik Schulze[1], Mihail Petrov[2], Frank Heyroth[3], Vadim Talalaev[1], and Alexey Novikov[4] — [1]Martin-Luther University, Halle (Saale), Germany — [2]ITMO University, Saint-Petersburg, Russia — [3]CMAT, Halle (Saale), Germany — [4]IPAM RAS, Nizhny Novgorod, Russia

We demonstrate the possibility of the light control at the nanoscale by using Silicon nanodisks with embedded Ge quantum dots (QDs). Our experimental measurements of the microluminescence reshaping in such structures confirm that Ge QD emission is coupled to the localized Mie modes, and agree well with numerical modeling. We discuss the coupling mechanism and show both numerically and experimentally how the design of the resonators affects the radiative decay rate. For the first time, we demonstrate the Purcell effect in Si/Ge QDs structures from time-resolved microluminescence measurements and discuss how it can be further enhanced by exploiting collective Mie modes in oligomer structures. The work contributes to the development of the near-infrared (NIR) light sources for the telecommunication applications.

HL 21.5 Tue 15:00 H33

Quantization of open and dissipative cavities using quasinormal modes — •Sebastian Franke[1], Stephen Hughes[2], Mohsen Kamandar Dezfouli[2], Philip Trøst Kristensen[3], Kurt Busch[3,4], Andreas Knorr[1], and Marten Richter[1] — [1]Technische Universität Berlin, Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Department of Physics, Engineering Physics and Astronomy, Queen's University, Kingston, Ontario, Canada K7L 3N6 — [3]Institut für Physik, Humboldt Universität zu Berlin, 12489 Berlin, Germany — [4]Max-Born-Institut, 12489 Berlin, Germany

In many cavity-QED platforms, photons are usually described by lossless normal modes, e.g., in the Jaynes-Cummings model. However, for metallic or open cavities, the so-called quasinormal modes[1] (QNMs) with complex eigenfrequencies are more appropriate, and are the natural modes to quantize. Here, we develop a powerful quantization scheme for these modes in absorptive and spatially inhomogeneous media, using a Green's function quantization method[2]. We derive the corresponding Fock state basis for symmetrized QNMs, leading to an intrinsic inter-mode coupling in the QNM master equation[3]. Applications of cavity-QED for metal resonators and hybridized plasmonic-photonic crystal cavities are derived and discussed.

[1] P. T. Leung *et al.*, *Phys. Rev. A* **49**, 3057, 1994
[2] T. Gruner, and D.-G. Welsch, *Phys. Rev. A* **53**, 1818, 1996
[3] S. Franke *et al.*, arXiv:1808.06392v2

HL 21.6 Tue 15:15 H33

Strain spectrally-tunable single photon source based on quantum dots in micropillar cavities — •Magdalena Moczała-Dusanowska[1], Łukasz Dusanowski[1], Stefan Gerhardt[1], Yu-Ming He[2], Marcus Reindl[3], Armando Rastelli[3], Rinaldo Trotta[3,4], Christain Schneider[1], and Sven Höfling[1,5] — [1]Technische Physik, Physikalisches Institut, Würzburg University, Germany — [2]Hefei National Laboratory for Physical Sciences, University of Science and Technology of China, Hefei, China — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Austria — [4]Department of Physics, Sapienza University of Rome, Italy — [5]SUPA, School of Physics and Astronomy, University of St Andrews, UK

In this contribution we demonstrate results of emission tuning of QDs inserted in micropillar cavities. A sample containing an InAs/GaAs QDs embedded in a planar cavity based on Bragg reflectors has been integrated onto the PMN-PT piezo crystal. Subsequently micropillars have been fabricated by electron-beam lithography and reactive ion-etching. The application of an external stress produces roughly linear shifts of QDs emission which could be tuned into the resonance

with fundamental cavity mode. Clear enhancement of QD emission have been observed and a Purcell factor as large as 4.43+/0.64 was extracted from time-resolved measurements based on strain tuning. Second-order autocorrelation histogram for pulsed resonant excitation with a π-pulse has been recorded, indicating high purity single-photon emission.

HL 22: Quantum dots and wires: Transport properties

Time: Tuesday 14:00–15:45 Location: H34

HL 22.1 Tue 14:00 H34

Influence of the Current Density on Universal Conductance Fluctuations in GaN Nanowires — •Patrick Uredat[1,2], Pascal Hille[1,2], Jörg Schörmann[1,2], Martin Eickhoff[3], Matthias T. Elm[1,2], and Peter J. Klar[1,2] — [1]Center for Materials Research, Justus Liebig University, 35392 Giessen, Germany — [2]Institute for Experimental Physics I, Justus Liebig University, 35392 Giessen, Germany — [3]Institute of Solid State Physics, University of Bremen, 28359 Bremen, Germany

We present investigations of the magnetotransport properties of single Ge-doped GaN nanowires grown by molecular-beam epitaxy which exhibit quantum-interference effects at low temperatures. By analyzing the emerging quantum-interference effects the phase-coherence length can be determined in different ways, i.e. based on universal conductance fluctuations (UCF) and weak localization effects. As the phase-coherence length is solely defined by inelastic scattering events the phase-coherence is independent of the current applied. Nevertheless, we show, that the magnitude of the conductance fluctuations rms(ΔG) is strongly affected by the applied current density resulting in an alleged reduction of the obtained phase-coherence length. The decrease of the magnitude rms(ΔG) with increasing current density occurs due to more k-states close to the Fermi energy contributing to the transport which smears out the UCF. We provide a theoretical model to describe the influence of applied current density on the UCF which furthermore enables us to obtain the carrier concentration and carrier mobility of a single Ge-doped GaN nanowires.

HL 22.2 Tue 14:15 H34

Carrier Dynamics in $CuInSe_2$ QD Solids studied by THz Spectrocopy — •Michael Deffner[1,2], Friederieke Gorris[1], Shekhar Priyadarshi[1], Christian Klinke[3], Horst Weller[1,2], and Holger Lange[1,2] — [1]Insitute for Physical Chemistry, University Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [3]Department of Chemistry, Swansea University, United Kingdom

$CuInSe_2$ (CIS) is a cheap, low toxic and stable material to be used as an absorber in solar cells. It has a high absorption coefficient and a tunable optical bandgap [1].

Here, the transport properties of quantum dot (QD) films prepared with colloidal $CuInSe_2$ QDs are studied using optical-pump-terahertz-probe. Using post-synthesized ligand exchange, the transport properties can be increased significantly and the low conductance of this QD solid can be overcome.

Our studies confirm the results of traditional four-point or FET-based measurements and show a much higher carrier mobility after photo-excitation for QD films with specific bridging ligands. Nevertheless, the responses of the films are distinctly different for different ligands and will be discussed in this talk.

[1] Nano Lett. 2008, 8, 9, 2982-2987

HL 22.3 Tue 14:30 H34

A quantum-dot heat engine operating close to the thermodynamic efficiency limits — •Martin Josefsson, Artis Svilans, Adam Bruke, Eric Hoffmann, Sofia Fahlvik, Claes Thelander, Martin Leijnse, and Heiner Linke — NanoLund and Solid State Physics, Lund University, Sweden

Particle-exchange heat engines work by using an energy filter to control a thermally driven particle flow between two or more reservoirs at different temperatures. These engines have been predicted to reach the same ideal thermodynamic efficiency limits as those accessible to classic cyclical engines, but this prediction has never been verified. In this work[1] we realize a thermoelectric particle-exchange heat engine based on a quantum dot embedded in a InAs/InP nanowire. We demonstrate an electronic efficiency at maximum power close to the Curzon-Ahlborn efficiency and at the maximum efficiency ($\approx$ 70% of Carnot efficiency) the QD still produces finite power output equal to roughly half of the maximal amount.

These results were obtained by measuring the engine's steady state power output and combining it with the calculated electronic heat flow. This procedure is made possible by an excellent agreement between the modeled and measured generated current, which allows for a quantitative estimate of the heat flow.

[1] Josefsson et al. Nature Nanotechnology 13, 920 (2018)

HL 22.4 Tue 14:45 H34

Local Density of States Fluctuations and Its Influence on the Fermi-edge-singularity in a Quantum Dot — •Jan K. Kühne and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Deutschland

Transport measurements in quantum dots can be used as a spectrometer to study the density of states in the connected leads [1]. By tuning the applied source drain voltage, the current through the quantum dot is changed depending on the number of available states in both leads with the corresponding energy.

We study the transport properties of a self-assembled InAs quantum dot at low temperatures and observe strong fluctuations in the local density of states (LDOS) in dependence of magnetic field B and voltage V. This results in lines of constant differential conductance with a constant slope dB/dV. It is known that interaction effects in quantum dots, such as the Fermi-edge-singularity (FES), strongly depend on the dimensionality and the density of states in the leads [2]. By comparing the LDOS and the interaction due to the FES we find a clear anti-correlation between the strength of the FES and the number of states in the emitter.

[1] T. Schmidt, et al., Phys. Rev. Lett. 78, 1540 (1997).
[2] J. K. Kühne, et al., accepted in Phys. Status Solidi B (2018).

HL 22.5 Tue 15:00 H34

Excess noise in $Al_xGa_{1-x}As$/GaAs based quantum rings — •Christian Riha[1], Sven S. Buchholz[1], Olivio Chiatti[1], Dirk Reuter[2], Andreas D. Wieck[3], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, D-12489 Berlin — [2]Optoelektronische Materialien und Bauelemente, Universität Paderborn, D-33098 Paderborn — [3]Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum

The characteristics of electrical noise provide various information about an electronic system. In ballistic 1D quantum devices [1] excess noise was already found to be related to an electron's transmission probability. In this work, cross-correlated noise measurements are performed in etched $Al_xGa_{1-x}As$/GaAs based ballistic quasi 1D quantum rings [2] at a bath temperature of $T_{bath} = 4.2$ K in equilibrium. The measured white noise exceeds the thermal noise expected from the measured electron temperature T_e and the electrical resistance R of the devices. This excess noise decreases as T_{bath} increases and is not observable anymore at $T_{bath} \geq 12$ K. Furthermore, a reduction of the excess noise is observed when one arm of a quantum ring becomes electrically non-conducting. This excess noise is not observed in 1D-constrictions that share a comparable length and width with the quantum rings. The results suggest that the excess noise is a result of electron interference in the quantum ring.

[1] C. Riha *et al.*, Phys. Status Solidi A **213**, 571 (2016).
[2] C. Riha *et al.*, Appl. Phys. Lett. **106**, 083102 (2015).

HL 22.6 Tue 15:15 H34

Multigate Structures for the Realization of Electrostatically Tunable Devices — •Thomas Grap[1,2], Felix Riederer[1], and Joachim Knoch[1] — [1]Institute of Semiconductor Electronics, RWTH Aachen, Germany — [2]Peter Grünberg Institute 11, FZ Jülich, Germany

One-dimensional (1-D) materials such as nanowires (NW) and nanotubes (NT) have attracted a great deal of attention as buildings blocks

of future nanoelectronics systems. This interest is in part due to the small geometry that allows realizing optimum scalability of the devices. In addition, NW and NT enable one-dimensional electronic transport that has a number of benefits such as a rather long mean free path for scattering.

In order to characterize such nanostructures, we developed a template structure, which allows to electrostatically tune 1-D materials on the nanoscale and thus exploit quantum effects. We present a study on a multi-gate device architecture where a large number of buried gates (on the order of 10 and more) are fabricated in a damascenelike process. The gates exhibit lengths well below 10nm and are placed next to each other with a few nanometers inter-gate distance. Each gate is contacted individually via Ebeam-lithography, so that this device-layout enables a tight control over the potential distribution within a 1-D nanostructure. First measurements of the electronic transport along a VLS-grown InAs-NW by applying appropriate voltages to the buried multi-gates are presented.

HL 22.7 Tue 15:30 H34

Thickness dependence of the magnetic field induced metal-insulator transition in graphite — •Laetitia Paula Bettmann, Jose Luis Barzola Quiquia, Markus Stiller, and Pablo Esquinazi — Division of Superconductivity and Magnetism, Felix-Bloch Institute for Solid State Physics, University of Leipzig, 04103 Leipzig, Germany

We have measured the temperature dependence of the resistance and magnetoresistance of bulk and multigraphene samples prepared from a natural graphite sample from Sri Lanka. The samples were measured at different constant magnetic fields in order to observe the well-known magnetic-field-induced metal-insulator transition in graphite. Our results indicate that the transition has a thickness dependence, i.e. in the case of thin samples (thickness less than 30 nm) this effect vanishes. We attribute the field induced metal-insulator transition to the presence of metallic-like two-dimensional interfaces formed between the crystals, which disappear when the sample thickness is of the order of the single crystalline regions of the sample. Our experimental results can be well understood using a model, which takes explicitly into account the interfaces contributing in parallel to the semiconducting crystalline regions.

HL 23: Two-dimensional Materials II: graphene (joint session HL/CPP)

Time: Tuesday 14:00–15:45 Location: H36

HL 23.1 Tue 14:00 H36

Field-controllable spin relaxation anisotropy in graphene/hBN heterostructures — •Klaus Zollner[1], Martin Gmitra[2], and Jaroslav Fabian[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institute of Physics, P. J. Šafárik University in Košice, 04001 Košice, Slovakia

Measurements show a large and tunable anisotropy in the spin relaxation of hBN encapsulated bilayer graphene [1,2], similar to what is observed in graphene/TMDC heterostructures [3]. Combining systematic first principles calculations for graphene/hBN heterostructures with a minimal tight-binding model, we extract spin-orbit coupling parameters of graphene in the μeV range. The extracted model parameters depend on (i) interlayer distances, (ii) stacking configurations, and (iii) an external electric field, resulting in a rich parameter space. Based on the Dyakonov-Perel formalism we calculate spin relaxation times for graphene, in the nanosecond range, in agreement with recent experimental measurements. A very important finding is that the spin relaxation anisotropy is maximum close to the charge neutrality point, decreasing with the doping level. In addition, we also show that the anisotropy can be tuned by means of an external electric field, via the precise control of the Rashba SOC.

This work is supported by the DFG SPP 1666.

[1] Xu et al., PRL 121, 127703 (2018)
[2] Leutenantsmeyer et al., PRL 121, 127702 (2018)
[3] Cummings et al., PRL 119, 206601 (2017)

HL 23.2 Tue 14:15 H36

Microscopic theory of band gap opening and spin-orbit splitting in graphene/TMDC heterobilayers — •Alessandro David[1], Andor Kormányos[2], and Guido Burkad[1] — [1]Department of Physics, University of Konstanz, Konstanz, Germany — [2]Department of Physics of Complex Systems, Eötvös Loránd University, Budapest, Hungary

Bilayers of graphene and monolayer transition metal dichalcogenides (TMDCs) are fascinating van der Waals heterostructures with an interesting electronic band structure. Theoretical ab initio calculations have shown a gap opening and a spin-orbit splitting in the band structure of graphene that are induced by the TMDC layer [1, 2]. These results have been experimentally confirmed by recent magnetotransport experiments showing weak antilocalisation (WAL) [2, 3]. Using perturbation theory, we propose a microscopic model to explain the origin of the gap and of the spin-orbit splitting. We also consider the dependence of the spin-orbit splitting on the misalignment of graphene and TMDC layers.

[1] M. Gmitra, D. Kochan, P. Högl, and J. Fabian, Phys. Rev. B 93, 155104 (2016). [2] Z. Wang, D.-K. Ki, H. Chen, H. Berger, A. H. MacDonald, and A. F. Morpurgo, Nat. Comm. 6, 8339 (2015). [3] T. Wakamura, F. Reale, P. Palczynski, S. Guéron, C. Mattevi, and H. Bouchiat, Phys. Rev. Lett. 120, 106802 (2018).

HL 23.3 Tue 14:30 H36

Spatio-temporal dynamics in graphene — •Roland Jago, Samuel Brem, and Ermin Malic — Chalmers University of Technology, Gothenburg, Sweden

While the time- and energy resolved non-equilbirium dynamics in graphene is well understood [1], there is only little known about spatio-temporal electron dynamics. Optically excited carriers at the interfaces of inhomogeneities (e.g. p-n junctions, different substrate regions) create density and temperature gradients resulting in diffusion of carriers. Since many-particle interactions and diffusion depend on the conditions of the inhomogeneity, the transport of carriers is asymmetric and results in a photocurrent.

In this work, we apply the density matrix formalism solving the spatio-temporal graphene Bloch equations. We provide microscopic access to time-, momentum and spatially resolved optical excitation, Coulomb- and phonon-induced relaxation dynamics, and conversion of light into electrical current in graphene. The gained microscopic insights allow us to predict optimal conditions for photodetection in graphene.

[1] E. Malic and A. Knorr, Ultrafast optics and relaxation dynamics, VCH-Wiley, Berlin (2013)

HL 23.4 Tue 14:45 H36

How Laser-induced defects modify optical properties of semiconducting Armchair Graphene Nanoribbons — •Seyed Khalil Alavi[1,2], Boris V. Senkovskiy[3], Markus Pfeiffer[1], Danny Haberer[4], Felix R. Fischer[4], Alexander Grüneis[3], and Klas Lindfors[1] — [1]Department of Chemistry, Universität zu Köln, Luxemburger Str. 116, 50939 Köln, Germany — [2]Institut für Angewandte Physik der Universität Bonn, Wegeler Strasse 8, 53115 Bonn, Germany — [3]II. Physikalisches Institut, Universität zu Köln, Zülpicher Strasse 77, 50937 Köln, Germany — [4]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

Armchair graphene nanoribbons (AGNRs) with tunable band gap are promising candidate for optoelectronic devices. We have earlier shown how photoluminescence emission is boosted via formation of laser-induced defects in AGNRs lattices [1]. Here we probe the origin of this modification by measuring the extinction spectrum of a layer of AGNRs. Our results show that there are two pronounced peaks at approximately 2.4 and 1.8 eV in the spectrum of pristine GNRs. The latter peak energetically coincides with emission feature. This peak surprisingly disappears from the extinction spectrum after defects formation. We thus attribute the 1.8 eV peak to a quenching state. We additionally extract the absolute absorbance of AGNRs and find that it is a factor of three higher than graphene absorbance in visible range.

[1] B. V. Senkovskiy, M. Pfeiffer, S. K. Alavi, et al., Nano Lett. 17, 4029-4037, 2017.

HL 23.5 Tue 15:00 H36

Anisotropic strain induces a transition between rhombo-

hedral and Bernal stacking in multilayer graphene flakes — Fabian Geisenhof[1], Raúl Guerro-Aviles[2], Marta Pelc[2], Felix Winterer[1], Tobias Gokus[3], Yasin Durmaz[3,4], Daniela Priesack[1], Jakob Lenz[1], Fritz Keilmann[4,5], Andres Ayuela[2], and •Thomas Weitz[1,4,5,6] — [1]AG Physics of Nanosystems, Faculty of Physics, LMU München, Germany — [2]Donostia International Physics Center, San Sebastian, Spain — [3]Neaspec GmbH, München, Germany — [4]Department of Physics, LMU München, Germany — [5]Center for Nanoscience (CeNS), München, Germany — [6]Nanosystems Initiative Munich (NIM), München, Germany

Graphene multilayers are still full of surprises - this is clear at latest since the recent discovery of unconventional superconductivity in 'magic-angle' bilayer graphene. Not only in bilayers the density of states critically depends on the lateral alignment of subsequent layers, but also in thicker graphene stacks (e.g. in trilayers). There, two different forms of stacking, so called Bernal and rhombohedral stacking exist, each with distinct charge transport properties. Via combined theoretical and experimental efforts we have surprisingly found [1], that during the fabrication process with conventional e-beam lithography, anisotropic strain forces rhombohedrally stacked regions towards Bernal stacking. We have experimentally identified the stacking change with Raman spectroscopy and s-SNOM measurements and devised methods how to avoid the transformation. [1] F.G. Geisenhof et al. ArXiv:1810.00067 (2018)

HL 23.6 Tue 15:15 H36

Bio-compatible graphene exfoliation assisted by flavin mononucleotide sodium: a molecular dynamics study — •Shirong Huang[1], Alexander Croy[1], Viktor Bezugly[1,2], and Gianaurelio Cuniberti[1,3] — [1]Institute for Materials Science and Max Bergmann Center for Biomaterials, Technische Universität Dresden, 01062 Dresden, Germany — [2]Life Science Inkubator Sachsen GmbH & Co. KG, Tatzberg 47, 01307 Dresden, Germany — [3]Dresden Center for Computational Materials Science (DCMS), TU Dresden, 01062 Dresden, German

Flavin mononucleotide sodium (FMNS) was reported as a highly efficient bio-dispersant for the exfoliation of aqueous dispersions of defect-free, few-layer graphene flakes. Most importantly, FMNS is innocuous and environment friendly and can facilitate bio-medical applications of graphene. Although there is some experimental work on graphene exfoliation assisted by FMNS, it is not clear how FMNS molecules behave on the graphene flake. Here, we clarify the interaction between FMNS and graphene flakes via all-atom molecular dynamic simulations. The exfoliation mechanism of FMNS on the graphene flake is investigated by the potential of mean force (PMF) of pairs of graphene flakes coated with FMNS. This work provides a basis for understanding of graphene exfoliation assisted by FMNS-like surfactants and paves a path to design highly efficient dispersants for defect-free, few layer graphene.

HL 23.7 Tue 15:30 H36

Scanning Nitrogen-Vacancy Center Magnetic Imaging of Graphene Devices — •Susanne Baumann, Alec Jenkins, Simon Meynell, Haoxin Zhou, Andrea Young, and Ania Bleszynski Jayich — UC Santa Barbara, Santa Barbara, USA

The NV center is a quantum probe that is sensitive to a variety of fields (magnetic, electric, thermal, strain), can achieve nanoscale spatial resolution, is non-invasive, and can operate over a wide range of temperatures; hence it is an ideal tool for studying novel phases of matter that often emerge only below a critical temperature. Here we use a cryogenic scanning NV magnetometer to probe the stray magnetic field of a current running through a single layer graphene device. With this technique we are able to probe different regimes of current flow via their local signatures over a variety of temperatures.

HL 24: Nitrides: Preparation and characterization I

Time: Wednesday 9:30–13:00 Location: H31

HL 24.1 Wed 9:30 H31

Band Offset at the Ga(N,As,P)/GaP Heterointerface — •Florian Dobener[1,3], Sebastian Gies[1], Jan O. Oelerich[1], Peter Ludewig[2], Kerstin Volz[1], Stephan W. Koch[1], Wolfgang Stolz[1,2], Wolfram Heimbrodt[1], and Sangam Chatterjee[3] — [1]Faculty of Physics and Material Sciences Center, Philipps-Universität Marburg, D-35032 Marburg — [2]NAsP III/V GmbH, Am Knechtsacker 19, D-35041 Marburg — [3]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-University Giessen, D-35392 Gießen

We investigate a series of Ga(N,As,P) multiple quantum well samples grown by MOVPE. The well thickness is varied, while the composition is kept quasi-constant. The samples are examined by PL excitation spectroscopy to reveal the absorptive states in the sample, which contribute to the actual PL intensity. Besides higher states, we find two clear peaks slightly above the band-gap energy, which we attribute to the highest-energy heavy-hole valence band to lowest-energy conduction band energy and highest-energy light-hole valence band to lowest-energy conduction band energy transitions of the samples. Consequently, we are able to model the band offset between the Ga(N,As,P) quantum well and the GaP barrier with a band anti-crossing model and the model solid theory to attribute for strain in the sample. Additionally, depth-scan X-ray and UV photoelectron spectroscopy reveals the valence band-offset at the GaP/Si and Ga(N,As,P)/GaP interface, too. Overall, a rather shallow valence band offset is found by comparing the outcomes to the optical studies and to DFT calculations.

HL 24.2 Wed 9:45 H31

Growth rate reduction of cubic III-nitrides at high doping levels in molecular beam epitaxy — •Michael Deppe[1], Jürgen W. Gerlach[2], Dirk Reuter[1], and Donat J. As[1] — [1]University of Paderborn, Department of Physics, Warburger Straße 100, 33098 Paderborn — [2]Leibniz Institute of Surface Engineering (IOM), Permoserstraße 15, 04318 Leipzig

The most common donor for n-type doping of cubic GaN (c-GaN) is silicon. Recently we have also investigated germanium as an n-type donor for c-GaN and found that it is a well-suited alternative to silicon. We present the growth of c-GaN layers doped by Si and Ge up to the order of 10^{20} cm^{-3}. Layers are grown by plasma-assisted molecular beam epitaxy on 3C-SiC (001) substrates. Thicknesses of the c-GaN layers are determined by reflectometric interference spectroscopy and time-of-flight secondary ion mass spectrometry. We find that the growth rate remains constant up to donor concentrations around 10^{19} cm^{-3} and decreases at higher doping levels both with Ge and Si dopants. The growth rate of the highest Ge-doped sample is reduced by 40% compared to undoped samples and it is reduced by 23% for the highest Si doping. Additionally, Ge-doped c-$Al_{0.25}Ga_{0.75}N$ layers are grown with donor concentrations comparable to the c-GaN layers. No reduction of the growth rate could be observed for c-$Al_{0.25}Ga_{0.75}N$. We suppose the growth rate reduction in c-GaN is among others due to higher bond dissociation energies of Ge-containing bonds compared to Ga-containing bonds. Dissociation energies of bonds involving Al however are higher, thus the effect is not observed in c-AlGaN.

HL 24.3 Wed 10:00 H31

Molecular beam epitaxial growth of GaZnON layers for photocatalytic applications — •Elise Sirotti, Max Kraut, Florian Pantle, Marvin Koch, and Martin Stutzmann — Walter Schottky Institut and Physics Department, Technische Universität München, Am Coulomb-wall 4, 85748 Garching, Germany

GaN and ZnO have a favorable energy position of their band edges with respect to the redox levels of many electro-chemical reactions. Still, their large band gap limits the use for simultaneous solar light absorption and photocatalytic activity. One possibility to tune the bandgap into the visible regime are compounds of Ga, Zn, O, N, for which the valence band edge can be shifted to higher energies with respect to the vacuum level without affecting the conduction band energy.

We present the growth of GaZnON layers by means of plasma-assisted molecular beam epitaxy (MBE) on c-plane sapphire. The quality and composition of the quaternary compound have been optimized by varying the temperature, metal fluxes and nitrogen-to-oxygen ratio during deposition. We performed photothermal deflection spectroscopy, transmission, and photoluminescence measurements to investigate the optical properties, as well as, AFM and Raman spec-

troscopy for insights into the structural properties of the as-grown layers. Furthermore, the MBE-growth of GaN\GaZnON nanowire (NW) core\shell structures is demonstrated. This geometry benefits from the efficient outcoupling of light from backside illumination through the GaN NWs and the promising catalytic properties of the GaZnON shells.

HL 24.4 Wed 10:15 H31

All-optical determination of free-carrier concentration and composition in cubic GaN and AlGaN — •Elias Baron[1], Michael Deppe[2], Fabian Tacken[2], Donat Josef As[2], Martin Feneberg[1], and Rüdiger Goldhahn[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Department Physik, Universität Paderborn, Germany

The doping by Ge is shown to be a very efficient way to achieve free electron concentrations n above $10^{20}\mathrm{cm}^{-3}$ in wurtzite and zincblende GaN and AlGaN layers, while maintaining excellent structural properties. Here, thin films of zincblende III-N were deposited by plasma-assisted molecular beam epitaxy on 3C-SiC substrates. Utilizing Kane's model and the optical effective mass in semiconductors a consistent approach to determine the band structure near the Γ-point of the Brillouin zone is achieved, which is necessary to understand the optical properties. We present a characterization of GaN and AlGaN by spectroscopic ellipsometry from which the complex dielectric function (DF) is obtained. The analysis of the DFs in the mid-infrared yields the transverse-optical phonon frequencies as well as the plasma frequency for doped material. From the latter, the free-carrier concentration can be deduced. On the other hand, studies around the fundamental absorption edge indicate the superposition of n dependent Burstein-Moss effect, band gap renormalization and in case of AlGaN band gap bowing. A self-consistent description of plasma frequency and absorption onset yields both the free-carrier concentration and the composition in case of AlGaN.

HL 24.5 Wed 10:30 H31

Photo-induced selective etching of GaN nanowires in water — •Florian Pantle, Max Kraut, Julia Winnerl, Martin Hetzl, Felix Eckmann, and Martin Stutzmann — Walter Schottky Institut and Physics Department, Technische Universität München, Garching, Germany

GaN nanowires (NWs) have gained much interest in current research as they are promising candidates for photo-catalytic water splitting devices. A key requirement is the stability of these nanostructures under operational conditions. Despite many reports regarding anodic oxidation and photo-electrochemical stability of bulk GaN, both including p- and n-type material and different crystallographic facets in aqueous environments, these properties have remained widely unexplored for GaN NWs.

We have investigated the stability of GaN NWs under illumination in water. While the non-polar m-plane side walls of the NWs are decomposed under the applied conditions, the polar c-plane top facet is stable. Photo-induced holes are found to be responsible for this effect. Further, the crystal quality is found to be a decisive parameter. All hexagonal NWs show a characteristic etching morphology, which is explained by means of numerical band structure simulations. Additionally, we present a chemical and a structural pathway to stabilize the GaN NWs against the applied environments.

HL 24.6 Wed 10:45 H31

Integrated GaN Light Emitting Diode - GaN Nanowire Devices for Photocatalysis — •Sabrina Artmeier, Julia Winnerl, and Martin Stutzmann — Walter Schottky Institut and Phyics Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

Gallium nitride (GaN) nanowires (NWs) have attracted much interest for device fabrication due to their large surface-to-volume ratio and their optical waveguide character. Moreover, the favorable energy position of their bands with respect to many redox potentials in liquid electrolytes make them promising candidates for photocatalytic applications, such as water splitting or CO2 conversion. GaN NWs integrated on a planar light emitting diode (LED), serving as a platform for photocatalytic reactions, enable the efficient coupling of the light from the LED to the waveguide modes supported within the NWs.

Using an LED as the light source for photocatalytic reactions enables the choice of a specific wavelength, which is matched to the photocatalytic reaction targeted, and pulsed operation, which is matched to the chemical reaction kinetics. Here, we present a systematic study of the time-resolved electroluminescence (EL) emitted from an LED operated in pulsed mode and coupled out through different GaN NW arrays. We have investigated the influence of the pulse length, the pulse form as well as the NW array geometry, namely the NW diameter and the period and compared the results to those of a bare LED. We found different behaviour of the turn-on delay time, the rise and the decay time for the different samples investigated.

15 min. break

HL 24.7 Wed 11:15 H31

Optical properties of homoepitaxial AlGaN/GaN MQWs — •Markus Schleuning[1], Markus Wagner[1], Benjamin Damilano[2], and Axel Hoffmann[1] — [1]Technische Universität Berlin, Berlin, — [2]CRHEA-CNRS, Valbonne, France

AlGaN/GaN MQWs with varying well thickness, Al barrier content and number of stacks were grown by homoepitaxial MBE on c-plane GaN substrates and investigated using PL, TRPL and CL spectroscopy. The quantum well structures exhibit a low surface roughness of $R_{RMS} \approx 0.3\,\mathrm{nm}$. The MQW emission energies could be adjusted between 3.3 eV and 3.5 eV as function of well width and Al composition of the barrier. TRPL measurements reveal radiative lifetimes between 0.5 ns and 0.5 μs. The luminescence shift to lower energies and increase of lifetimes are interpreted as consequence of the quantum confined Stark effect (QCSE) that has its origin in piezoelectric and spontaneous polarization fields. Furthermore localization energies at 10 K of up to 30 meV are found using temperature resolved PL. Especially the 3 nm thick MQWs show efficient free exciton luminescence with a FWHM of only 40 meV at 300 K caused by large exciton binding energies in the confined structure.

HL 24.8 Wed 11:30 H31

Effect of optimized GaN underlayers on the radiative efficiency of GaInN/GaN quantum wells — •Philipp Horenburg[1], Philipp Henning[1], Savutjan Sidik[1], Uwe Rossow[1], Heiko Bremers[1,2], and Andreas Hangleiter[1,2] — [1]Institute of Applied Physics, Technische Universität Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany

We present the influence of optimized low temperature GaN underlayers on the efficiency of GaInN/GaN quantum well (QW) structures prepared by metal-organic vapor phase epitaxy (MOVPE).
As light emission from group-III nitride QW structures is governed by radiative and nonradiative processes, the active region is highly susceptible to structural defects, acting as nonradiative recombination centers and therefore diminishing the radiative efficiency. Insertion of a low indium content GaInN underlayer prior to the QW structure has become a widely used strategy to bury crystallographic defects outside the active region. In this context, the In atoms have been ascribed to play a special role in the defect trap mechanism.
We have grown a series of c-plane single and multiple QW structures by low-pressure MOVPE on sapphire and GaN substrates. By introducing a GaN pre-barrier prior to the GaInN/GaN QWs and optimizing the growth conditions of the former, we find improved efficiency as observed by photoluminescence measurements. Thus, we argue that not merely the material composition of the underlayer, but particularly the growth parameters, such as the temperature and the precursor fluxes, crucially affect the efficiency of GaInN/GaN QW structures.

HL 24.9 Wed 11:45 H31

Reactive pulsed sputtering of AlN and GaN — •Florian Hörich, Christopher Kahrmann, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Otto-von-Guericke University, Universitätsplatz 2, 39106 Magdeburg, Germany

GaN based devices require high quality buffer layers difficult to achieve on Si(111) substrates. There are several limitations in common growth techniques as MOVPE growth struggles with residual Ga in the AlN nucleation layer and a high thermal mismatch between substrate and grown layer. MBE growth suffers from low lateral growth rates and a sophisticated vacuum system. Here we present a cost-effective growth technique using high purity metal targets and gases in a reactive pulsed sputter process. Plasma generation is carried out by a bipolar pulsed voltage. At negative voltages the targets are sputtered by Ar-ions whereas the positive pulse leads to a stabilisation of the target preventing the increase of an insulating nitride layer on the target. Growth of AlN and GaN on MOVPE grown AlN and GaN templates is investigated to study the process parameters. Growth pressure and gas

composition impact surface morphologies of the layers as observed by AFM measurements. Below 750 °C surfaces show grainy appearance with grain sizes between 10 and 50 nm. Substrate temperatures of 750 °C lead to smoother surfaces with grain sizes up to 250 nm and improved crystal quality determined by XRD measurements. FWHM values in (002) and (103) direction reveal the same values for the grown layer and the MOVPE grown templates.

HL 24.10 Wed 12:00 H31

Influence of Electron Beam Irradiation on the Emission Spectra of InGaN/GaN MQWs — •Hendrik Spende[1], Johannes Ledig[2], Christoph Margenfeld[1], Hergo-Heinrich Wehmann[1], and Andreas Waag[1] — [1]Institute of Semiconductor Technology and Laboratory for Emerging Nanometrology, Braunschweig University of Technology, 38106 Braunschweig — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

A scanning electron microscope equipped with a cathodoluminescence (CL) detection system is a powerful tool for investigating the optical properties of semiconductor microstructures with high spatial resolution. Due to the high kinetic energy of the probe, electrons are scattered and many electron-hole-pairs are generated in the material. As a result, the excitation and recombination rate inside the material are spatially inhomogeneous.

Here we analyze CL spectra of InGaN/AlGaN/GaN samples, each containing MQWs emitting at different wavelengths. By varying the electron beam energy, the electron penetration depth changes and thus the obtained CL signal gives insight into the excitation ratios and relative efficiencies of the different MQWs. We also observe an unexpected and persistent change in the room temperature CL emission of the samples, indicating electron beam induced changes in carrier dynamics within the active area. Electrochemical capacitance-voltage measurement profiles show changes in the active carrier concentration in irradiated regions. Both can be reset by thermal annealing, indicating that the irradiation changes crystal bonds or the charge of trap states.

HL 24.11 Wed 12:15 H31

Thermal activation of non-radiative recombination processes in III-nitride quantum wells — •Philipp Henning, Torsten Langer, Fedor Alexej Ketzer, Silvia Müllner, Philipp Horenburg, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik & Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, 38106 Braunschweig, Germany

In order to understand the origins of defect-related non-radiative charge carrier losses in III-nitride quantum wells, the thermal activation of non-radiative charge carrier recombination is analyzed. Therefore, time-resolved photoluminescence measurements are performed in a wide temperature range between 3.5 and 500 K, which allows a more accurate determination of activation energies compared to an analysis limited to room temperature. Among the possible non-radiative mechanisms are thermal activation over potential barriers, exciton dissociation and multi-phonon capture, which may also be present at low temperatures via tunneling-assisted processes. We compare quantum well samples with different crystal orientations and substrate qualities, as well as the impact of intentionally introduced defects by ion implantation, in order to distinguish the thermal activation of different non-radiative recombination mechanisms. The measurements show activation energies of 5 to 50 meV, reaching up to hundreds of meV. At room temperature, a broad range of non-radiative lifetimes between <100 ps and several 10 ns is found, depending on the crystal orientation and the defect density controlled by the implantation dose.

HL 24.12 Wed 12:30 H31

Dislocation bending in GaN/step-graded (Al,Ga)N/AlN buffer layers on Si(111) investigated by STM and STEM — •Yuhan Wang[1], Lei Zhang[2], Verena Portz[1], Michael Schnedler[1], Lei Jin[3], Xiaopeng Hao[2], Holger Eisele[4], Rafal E. Dunin-Borkowski[1,3], and Philipp Ebert[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, Jülich, 52425, Germany — [2]State Key Lab. of Crystal Materials, Shandong Univ., Jinan, China — [3]Ernst Ruska Centrum, Forschungszentrum Jülich GmbH, Jülich, Germany; — [4]Institut für Festkörperphysik, Technische Universität Berlin, Germany

The distribution and bending of dislocations in GaN/step-graded (Al,Ga)N/AlN buffer layers grown on Si(111) are investigated by cross-sectional scanning tunneling microscopy (STM) and scanning transmission electron microscopy (STEM). We observe dislocations with {a/3}<11-20>-type Burgers vector intersecting the m-plane cleavage surface and having line directions bent off the [0001] growth direction toward non-polar directions. The spatial distribution of dislocations intersecting the m-plane cleavage surface indicates consecutive bending of dislocations due to strain at interfaces between subsequent lattice mismatched buffer layers and at doping junctions, reducing the density of threading dislocations at the (0001) growth front. No interface misfit dislocations, v-shaped defects, or loss of crystalline quality are observed, demonstrating the high performance of the step-graded (Al,Ga)N/AlN buffer layers on Si for relaxing the lattice constant without creating large defect concentrations.

HL 24.13 Wed 12:45 H31

Electron affinity and surface states of GaN m-plane facets: Implication for electronic self-passivation — Verena Portz[1], Michael Schnedler[1], Holger Eisele[2], Rafal E. Dunin-Borkowski[1], and •Philipp Ebert[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, Jülich, 52425, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Germany

The electron affinity and surface states are of utmost importance for designing the potential landscape within (heterojunction) nanowires and hence for tuning conductivity and carrier lifetimes. Therefore, we determined for stoichiometric nonpolar GaN($10\bar{1}0$) m-plane facets, i.e., the dominating sidewalls of GaN nanowires, the electron affinity to 4.06±0.07 eV and the energy of the empty Ga-derived surface state in the band gap to 0.99±0.08 eV below the conduction band minimum using scanning tunneling spectroscopy. These values imply that the potential landscape within GaN nanowires is defined by a surface state-induced Fermi-level pinning, creating an upward band bending at the sidewall facets, which provides an electronic passivation.

HL 25: Group IV (other than C): Si/Ge/SiC

Time: Wednesday 9:30–12:00 Location: H33

HL 25.1 Wed 9:30 H33

Room-temperature coherent electrical readout of silicon vacancy defect spins in silicon carbide — •Matthias Niethammer[1], Matthias Widmann[1], Torsten Rendler[1], Naoya Morioka[1], Yu-Chen Chen[1], Rainer Stöhr[1], Jawad Ul Hassan[3], Sang-Yun Lee[2], Amlan Mukherjee[1], Junichi Isoya[4], Nguyen Tien-Son[3], and Jörg Wrachtrup[1,5] — [1]3rd Institute of Physics, IQST and SCOPE, University of Stuttgart — [2]Korea Institute of Science and Technology — [3]Linköping University — [4]University of Tsukuba — [5]Max Planck Institute for Solid State Research

4H-Silicon Carbide (SiC) is a matured semiconductor with advanced manufacturing technology and is widely used in the power electronics industry. Recently, it has gained lot of attention as a host material for point defects which can be exploited to build quantum sensors. Optical readout of single spin defects with long-lived coherence has already been demonstrated at room temperature. Here we combine the quantum properties of the spin defects in SiC with electrical readout. We demonstrate, electrical readout of the spin state of an silicon vacancy (V_{Si}^-) ensemble in SiC at room temperature using two-photon absorption and photo-current detection technique in a metal-semiconductor-metal device. We show coherent control of the spin states indicating spin preserving nature of the electrical readout technique. Such a technique apart from being scalable, is also compatible with advanced control techniques, which can be directly adapted from the optical domain for an increased sensitivity or other sensing purposes.

HL 25.2 Wed 9:45 H33

Investigation of the Temperature Dependence of the Critical Points E_0 and $E_0+\Delta_0$ of Bulk Ge — •Carola Emminger, Nuwanjula Samarasingha, Farzin Abadizaman, and Stefan Zollner — New Mexico State University, Las Cruces, USA

Knowledge of the behavior of critical points (CPs) of Ge and other semiconductors is valuable for the further development of electronic and optoelectronic devices. The authors investigate the dielectric function of Ge between 0.5 eV and 1.3 eV using spectroscopic ellipsometry at various temperatures between 10 K and 740 K. The interband CPs E_0 and $E_0+\Delta_0$, where E_0 is the direct band gap of Ge and Δ_0 is the spin-orbit splitting occurring at the center of the Brillouin zone, lie in this energy range and are subject of our investigations. Applying an analysis in reciprocal space by performing a discrete Fourier transform of the data points and fitting the resulting Fourier coefficients, the parameters describing the line shape of E_0 are found as a function of temperature. Like for the CPs at higher energies, the authors find a red shift of the E_0 and $E_0+\Delta_0$ energies which can be described by a Bose-Einstein factor accounting for electron-phonon interactions. The results of the reciprocal-space analysis are compared to the parameters determined by a parametric semiconductor fit.

HL 25.3 Wed 10:00 H33

Application of Flash Lamp Annealing for Controlled Nickel Silicidation of Silicon Nanowires — •Muhammad Bilal Khan, Dipjyoti Deb, Slawomir Prucnal, Artur Erbe, and Yordan M. Georgiev — Institute Of Ion Beam Physics And Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Silicon (Si) nanowires (NWs) have potential applications in various areas including electronics, opto-electronics and biochemical sensing. These wires are used to fabricate electronic devices with new architectures to complement the scaling down of electronic circuits. Our work focuses on one such architecture called Reconfigurable field effect transistors (RFET). An RFET is a Nickel(Ni)Si_2-Si-NiSi_2 Schottky junctions based device, which has an intrinsic Si channel. To fabricate an RFET, SiNWs are silicided at both ends to form Schottky junctions with the Si channel. Typically, it has two gates placed on each of the two Schottky junctions. It can be tuned to p- or n- polarity by applying appropriate electrostatic potential at one of the gates. Therefore, functional complexity and performance of electronic circuits can be enhanced using such FETs. Formation of $NiSi_2$ is a pre-requisite for proper operation of these devices because metal work function of $NiSi_2$ aligns itself near the mid-bandgap of Si. This enables band bending by application of an appropriate electrostatic potential for the operation of devices either as p- or as n- FET. We report our results on Ni silicidation using flash lamp annealing. By optimizing the silicidation process, control over the diffusion of Ni into the nanowire and proper silicide phase formation is achieved.

HL 25.4 Wed 10:15 H33

Engineering the light emission properties of hexagonal Ge by structural modifications — •Jens Renè Suckert, Claudia Rödl, Jürgen Furthmüller, Friedhelm Bechstedt, and Silvana Botti — Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

The design of CMOS integrable laser sources allows for intra- and interchip optical communications at an attojoule/bit energy consumption. To this end, a pure silicon laser would be the ideal solution, but unfortunately Si has an indirect gap and, therefore, it is not suitable for laser applications.

Hexagonal Ge, on the other hand, may represent a viable alternative: It features excellent CMOS compatibility and, even though its direct gap of 0.3 eV is only weakly dipole allowed, the strongly dipole-active optical transition to the second conduction band is only about 0.3 eV higher in energy. This opens the way to band-structure engineering by structural modifications, such as nanostructuring, alloying, or straining.

Here, we use *ab initio* density-functional theory to investigate the impact of various lattice strains (hydrostatic pressure, biaxial strain, uniaxial strain, etc.) on the electronic structure of hexagonal Ge. We demonstrate that the order of the two lowest conduction bands can be inverted with less than 5 % of tensile uniaxial strain which strongly improves the light-emission properties of hexagonal Ge.

HL 25.5 Wed 10:30 H33

Atomic Effective Pseudopotentials for Large Scale Defect Calculations — •Walter Pfäffle and Gabriel Bester — University of Hamburg, Hamburg, Germany

We present a method to derive atomic effective potentials for defects in semiconductors (AEPs) based on the total screened potentials calculated using density functional theory that involves no free parameters and features a robust procedure for achieving a dense G-space sampling. We take advantage of the fundamentally short-ranged nature of impurity-induced potential changes and demonstrate that impurity potentials obtained using the self-consistently calculated potentials for small supercells can be accurately applied in non-self-consistent calculations for different geometries and substantially larger systems. This approach allows an accurate treatment of impurity problems free from the significant restrictions usually associated with finite supercell size. Impurity potentials for substitutional Mn and group-IV acceptors in GaAs are presented.

15 min. break

HL 25.6 Wed 11:00 H33

Group IV Nanowires: Fabrication and Particular Applications — •Yordan M. Georgiev[1], Muhammad Bilal Khan[1], Dipjyoti Deb[1], Ahmad Echresh[1], Shima J. Ghamsari[1], Slawomir Prucnal[1], Lars Rebohle[1], Artur Erbe[1], Manfred Helm[1], Anushka S. Gangnaik[2], Alexander D. Game[2], Subhajit Biswas[2], Nikolay Petkov[2], and Justin D. Holmes[2] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]School of Chemistry and Tyndall National Institute, University College Cork, Cork, Ireland

Group IV semiconductor nanowires (NWs) are very attractive because of the variety of possible applications as well as of the good silicon (Si) compatibility, which is important for their integration into the existing semiconductor technology. We will give an overview of our activities on fabrication and application of group IV NWs. These include top-down fabrication (based on electron beam lithography and reactive ion etching) of Si and germanium (Ge) NWs having widths down to 6-7 nm as well as bottom-up (vapour-liquid-solid) growth of alloyed germanium-tin (Ge1-xSnx) NWs with x = 0.07-0.1 and diameters of 50-70 nm. We will discuss the innovative nanoelectronic devices that we are working on: junctionless nanowire transistors (JNTs) and reconfigurable field effect transistors (RFETs). We will present results on Si JNTs for sensing application as well as on Ge and GeSn JNTs for digital logic. We will also show results on Si RFETs as well as preliminary data on SiGe and GeSn RFETs, which are expected to outperform the Si RFETs.

HL 25.7 Wed 11:15 H33

Laser-induced nonthermal diffusion of impurities and vacancies — •Christelle Inès Kana Mebou, Tobias Zier, and Martin E. Garcia — Theoretische Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Laser-induced disordering processes like nonthermal-melting have been studied intensively during the last three decades. In this work, we present first investigations of laser induced ordering processes. With the help of ab-initio molecular dynamics (MD) using our code CHIVES (Code for Highly Excited Valence Electron Systems) we have studied the motion of sulfur impurities and vacancies in silicon. The aims is to study the impact of laser excitation on the mechanisms of defects (vacancies and impurity atoms) migrations in Silicon (Si). Starting from initially randomly distributed defects, we simulated the ultrashort time dynamics of the system after laser heating. Preliminary results show a tendency of the vacancies to become more ordered. Electronic structure of Si doped with sulfur are analysed in the scope of these results.

HL 25.8 Wed 11:30 H33

Ordered Si nanopillar arrays with alternating diameters by metal-assisted chemical etching — •Michael Kismann, Thomas Riedl, Xia Wu, Bertram Schwind, Thorsten Wagner, and Jörg K.N. Lindner — Paderborn University, 33098 Paderborn, Germany

Ordered Si nanopillar arrays have a great potential for e.g. photonic, sensing and electronic devices. In the present contribution, we employ nanosphere lithography combined with metal-assisted chemical etching (MACE), which permits the fabrication of well ordered Si nanopillar arrays on large areas. Compared with conventional fabrication techniques such as optical lithography combined with deep RIE or CVD our approach is more cost-effective and enables realization of high aspect ratio structures. Moreover, as a new feature of MACE we demonstrate the formation of Si nanopillars with alternating diameters by variation of the etch solution composition, which is accomplished by varying the HF/H_2O_2 ratio. In this way single and multiple necks can be formed in each nanopillar. By controlled oxidation in water vapour we obtain nanoscale Si inclusions surrounded by an amorphous SiO_2 shell. The morphology and structure of these pillar arrays are analyzed

by SEM and TEM, complemented by optical measurements and band structure calculations. The obtained necked Si pillar morphologies are attractive for vertical nanopillar FETs and vertical tunneling FETs. In addition, they are of interest for thermoelectric generators because of the strongly reduced thermal conductivity in the nanostructures and the possibility of resonant tunneling through the SiO_2 necks.

HL 25.9 Wed 11:45 H33

Time-resolved spectroscopic ellipsometry on Ge and Si — •Steffen Richter[1], Shirly Espinoza[1], Oliver Herrfurth[2], Mateusz Rebarz[1], Rüdiger Schmidt-Grund[2], Jakob Andreasson[1,3], and Stefan Zollner[4] — [1]ELI Beamlines, Za Radnicí 835, Dolní Břežany, Czech Republic — [2]Universität Leipzig, Felix-Bloch-Instiut für Festkörperphysik, Linnéstr. 5, 04103 Leipzig, Germany — [3]Chalmers tekniska högskola, Institutionen för fysik, Kemigården 1, 41296 Göteborg, Sweden — [4]New Mexico State University, Department of Physics, PO Box 30001, Las Cruces, NM, 88003-8001, USA

Highly excited semiconductors feature a large number of concurrent processes of carrier scattering, relaxation, ambipolar diffusion and recombination. Discriminating them and understanding their dynamics is crucial for potential applications. To this aim, the distinction between amplitude and phase information of the optical response is essential. This cannot be provided by conventional transient spectroscopy. Here, we report on recent progress in developing pump-probe broadband ellipsometry with sub-picosecond resolution. We present measurements carried out on Ge, Si and InP single crystals. The obtained pseudo dielectric-functions hint on band gap renormalization of higher conduction bands and band filling by electrons at the minima of the conduction band. Their dynamics allow to understand scattering mechanisms for the hot charge carriers, and also indicate phonon coupling.

HL 26: Focus Session: Quantum light sources for applications in quantum communication networks

The present focus session aims at discussing current state-of-the-art of non-classical light sources which can be found compatible with short- (few meters), mid- (few kilometers) or long-distance (several tens of km) quantum networks. Different approaches for the generation of non-classical light will be discussed, both experimentally and theoretically. We aim at stimulating the discussion on advantages and limitations of these approaches and under which aspects they can be find promising.

Organizers: Simone Luca Portalupi and Peter Michler (Uni Stuttgart)

Time: Wednesday 9:30–13:00 Location: H34

Invited Talk HL 26.1 Wed 9:30 H34

GaAs quantum dots as tunable sources of entangled and indistinguishable photons — •Armando Rastelli — Institut für Halbleiter und Festkörperphysik, Johannes Kepler Universität Linz, Österreich

Among different solid-state emitters of quantum light, epitaxial GaAs quantum dots (QDs) have recently emerged as nearly-ideal sources of triggered polarization entangled photon pairs [1]. This property, combined with the strongly suppressed probability of multiphoton emission [2] has allowed the implementation of quantum teleportation using photons subsequently emitted by a single QD [3].

In this talk I will discuss the peculiar properties of GaAs QDs, their performance as emitters of both single and entangled photons, as well as possible methods to engineer their light emission characteristics [1,4] to meet the demanding requirements imposed by photonic quantum technologies.

[1] D. Huber et al. Phys. Rev. Lett. 121, 033902 (2018).
[2] L. Schweickert et al. Appl. Phys. Lett. 112, 093106 (2018).
[3] M. Reindl et al. Science Adv. (2018).
[4] X. Yuan et al. Nat. Comm. 9, 3058 (2018).

HL 26.2 Wed 10:00 H34

Influence of the excitation scheme on coherence properties of InAs/InGaAs quantum dots emitting in the telecom C-band — •Cornelius Nawrath, Fabian Olbrich, Matthias Paul, Jan Kettler, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

The emission of semiconductor quantum dots (QDs) has been shown to exhibit excellent properties in terms of single-photon purity, photon indistinguishability and entanglement fidelity, i.e. essential prerequisites for most applications in the field of quantum computing and quantum communication. The latter will benefit strongly from emission around 1550nm (telecom C-band) due to the global absorption minimum in standard silica fibers employed in the existing global fiber network.

The coherence properties of photons emitted from InAs/InGaAs QDs, grown on a metamorphic buffer to achieve C-band emission, are examined by measurements in the frequency and time domain comparing different optical charge carrier excitation schemes, namely above the band gap of the barrier material (above-band), via the phonon sideband (phonon-assisted) and in resonance fluorescence. This work highlights the importance of quasi-resonant or resonant excitation for applications relying on good coherence.

Invited Talk HL 26.3 Wed 10:15 H34

Phonon-assisted bright and dark exciton preparation in a semiconductor quantum dot — •Doris Reiter — Institut für Festkörpertheorie, Universität Münster, 48149 Münster, Germany

To use semiconductor quantum dots as source of single or entangled photons, a reliable control of the excitonic states in a quantum dot is required. An obstacle to overcome for several preparation schemes like Rabi rotations or adiabatic rapid passage is the interaction of the electrons with the phonons, which in these schemes may strongly hinder the state preparation [1]. In contrast, the phonon-assisted state preparation makes use of phonons to prepare the exciton or biexciton state in a robust way [2]. Phonon-assisted schemes in combination with a tilted magnetic field can further be used to prepare the dark exciton in a quantum dot, which has parallel electron and hole spin and hence is optically inactive [3]. The dark exciton state can be very useful for a controlled biexciton preparation to act as source of entangled photons. In my talk, I will discuss how to make use of the electon-phonon interaction to prepare different exciton states.

[1] Reiter et al., J. Phys.: Condens. Matter 26, 423203 (2014)
[2] Barth et al., Phys. Rev. B 94, 045306 (2016)
[3] Lüker et al., Phys. Rev. B 95, 195305 (2017)

HL 26.4 Wed 10:45 H34

Optical properties of qubit centers in SiC — •Michel Bockstedte — Chemistry and Physics of Materials, University of Salzburg, Salzburg, Austria — Solid State Theory, Friedrich-Alexander-Universität Erlangen-Nürnberg

Several defect centers in silicon carbid represent quantum bits for applications like quantum sensing or can be employed as single photon emitters. The excited defect states and the photons emitted in transitions between them and the groundstate alongside spin-selective, nonradiative transitions via intermediate low-spin states are pivotal parts of the mechanism underlying qubit applications. Optical excitation of the qubit may also lead to an ionization into other charge states in which the qubit is silent. The ability to control and deliberately switch the charge state is pivotal for applications and has recently been explored in experiments [1]. However, the charge states actually involved in the switching and their optical properties are often not clear. Here we investigate the optical ionization of the divacancy and the silicon vacany within the frame work of the CI-CRPA approach [2]. We shine

light onto ionizing single and two-photon processes. Our results show that an enhanced ionization cross section can occure for photon energies well above the ionization thresholds. This determines the charge state yielded by the ionization.

[1] Golter and Lai, Sci. Reports 7, 13406 (2017).
[2] Bockstedte *et al.* njp Quantum Materials 3, 31 (2018).

15 min. break

Invited Talk HL 26.5 Wed 11:15 H34

Towards Quantum Communication Networks Exploiting Solid-State Quantum-Light Sources — •Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Tremendous progress has been achieved in the engineering of solid-state-based non-classical light sources during the last two decades. In this context, quantum-light sources based on semiconductor quantum dots (QDs) are of particular interest. Allowing for the generation of close-to-ideal flying qubits these devices are predestinated for implementations of quantum communication.

In my talk, I will review our progress in this field, striving towards the ultimate goal of a global secure communication. I will revisit first proof-of-concept QKD experiments and discuss the development of state-of-the-art components for quantum key distribution (QKD), such as plug-and-play single-photon sources and receiver modules. In this context, the metrology of the quantum light sources together with a thorough security analysis of the measurement devices are essential for implementations of QKD. Assembling these building blocks to finally realize functional multi-user quantum-secured communication networks will be a grand challenge in quantum technologies, which is tackled within my recently founded Junior Research Group at Technische Universität Berlin.

Invited Talk HL 26.6 Wed 11:45 H34

Single Organic Molecules for Quantum Optics — •Ilja Gerhardt[1,2], Mohammad Rezai[1], and Jörg Wrachtrup[1,2] — [1]Institute for Quantum Science and Technology (IQ^{ST}) and 3rd Institute of Physics, D-70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstr. 1, D-70569 Stuttgart, Germany

Single organic molecules at cryogenic conditions allow for the generation of narrow-band (14 MHz), and simultaneously high-flux single photons. In the last years, we managed to combine them with atomic vapors such that effects like slow light on the sodium D_2-line (589 nm) could be observed [1]. Now we extend our experiments towards all-optical configurations and high-visibility Hong-Ou-Mandel interference [2]. This configuration is extended towards a "delayed-choice" quantum eraser and allows for the generation of degenerate entangled photon-pairs. The raw data violates Bell's inequality with a Bell parameter of S=2.24 [3].

[1] – *Molecular photons interfaced with alkali atoms*, Petr Siyushev, Guilherme Stein, Jörg Wrachtrup, and Ilja Gerhardt, Nature, **509**, 66-70 (2014);
[2] – *Coherence Properties of Molecular Single Photons for Quantum Networks*, Mohammad Rezai, Jörg Wrachtrup, and Ilja Gerhardt, Phys. Rev. X, 2018, **8**, 9 (2018);
[3] – *Polarization-entangled photon pairs from a single molecule*, Mohammad Rezai, Jörg Wrachtrup, and Ilja Gerhardt, Optica, **6**, 34-40 (2019);

HL 26.7 Wed 12:15 H34

Receiver Module for QKD using Real-Time Security Monitoring with Single-Photon Sources — •Timm Kupko, Lucas Rickert, Stephan Reitzenstein, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Solid-state single-photon sources have the potential to boost the performance of quantum-key-distribution (QKD) systems [1]. The security of QKD, however, critically relies on the performance of the quantum light source [2]. In addition, many attacks are known for trusted-device QKD, making a profound security analysis mandatory. Here, we evaluate the performance of a receiver module designed for free-space polarization-encoded QKD via the BB84 protocol using solid-state single-photon sources. The receiver module is tested with respect to the susceptibility to spatial-side-mode channel attacks. Furthermore, we analyze the effect of temporal filtering on the performance of QKD systems implemented with realistic quantum-light sources. A trade-off between quantum bit error rate and sifted key rate is necessary to achieve optimum performance. Finally we show, that real-time monitoring of the antibunching $g^{(2)}(0)$ inside the quantum channel enables a convenient security assessment during key generation. Our work lays the basis for the development of QKD-secured communication networks based on quantum-light sources.

[1] T. Heindel et al., New J. Phys. 14, 083001 (2012)
[2] E. Waks et al., Phys. Rev. A **66**, 042315 (2002)

Invited Talk HL 26.8 Wed 12:30 H34

Quantum repeater development based on entangled photons from quantum dots — •Michael Zopf[1,2], Robert Keil[1], Yan Chen[1], Jingzhong Yang[1,2], Fei Ding[1,2], and Oliver G. Schmidt[1,3] — [1]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, Germany

Distributing entangled states over long distances is essential for quantum communication networks. However, due to the transmission losses in optical fibers quantum repeaters have to be developed, as an equivalent for classical signal amplifiers. A promising approach is the combination of the polarization entangled photon emission from semiconductor quantum dots with atomic quantum memories. Here we show that, with an emerging family of GaAs/AlGaAs quantum dots, the stringent requirements for quantum repeaters can be addressed: Large ensembles of polarization-entangled photon emitters are obtained, with precisely tailored emission wavelengths for coupling with rubidium-based quantum memories. Unprecedented entanglement fidelities and photon indistinguishabilities of >90% are observed. Integration with piezoelectric actuators enables wavelength tuning and frequency-stabilization to rubidium transitions. On-demand photon generation with extraction efficiencies up to 65% is achieved with dielectric optical antenna structures, facilitating event-ready applications. These quantum light sources therefore enable entanglement swapping schemes, a major step for quantum repeater applications.

HL 27: Two-dimensional Materials III (joint session HL/CPP)

Time: Wednesday 9:30–13:00 Location: H36

HL 27.1 Wed 9:30 H36

Defect dominated charge transport and fermi level pinning in TMDC/metal contacts — •Kai Sotthewes, Rik van Bremen, Edwin Dollekamp, Harold Zandvliet, and Pantelis Bampoulis — Physics of Interfaces and Nanomaterials, MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500AE Enschede, The Netherlands

Understanding the electron transport through transition metal dichalcogenides (TMDCs) based semiconductor/metal junctions is vital for the realization of future TMDC based (opto-) electronic devices. Strong Fermi level pinning was observed in TMDC based devices, reducing the tenability of the Schottky barrier height. We use conductive atomic force microscopy to construct nanoscopic metal-TMDC junctions in order to understand the Fermi level pinning mechanism on TMDCs and the influence of defects on the electron transport. The barrier heights of the pristine surface can be explained by metal induced gap states (MIGS), inducing partial Fermi level pinning. The Schottky barrier height further reduces (Fermi level pinning increases) at defects, where the magnitude of the decrease depends on the metal contact. These defects provide low-resistance conduction paths in TMDC-based nanodevices and will play a prominent role as the device junction contact area decreases in size.

HL 27.2 Wed 9:45 H36

Localized quantum emitters in Van der Waals crystals — •Amlan Mukherjee[1], Nathan Chejanovsky[1,2], Youngwook Kim[2], Durga Dasari[1,2], Jurgen H. Smet[2], and Jörg Wrachtrup[1,2] — [1]3rd Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Point defects in semi-conductors are renowned for single photon emission apart from having important implications on optical and transport properties of their host crystal. Various two dimensional Van der Waals (2D) crystals can provide a plethora of defects [1][2] and have revolutionized scientific research with unique phenomena related to their reduced dimensional. We summarize optical investigations of localized quantum emitters in 2D semi-conductors with sub band-gap excitation energizes, emphasizing those in hexagonal boron nitride that exhibit para-magnetic responses to applied external magnetic fields.

References: [1] Chejanovsky, N. et al. Nano letters 2016, 16, 7037-7045. [2] Chejanovsky, N. et al. Scientific reports 2017, 7, 14758 (1-14).

HL 27.3 Wed 10:00 H36

High magnetic field measurements of interlayer excitons in van der Waals heterostructures — •Johannes Holler[1], Michael Kempf[1], Jonas Zipfel[1], Mariana Ballottin[2], Anatolie Mitioglu[2], Philipp Nagler[1], Fabian Mooshammer[1], Alexey Chernikov[1], Peter Christianen[2], Christian Schüller[1], and Tobias Korn[3] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]High Field Magnet Laboratory (HFML EMFL), Radboud University Nijmegen, Netherlands — [3]Institut für Physik, Universität Rostock, Germany

In the recent years, research in the field of two-dimensional materials has intensified a lot. Besides graphene, the most prominent representatives for this field are the transition metal dichalchogenides. These materials exhibit interesting physics in the monolayer, such as spin-valley locking, and by combining them to heterostructures new excitonic properties emerge.

Here, we study $MoSe_2$-WSe_2 heterostructures, which create a type-II band alignment. This results in a spatial separation of the electron-hole pairs, leading to the formation of interlayer excitons (IEXs). In low-temperature photoluminescence measurements in magnetic fields up to 30T, we observe a giant valley-selective splitting and a resulting near-unity valley polarization. Furthermore, we probe the valley dynamics of the IEX in dependence of the magnetic field, detecting very long lifetimes in contrast to intralayer excitons. We are able to observe the build-up of the valley polarization after unpolarized excitation, revealing different dynamics and lifetimes for the different valleys.

HL 27.4 Wed 10:15 H36

Tunable 2D superlattices in graphene — •Robin Huber[1], Martin Drienovsky[1], Andreas Sandner[1], Kenji Watanabe[2], Takashi Taniguchi[2], Dieter Weiss[1], and Jonathan Eroms[1] — [1]Institue of Experimental and Applied Physics, University of Regensburg, Germany — [2]National Institute for Materials Science, Tsukuba, Japan

One fascinating way to study the effect of superlattices on graphene are graphene/hBN heterostructures in which moiré superlattices with lattice periods of about 10 nm can be created. These systems made it possible to observe e.g. the famous Hofstadter butterfly in all its beauty. Here we present an alternative method to induce tunable superlattice effects in graphene by the combined action of a global silicon backgate and a patterned bottom gate made from few layer graphene using standard e-beam lithography techniques. We show low temperature transport measurements on an artificially fabricated and gate tunable 2D superlattice in graphene with a lattice period of 40 nm. By switching on a 2D periodic charge carrier density modulation additional Dirac peaks can be observed which are the source of additional Landau fans in magnetotransport. Due to the interplay between the lateral 2D superlattice and a magnetic field, features of the Hofstadter butterfly energy spectrum can be resolved. In addition we show magnetotransport data at an elevated temperature of 120 K where Landau quantization vanishes but Brown-Zak oscillations, which are caused by the 2D periodic potential, are still visible.

HL 27.5 Wed 10:30 H36

Charge carrier localization in molybdenum disulfide nanobubbles due to the interplay of surface wrinkling, strain, and dielectric confinement — •Christian Carmesin, Michael Lorke, Matthias Florian, Daniel Erben, Tim O. Wehling, and Frank Jahnke — Institut für Theoretische Physik, Universität Bremen

The observation of quantum light emission from atomically thin transition metal dichalcogenides has opened a new field of applications for these material systems. The corresponding charge carrier localization has been linked to defects and strain, however open questions remain about the microscopic origin. We demonstrate that bending of two-dimensional layers leads to surface wrinkling due to bond deformation within the atomically thin sheet. The resulting strain-field facilitates strong charge carrier localization due to its pronounced influence on the band gap. Additionally, we consider confinement as a result of local changes of the dielectric environment and show that both effects contribute to modified electronic states and optical properties. The interplay of surface wrinkling, strain-induced confinement and local changes of the dielectric environment is demonstrated for the example of nanobubbles that form when monolayers are deposited either on substrates or other two-dimensional materials.

HL 27.6 Wed 10:45 H36

Electric field control of interlayer excitons in MoS2/WS2 heterobilayers — •Fabian Kronowetter[1], Jonas Kiemle[1], Florian Sigger[1,2], Alexander Holleitner[1,2], and Ursula Wurstbauer[1,2,3] — [1]Walter Schottky Institut and Physics-Department, Technical University of Munich, Germany — [2]Nanosystems Initiative Munich (NIM), Germany — [3]Institute of Physics, WWU Münster, Germany

Ensembles of interlayer excitons (IXs) are intriguing systems to explore classical and quantum phases of interacting bosonic ensembles with enlarged lifetimes due to reduced overlap of the electron-hole wave functions. We demonstrate electric field control of the IX in MoS2/WS2 heterobilayer embedded in a field effect structure with few layer hexagonal boron nitrite (hBN) as insulator and few-layer graphene as gate-electrodes. We observe a multiplet structure in the IX emission band even at room temperature. Stark shift measurements reveal the presence of a finite out-of plane dipole of the IX. The different strength of the dipole and a distinct temperature dependence identify the IXs to stem from optical interband transitions with electrons and holes located in different valleys of the heterostructures. For the lowest emission line, we observe field dependent level anti-crossing at low temperatures. We discuss this behavior in terms of coupling of electronic states from the two TMDC monolayers. Our results demonstrate the design of novel nano-quantum materials prepared from artificial van der Waals solids with the possibility to in-situ control their physical properties via external stimuli such as electric fields.

15 min. break

HL 27.7 Wed 11:15 H36

excitons localized by physisorbed gas molecules in MoSe2 monolayer — •Tommaso Venanzi[1,2], Stephan Winnerl[1], Alexej Pashkin[1], Manfred Helm[1,2], and Harald Schneider[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany

In the study of 2D materials an extremely relevant topic is the presence of defects. We have studied excitons localized by physisorbed gas molecules in MoSe2 monolayer by means of low-temperature photoluminescence. We have investigated how the localized exciton depends on temperature taking care of the effects of laser irradiation. We observe a red-shift of the photoluminescence peak with temperature that is not only addressable to renormalization of the bandgap or thermal instability of the localization. On the other hand we observe a blue-shift of the peak when increasing the laser irradiation dose. Finally we propose a physical mechanism that can explain our experimental observations.

HL 27.8 Wed 11:30 H36

Silicene passivation by few-layer graphene — •Jakob Genser[1], Viktoria Ritter[1], Daniele Nazzari[1], Ole Bethge[2], Emmerich Bertagnolli[1], and Alois Lugstein[1] — [1]Institute of Solid State Electronics, Technische Universität Wien, Gußhausstraße 25-25a, 1040 Vienna, Austria — [2]Infineon Technologies Austria AG, Siemensstraße 2, 9500 Villach, Austria

Silicene is of foremost interest for the development of next generation, high performance devices, due to its ultra-high carrier mobility combined with a tuneable bandgap and good integrateability into the current silicon based semiconductor industry. However, the synthesis of silicene remains challenging and thus far is only achieved under UHV conditions, whereas exposure to air leads to an immediate degradation. Therefore, the stabilization of silicene at ambient conditions is essential for its characterization, future processing and device integration. Here, we demonstrate the first in-situ encapsulation of 4x4 silicene grown on Ag(111) by exfoliated few-layer graphene (FLG) flakes. This encapsulation method allowed subsequent highly detailed Raman analysis that so far has only been possible by means of in-situ Raman measurements. The acquired data proved that FLG capping serves as an effective passivation layer, preventing degradation of silicene for up to several days. Additional polarization-dependent measurements showed that the symmetry properties of silicene remain unaltered by the capping process. Furthermore, the experiments demonstrated the compatibility between graphene and silicene, representing a step forward towards the possible integration of silicene into 2D heterostructures.

HL 27.9 Wed 11:45 H36

Internal structure and ultrafast dynamics of interlayer excitons in van der Waals heterostructures — •Philipp Merkl[1], Philipp Steinleitner[1], Fabian Mooshammer[1], Kai-Qiang Lin[1], Philipp Nagler[1], Johannes Holler[1], Christian Schüller[1], John M. Lupton[1], Tobias Korn[1], Simon Ovesen[2], Samuel Brem[2], Ermin Malic[2] und Rupert Huber[1] — [1]Department of Physics, University of Regensburg, D-93040 Regensburg, Germany — [2]Department of Physics, Chalmers University of Technology, SE-41258 Göteborg, Sweden

In heterostructures of transition metal dichalcogenides, electrons and holes residing in adjacent monolayers can bind into spatially indirect excitons. Even though these interlayer bound pairs have attracted tremendous interest owing to their strong promise for novel optoelectronics and valleytronics, their binding energies have not been directly measured. Here we introduce a direct ultrafast access to Coulomb correlations acting between monolayers. For the prototypical case of WSe2/WS2 hetero-bilayers, phase-locked mid-infrared pulses allow us to measure the binding energy of interlayer excitons of 118 meV by revealing a novel 1s-2p resonance, well explained by a fully quantum mechanical model. Furthermore, we trace how an exciton gas photogenerated in the WSe2 layer directly transforms into interlayer excitons, without a strong intermediate phase of unbound electron-hole pairs. Depending on the stacking angle, intra- and interlayer species coexist on picosecond scales and relax into quantum confined states in moiré-induced nanodots.

HL 27.10 Wed 12:00 H36

Plasmonic Coupling and Engineering of Single Photon Emitters in WSe2 Monolayers — •Oliver Iff[1], Nils Lundt[1], Simon Betzold[1], Łukasz Dusanowski[1], Magdalena Moczała-Dusanowska[1], Laxmi Narayan Tripathi[1], Young Jin Lee[2], Soon-Hong Kwon[2], Sven Hoefling[1,3], and Christian Schneider[1] — [1]Technische Physik, Universität Würzburg, Wuerzburg, Germany — [2]Department of Physics, Chung-Ang University, Seoul, South Korea — [3]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Single photon sources are an important building block in quantum technologies. The rediscovery of transition metal dichalcogenides this century revealed the availability of quantum emitters in monolayers of WSe2 or MoSe2. Here, we investigate the resonant coupling of such emitters to metallic nanostructures of different shapes and sizes. Auto correlation measurements prove their single photon emission as well as lifetime measurements unveil a reduction in their decay times, confirming the coupling between the metal surface and the quantum emitters. Furthermore, by utilizing an array of gold nanopillars as well as strain-engineering and -tuning of monolayers, site-controlled positioning of localized emitters is possible and represents an important step towards their reproducible manipulation. These findings demonstrate the potential of transition metal dichalcogenide based, strain engineered devices for quantum electrodynamic systems.

HL 27.11 Wed 12:15 H36

Understanding the formation of interlayer excitons in the case of MoS_2 on GaSe. — •Christian Wagner[1,2], Mahfujur Rahaman[2], Dietrich R.T. Zahn[2], and Sibylle Gemming[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute of Physics, Technische Universität Chemnitz, Chemnitz, Germany

The fabrication of hybrid van-der-Waals heterostructures of two-dimensional nano materials is an emerging field of study: The (weak) electronic interaction between two layers is often reasonably described by a perturbation of the physical effects of the isolated layers, such as electrostatic doping and screening of intralayer excitons. However, it turns out that this picture of the weak interaction is not exhaustive in terms of optical properties: the formation of bound excitons from electrons of one layer and the holes from another layer yields the formation of interlayer excitons. These states are measured experimentally by photoluminescence and photocurrents, e.g. in the case of MoS_2 on GaSe due to type-II band alignment.

This contribution elucidates the conditions for the formation of interlayer excitons from a first-principles point of view. For this, first-principles studies of a minimal test system are conducted. One perspective is then to predict these states as a function of the heterostack in order to specifically taylor efficient solar cells.

HL 27.12 Wed 12:30 H36

Transfer of electrodeposited MoS_2 to silicon substrate for electronic devices — •Talha Nisar, Torsten Balster, and Veit Wagner — Jacobs University Bremen gGmbH, Campus Ring 1, 28759, Bremen, Germany

Molybdenum disulfide is a promising candidate for future electronics due to its 2 dimensional nature. It can be deposited by various methods such as mechanical exfoliation and chemical vapor deposition (CVD). In our approach we use electrodeposition as an alternative large area deposition method to CVD. For this purpose a MoS_4 ion precursor is used in the anodic regime. The electrodeposited layer consists of MoS_3 as confirmed by Raman and XPS measurements. Such layers are converted to MoS_2 by post annealing at temperature above 450°C. Raman analysis shows that the crystallinity of such film improves with higher post annealing temperatures. In addition, UV-Vis and AFM measurements confirm MoS_2 formation in flakes with smooth surface. We demonstrated that these layers can successfully be mechanically transferred to a SiO_2/Si.

HL 27.13 Wed 12:45 H36

Optical properties of Monolayer MoS_2 exposed to helium ions — Julian Klein[1,2], •Sergio Rey Puentes[1], Michael Lorke[3], Matthias Florian[3], Florian Sigger[1,2], John Cerne[4], Jakob Wierzbowski[1,2], Kai Müller[1,2], Lukas Sigl[1,2], Takashi Taniguchi[5], Kenji Watanabe[5], Michael Kaniber[1,2], Ursula Wurstbauer[1,2], Michael Knap[6], Richard Schmidt[6], Jonathan Finley[1,2], and Alexander Holleitner[1,2] — [1]Walter Schottky Institut and Physik Department, Technische Universität München, Garching, Germany — [2]Nanosystems Initiative Munich (NIM), Munich, Germany — [3]Institut für Theoretische Physik, Universität Bremen, Bremen, Germany — [4]Department of Physics, University at Buf-

falo, The State University of New York, Buffalo, USA — [5]National Institute for Materials Science, Tsukuba, Japan — [6]Department of Physics and Institute for Advanced Study, Technical University of Munich, Garching, Germany

We present a spectroscopic study on mono- and few-layers of 2H stacked MoS_2 and WSe_2 exposed with helium ions. Distinct changes of the first-order Raman bands, additional defect luminescence and strong modification of the intrinsic valley spin relaxation properties are observed. The exposed locations were investigated by Raman spectroscopy, low-temperature confocal micro-photoluminescence (μ-PL) and atomic force microscopy (AFM). Our results demonstrate the potential of helium ion microscopy applied to 2D layered materials for modifying intrinsic optical properties and fundamental understanding of disorder.

HL 28: Diamond II (joint session KFM/HL)

This session represents the physics, the production and applications of diamond and diamond related materials in the fields of dielectrics, electronics, high frequency techniques, GHz * THz * applications, mechanics and optics and biological applications as well. Defects in diamond have a large influence to the physical properties (e. g. NV-centers). Applications of diamond (single, poly-crystalline, UNCD, etc.) or related materials in technical systems are part of this session (Nuclear fusion applications, high frequency heating systems and material processing).

Chair: Theo Scherer (KIT)

Time: Wednesday 9:30–11:30 Location: PHY 5.0.20

HL 28.1 Wed 9:30 PHY 5.0.20

Antibacterial propensities of UNCD with embedded silver nanodroplets — •Daniel Merker[1], Blagovesta Popova[2], Tobias Weingärtner[3], Thomas Bergfeldt[3], Gerhard Braus[2], Johann Peter Reithmaier[1], and Cyril Popov[1] — [1]Institute of Nanostructure Technologies and Analytics, Universität Kassel, Kassel, Germany — [2]Institute for Microbiology and Genetics, Universität Göttingen, Göttingen, Germany — [3]Institute of Applied Materials - Applied Materials Physics, Karlsruher Institut für Technologie, Eggenstein-Leopoldshafen, Germany

Thin diamond films are considered a promising material for coating of implants due to the mechanical and chemical durability in combination with biological compatibility. These properties are utilized to increase the lifetime and support the tissue integration of the implant. In this work we address another issue for implantation surgery, namely the danger of a bacterial infection. We prepared ultrananocrystalline diamond (UNCD) films with embedded silver nanodroplets to utilize the well-known antibacterial effect of silver ions. The changes in the morphology of the Ag nanodroplets depending on the conditions for their preparation was investigated by SEM and AFM and afterwards the composition of the resulting UNCD/Ag/UNCD layers was revealed by AES. The thickness of the capping UNCD layer can provide a control mechanism for the silver release. Therefore, we prepared samples with different capping layer thicknesses and investigated the amount of the released Ag into water with ICP-MS. Finally, we tested the layers against two bacteria: E. coli and B. subtilis.

HL 28.2 Wed 9:50 PHY 5.0.20

Fabrication of Photonic Crystals Based on Planarized Nanocrystalline Diamond Films — •Julia Heupel, Johann Peter Reithmaier, and Cyril Popov — Institute of Nanostructure Technologies and Analytics, Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Utilizing nanocrystalline diamond (NCD) membranes deposited on silicon dioxide/silicon substrates, two-dimensional photonic crystal slabs were fabricated. For adjusting the NCD film thickness as well as for smoothening the intrinsically rough surface, a planarization process was developed and investigated regarding the NCD surface roughness and overall thickness reduction. This procedure comprises the application and polymerization of spin-on glass (SOG), forming an even surface layer on NCD, followed by an inductively coupled plasma reactive ion etching (ICP RIE) step. The photonic crystal structures were prepared in NCD samples with a planarized surface by means of electron beam lithography (EBL) and ICP RIE. By underetching of the sacrificial silicon dioxide layer with a hydrofluoric acid solution, the photonic crystals were made suspended in air. The effect of the variation of the exposure dose factors on the air hole diameter and shape in the photonic hexagonal lattice was examined. Different established recipes for dry etching of the silicon dioxide hard mask were studied and analyzed.

HL 28.3 Wed 10:10 PHY 5.0.20

Improving magnetic nanoimaging using diamond-AFM-tips containing NV centers — •Arne Götze, Christoph Schreyvogel, Christian Giese, Claudia Widmann, Christoph Nebel, and Oliver Ambacher — Fraunhofer Institut für angewandte Festkörperphysik, Tullastraße 72, 79108 Freiburg, Germany

The fabrication of microelectronic components is approaching its physical limits. The gate length of modern transistors is now below 10 nm. Further miniaturization could lead to a reduction in costs and energy consumption, but as the devices become smaller the failure rate during production increases. Diamond-AFM-tips containing single NV centers that enable the imaging of the magnetic field strength with high sensitivity and spatial resolution even at room temperature will help uncover the reasons for this.

The focus of our work is to improve the performance of the NV-tips by producing diamond with high crystal quality and single NV centers. One goal is to create single NV centers close to the surface of the tip during CVD diamond growth by coating microstructured diamond tips with a thin layer of N-doped diamond. This will lead to longer spin coherence times and improved sensitivity compared to N-implantation. In order to better understand the N-doping and NV-formation processes we study the tips by using a confocal microscope and measuring 3D photoluminescence distributions. With this knowledge we are able to tailor the CVD processes and improve the measurement capabilities of magnetic imaging using diamond-AFM-tips.

Break 20 min

HL 28.4 Wed 10:50 PHY 5.0.20

High nitrogen doping of CVD-diamond — •Julia Langer[1], Volker Cimalla[1], Verena Zürbig[1], Jan Jeske[1], Tim Eichhorn[2], Brett Johnson[3], Lutz Kirste[1], Christoph Schreyvogel[1], Arne Götze[1], and Oliver Ambacher[1] — [1]Fraunhofer Institute for Applied Solid State Physics, Tullastraße 72, 79108 Freiburg — [2]NVision Imaging Technologies GmbH, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [3]The University of Melbourne, Victoria 3010, Australia

Nitrogen-vacancy centers in diamond are studied extensively over the past decades. Their properties as quantum system feature a wide range of applicability. A new approach is the growth of high nitrogen doped CVD-diamond to create ensembles of nitrogen-vacancy centers for the purpose of measuring sensitive magnetic fields by laser threshold magnetometry. The challenge arises from keeping detrimental material effects low such as absorption and the incorporation of other magnetic moments. Within this study we investigate the nitrogen incorporation in CVD-diamond depending on nitrogen flow and growth rates. A comparison of growth series with different crystallographic oriented substrates shows new insight in the varying dependencies.

HL 28.5 Wed 11:10 PHY 5.0.20

Thermoelectric generator made of tailored carbon allotropes — •Rudolf Borchardt, Timo Fromm, and Stefan Rosiwal — Chair of Materials Science and Engineering for Metals, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

A thermoelectric generator (TEG) can be used to recover energy by the conversion of waste heat into electricity. Therefore such generators use thermoelectric materials that directly generate electrical power from a temperature difference, without any moving parts. However common thermoelectric materials suffer from rarity, are toxic or are not temperature stable for a long time. Our aim is to develop new thermoelectric materials with good availability base on carbon allotropes. Here we show a TEG made out of three different kinds of carbon allotropes: micro crystalline diamond for fast thermal transport, as well as p-type nano crystalline diamond and n-type graphene nanowalls as the active materials for the energy conversion. The materials were produced as freestanding foils by chemical vapor deposition (CVD), and laser cut pieces of the foils were brazed with an active silver-titanium solder to fabricate the TEG. This TEG was tested up to a temperature difference of 200 K, resulting in an open circuit voltage of over 120 mV and an output power of 118 μW.

HL 29: Microscopy, Tomography and Spectroscopy with X-ray Photons, Electrons, Ions and Positrons (joint session KFM/HL)

Chair: Enrico Langer (Technische Universität Dresden)

Time: Wednesday 9:30–12:10 Location: H47

HL 29.1 Wed 9:30 H47

Phase Retrieval in X-Ray Near-Field Holography on Strong Objects — •Johannes Hagemann — DESY, Notkestraße 85, 22607 Hamburg

Lensless imaging techniques in the hard x-ray regime have become popular over the last two decades since no image forming optic is needed. Instead, the image is formed a posteriori numerically by reconstruction algorithms, which solve the ill-posed phase problem inherent to the measured data. Lensless techniques are demanding in terms of the radiation's properties used for illumination i.e. coherence, monochromaticity and fluence. The image reconstruction is often carried out under idealized assumptions of the probing illumination. The effects of failing these assumptions on the result of the reconstruction have been studied earlier in greater detail [1, 2]. For this work we study the effects of the object under reconstruction in the setting of x-ray near-field holography in greater detail. By numerical modelling and experiment we investigate the aspects of (i) the contrast of a hologram as a function of Fresnel number and phase shift, and (ii) the influence of strong objects on the image reconstruction process by phase retrieval. Our results indicate a maximum of contrast at Fresnel number $10^{-5} - 10^{-4}$.

[1] J. Hagemann and T. Salditt, "The fluence-resolution relationship in holographic and coherent diffractive imaging", J. Appl. Crystallogr., 50 (2017)

[2] J. Hagemann and T. Salditt, "The Coherence-resolution relationship in holographic and coherent diffractive imaging", Opt. Express, 26 (2017)

HL 29.2 Wed 9:50 H47

X-ray phase-contrast micro-CT of biological tissues at a rotating anode source — •Jasper Frohn and Tim Salditt — Institut für Röntgenphysik, Göttingen

X-ray phase-contrast offers the possibility of enhancing the image contrast for low absorbing materials such as biological soft tissues. Applied in a tomographic setup, the phase-contrast can be utilized to investigate the structure of such samples in 3d in a non-invasive way. One method to realize phase contrast images is "propagation-based imaging (PBI)", which is based on the free space propagation from the sample to the detector. To perform PBI tomography inhouse, x-ray sources are required with a certain degree of coherence. We were able to establish a high resolving propagation-based phase-contrast tomographic setup at a microfocus x-ray source with a rotating copper anode in our laboratory. The 3d resolution is in the range of few micrometers, achieved with a high resolving detector in inverse geometry. Results will be presented and compared with the synchrotron tomography endstation "GINIX" (P10 at PETRA III/DESY).

HL 29.3 Wed 10:10 H47

Atomic Resolution Differential Phase Contrast STEM investigations of electric fields in ZnO nanostructures — •Julius Bürger, Julia Weiss, Dennis Meinderink, Katja Engelkemeier, Wolfgang Bremser, Guido Grundmeier, Mirko Schaper, and Jörg K. N. Lindner — Paderborn University, Paderborn, Germany

Differential phase contrast (DPC) is one of the most promising techniques for future research with scanning transmission electron microscopy (STEM) giving rise to a new range of measurable material properties. By detecting phase gradients, i.e. by quantifying the electron beam deflection on a specimen site with a segmented detector, electric and magnetic field components can be detected. With an installed C_s-corrector the projected charge carrier distribution and electric fields can be estimated with a resolution much smaller than typical atomic distances. Zinc oxide (ZnO) is a piezoelectric material with excellent optical and semiconductor properties. Hence ZnO is promising for green energy harvesting converting mechanical stress into electric energy. For optimization of ZnO-based piezoelectric devices the operating principles and charge carrier displacements resulting from mechanical stress have to be understood down to the sub-nanoscale. In this presentation, the electric fields and charge carrier distributions of bent ZnO nanobelts, ZnO nanorods, nanowall network hollow body microspheres and ZnO-functionalized carbon fibers are revealed for the first time by DPC-STEM both at a macroscopic scale and with atomic resolution.

HL 29.4 Wed 10:30 H47

Investigation of superlattice defects in magnetite mesocrystals via (S)TEM tomography — •Sebastian Sturm[1], Daniel Wolf[1], Julian Brunner[2], Elena Sturm[2], Axel Lubk[1], and Bernd Büchner[1] — [1]IFW Dresden, Deutschland — [2]FB Chemie, Universität Konstanz, Deutschland

Mesocrystals are a special sub class of colloidal crystals fulfilling the definition of a crystal on two different hierarchical levels, exhibiting single crystal like diffraction pattern in small angles as well as single or texture like pattern in wide angles. They are thus formed by assembly of single crystalline building blocks in a long range ordered superlattice with reoccurring specific crystallographic orientation of the crystalline building blocks. In order to characterize the growth mechanism and investigate the defect structure of 3D iron oxide self-assembled mesocrystaline materials, we employed electron tomography on specifically picked areas. This allows to resolve structural defects generated within the superlattice during the self-assembly process inside the crystal in three dimensions. In case of a mesocrystal with fcc superlattice, grown by dislocation driven crystal growth mechanism, the disintegration of a (111) plane intersecting screw dislocation defect structure, in two Shockley-partials has been resolved, very similar to traditional fcc crystals. The aim is to study the structure of these partials and relate it to the elastic properties of the mesocrystal.

HL 29.5 Wed 10:50 H47

Thickness Determination on Molecular Thick Carbon Nanomembranes by HIM, XPS and EFTEM — •Daniel Emmrich[1], Annalena Wolff[2], Nikolaus Meyerbröker[3], Jörg K. N. Lindner[4], André Beyer[1], and Armin Gölzhäuser[1] — [1]Bielefeld University, Germany — [2]Queensland University of Technology, Australia — [3]CNM Technologies GmbH, 33607 Bielefeld, Germany — [4]Paderborn University, Germany

The Helium Ion Microscope (HIM) offers a lateral imaging resolution of 0.3 nm and is known for its excellent sub 10 nm milling capabilities [1]. While imaging with secondary electrons (SE) is well established for this microscope, the ion transmission signal attracts growing attention. Imaging in transmission offers additional information on membranes [2] and core shell nanoparticles [3]. Monolayer thin membranes have not been studied so far. Our systems are molecular thick Carbon Nanomembranes which are made of self-assembled monolayers that are cross-linked by low energy electrons [4]. We are able to measure dark field transmission of the same sample area at different acceptance angles using a SE conversion holder. The image contrast at different

acceptance angles is compared to simulations and the membrane thickness is determined. We demonstrate our concept for different energies and thicknesses. We compare our results to standard techniques, e.g., XPS and EFTEM. [1] G. Hlawacek, A. Gölzhäuser (Eds.), Springer Intl., Switzerland 2016. [2] A. R. Hall, Microsc Microanal 2013, 19, 740. [3] T. J. Woehl et al., Microsc Anal, 2016, 22, 544. [4] A. Turchanin, A. Gölzhäuser, Adv. Mater 2016, 28, 6075.

Break 20 min

HL 29.6 Wed 11:30 H47

Positron Annihilation Studies using a Superconducting Electron LINAC — •Maik Butterling[1], Andreas Wagner[1], Maciej Oskar Liedke[1], Eric Hirschmann[1,2], Ahmed G. Attallah Elsherif[1], Reinhard Krause-Rehberg[2], and Kay Potzger[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstr. 400, 01328 Dresden, Germany — [2]Martin-Luther-Universität Halle, Institut für Physik, 06099 Halle, Germany

The Helmholtz-Center at Dresden-Rossendorf operates several user beamlines for materials research using different techniques for positron annihilation spectroscopy. Two of them are being operated at a superconducting electron linear accelerator producing positrons via pair production from electron-bremsstrahlung. While one of the sources uses bremsstrahlung to directly generate positrons inside the sample of interest, in the second source (MePS), monoenergetic positrons with energies ranging from 500 eV to 25 keV are used for thin-film studies of porosity and defect distributions. The MePS beam line is currently complemented by a new in-situ end station (AIDA-2), where defect studies can be performed in a wide temperature range during thin film growth and ion irradiation. Developments as well as examples of recent experimental results at all facilities will be presented. The MePS facility has partly been funded by the Federal Ministry of Education and Research (BMBF) with the grant PosiAnalyse (05K2013). The AIDA facility was funded by the Impulse- und Networking fund of the Helmholtz-Association (FKZ VH-VI-442 Memriox) and through the Helmholtz Energy Materials Characterization Platform.

HL 29.7 Wed 11:50 H47

The influence of trace element additions to Al-1.7 at.% Cu alloys: preservation of quenched-in vacancies and atomistic mechanisms supporting θ'-formation — •Torsten E.M. Staab[1], Frank Lotter[1], Uwe Mühle[2], Mohamed Elsayed[3], Danny Petschke[1], Thomas Schubert[4], Reinhard Krause-Rehberg[3], and Bernd Kieback[2,4] — [1]University Wuerzburg, Dep. of Chemistry, LCTM, Roentgenring 11, D-97070 Wuerzburg — [2]TU Dresden, Institute of Materials Science; Helmholtzstr. 7, D-01069 Dresden — [3]Martin-Luther-University Halle-Wittenberg; Faculty of Natural Science II; von-Danckelmann-Platz 3; D-06120 Halle — [4]Fraunhofer IFAM, Winterbergstrasse 28, D-01277 Dresden

Aluminium-copper alloys of the 2xxx type receive their strength during hardening at room or elevated temperature by the formation of copper-rich precipitates. They are responsible for the final mechanical properties of these alloys. Alloying small amounts of Cd, In or Sn influences the precipitation behavior as well as the final strength of Al-Cu alloys. Obviously, quenched-in vacancies are bound to trace element atoms in the aluminium matrix. Thus, the diffusion behavior of the copper atoms is influenced and the main type of the formed precipitates changes. For high-purity ternary alloys we investigate the interaction of copper atoms and trace elements (In, Sn, and Pb) with quenched-in vacancies. By employing Differential Scanning Calorimetry (DSC), Small Angle X-Ray Scattering (SAXS), Positron Annihilation Lifetime Spectroscopy (PALS) as well as Transmission Electron Microscopy (TEM) we obtain a comprehensive picture.

HL 30: Invited talk Fomin

Time: Wednesday 12:15–12:45 Location: H33

Invited Talk HL 30.1 Wed 12:15 H33

Topology−driven excitonic Aharonov−Bohm effect in core−multishell nanowires — •Vladimir M. Fomin[1], Pierre Corfdir[2], Oliver Marquardt[3], Ryan B. Lewis[2], Chiara Sinito[2], Manfred Ramsteiner[2], Achim Trampert[2], Uwe Jahn[2], Lutz Geelhaar[2], and Oliver Brandt[2] — [1]Institute für Integrative Nanowissenschaften, Leibniz IFW Dresden, Dresden D-01069, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im FVB, D-10117 Berlin, Germany — [3]Weierstraß-Institut für Angewandte Analysis und Stochastik, Leibniz-Institut im FVB, D-10117 Berlin, Germany

The physics of quantum rings is a heuristically unique playground for topology-driven quantum-mechanical effects [1]. A novel insight in this field is achieved by extending the paradigm of topology-controlled properties from quantum rings onto a broad class of doubly-connected nanoarchitectures. Core-multishell GaAs/AlAs nanowires are shown to be an excellent platform for investigations of the Aharonov−Bohm effect of neutral and charged excitons [2]. The controlled fabrication of nearly perfect quantum rings in core-multishell GaAs/AlAs nanowires is ensured by combining all-binary radial heterostructures with axial crystal-phase quantum structures. Excitonic phase coherence is predicted theoretically and observed through the Aharonov−Bohm oscillations in the photoluminescence spectra in quantum rings with circumferences as large as 200 nm. [1] V. M. Fomin (Ed.), Physics of Quantum Rings, 2nd Edition (Springer International Publ., Cham, 2018), 586 p. [2] P. Corfdir et al., Adv. Mater. 31, 1805645 (2019).

HL 31: Nitrides: Preparation and characterization II

Time: Wednesday 15:00–17:15 Location: H31

HL 31.1 Wed 15:00 H31

GaN/AlGaN Microfin Core-Shell-Structures for Efficient DUV Emitters — •Christoph Margenfeld[1], Hendrik Spende[1], Hao Zhou[1], Hans-Jürgen Lugauer[2], Hergo-Heinrich Wehmann[1], and Andreas Waag[1] — [1]Institut für Halbleitertechnik, epitaxy competence center ec^2 and Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Braunschweig, Germany — [2]Osram Opto Semiconductors GmbH, Regensburg, Germany

Conventional DUV LEDs grown on c-plane sapphire substrates suffer from a high density of threading dislocations, which sensitively affects the internal quantum efficiency (IQE), an increasing fraction of TM mode radiation leading to low light extraction efficiency (LEE), and impaired carrier injection efficiency as a result of strong polarization fields. These issues can be circumvented by employing three-dimensional AlGaN microstructures with nonpolar sidewalls.

A GaN/AlGaN core-shell architecture based on microfin structures grown by selective area MOVPE is introduced and the solutions to challenges occurring during growth are discussed. Characterization by XRD reciprocal space mapping, hyperspectral CL mapping and temperature-dependent CL reveals very promising results such as high structural quality, low threading dislocation density and intense emission from nonpolar a-plane MQWs at 280 nm up to 100 °C.

HL 31.2 Wed 15:15 H31

Excess carrier density dependent recombination dynamics on GaN quantum wells — •Silvia Müllner[1], Philipp Hornburg[1], Philipp Henning[1], Heiko Bremers[1,2], Uwe Rossow[1], and Andreas Hangleiter[1,2] — [1]Institute of Applied Physics, TU Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany

Recombination dynamics in quantum wells (QW) are commonly described by the ABC-model. Previous results from *c*-plane GaN QW and recent results from *m*-plane GaN QW, however, disagree with this

model. Our time-resolved photoluminescence experiments provide information on recombination dynamics. By tuning the pulse energy density, P_{pulse}, the excess carrier density, δn, is varied systematically. The low injection region shows a linear dependence between the radiative process and δn suggesting a recombination process of excitonic nature, which is neglected in the ABC-model. The recombination dynamics in these QW will be compared and discussed for both orientation.

HL 31.3 Wed 15:30 H31

Towards a Deeper Understanding of Shell Growth on GaN Microstructures — •Irene Manglano Clavero[1], Christoph Margenfeld[1], Jana Hartmann[1], Hergo-Heinrich Wehmann[1], Adrian Avramescu[2], Hans-Juergen Lugauer[2], and Andreas Waag[1] — [1]Institut für Halbleitertechnik, epitaxy competence center ec[2] and Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Braunschweig, Germany — [2]Osram Opto Semiconductors GmbH, Regensburg, Germany

In the last decade, 3D nano and micro light emitting diodes with nonpolar planes have been regarded as promising optical devices to mitigate the droop and provide reduced density of extended defects. Although different groups have investigated the growth mechanism of these 3D structures, there is still no thorough understanding of the mechanisms governing the core-shell growth.

The impact of gallium supply and carrier gas composition on the morphology and growth rate of c- and a-plane shells on GaN microfins grown by selective area metal-organic vapor-phase epitaxy (SA-MOVPE) are studied. We evaluate the resulting growth rates in terms of a model based on Chapman-Enskog theory of gas phase diffusion and obtain qualitative and quantitative agreement. It is found that shell growth on 3D microstructures deviates significantly from the mass-transport limited regime which is conventionally observed for the planar case, as is concluded from evaluating the sticking coefficients obtained from the model for the polar and nonpolar crystal planes.

HL 31.4 Wed 15:45 H31

A quantum-mechanical study of pressure-induced isostructural transition in YN and ScN characterized by a reversal in their elastic anisotropy — •Martin Friák[1,2], Pavel Kroupa[1,3], David Holec[4], and Mojmír Šob[5,1,2] — [1]Institute of Physics of Materials, Academy of Sciences of the Czech Republic, Brno, Czech Republic — [2]Central European Institute of Technology, CEITEC MU, Masaryk University, Brno, Czech Republic — [3]Department of Physics, Imperial College London, London, United Kingdom — [4]Department of Materials Science, Montanuniversität Leoben, Leoben, Austria — [5]Department of Chemistry, Faculty of Science, Masaryk University, Brno, Czech Republic

Using quantum-mechanical calculations of 2[nd]- and 3[rd]-order elastic constants for YN and ScN with the rock-salt (B1) structure we predict that the studied materials change the fundamental type of their elastic anisotropy by rather moderate hydrostatic pressures of a few GPa. In particular, YN with its zero-pressure elastic anisotropy characterized by the Zener anisotropy ratio $A_Z = 2C_{44}/(C_{11} - C_{12}) = 1.046$ becomes elastically isotropic at the hydrostatic pressure of 1.2 GPa. The lowest values of the Young's modulus (so-called soft directions) change from ⟨100⟩ (in the zero-pressure state) to the ⟨111⟩ directions (for pressures above 1.2 GPa). It means that the crystallographic orientations of stiffest (also called hard) elastic response and that of the softest one become reversed. Qualitatively the same type of transition is predicted for ScN with the zero-pressure value of the Zener anisotropy factor $A_Z = 1.117$ and the transition pressure about 6.5 GPa.

15 min. break

HL 31.5 Wed 16:15 H31

Optical and structural properties of one-directionally lattice-matched $(11\bar{2}2)$ **oriented** $Al_{1-x}In_xN$**/GaN heterostructures** — •Savutjan Sidik[1], Philipp Horenburg[1], Heiko Bremers[1], Uwe Rossow[1], Tobias Meisch[2], Ferdinand Scholz[2], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, Technische Universität Braunschweig — [2]Institut für Optoelektronik, Universität Ulm

The difference of a/c-ratios of AlInN and GaN allows to realize an intentional one-directional relaxation of the AlInN lattice in a non-lattice-matched direction in semipolar structures. We investigate the evolution of emission features and polarization anisotropy of semipolar $(11\bar{2}2)$ AlInN samples by varying the layer thicknesses and compositions. These samples are grown via MOVPE on $(11\bar{2}2)$ GaN templates grown on patterned r-sapphire substrates. The room temperature photoluminescence spectroscopy (PL) results show a broad luminescence band at around 3.0 eV from AlInN layers intended to be lattice-matched in $[11\bar{2}\bar{3}]$ direction. Also, the spectral position of samples is red-shifted with increasing indium content. However, samples with lower In content do not show luminescence related to AlInN which is also observed in our *c*-plane AlInN structures. We investigate the effects of relaxation and anisotropic strain on polarization anisotropy of AlInN layers with a polarization-resolved PL setup. The measurements reveal polarization of 34%, 23% and 21% for samples with In content of 26.9%, 28.4% and 28.8%, respectively. Modeling of polarization properties based on $\mathbf{k}\cdot\mathbf{p}$ calculation by considering the anisotropic strain is in progress.

HL 31.6 Wed 16:30 H31

Optical properties of nonpolar GaN/AlN superlattice structures — •Michael Winkler[1], Hagen Brähmer[1], Martin Feneberg[1], Norbert Esser[2], Eva Monroy[3], and Rüdiger Goldhahn[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Leibniz-Institut für Analytische Wissenschaften - ISAS, Berlin, Germany — [3]University Grenoble-Alpes, CEA, Grenoble, France

Semiconductor superlattice structure are used in optoelectronic devices as active material, for strain management or are parts of waveguides. The dielectric losses in this multilayer structures have a significant impact on efficiency of such devices.

The anisotropic optical properties of $(1\bar{1}00)$ oriented gallium-nitride/aluminium-nitride superlattice structures were studied by synchrotron-based spectroscopic ellipsometry for photon energies up to 10eV. The samples were grown by plasma-assisted molecular-beam epitaxy. Samples with period length of 5.1nm, 5.9nm, and 6.7nm were studied.

Both, a multilayer and an effective layer approach were used to model the experimental data. From the latter, ordinary and extraordinary dielectric functions were deduced by fitting wavelength-by-wavelength. We compare the obtained DFs with results from the multilayer approach, photoluminescence data, and calculated interband transitions. The effects of the non-parabolic valence bands and the limits for the effective layer approach will be discussed in detail.

HL 31.7 Wed 16:45 H31

Nanoscale structural and optical properties of deep UV-emitting GaN/AlN quantum well stack — •Bowen Sheng[1,2], Yixin Wang[1], Xin Rong[1], Zhaoying Chen[1], Tao Wang[1], Ping Wang[1], Gordon Schmidt[2], Frank Bertram[2], Peter Veit[2], Jürgen Bläsing[2], Hideto Miyake[3], Hongwei Li[4], Shiping Guo[4], Zhixin Qin[1], Andre Strittmatter[2], Jürgen Christen[2], Bo Shen[1], and Xinqiang Wang[1] — [1]School of Physics, Peking University, Beijing, China — [2]Institute of Physics, Otto-von-Guericke-University Magdeburg, Magdeburg, Germany — [3]Department of Electrical and Electronic Engineering, Mie University, Mie, Japan — [4]Advanced Micro-Fabrication Equipment Inc., Shanghai, China

We successfully have grown 100 periods of GaN/AlN MQWs with monolayer-thick GaN quantum well on high-quality thermally annealed AlN template by MOCVD. The thickness of AlN barriers is nominally 10 nm. The STEM image contrast is evidencing that the GaN quantum wells are nicely embedded in AlN matrix with sharp interfaces and monolayer thickness of the GaN QWs. A cross-sectional CL linescan performed at 17 K overall reveals the emission evolution: at the beginning of GaN MQWs, the emission has a slight redshift from 225 to 230 nm, then stays perfectly constant towards the top surface. Finally, under higher magnification, the panchromatic CL map resolves the first 13 QW pairs. The CL intensity modulation matches perfect with HAADF contrast. Under this high spatial resolution we are able to resolve the distance between two quantum wells determined as 10.8 nm, not only in HAADF but also in CL intensity.

HL 31.8 Wed 17:00 H31

Ultrathin GaN/InN/GaN QW structures grown by MBE — •Frederik Lüssmann, Tobias Meyer, Jörg Malindretos, Michael Seibt, and Angela Rizzi — Georg-August Universität Göttingen, IV. Physikalisches Institut, 37077 Göttingen

Lately, topological insulators (TIs) have drawn much attention as a new state of quantum matter. In particular, two-dimensional TIs can be achieved by growing QWs with an inverted band structure. For InN/GaN it has been predicted that the large piezoelectric fields in

pseudomorphic QWs grown along the [0001] direction can trigger band inversion. The minimum critical thickness of InN for the topological phase transition is expected to be about 4 MLs. In this study we therefore aim at the fabrication of ultrathin pseudomorphic InN/GaN QWs. The samples are grown by MBE and analysed by AFM, STEM and PL. We have examined a growth mode, already known in literature, in which InN QWs are grown at elevated substrate temperatures of 620°C to 670°C, which is well above the dissociation temperature of InN. The high In supply and the subsequent capping with GaN are expected to induce a phase separation resulting in stable InN layer. Furthermore, segregation of the excess In occurs at the growing GaN cap surface. In this way, very well defined and sharp QWs can be grown, as shown by STEM. Sharp PL emission at low temperature also indicates the successful growth of the QW structures.

HL 32: Spintronics

Time: Wednesday 15:00–17:30 Location: H33

HL 32.1 Wed 15:00 H33

Computation of the spin-Hall conductivity from first principles using maximally-localized Wannier functions — •Ji Hoon Ryoo[1], Cheol-Hwan Park[1], and Ivo Souza[2] — [1]Department of Physics, Seoul National University, Seoul, Korea — [2]Centro de Física de Materiales, Universidad del País Vasco, San Sebastián, Spain

Being an essential element of spintronics, the spin Hall conductivities of dozens of materials ranging from simple metals and semiconductors to more complicated materials such as metallic alloys and topological insulators have been measured experimentally and calculated theoretically during the last decade. In this regard, it is important to compute spin-Hall conductivities of a material accurately from first principles. Often, however, the high cost for computing several matrix elements of spin-current and velocity operators between Bloch states has been considered as a bottleneck that significantly slows down the calculation. We discuss a computationally efficient method of computing spin-Hall conductivities from first principles through an interpolation of matrix elements and energy eigenvalues using maximally-localized Wannier functions and its application for computing the spin-Hall conductivities of platinum and gallium arsenide.

HL 32.2 Wed 15:15 H33

Investigation of spin-orbit interaction in the regime of the persistent spin helix — •Sven Gelfert[1], Christian Frankerl[1], Christian Reichl[2], Dieter Schuh[1], Gian Salis[3], Werner Wegscheider[2], Dominique Bougeard[1], Tobias Korn[1], and Christian Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, University of Regensburg, 93040 Regensburg, Germany — [2]Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland — [3]IBM Research-Zurich, 8803 Rüschlikon, Switzerland

In our experiments, low-energy intrasubband spin-density excitations (SDE) are driven by resonant inelastic light scattering experiments in 12-nm-wide (001)-oriented GaAs-AlGaAs single quantum wells with balanced Rashba and Dresselhaus spin-orbit interaction strengths. The resulting symmetry of the effective spin-orbit field supports the persistent spin helix. Spin-flip intrasubband SDE transitions in the conduction band show a highly anisotropic splitting and can be accessed by two different measurement geometries where a wave-vector transfer into the two-dimensional electron system is required. In backscattering and grazing incidence geometry we can precisely map the anisotropic spin splitting for arbitrary crystal directions by rotating the sample on a piezo-driven rotary stage. With external magnetic fields (up to 6 Tesla) a superposition of the intrinsic spin-orbit field and the external field occurs, which allows us to deduce the spin-orbit field strength, the electron g factor and the single-particle relaxation time from our observations.

HL 32.3 Wed 15:30 H33

Acoustic spin transport in planar GaAs quantum wires — •Paul L. J. Helgers[1,2], Klaus Biermann[1], Haruki Sanada[2], Yoji Kunihashi[2], and Paulo V. Santos[1] — [1]Paul-Drude Institut, Leibniz-Institut im Forschungsverbund Berlin e.V., Germany — [2]NTT Basic Research Laboratories, NTT Corporation, Atsugi, Japan

We investigate a concept for single-photon sources, based on planar GaAs quantum wires (QWR). The QWRs form during anisotropic overgrowth of a 10 nm quantum well (QW) on pre-patterned GaAs(001) substrates by molecular beam epitaxy. The fabrication process results in potential fluctuations along the QWR axis due to line-edge-roughness (LER). LER potentially leads to Elliot-Yafet spin relaxation. We measure LER to be small as compared to the QWR width and expect it to play only a minor role during spin transport.

We study charge transport in the QWRs by a surface acoustic wave (SAW) over tens of microns. Moreover, we detect SAW-assisted carrier transfer between the QWR and the surrounding QW, which is otherwise prevented by a potential barrier. The one-dimensionality of the QWR reduces Dyakonov-Perel (DP) spin dephasing, leading to enhanced spin lifetimes with respect to the QW. We observe acoustic spin transport up to at least 15 micron. During transport, the spins rotate around the Dresselhaus field with a precession length corresponding to the calculated one for these QWRs, proving that the spin transport takes place in the QWRs rather than in the surrounding QW.

HL 32.4 Wed 15:45 H33

Electron and Nuclear Spin Interaction in n-GaAs: Impact of Doping and Temperature — •Lida Abaspour, Pavel Serin, Jan Gerrit Lonnemann, Eddy Rugeramigabo, Jens Hübner, and Michael Oestreich — Institute for Solid State Physics, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

The mutual interaction of nuclear and electron spins in semiconductors has been identified as a major source of nuclear and electron spin relaxation (SR). Doping-dependent optical measurements and magneto-transport of the electron SR time in n-doped bulk GaAs structures reveal competing SR mechanisms (variable range hopping (VRH), hyperfine interaction (HF) and the Dyakonov Perel effect (DP)) below and around the metal to insulator transition (MIT) [1, 2]. At the onset of the transition to the DP effect, temperature-dependent measurements show the effect of non-degenerate DP for higher temperatures while VRH and HF affect the SR at low temperature.

Moreover, we measure the doping dependence of the nuclear spin dynamics for different n-GaAs samples. The number of localized electrons increases with increasing doping concentration below the MIT where hyperfine interaction reduces the SR time. In the metallic regime, delocalized electrons reduce the SR time. Furthermore, for the lowest doped sample, temperature dependent measurements allow distinguishing the mutual impact of the different mechanism involved.

[1] R. I. Dzhioev, et. al., Phys. Rev. B 66, 245204 (2002).
[2] J. G. Lonnemann, et. al., Phys. Rev. B 96, 045201 (2017).

HL 32.5 Wed 16:00 H33

Thermal fluctuations cause spin-polarized states in the semiconducting lead halide perovskite $(CH_3NH_3)PbI_3$ — •Daniel Niesner[1], Martin Hauck[2], Shreetu Shrestha[3], Ievgen Levchuk[3], Gebhard Matt[3], Andres Osvet[3], Miroslaw Batentschuk[3], Christoph Brabec[3], Heiko Weber[2], and Thomas Fauster[1] — [1]Lehrstuhl für Festkörperphysik, Univ. of Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen — [2]Lehrstuhl für Angewandte Physik, Univ. of Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen — [3]i-Meet, Department of Materials Science, Univ. of Erlangen-Nürnberg, Martensstr. 7, D-91058 Erlangen

$(CH_3NH_3)PbI_3$ is the prototypical lead halide perovskite used in thin-film photovoltaics. It is a direct semiconductor with single, non-degenerate valence and conduction bands. At 165 K, it undergoes a phase transition from a structure with antiferroelectric order into a phase with polar disorder and inversion symmetry on average. Performing photocurrent experiments with circularly polarized light, we find a circular photogalvanic effect in this phase, i. e. the current depends on the light helicity [1]. This implies the optical excitation of spin currents, an unexpected process for a centrosymmetric crystal. The effect gets stronger with increasing temperature, pointing towards a dynamical Rashba effect, i. e. a local symmetry breaking due to thermal fluctuations caused by large-amplitude, soft phonon modes. The dynamical Rashba effect is expected to be general to centrosymmetric materials with large-amplitude phonon modes containing heavy elements.

[1] D. Niesner et al., Proc. Natl. Acad. Sci. 115, 9505 (2018)

15 min. break

HL 32.6 Wed 16:30 H33

Long-lived photon echoes from localized trions and donor-bound excitons in CdTe/(Cd,Mg)Te quantum well — •Alexander Kosarev[1,3], Sergey Poltavtsev[1,2], Ilya Akimov[1,3], Leonid Golub[3], Mikhail Glazov[3], Grzegorz Karczewski[4], Maciej Wiater[4], Tomasz Wojtowicz[4,5], Matthias Salewski[1], Nikolai Kozyrev[3], Evgeny Zhukov[1], Dmitri Yakovlev[1,3], and Manfred Bayer[1,3] — [1]TU Dortmund, Dortmund, Germany — [2]Spin Optics Laboratory, St. Petersburg University, St. Peterburg, Russia — [3]Ioffe Institute, St. Petersburg, Russia — [4]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland — [5]International Research Centre MagTop, Warsaw, Poland

We perform time-resolved photon echo and pump-probe Kerr-rotation spectroscopy on molecular-beam epitaxy-grown single 20 nm CdTe/(Cd,Mg)Te quantum well at low temperatures under resonant excitation of donor-bound excitons and trions. We observe spin precession of donor-bound electrons and electrons localized at potential fluctuations in the applied transverse magnetic field through the dynamics of the stimulated three-pulse photon echo and pump-probe ellipticity signals. Spectral dependences of the homogeneous and inhomogeneous spin phase relaxation times by means of both techniques are obtained. Theoretical model, which takes into account different spin dephasing mechanisms including electron hopping, is developed.

HL 32.7 Wed 16:45 H33

Analysis of electronic bands in metal halide perovskite single crystals via angular-resolved photoelectron spectroscopy — •Maryam Sajedi[1,2], Dmitry Marchenko[1], Maxim Krivenkov[1,2], Andrei Varykhalov[1], Jaime Sánchez-Barriga[1], Eva Unger[1], and Oliver Rader[1] — [1]Helmholtz Zentrum Berlin für Materialien und Energie, Albert Einstein Str 15, D-12489, Berlin, Germany — [2]Department of physics, Potsdam University, Am Neuen Palais 10, D-14415, Potsdam Germany

Owing to their tunable optoelectronic characteristics, high carrier mobility, and lifetime, metal halide perovskites evoked phenomenal interest in versatile applications like photovoltaics and photodetectors. Likewise, they are fascinating novel materials for future spintronics, due to the strong spin orbit coupling in their structure. By angle-resolved photoemission spectroscopy we have attained the electronic band structures from cleaved (001) faces of two Br-based perovskite single crystals, namely MAPbBr3 and CsPbBr3. Our results reveal the four-fold symmetry, and highly reproducible and stable parabolic dispersive features of the valence band maximum, much more pronounced than in any published data. The time-dependent surface elemental composition was investigated by means of high resolution x-ray photoemission spectroscopy and showed reasonable radiation stability of inorganic CsPbBr3, and organic I-based MAPbI3, which is a precondition for enduring ARPES measurements.

HL 32.8 Wed 17:00 H33

Analysis of electronic bands in metal halide perovskite single crystals via angular-resolved photoelectron spectroscopy — •Maryam Sajedi[1,2], Dmitry Marchenko[1], Maxim Krivenkov[1,2], Andrei Varykhalov[1], Jaime Sánchez-Barriga[1], and Oliver Rader[1] — [1]Helmholtz Zentrum Berlin für Materialien und Energie, Albert Einstein Str 15, D-12489, Berlin, Germany — [2]Department of physics, Potsdam University, Am Neuen Palais 10, D-14415, Potsdam Germany

Owing to their tunable optoelectronic characteristics, high carrier mobility, and lifetime, metal halide perovskites evoked phenomenal interest in versatile applications like photovoltaics and photodetectors. Likewise, they are fascinating novel materials for future spintronics, due to the strong spin orbit coupling in their structure. By angle-resolved photoemission spectroscopy we have attained the electronic band structures from cleaved (001) faces of two Br-based perovskite single crystals, namely MAPbBr3 and CsPbBr3. Our results reveal the four-fold symmetry, and highly reproducible and stable parabolic dispersive features of the valence band maximum, much more pronounced than in any published data. The time-dependent surface elemental composition was investigated by means of high resolution x-ray photoemission spectroscopy and showed reasonable radiation stability of inorganic CsPbBr3, and organic I-based MAPbI3, which is a precondition for enduring ARPES measurements.

HL 32.9 Wed 17:15 H33

Spin noise spectroscopy of resident carriers in InGaAs/GaAs self-assembled QD in DBR — •Aleksandr Kamenskii, Alex Greilich, and Manfred Bayer — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

Spin noise spectroscopy is a developing method, that allows measurement of spin relaxation times by measurements of correlations of stochastic spin fluctuations with low perturbation. We apply this method to study the spin noise signal formation in n-doped quantum dots placed in DBR microcavity and use homodyne detection scheme to enhance the detection sensitivity. Due to DBR structure, the light-matter interaction becomes enhanced, and the Faraday rotation noise increases by Q-factor of DBR. In this way, the study of fine effects becomes available. We demonstrate and proof that spin noise information is carried by scattered light, as Gorbovitskii-Perel theorem predicts.

HL 33: Quantum light sources

Time: Wednesday 15:00–17:30 Location: H34

HL 33.1 Wed 15:00 H34

Development of Plug-and-Play Single-Photon Sources for Quantum Communication — •Lucas Rickert, Timm Kupko, Stephan Reitzenstein, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Quantum light sources are essential building blocks for novel applications in the fields of communication, metrology and sensing. The future success of quantum technologies, however, will critically rely on the applicability of quantum light sources outside shielded lab environments. First steps in this direction are very promising [1], but further developments are necessary to realize devices suitable for quantum communication scenarios.

In this work, we report on our recent progress in the development of plug-and-play single-photon sources (SPSs) based on semiconductor quantum dots. A compact Stirling cryocooler is employed as basis for user-friendly operation of our SPSs at cryogenic temperatures. We address the direct coupling of the SPS emission to optical single-mode fibers, representing a crucial step for applications. Furthermore we discuss approaches to realize compact spectral filtering based on interference bandpass filters or transmission gratings as well as the implementation of electrical operation. All these elements can finally be integrated into a single plug-and-play system, which would represent a major step towards the development of QKD-secured communication networks based on quantum-light sources.

[1] A. Schlehahn et al., Scientific Reports **8**, 1340 (2018)

HL 33.2 Wed 15:15 H34

Integrated quantum photonics based on InAs/GaAs quantum dots monolithically coupled to ridge waveguides — •Dominik Koeck[1], Lukasz Dusanowski[1], Soon-Hong Kwon[2], Christian Schneider[1], and Sven Hoefling[1] — [1]Technische Physik, University of Wuerzburg, Physikalisches Institut and Wilhelm-Conrad-Roentgen-Research Center for Complex Material Systems, Am Hubland, D-97074 Wuerzburg, Germany — [2]Department of Physics, Chung-Ang University, 156-756 Seoul, Korea

Hereby we show our recent advances in fabrication and optical characterization of InAs/GaAs QDs monotonically integrated with single- and multimode distributed Bragg reflector ridge waveguides. Identification of excitonic and biexcitonic transitions have been performed by power- and polarization-resolved microphotoluminescence studies. In order to evaluate the non-classicality of QD transitions, second-order auto-correlation measurements where performed in Hanbury Brown and Twiss configuration. In case of both, continuous and pulsed ex-

citation of the QD's transitions we observed clear signatures of single photon emission with $g^{(2)}(0)$ values below 0.1, confirming pure single photon character of the emitted light. Future directions include efforts towards more advanced integrated functionalities such as ring resonators and directional couplers needed for on-chip single photon processing.

HL 33.3 Wed 15:30 H34

Characterization of deterministically fabricated quantum dot microlenses under mechanical strain tuning — •Marco Schmidt[1,2], Sarah Fischbach[1], Martin von Helversen[1], Arsenty Kaganskiy[1], Sven Rodt[1], Tobias Heindel[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany

Quantum dots (QPs) are sources of single, indistinguishable photons as well as polarization entangled photon pairs. These highly efficient QP emitters are of highest interest for future quantum communication systems allowing for the interception-proof exchange of information by single photons. The spectral properties of QPs determined by the self-assembled growth and can be manipulated in limited range by experimental methods, e.g. temperature variation. The emission energy can also be tuned more elegantly to a target wavelength by applying external mechanical strain, while maintaining the good optical quality. We demonstrate a tunable single-photon source based on a deterministically fabricated QD microlens which is positioned on top of a piezoactuator by a flip-chip goldbonding technique. A control loop is implemented which stabilizes the strain and the emission wavelength of the QD. Characterizations of the system in terms of stability, modulation ranges, transfer functions and spectroscopic investigations will be presented.

HL 33.4 Wed 15:45 H34

Deterministically positioned InAs quantum dots in heterogeneous GaAs silicon integrated quantum photonic devices — •Peter Schnauber[1], Anshuman Singh[2,3], Johannes Schall[1], Jin-Dong Song[4], Sven Rodt[1], Kartik Srinivasan[2], Stephan Reitzenstein[1], and Marcelo Davanco[2] — [1]Inst. fuer Festkoerperphysik, TU Berlin — [2]Nat. Inst. of Standards and Technology, Gaithersburg — [3]MD NanoCenter, Uni. of Maryland — [4]KIST, Seoul

Through heterogeneous integration, III-V single photon emitters based on quantum dots (QDs) can be combined with low-loss, mature silicon-based photonic chips[1]. Recently, GaAs with InAs QDs has been wafer-bonded on SiN-SiO_2, and on the wafer-stack hybrid photonic devices were produced in which single photon emission from randomly aligned QDs is first captured into GaAs waveguides (WGs), then directed into SiN WGs via adiabatic mode transformers[2]. Here, using in-situ electron beam lithography[3] we integrate single pre-selected InAs QDs inside GaAs WG tapers and combine them with SiN WGs in such a hybrid system. High resolution micro-PL in p-shell excitation shows QD linewidthes down to 2 GHz, which indicates that the QD coherence properties are maintained during fabrication. Pulsed autocorrelation measurements with $g^{(2)}(0) < 0.1$ show triggered single-photon emission and two-photon interference (TPI) experiments in CW excitation reveal a raw TPI visibility of $\approx 40\,\%$ at zero time delay.

[1] Zadeh et al., Nano Letters 16, 2289 (2016)
[2] Davanco et al., Nature Communications 8, 889 (2017)
[3] Schnauber et al., Nano Letters 18, 2336 (2018)

HL 33.5 Wed 16:00 H34

MOVPE-grown single InGaAs quantum dots emitting in the telecom O-band with an AlAs monolayer anti-diffusion cap — •Jan Grosse, Nicole Srocka, Max Schlösinger, and Stephan Reitzenstein — Technische Universität Berlin, Institute for Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany

Epitaxially grown InAs/InGaAs quantum dots (QDs) are highly attractive for the realization of bright single-photon sources in the telecom O-band at 1.3 um [1]. However, their fabrication is very challenging because they suffer from major indium diffusion problems during the deposition of a strain-reducing layer (SRL). This leads to a clustering and coupling process during the overgrowth process, which diminishes the optical quality (brightness and spectral separability) of the final QD/SRL system. Here, we present an advanced growth concept which is based on the introduction of a monolayer of AlAs between the QDs and the SRL to counteract the high surface mobility of the indium atoms. We present results on the optical and structural characterization of the modified system and discuss the effects of the AlAs monolayer on QD density and quality.

[1] Bloch, J. et al. Appl. Phys. Lett. 75, 2199 (1999).

15 min. break

HL 33.6 Wed 16:30 H34

Wigner time delay induced by a single quantum dot — •Marcel Hohn[1], Max Strauss[1], Alexander Carmele[2], Julian Schleibner[2], Christian Schneider[3], Sven Höfling[3], Janik Wolters[1,4], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, D-10263 Berlin, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, D-10263 Berlin, Germany — [3]Technische Physik, Physikalisches Institut, Wilhelm Conrad Röntgen Center for Complex Material Systems, Universität Würzburg, D-97074, Germany — [4]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

Resonant scattering of weak coherent laser pulses on a single two-level system (TLS) realized in a semiconductor quantum dot is investigated with respect to a time delay between incoming and scattered light [1]. This type of time delay was predicted by Wigner in 1955 for purely coherent scattering and was confirmed for an atomic system [2]. In presence of electron-phonon interaction we observe deviations from Wigner's theory related to incoherent and strongly non-Markovian scattering processes which are hard to quantify in a phenomenological T_2-time. We observe Wigner delays of up to 530 ps in our experiments which quantifies the effective pure dephasing constant to $T_2 = (445 \pm 16)$ ps, supported by microscopic theory.

[1] M. Strauss et al., arXiv:1805.06357
[2] R. Bourgain et al., Opt. Lett. 38, 1963-5 (2013)

HL 33.7 Wed 16:45 H34

Chiral light-matter coupling in deterministic quantum dot waveguides — •Paweł Mrowiński[1], Peter Schnauber[1], Arsenty Kaganskiy[1], Philipp Gutsche[2], Sven Burger[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany — [2]Zuse Institute Berlin, Takustraße 7, D-14195 Berlin, Germany

Quantum dots embedded in waveguides can exhibit directional emission or non-reciprocal transmission on a single-photon level via chiral light-matter interactions, which is important for realization of large-scale on-chip quantum circuits [1,2]. In this work, we study directional emission of a single InAs/GaAs quantum dot (QD) in a ridge waveguide (WG) structure with bottom AlGaAs/GaAs DBR mirror (cf. Fig. 1a). The QD is pre-selected and deterministic integrated into the WG by using in-situ electron-beam lithography, as described in [3]. We fabricated a series of WG structures containing single QD varying the in-plane position to explore the position dependence on directional emission. The directional propagation is reflected in the polarization resolved photoluminescence for the outcoupled light influenced by the external magnetic field applied in Faraday configuration. A significant contrast (C) of 90 % is observed for right/left circularly polarized QD emission from charged exciton in case of QD located at highly off-center position, which indicates chiral coupling in this system (cf. Fig 1b). Furthermore, we studied in detail the contrast vs QD position dependence and we obtain agreement with the calculated dependence by Finite Element Method (JCMwave).

HL 33.8 Wed 17:00 H34

Impact of the excitonic spin dynamics on the entanglement from a InGaAs quantum dot — •Samir Bounouar[1], Gabriel Rein[1], Julian Schleibner[2], Alexander Carmele[2], Peter Schnauber[1], Andre Strittmatter[1,3], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Berlin, Germany — [3]Abteilung für Halbleiterepitaxie, Otto-von-Guericke, Universität, Magdeburg, Germany

Maximal entanglement is an important resource in photonic quantum technology and can be in principal generated by a semiconductor quantum dot even in the presence of finite fine structure splitting [1]. However, the exciton spin dynamics constitutes an important obstacle to perfect entanglement. We report on photon-correlation experiments performed on single InGaAs quantum dots integrated deterministi-

cally into monolithic microlenses. Non-phonon-mediated spin decoherence processes are systematically investigated and their influence on the quality of the generated entanglement by quantum dots is evaluated. In particular, exchange interaction, decoherence and nuclear spin induced precessions are evidenced through a series of tomography measurements on a large number of single quantum dots. A drop of the entanglement due to these processes is evidenced for small excitonic fine structure splittings and is discussed by a theoretical model introducing exchange interaction.

[1] S. Bounouar et al., Applied Physics Letters 112, 153107 (2018)

HL 33.9 Wed 17:15 H34

Quantum Metrology of Solid-State Single-Photon Sources using Photon-Number-Resolving Detectors — •Martin von Helversen[1], Jonas Böhm[1], Marco Schmidt[1], Manuel Gschrey[1], Jan-Hindrik Schulze[1], André Strittmatter[1,3], Sven Rodt[1], Jörn Beyer[2], Tobias Heindel[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Physikalisch Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin, Germany — [3]Institut für Experimentelle Physik, Otto-von-Guericke Universität Magdeburg, PF4120, Magdeburg, Germany

Quantum-light sources based on semiconductor quantum dots (QDs) are promising candidates for applications in quantum photonics and quantum communication. Important emission characteristics of such emitters, namely the single-photon purity and photon indistinguishability, are usually assessed via time-correlated measurements using standard 'click' detectors in Hanbury-Brown and Twiss (HBT-) or Hong-Ou-Mandel (HOM-) type configurations. In this work, we employ a state-of-the-art photon-number-resolving (PNR) detection system based on superconducting transition-edge sensors (TESs) to directly access the photon-number distribution of deterministically fabricated solid-state single-photon sources. The obtained results reveal excellent quantitative agreement of the degree of indistinguishability obtained with PNR (90 ± 7 %) and standard detectors (90 ± 5 %). Our work demonstates that TES-based detectors are perfectly suitable for the quantum metrology of non-classical light sources.

HL 34: Photovoltaics (joint session HL/CPP)

Time: Wednesday 15:00–17:30 Location: H36

HL 34.1 Wed 15:00 H36

Revisiting the electronic structure of vanadium doped In_2S_3 — •Elaheh Ghorbani[1], Paul Erhart[2], and Karsten Albe[1] — [1]Institut für Materialwissenschaft, Technische Universität Darmstadt, Darmstadt, Germany — [2]Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

Transition metal impurities often have noticeable impacts on the electronic and optical properties of the host material. Recently, they have been suggested as intentional dopants for the purpose of creating intermediate metallic bands within the band gap of parent semiconductor. These intermediate bands (IB), if partially filled and optimally placed between valence and conduction bands, can collect photons of sub-band gap energies and enhance the photocurrent density. In this context, the formation of an IB in V-doped In_2S_3 (In_2S_3:V) was predicted by first-principles calculations. In this contribution, we revisit In_2S_3:V, using a band gap corrected method (hybrid functional) and show that V^{3+} (with $3t_{2g}^2 e_g^0$ configuration) substituting for octahedral In^{3+} is a Jahn-Teller active ion. The aroused Jahn-Teller distortion necessitates removing the degeneracy of t_{2g} levels through splitting it into filled e and empty a sublevels, which reside at the top of the valence band and bottom of the conduction band, respectively. Consequently, no IB forms, when both V and In are in 3+ oxidation state. To give a fuller picture of In_2S_3:V, we studied the rehybridization of V d orbitals with S p orbitals for different oxidation numbers of V. Our results show that in the presence of a reducing agent, like H^+, a totally filled t_{2g} level can form inside the gap.

HL 34.2 Wed 15:15 H36

Angle-resolved electroreflectance spectroscopy on CIGS solar cell absorber and buffer layers — •Jasmin Seeger[1], Jonas Grutke[1], Wolfram Witte[2], Dimitrios Hariskos[2], Oliver Kiowski[2], Heinz Kalt[1], and Michael Hetterich[1,3] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany — [3]Light Technology Institute, KIT, 76131 Karlsruhe, Germany

Thin-film $Cu(In,Ga)Se_2$ (CIGS) solar cells can be further improved by replacing the standard CdS buffer layer with an alternative material, which leads to less absorption losses and therefore higher efficiencies. We employ electroreflectance spectroscopy (ER) for the destruction-free determination of the bandgap energies of different buffer materials grown by chemical bath deposition and to get insights into potential interdiffusion processes at the buffer/absorber interface. In this contribution, a new ER technique called angle-resolved electroreflectance spectroscopy (ARER) is presented, which allows the determination of the buffer's bandgap energy. This is possible despite interference effects occurring due to the layered structure and despite the low signal due to the small buffer thickness. To demonstrate the applicability of ARER, results for absorber and CdS buffer layers are shown and compared to results from other ER measurement methods. Additionally, ARER is applied to solar cells with Zn(O,S) buffer layers, enabling the determination of the sulfur to oxygen ratio of the Zn(O,S) buffer and yielding hints for the possible formation of mixed phases.

HL 34.3 Wed 15:30 H36

Spatially resolved composition and functionality of high efficiency Cu(In,Ga)Se2 thin film solar cells — •Christian Plass[1], Maurizio Ritzer[1], Philipp Schöppe[1], Sven Schönherr[1], Philip Jackson[2], Roland Wuerz[2], Claudia S. Schnohr[1], and Carsten Ronning[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Stuttgart, Germany

Cu(In,Ga)Se2 solar cells yield one of the highest efficiencies among all thin film photovoltaics. Compositional variations of the absorber elements as well as incorporated alkali elements significantly affect the conversion efficiency. Hence there is a strong need to determine the composition spatially resolved.

High resolution synchrotron based methods like X-ray fluorescence analysis (XRF) and X-ray beam induced current (XBIC) enable insight into such compositional and functional variations. Simultaneous XRF and XBIC measurements of complete solar cells were conducted in plan-view geometry: The highly focused X-ray nanobeam at the ID16B-NA station of the European Synchrotron Radiation Facility scanned the solar cell and by analyzing the emitted X-Ray fluorescence radiation together with the corresponding induced current correlating maps are obtained. As the spatial resolution is about 50 nm, we can show how different elemental compositions, grains and grain boundaries influence the measured current.

HL 34.4 Wed 15:45 H36

Intrinsic point defects in kesterite-type $Cu_2ZnGeSe_4$ compound semiconductors — •Daniel Fritsch[1] and Susan Schorr[1,2] — [1]Department Structure and Dynamics of Energy Materials, Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [2]Department of Geosciences, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany

In recent years, kesterite-type compound semiconductors such as Cu_2ZnSnS_4 and $Cu_2ZnSnSe_4$ (CZTSSe) received a lot of attention due to their possible application as absorber layers in low-cost thin-film solar cells. However, substituting Ge^{4+} for Sn^{4+} in CZTSSe kesterite-type absorber layers has been shown to improve the optoelectronic properties [1].

Here, we address the computational modelling of intrinsic point defects in kesterite-type $Cu_2ZnGeSe_4$ employing density functional theory together with the PBE and the more accurate hybrid functional HSE06. Details of the intrinsic defects' characteristics will be discussed, as well as their influence on the electronic and optical properties.

This work made use of computational resources provided by the North-German Supercomputing Alliance (HLRN), and the Soroban

and Dirac HPC facilities of the Freie Universität Berlin and the Helmholtz-Zentrum Berlin, respectively.

[1] R. Gunder, J. A. Márquez-Prieto, G. Gurieva, T. Unold, and S. Schorr, Cryst. Eng. Comm. **20**, 1491 (2018).

15 min. break

HL 34.5 Wed 16:15 H36

2D sb2s3 periodic structure induced absorption enhancement — •Wei Wang, Patrick Pfeiffer, and Lukas Schmidt-Mende — Konstanz University

Sb2S3 is a promising candidate for solar cell absorbers due to its high absorption coefficient, suitable band gap and earth-abundant constituents. Here we present the fabrication of 2D Sb2S3 structures by direct laser interference method and direct electron beam lithography method. The periodic structure induced absorption enhancement can be observed by UV-VIS absorption spectrum and verified by finite difference time domain (FDTD) simulation.

HL 34.6 Wed 16:30 H36

Numerical and experimental analysis of the time resolved photo-luminescence method at the buffer-absorber interface of CIGS thin film solar cell — •Ashwin Hariharan, Ievgeniia Savchenko, Jörg Ohland, Hippolyte Hirwa, and Stephan Heise — LCP, University of Oldenburg, Oldenburg, Germany

The minority carrier lifetime is an important second level parameter which affects the primary parameters of the solar cell. To study the minority carrier lifetime - or more generally, the carrier dynamics -, time-resolved photoluminescence (TRPL) method is a powerful technique. The main result obtained from TRPL is the luminescence decay time (or in some cases more than one decay constant), after which two questions follow: (i) under which circumstances is the decay time a direct indicator of minority carrier lifetime, and (ii) is the correlation between minority carrier lifetime and open-circuit voltage valid across all cases. The primary objective of this research is to understand the first correlation in a more perfect manner by studying the charge carrier separation near the heterojunction of CdS/CIGSe. The study includes both experimental analysis and simulation using, Synopsys TCAD. Experimentally, the main analysis involves wavelength-dependent pulsed illumination through which one gains control of the carrier injection density at different depths inside the absorber layer. For simulation, accurate representation of material parameters in the space charge region of the junction will be done. Based on the baseline model, dependence between physical parameters must be found in order to establish the agreement between numerical and experimental decay curves.

HL 34.7 Wed 16:45 H36

The impact of solar cell layer variations on the temperature coefficient of CIGS thin film solar cells — •Hamsa Ahmed[1], Janet Neerken[1], Jörg Ohland[1], Ievgeniia Savchenko[1], Hippolyte Hirwa[1], Alfons Weber[2], Robert lchner[2], Jürgen Parisi[1], and Stephan Heise[1] — [1]University of Oldenburg, D-26111 Oldenburg, Germany — [2]Avancis GmbH, Munich, Germany

One of the most promising alternatives in photovoltaic technologies is Cu(In,Ga)(S,Se)2 (CIGS)-based thin *lm solar cells, mainly because it has reached over 22% efficiency during the recent years, its high energy yield production, and relatively low temperature coefficients (βx). The temperature coefficients quantify how the solar cell performance changes with temperature and they play a significant role to maximize the energy yield. In order to investigate the impact of the individual solar cell layers on the temperature coefficients, in this study a systematic characterization was performed on various CIGS solar cells with different layer variations such as the absorber, back contact, and buffer layer. The temperature coefficients were extracted from IV (current-voltage) measurements indoor at different illumination intensities in the range of (20*50)°C. Low temperature IV measurements were accomplished in order to assess the activation energies, and to compare them with the band gap values from glow-discharge optical emission spectroscopy (GDOES) and external quantum efficiency (EQE) measurements. Further analyses were accomplished to examine the recombination; such as thermal admittance spectroscopy (TAS) to correlate it with the diode parameters n and J0.

HL 34.8 Wed 17:00 H36

The impact of solar cell layer variations on the temperature coefficient of CIGS thin film solar cells — •Hamsa Ahmed[1], Janet Neerken[1], Jörg Ohland[1], Ievgeniia Savchenko[1], Hippolyte Hirwa[1], Alfons Weber[2], Robert lchner[2], Jürgen Parisi[1], and Stephan Heise[1] — [1]University of Oldenburg, D-26111 Oldenburg, Germany — [2]Avancis GmbH, Munich, Germany

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HL 34.9 Wed 17:15 H36

2D sb2s3 periodic structure induced absorption enhancement — •Patrick Pfeiffer, Wei Wang, and Lukas Schmidt-Mende — Konstanz University

Sb2S3 is a promising candidate for solar cell absorbers due to its high absorption coefficient, suitable band gap and earth-abundant constituents. Here we present the fabrication of 2D Sb2S3 structures by direct laser interference method and direct electron beam lithography method. The periodic structure induced absorption enhancement can be observed by UV-VIS absorption spectrum and verified by finite difference time domain (FDTD) simulation.

HL 35: HL Poster II

Time: Wednesday 17:30–20:00 Location: Poster E

HL 35.1 Wed 17:30 Poster E

Temperature dependent capacitance-voltage spectroscopy of self-assembled GaN quantum dot ensembles — •Carlo Alberto Sgroi[1], Julien Brault[2], Jean-Yves Duboz[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CNRS - CRHEA, Rue Bernard Grégory, 06560 Valbonne, France

We present temperature dependent capacitance voltage (CV) measurements of charge-tunable self-assembled wurtzite GaN quantum dots (QDs) in an $Al_xGa_{1-x}N$ matrix grown by MBE. GaN and its alloys have excellent properties such as their thermal stability, high thermal conductivity and wide bandgap energies which make them an ideal candidate for next-generation GaN-based power devices and QD storage devices. Due to polarization effects in wurtzite $GaN/Al_xGa_{1-x}N$ heterostructure layers the band structure is deformed and large electric fields promote charge transfer through defect states. Performing temperature dependent CV spectroscopy from 200 K to 300 K we were able to observe two different charging features that we attribute to trap state and quantum dot resonances.

HL 35.2 Wed 17:30 Poster E

Quantum well states of GaN/AlN studied by angle-resolved photoelectron spectroscopy — •Felix Passlack[1], Mahdi Hajlaoui[1], Stefano Ponzoni[1], Mirko Cinchetti[1], Thomas Zentgraf[2], Donat Josef As[2], and Michael Deppe[2] — [1]Experimentelle Physik VI, TU Dortmund, Otto-Hahn-Straße 4, 44227 Dortmund, Germany — [2]Universität Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

Quantum well states (QWS) are attracting a lot of interests due to their unique electronic properties. They have been used for many applications for electronic and optical devices such as diode lasers, high electron mobility transistors, thermoelectric devices, and solar cells. Understanding their ability for improving and developing new applications devices, requires experimental details of their electronic structure. In this contribution, we employ angle-resolved photoelectron spectroscopy (ARPES) to study the QWS in the GaN/AlGaN heterostructure. The experiments have been carried out at the DELTA synchrotron facility at the TU Dortmund University, where the photon energy was varied between 10 eV and 100 eV. We will compare the results with those recorded using a laser-based ARPES setup using an excitation energy of 6 eV.

HL 35.3 Wed 17:30 Poster E

Comparison of GaN layers grown by Molecular Beam Epitaxy and by Sputtering technique — •Anne Sekels, Pascal Hille, Philipp Schurig, Martin Becker, Jörg Schörmann, and Angelika Polity — Institute for Exp. Physics I and Center for Materials Research (LaMa), Justus Liebig University Giessen, Germany

In the last decade, group III-nitrides have become one of the most important classes of semiconductor materials. In particular, GaN and the ternary compounds (Al, In, Ga)N thin films are used in a variety of commercial optoelectronic and electronic devices. Nitride materials are pre-dominantly grown by heteroepitaxy on different substrates. Metal organic vapor phase epitaxy and molecular beam epitaxy (MBE) are the most important growth techniques. However, these substrates and growth techniques are quite expensive. In this study we compare cheap sputtering technique and plasma-assisted molecular beam epitaxy to grow GaN homoepitaxially on GaN/Si (001) templates. The GaN layer thickness was about 400-500 nm in both cases. The influence of growth parameters, e.g. Ga-flux, N-flux during MBE and additional Ar-flux during sputter process on the structural properties, carried out by X-ray diffraction (XRD) and atomic force microscopy (AFM), is investigated.

HL 35.4 Wed 17:30 Poster E

Electron Beam Induced Current (EBIC) Investigations of Freshly Introduced a-screw Dislocations in GaN — •Tobias Westphal and Michael Seibt — University of Göttingen, IV. Physical Institute, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Even though GaN is already a widely used semiconductor, the effect of defects on the properties of GaN is not fully understood yet. As GaN has a quite high grown-in dislocation density, in the order of $10^6\,cm^{-2}$ - $10^8\,cm^{-2}$ depending on the growth technique, investigating the electrical properties of dislocations is of particular interest.

In previous work it was shown that indentation perpendicular to the basal (0001) plane in specially undoped low-resistance GaN creates a-screw dislocations. Those freshly introduced dislocations are showing dislocation related luminescences (DRL) with an energy peak at around 3.18 eV. This red shift of about 300 meV with respect to the band gap can not be explained by a perfect dislocation. However a dissociated dislocation, where the stacking fault ribbon forms a quantum well, would be a possible explanation. Therefore, structural investigations of the dislocation core with high spatial resolution are of tremendous interest.

The freshly introduced dislocations as well as the grown-in dislocations are investigated with EBIC to make recombination centres visible. Under electron beam irradiation recombination enhanced dislocation glide (REDG) occurs, making high resolution TEM (HRTEM) challenging. Hence, EBIC studies of REDG are performed in order to prepare for HRTEM measurements.

HL 35.5 Wed 17:30 Poster E

Photoelectrochemical Etching of GaN/AlGaN Heterostructures — •Lukas Peters[1,2], Christoph Margenfeld[1,2], Hergo-Heinrich Wehmann[1,2], and Andreas Waag[1,2] — [1]Institut für Halbleitertechnik und epitaxy competence center ec[2], Technische Universität Braunschweig, 38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, 38092 Braunschweig, Germany

In this work, we demonstrate the adaptation of photoelectrochemical (PEC) wet etching on bandgap selective etching of three-dimensional core-shell GaN/AlGaN heterostructures using potassium hydroxide (KOH). As a basis, the influence of KOH molarity, temperature, and UV-A illumination power on the etch rate and surface morphology were studied. Analyses by profilometry, scanning electron microscopy (SEM), and cathodoluminescence (CL) confirm a strong etch rate enhancement using PEC etching compared to conventional KOH-based wet-etching, as well as strong selectivity to GaN. Furthermore, PEC etching was employed on core-shell structures for selective removal of the GaN core with respect to an AlGaN shell whose demonstration would constitute a major step towards manufacturing three-dimensional UV emitters.

HL 35.6 Wed 17:30 Poster E

Spectroscopic characterization of sputtered ScAlN thin films — •Tim Hofmann[1], Katja Tonisch[1], Bernd Hähnlein[1], Jaroslav Kovic Jr.[2], Jörg Pezoldt[1], and Stefan Krischok[1] — [1]TU Ilmenau, Ehrenbergstr. 29, 98693 Ilmenau — [2]Slovak University of Technology, Ilkovicova 3, Bratislava 81219, Slovakia

Wide-bandgap semiconductors represent an attractive option to meet the demands of microelectromechanical systems (MEMS). Especially aluminum nitride (AlN) is the material of choice when it comes to integrated MEMS structures for sensing, actuating and energy harvesting applications requiring a piezoelectric thin film. However, next to a low electromechanical coupling coefficient, the piezoelectric response is much lower than that of PZT, both facts limiting the scope of possible applications. Thus, increasing interest concentrates on a new, recently emerging ternary nitride alloy, namely scandium aluminum nitride or Sc(x)Al(1-x)N, whose piezoelectric response is reported to increase 5-fold for x = 0.3 compared to that of pure AlN. Next to its piezoelectric properties, also the structural, mechanical, electrical and optical properties need to be understood to implement ScAlN into new technological concepts. We analyzed the dependency of the built-in strain on the Scandium content for sputtered ScAlN thin films with a maximum Scandium content of x = 0.25 by X-ray diffraction. Additional Raman spectroscopy and infrared spectroscopy showed a strain dependent shift of the observed optical phonon modes in accordance with the XRD measurements. The stoichiometry of all samples was determined by X-ray photoemission spectroscopy.

HL 35.7 Wed 17:30 Poster E

A comparative study of ultrathin c-plane GaInN/GaN quantum wells grown by MBE and MOVPE — •André Schendel, Dominic Tetzlaff, Heiko Bremers, Uwe Rossow, and Andreas

Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

In this contribution we present our study of ultrathin c-plane GaInN/GaN quantum wells (QWs) grown by molecular beam epitaxy (MBE) compared to those grown by metal-organic vapor phase epitaxy (MOVPE) in terms of morphology and composition homogeneity. The ternary semiconductor GaInN has many opportunities for applications as optoelectronic device with its direct band gap tunable between 0.65 eV for InN and 3.42 eV for GaN. For large scale production of devices with GaInN/GaN QWs MOVPE is the fabrication process of choice nowadays. But due to the high operating temperatures of the MOVPE which are needed to break the ammonia bonds for nitrogen supply, MOVPE grown GaInN layers have a tendency to form indium clusters on the growth surface which cause an inhomogeneity of the composition. In contrast to that, growth temperatures used by MBE can be much lower which reduces the diffusion length of indium and therefore MBE grown layers should have a more homogeneous composition and very high indium concentrations can be more easily realized. In which extend the structural and optical properties of GaInN/GaN QWs differ by the named growth methods is the topic of our investigation and gives more insight into the growth process.

HL 35.8 Wed 17:30 Poster E

Optical properties of oxygen-doped TiN thin films — •Felix-Florian Delatowski, Chris Sturm, Michael Lorenz, Florian Jung, Stefan Hohenberger, and Marius Grundmann — Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig, Linnéstraße 5, 04103Leipzig

The epitaxial growth of MgO and TiN superlattices allows the realization of optical hyperbolic metamaterials [1]. Due to the high oxygen affinity of titanium, diffusion of the oxygen of the MgO layer into the TiN layers takes place [2]. Here we investigate the structural and optical properties of oxygen-doped TiN thin film layers as a function of the doping concentration in order to understand the impact of the oxygen doping on the properties of the superlattices. The thin films were fabricated by pulsed laser deposition on MgO substrates [3]. The oxygen doping was realized by using an oxygen-argon gas mixture during the deposition process.

The crystal properties and the thickness were measured using X-ray diffraction and reflection, whereas atomic force microscopy was used in order to investigate the surface properties. The dielectric function of the thin films was determined by spectroscopic ellipsometry. We found hints that even for an oxygen-argon gas mixture of 1 : 99 and less, we obtain a deposition of titanium oxides instead of TiN.

[1] G. Naik *et al.*, PNAS **111**, 7546-7551 (2014)

[2] F. Jung, *Optical and structural properties of TiN/MgO superlattices*, Master thesis (Universität Leipzig) (2018).

[3] M. Bonholzer *et al.*, Phys. Status Solidi A **211**, 2621-2624 (2014).

HL 35.9 Wed 17:30 Poster E

Capacitance spectroscopy on GaN quantum dots — •Peter Conrad[1], Carlo Sgroi[1], Julien Brault[2], Laurin Schnorr[3], Andreas D. Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CNRS-CRHEA, Rue Bernard Grégory, 06560 Valbonne, France — [3]Lehrstuhl für Festkörperphysik, Heinrich-Heine-Universität Düsseldorf, D-40204 Düsseldorf, Germany

The aim of this work is to gain insights in the tunnel behaviour of charge carriers in self-assembled GaN quantum dots by means of different measurement methods. Based on previous capacitance-voltage measurements (CV measurements) on GaN quantum dots, CV measurements under illumination will be performed in this thesis [1]. On the basis of these measurements we will try to characterize defects in the sample more precisely. In addition, the CV measurement under illumination can be carried out as a function of the temperature in order to gain further information about their thermal activation energy. Another method to be used to investigate electrically active defects is the Deep Level Transient Spectroscopy (DLTS). With the help of the signals obtained by the DLTS measurement, it is possible to determine the activation energy at the GaN quantum dot interface.

[1] Labud et al.: Physical Review Letters 112 (4), 046803

HL 35.10 Wed 17:30 Poster E

Structural and optical investigation of metamorphic AlInGaN barriers — •Carina Walz, Michael Jetter, and Peter Michler — IHFG, Universität Stuttgart

Nitride semiconductors are already widely used as they are key components for solid-state lightning and have the ability to cover the complete visible spectral range. A drawback in this material system is the piezoelectric effect in hetero-structures, which gets more pronounced as larger the lattice mismatch between the barrier layers and the light emitting quantum well (QW) gets. These intrinsic electric fields lead to a reduced recombination, respectively emission efficiency due to the quantum confined Stark effect (QCSE). In order to reduce this QCSE and reach higher emission efficiencies at higher In-content inside the InGaN QWs, the implementation of metamorphic aluminum-indium-gallium-nitride (AlInGaN) barriers can be advantageous. With AlInGaN barriers the strain situation and the band offsets to the QW can be adjusted in a certain range independently, thus reduce the electric field at the position of the InGaN QW.

In our contribution a sample series of quaternary nitride barriers with varying strain state from tensile to compressive with respect to the GaN layer were fabricated by metal-organic vapour-phase epitaxy (MOVPE. The structural properties of the AlInGaN layers were investigated by high-resolution x-ray diffraction (XRD) measurements. In order to examine surface defects atomic force microscopy (AFM) and scanning electron microscopy (SEM) is used. Additionally, photoluminescence spectra of the sample series were recorded.

HL 35.11 Wed 17:30 Poster E

Micro-photoluminescence spectroscopy of microstructured light emitters based on InGaN quantum wells — •Jonas Quatuor[1], Mursal A. Baggash[1], Ulrich T. Schwarz[1], Jana Hartmann[2], and Andreas Waag[2] — [1]Institute of Physics, Chemnitz University of Technology — [2]Institute for Semiconductor Technology, Braunschweig University of Technology

Light emitters with mictrostroctured, threedimensional surface have several advantages with respect to such with planar ones: the InGaN quantum wells on side facets of microstructures like μ-rods or fins may be of semi- or nonpolar orientation with reduced internal fields, the ratio of QW area to wafer area is increased, threading dislocation density in the QWs is reduced, and the indium uptake during epitaxy is enhanced. We investigate the spectral properties (wavelength shift, intensity, linewidth) of the InGaN QW by micro-photoluminescence. From temperature dependent droop measurements we estimate the internal quantum efficiency (IQE). Nonpolar QWs on sidewalls emit polarized light because of the lower symmetrie. From excitation density dependent measurements of the degree of polarization, we determine the carrier density.

HL 35.12 Wed 17:30 Poster E

Low temperature spectroscopy of phonon replica in group-III-nitride quantum wells — •Conny Becht, Mursal A. Baggash, and Ulrich T. Schwarz — Institude of Physics, Chemnitz University of Technology, Experimental Sensor Science

Phonon replica are side peaks of photoluminescence emission spectra. For InGaN quantum wells (QWs), the energy difference between phonon replica and main peak are multiple of 91 meV, given by the energy of the longitudinal optical phonon (LO phonon). The relative height of the phonon replica and correspondingly for electron-phonon coupling strength is the Huang-Rhys factor S. As coupling to the phonons is relevant for recombination processes, we investigate the spatial variation of the Huang-Rhys factor in InGaN multi quantum well samples. We observe a spatial correlation of the Huang-Rhys factor with dislocation distribution in these samples. The aim of the study is to develop an understanding of the role of phonons in Shockley-Read-Hall and Auger nonradiative recombination.

HL 35.13 Wed 17:30 Poster E

Temperature-dependent electroluminescence studies of AlGaN-based UVB-LEDs — •Jakob Höpfner[1], Priti Gupta[1], Martin Guttmann[1], Markus Weyers[2], Tim Wernicke[1], and Michael Kneissel[1,2] — [1]Technische Universität Berlin, Institut of Solid State Physics, Berlin, Germany — [2]Ferdinand Braun Institut, Berlin, Germany

One of the important contributors to the external quantum efficiency (EQE) and output power of the AlGaN-based deep UV-LEDs is the injection efficiency (η_{inj}). It is mainly determined by electron overflow into the p-doped region and the restricted hole Transport into the quantum wells due to a high acceptor activation energy and band offsets at heterointerfaces. By measuring the temperature (T)-dependent electroluminescence (EL) characteristics of UVB-LEDs, we can provide insights on hole and electron transport in these LEDs. From the T (20-

350 K)-dependent EL specta, current-voltage and current-light output power characteristics, we observed the typical behavior of UVB-LEDs. Starting at 350 K, the EQE first increases with decreasing T due to the reduced non-radiative recombination rate within the quantum wells. At a certain T, the EQE decreases strongly staying at low values for lower T. The origin of the EQE breakdown is possibly the freeze out of holes in conjunction with increased electron overflow. Our results show that the temperature, at which EQE reaches its maximum, depends strongly on the η_{inj}, which can be pushed to even lower temperature with improved p-doping and bandgap profile.

HL 35.14 Wed 17:30 Poster E

AlGaN-based LEDs with extremely short emission wavelengths — Frank Mehnke, Luca Sulmoni, Martin Guttmann, •Tim Wernicke, and Michael Kneissl — Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany

In this paper, we will present the development of AlGaN-based multiple quantum well (MQW) LEDs with emission between 217 nm and 239 nm applicable in gas sensing systems (e.g. NO: $\lambda = 226$ nm, NH_3: $\lambda = 217$ nm). Commonly a strong decrease in emission power and external quantum efficiency is observed with decreasing emission wavelength and attributed to a reduction of carrier injection efficiency and light extraction efficiency. We discuss systematical variations of the heterostructure in order to improve the device efficiency. In order to maximize the spectral power needed for applications, the tradeoff between the cut-off wavelength of the current spreading layer and its conductivity needs to be considered. Additionally, realizing ohmic contacts to $Al_xGa_{1-x}N$:Si with high aluminum content is extremely challenging and typically results in high operating voltages. By optimizing the four-metal electrode V/Al/Ni/Au configuration, we were able to sensibly reduce the contact resistivity of the n-contacts on $Al_{0.9}Ga_{0.1}N$:Si. Finally, we fabricated UV LEDs emitting between 239 nm and 217 nm with on-wafer measured integrated output powers ranging between 310 μW and 0.15 μW, respectively, at 20 mA in cw operation. Additionally, electroluminescence measurements under pulsed mode operation will be presented.

HL 35.15 Wed 17:30 Poster E

Optical polarization of AlGaN multiple quantum wells emitting between 212 nm and 261 nm — •Bettina Belde[1], Fynn Wolf[1], Frank Mehnke[1], Martin Guttmann[1], Christoph Reich[1], Luca Sulmoni[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

The output power and external quantum efficiency of AlGaN based LEDs is dropping rapidly for emission wavelengths below 240 nm. This can partly be explained by the transition of the optical polarization from transverse electric (TE) to transverse magnetic (TM) which is determined by the valence band ordering and symmetry in multiple quantum wells (MQW) that depend strongly on the aluminum content.

Using photoluminescence (PL), the optical polarization of the emitted light of AlGaN MQW has been investigated at room temperature in dependence of the aluminum content in the QWs and the barriers. The polarization degree P=(TE-TM)/(TE+TM) for 1 nm $Al_xGa_{1-x}N$ / $Al_yGa_{1-x}N$ QWs changes from +0.85 (TE) for x=0.48 and y=0.61 to -0.58 (TM) for x=0.9 and y=100. The transition from TE to TM occurs at an emission wavelength of 238 nm in good agreement with simulations based on $\boldsymbol{k \cdot p}$-perturbation theory. Furthermore, the investigation of the polarization degree was confirmed by polarization resolved electroluminescence (EL) measurements of processed LEDs with similiar active regions.

HL 35.16 Wed 17:30 Poster E

UVB LED with narrow emission angle using advanced silicon-based reflector package and Fresnel lens — •Anna Ghazaryan[1], Martin Guttmann[1], Tim Wernicke[1], Neysha Lobo Ploch[2], Tim Kolbe[2], Katrin Hilbrich[2], Steffen Knigge[2], Dennis Mitrenga[3], Indira Käpplinger[3], Thomas Ortlepp[3], Sven Einfeldt[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany — [3]CiS Forschungsinstitut für Mikrosensorik GmbH, Erfurt, Germany

InAlGaN-based LEDs in the UVB spectral range are interesting for a number of applications. Depending on the application of the UVB LEDs, a specific radiation pattern typically with a strong forward emission is needed. In this paper we investigate the influence of different package designs and optical elements on the far-field radiation pattern of UVB LEDs emitting around 310 nm by measuring the angle dependent electroluminescence and total output power. The optimized package with Al reflector and Fresnel lens allows a more directional light emission, a remarkable threefold increase of the radiant intensity from 0.34 mW/sr to 0.92 mW/sr at $\theta = 0°$ and 20 mA as well as a twofold increase of the total optical power from 0.43 mW to 0.86 mW emitted within a cone of half opening angle of $\theta = 35°$ at 20 mA.

HL 35.17 Wed 17:30 Poster E

MOVPE Growth of Semipolar (11-22) $Al_{0.8}Ga_{0.2}N$ on (10-10) Sapphire — •Sarina Graupeter, Humberto M. Foronda, Frank Mehnke, Tim Wernicke, and Michael Kneissl — Institute of Solid State Physics, Technische Universität Berlin

AlGaN materials grown along the polar c-axis are the most common approach to realize optoelectronic devices in the deep ultraviolet spectral range. However, the external quantum efficiency (EQE) at emission wavelenghts below 240 nm drops drastically. This can be explained by the light emission polarized with electrical field vector parallel to the c-axis with increasing aluminum content. UV emitters grown on semipolar AlGaN offer a promising alternative due to the improved light extraction and the reduced quantum confined stark effect (QCSE). In this study we investigate the growth of semipolar AlGaN on m-plane sapphire by metalorganic vapor phase epitaxy (MOVPE). However, the growth of high quality semipolar AlGaN layers is challenging due to the simultaneaus formation of crystallites with other orientations leading to a deterioration of layer quality. We investigated the influence of growth parameters on the surface morphology and density of misoriented grains to achieve high quality AlGaN buffer layers. Variations of the reactor pressure, V/III ratio and metal organic flows all influenced the grain density. By analyzing the data we found that the grain density is correlated mainly to the growth rate. By growing a buffer layer 0.15 μm/h a grain density as low as $3 \cdot 10^6\ cm^{-2}$ was achieved. This was grain density was preserved also when subsequent layers where grown at higher growth rates.

HL 35.18 Wed 17:30 Poster E

Stopping in Gallium Arsenide — •Alrik Stegmaier and Hans Hofsäss — 2. Physikalisches Institut, Georg-August Universität Göttingen

GaAs is a technologically important III-V compound semiconductor. Doping of this material via ion implantation is common and requires an accurate understanding of the stopping process of ions. The electrical properties are further influenced by the amount of defects that are produced during irradiation, which has applications in implantation isolation or proton beam writing.

Because of this, accurate simulations are required for planning implantation, predicting defect production and even simulations of sputtering and ion induced surface dynamics.

Here we compare several common simulation methods against experimental data and DFT and TDDFT simulations. We present a new software to accurately predict the implantation, sputtering and defect production of GaAs during ion irradiation.

HL 35.19 Wed 17:30 Poster E

Measuring the 1D subband energies of wurtzite GaAs wires by inelastic light scattering — •Sebastian Meier, Florian Dirnberger, Paulo de Faria Junior, Jaroslav Fabian, Dominique Bougeard, and Christian Schüller — Universität Regensburg, 93040 Regensburg, Germany

Resonant Raman scattering has been performed to measure the subband energies of wurtzite GaAs nanowires. Our wires were grown by MBE using the VLS method and are nominally undoped. They have a GaAs core of down to 25 nm thickness which is protected by an AlGaAs shell. For laser excitation, we use a Ti:Sapphire laser, which can be tuned continuously in the energy region of the band gap.

In our Raman experiment, we find a number of peaks which are resonantly enhanced at different excitation energies. We interpret the peaks to stem from intersubband excitations of photoexcited electrons or holes. Therefore, every peak can be attributed to the energy splitting of different neighboring subbands. We also did PLE measurements to investigate the absorption behavior of the wires, and explain for which excitation energies Raman peaks are observable.

HL 35.20 Wed 17:30 Poster E

Capacitance-voltage spectroscopy on no-wetting layer quantum dots — •Ismail Bölükbasi, Sven Scholz, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, D-44780 Bochum, Germany

Quantum dots have interesting physical properties and allow research in zero dimensional systems. They are used in modern displays and may become important for the progress of semiconductor and information technology in the form of qubits in quantum computers and quantum memories or quantum communication applications.

Quantum dots are created by molecular-beam-epitaxy (MBE) in Stranski-Krastanov growth. InAs is deposited epitaxially onto GaAs and grows without relaxation to up to 1.5 monolayers of InAs. This layer is called the wetting layer, on top of which the self-organized quantum dots form. We find, that a monolayer of AlAs after the growth of quantum dots can suppress certain states in this wetting layer, allowing to purify the quantum dots from electronic contributions such as for example a two-dimensional-electron gas.

Capacitance-voltage measurements are carried out to investigate the effects of this monolayer of AlAs on the physical properties of the quantum dots and the modified charging behaviour around flat band conditions.

HL 35.21 Wed 17:30 Poster E

Degradation of telecom wavelength LEDs by high energy proton irradiation — •Heinz-Christoph Neitzert[1], Giovanni Landi[1], Juergen Bundesmann[2], and Andrea Denker[2] — [1]Dept. of Industrial Engineering (DIIn), Salerno University, Via Giovanni Paolo II 132, 84084 Fisciano (SA), Italy — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Protons for Therapy, Hahn-Meitner Platz 1, 14109 Berlin, Germany

Future space mission utilize more and more optical links for internal data transmission but also for long-range open-space communications between different satellites. While silicon based components are strongly degrading under high energy particle irradiation, wide bandgap semiconductors are generally found to be more radiation hard. Low bandgap semiconductors are, however also often employed in space for data transmission and for high efficient solar cells. InGaAsP LEDs emitting at 1550 nm have been irradiated with a 68 MeV proton beam with fluences up to 1e13 p+/cm^2. While the peak emission wavelength and the spectral width did not change with irradiation, a more than 2 orders of magnitude decrease of the emitted power has been found for maximum fluence. Besides the properties as light emitters, also the complete characterization of the electrical characteristics as receiver under illumination with 1550 nm light has been done. The changes of the extracted device parameters are discussed, which enabled, together with impedance spectroscopy data to give a detailed picture of the irradiation induced electronic defects.

HL 35.22 Wed 17:30 Poster E

Influence of ohmic contact material, doping and temperature on current-induced charge carrier density change — •Zoe Fiedler, Christian Schulte-Braucks, Carlo Alberto Sgroi, Carsten Ebler, Andreas Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Deutschland

The charge carrier density and mobility in heterostructures made of GaAs and AlGaAs can be varied by illumination, gate voltage and also voltage pulses applied to the ohmic contacts [Zitat: APL Christian Schulte-Braucks].

Based on the latter effect, the current-induced charge carrier density change is examined in detail both at different temperatures from 4.2K to 40K (above that, the effect subside too quickly) and with different contact materials.

The explanation of the charge carrier density change is related to DX centers, which are probably caused by a combination of donor atoms and As defects [Zitat: Mooney1990], which is why the doping method is also varied from volume doping to delta doping.

It will also be tested whether the change in charge carrier density can be reversed with voltage pulses.
The procedure and first results will be presented.

HL 35.23 Wed 17:30 Poster E

CVD growth of ZnO on sapphire with methane as reducing agent: Initial crystal formation process. — •Raphael Müller[1], Florian Huber[1], Okan Gelme[1], Manfred Madel[1], Alexander Minkow[2], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University — [2]Institute for Functional Nanosystems, Ulm University

he initial crystal formation of zinc oxide (ZnO) layers in a high temperature chemical vapor deposition (CVD)-based growth process was investigated. In our process we use methane (CH_4) to reduce ZnO powder. The resulting zinc vapor is locally re-oxidized at the spot of the substrate with pure oxygen, and thereby formes a ZnO layer. By controlling the gas flows one can control the II-VI ratio very precisely, as well as the duration of the growth. In the work presented, this scheme was used to grow a series of samples with increasing supply of zinc vapor in order to monitor the resulting layer formation. C-plane sapphire with aluminum nitride nucleation layer were used as substrates. To visualize and characterize the samples grown, atomic force microscopy, scanning electron microscopy and electron backscatter diffraction measurements were performed, as well as high resolution X-ray diffraction and photoluminescence measurements. We show that the ZnO heteroepitaxial layer is growing in c-direction right from the start of the process and forms a closed, smooth, high-quality single crystalline layer after a growth time of ten minutes only. The fundamental understanding of the layer formation is important for the ongoing studies of doping the ZnO layers with various donors.

HL 35.24 Wed 17:30 Poster E

Investigation of optical properties for Fe^{3+} in ZnO — •Martin Mangold[1], Raphael Müller[1], Florian Huber[1], Benjamin Neuschl[1], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter, Semiconductor Physics Group, University Ulm, Germany — [2]Institute for Functional Nanosystems, University Ulm, Germany

Ferromagnetism in II-VI-semiconductors like ZnO, due to doping with transition metals, rose attention over the last years. A candidate for realization are iron impurities which can be incorporated in high concentrations. In this study high-quality crystalline wurtzite ZnO layers grown by a CVD-based method were used as a host crystal for the investigation of internal spin-forbidden electric-dipole transitions of Fe^{3+}. Therefore iron was incorporated by a seed growth technique using iron(II) acetate. High-resolution, low-temperature Photoluminescence and magneto-optical photoluminescence investigations on the iron atom and its optical band at 1.78 eV are presented. This band emerges for a transition from the excited state $^4T_1(G)$ to the ground state $^6A_1(S)$.

HL 35.25 Wed 17:30 Poster E

CVD based growth of ZnO layers on Si(111) with AlN nucleation layer — •Matthias Töws[1], Okan Gelme[1], Raphael Müller[1], Florian Huber[1], Jan-Patrick Scholz[2], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, Germany — [2]Institute for Functional Nanosystems, Ulm University, Germany

In the present work, zinc oxide (ZnO) layers were grown by methane (CH_4) based CVD on Si(111) substrate with aluminum nitride (AlN) nucleation layer. For the AlN nucleation layer growth temperature, III-V-ratio, and the growth duration of the MOVPE process were varied. The resulting nucleation layers were analyzed by scanning electron microscopy and atomic force microscopy. Afterwards, the different nucleation layers were overgrown with ZnO. In order to find the best combination of growth parameters for both processes, a whole series of growth parameters for the ZnO deposition was tested on each of the nucleation types. For the evaluation of the sample quality, scanning electron microscopy, electron backscatter diffraction, high resolution X-ray diffraction, and low temperature photoluminescence measurements were performed.

HL 35.26 Wed 17:30 Poster E

Growth of epitaxial ZnO layers on Si(111) by chemical vapor deposition with methane as reducing agent — •Okan Gelme[1], Raphael Müller[1], Florian Huber[1], Alexander Minkow[2], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, Germany — [2]Institute for Functional Nanosystems, Ulm University, Germany

Epitaxial zinc oxide (ZnO) layers were grown on Si(111) substrate using a high temperature chemical vapor deposition (CVD)-based growth method. The process requires two steps, which both were investigated in detail. In the first step zinc acetate ($C_4H_6O_4Zn$) is heated up and

thereby elementary zinc vapor is created, which is transported in an argon flow and with the aid of pure oxygen re-oxidized, forming ZnO seed crystals on the Si substrate. In the second step ZnO powder is reduced by CH_4 in order to obtain again a constant flow of elementary zinc vapor. By the provided pure oxygen the zinc vapor is re-oxidized at the spot of the substrate, which then results in the formation of a heteroepitaxial ZnO layer. For both steps the influence of different growth parameters was investigated, in order to optimize the crystal quality. The samples were characterized by scanning electron microscopy, electron backscattering diffraction, high resolution X-ray diffraction, and low temperature photoluminescence.

HL 35.27 Wed 17:30 Poster E

Optical and magnetic studies of CrSe thin films on ZnSe and CdSe buffer layers — •Johannes Röder[1], Dana Vieweg[2], Hans-Albrecht Krug von Nidda[2], Alois Loidl[2], and Wolfram Heimbrodt[1] — [1]Department of Physics and Material Science Center, Philipps University, Marburg, Germany — [2]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Germany

Theoretical calculations predicted Chromium chalcogenides in the zinc blende (ZB) structure to be promising candidates for half-metallic spin-aligner at room temperature. The thermodynamically stable phase of CrSe is the hexagonal NiAs-structure which exhibits antiferromagnetic behaviour.

We investigated and compared two different approaches to stabilize the ZB state of CrSe. CrSe layers have been grown by MBE either on a ZB-CdSe buffer on InAs substrate or on a ZB-ZnSe buffer on GaAs substrate. To study the magnetic phase transitions we did temperature dependent SQUID measurements. We observed ferromagnetic behaviour for the sample on ZnSe but anti-ferromagnetic behaviour for the sample grown on CdSe.

Furthermore, we did cw- as well as time resolved optical spectroscopic measurements. We were able to observe different excitonic transitions from the CrSe as well as from the ZnSe or CdSe layers. Of special interest was a spatially indirect transition in the CrSe/ZnSe heterostructure with the holes in ZnSe and the electrons in CrSe. The lifetimes and the polarization propertuies will be discussed in detail.

HL 35.28 Wed 17:30 Poster E

Influence of substrate material and growth parameters on donor concentration in CVD grown ZnO layers — •Stefan Pokrivka[1], Raphael Müller[1], Okan Gelme[1], Tom Lacmann[1], Florian Huber[1], Ulrich Herr[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University, Germany — [2]Institute for Functional Nanosystems, Ulm University, Germany

In the present work, the influence of different substrate materials and growth parameters on the donor concentration in high temperature CVD grown ZnO layers is investigated. Capacitance-voltage measurements with a circular contact structure, as well as Hall measurements were performed on ZnO layers grown either directly on Si(111) or on c-plane sapphire with aluminum nitride nucleation layer underneath. These measurements show, that in the ZnO layers grown on sapphire the donor concentration is slightly higher than in samples grown on silicon. From these results and by correlation with findings from low temperature photoluminescence measurements, we conclude that aluminum diffuses from the aluminum nitride nucleation layer into the ZnO layer. Despite the fact, that the layers on silicon substrate were grown at lower temperature as compared to those grown on sapphire, we find similar donor concentrations for both cases. Furthermore, the influence of in-situ annealing for samples grown on sapphire was evaluated in order to confirm our conclusions.

HL 35.29 Wed 17:30 Poster E

Optoelectronic Interaction Between Colloidal Quantum Dots and Buried Quantum Wells — •Mikko Wilhelm[1], Shyam Kommadath[1], Atif Masood[1], Torsten Henning[2], Wolfgang Parak[3], and Wolfram Heimbrodt[1] — [1]Philipps-Universität Marburg — [2]Justus-Liebig-Universität Gießen — [3]Universität Hamburg

The optoelectronic coupling between colloidal quantum dots and different substrates is studied. CdS quantum dots and CdS/ZnS core/shell quantum dots are deposited via drop casting and spin coating on the substrates, for which different semiconductor and quantum well structures are used. The MBE grown quantum well structures consist of a 5nm thick ZnSe quantum well between (Zn, Mn)Se barriers, which differ in their manganese concentration. The thickness of the top barrier of the quantum well structure is modified by chemical etching. The energy transfer between the quantum dots and the substrate is investigated with time-resolved photoluminescence measurements in the nano- and picosecond range at different temperatures. The results are discussed in detail.

HL 35.30 Wed 17:30 Poster E

Exciton spin relaxation and recombination dynamics in CdSe nanocrystals in glass matrix — •Gang Qiang[1], Elena V. Shornikova[1], Dmitri R. Yakovle[1,2], Aleksandr A. Golovatenko[2], Anna V. Rodina[2], Evgeniy A. Zhukov[1], Alexsei A. Onushchenko[3], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany. — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia. — [3]ITMO University, 199053, St.-Petersburg, Russia.

We studied CdSe nanocrystal (NC) samples with diameter from 2.8 to 6.2 nm grown in glass matrix in this work. Temperature and magnetic field dependence of photoluminescence (PL) decay demonstrates the exciton nature of emission states. The longest component of the PL decay is ascribed to the dark exciton with a time constant 212 ns at 0 T, 2.2 K, which decreases to 118 ns at 17 T because of the magnetic field induced mixing between bright and dark states. The time and polarization resolved PL intensity reveals very fast spin relaxation dynamics which is beyond our time-resolution. And the acoustic phonons are expected to be involved in the coupling between upper 0 and 2 levels and give rise to the emission of linearly polarized light.

HL 35.31 Wed 17:30 Poster E

Exciton spin relaxation and recombination dynamics in CdSe nanocrystals in glass matrix — •Gang Qiang[1], Elena V. Shornikova[1], Dmitri R. Yakovle[1,2], Aleksandr A. Golovatenko[2], Anna V. Rodina[2], Evgeniy A. Zhukov[1], Alexsei A. Onushchenko[3], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany. — [2]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia. — [3]ITMO University, 199053, St.-Petersburg, Russia.

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HL 35.32 Wed 17:30 Poster E

First-principles study of the structural and electronic properties of the GaP surface and GaP/Si interface — •Marsel Karmo[1] and Erich Runge[2] — [1]TU ILmenau,Weimarer Str.32,98693 ILmenau — [2]TU ILmenau,Weimarer Str.32,98693 ILmenau

The heteroepitaxial growth of III-V semiconductors on silicon enables the combination of the advantages of both materials. GaP/Si(001) is an attractive quasi-substrate. However, both, the GaP-interface as well as the GaP surface with its crystal quality and electronic properties has a high impact on the device performance. Thus, surface and interface need to be studied in detail. The atomic and electronic band structure of abrupt and mixed GaP/Si interfaces were investigated by ab-initio density functional theory calculations using the Vienna Ab initio Simulation Package (VASP). Thereby the electronic band structure and dielectric function of both types of termination, i.e. of abrupt Si-P and Si-Ga interfaces was calculated. Moreover, the GaP surface with hydrogen adsorption was studied, as it is a typical result of MOCVD epitaxial growth.

HL 35.33 Wed 17:30 Poster E

Influence of material supply and capping layer thickness on the density and emission properties of MOVPE grown InAs quantum dots on linear-graded InGaAs metamorphic buffers — •Robert Sittig, Diana Pfezer, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart, Allman-

dring 3, 70569 Stuttgart

Semiconductor quantum dots (QDs) are an excellent source of non-classical light, which is a key element for quantum information technologies. For compatibility with low-loss glass fiber communication networks, emission at telecom wavelengths is crucial.

We have recently shown single-photon emission at 1.55 μm from InAs QDs grown on a linear-graded InGaAs metamorphic buffer (MMB), which reduces the lattice misfit to the GaAs substrate. Here, we maintain the MMB design but vary the material supply during QD growth and the capping layer thickness. The influence of those parameters on the QD emission is studied via (μ-)photoluminescence spectroscopy. On the basis of the resulting spectra the QD size distribution and density is discussed, with special focus on the impact of metamorphic lattice relaxation processes.

HL 35.34 Wed 17:30 Poster E

Non-Markovian quantum feedback control of driven few-level quantum systems — Leon Droenner, •Kisa Barkemeyer, Andreas Knorr, and Alexander Carmele — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Motivated by classical Pyragas control and its impressive successes in laser physics and self-organizing nonlinear systems [1], the concept of non-invasive, coherent feedback is investigated in the quantum regime. In case of a pulsed excitation, a few-level system fundamentally acts as a single-photon source when excited with a π-pulse, while for a 2π-pulse two-photon emission is more likely to occur [2]. Employing feedback, we observe a qualitatively different reaction of single- and two-photon events to the feedback-induced coupling strength. The delay-dependent phase of the feedback signal results either in the enhancement or the suppression of single-photon events, whereas two-photon events become more probable [3]. Furthermore, we discuss how the delay-dependent phase shapes the photon-statistics and how this phase can be addressed externally.

[1] E. Schöll, S. H. Klapp, and P. Hövel (Eds.), *Control of Self-Organizing Nonlinear Systems* (Springer, 2016).
[2] K. A. Fischer, L. Hanschke, J. Wierzbowski, T. Simmet, C. Dory, J. J. Finley, J. Vučković, and K. Müller, Nature Physics 13, 649 (2017).
[3] L. Droenner, N. L. Naumann, A. Knorr, and A. Carmele, arXiv:1801.03342v2 (2018).

HL 35.35 Wed 17:30 Poster E

Pulsed electrically excited single-photon emission from a determnistically integrated quantum dot in a resonant cavity light emitting diode — •Simon Seyfferle, Marc Sartison, Sascha Kolatschek, Simone L. Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart

The realization of future quantum technologies based on semiconductor single-photon sources and the performances of the individual implemented device crucially depend on the systems parameters such as a high repetition rate of pure and triggered single photons, high transfer rates and a convenient method of excitation.

On the way to realizing an efficient device satisfying these requirements, we combine two promising approaches, namely deterministic integration of a quantum dot (QD) into the device by in-situ lithography and electric excitation of the resulting resonant cavity light emitting diodes (RCLED). With the in-situ approach we selectively place a single InP QD into the intrinsic region of a *pin*-diode, which in turn enables the pulsed electric excitation of the RCLED with high repetition rates. The inclusion of InP dots allows for emission in the red spectral regime, where the maximum detection efficiency of conventional silicon-based photo-detectors is situated, thus high transfer rates in future quantum information processing experiments should be feasible.

We show the process of such a device as well as first results on electrically triggered single-photon emission.

HL 35.36 Wed 17:30 Poster E

Implementing Emission Tuning Mechanisms in Photonic Integrated Circuits — •Florian Hornung[1], Mario Schwartz[1], Ekkehart Schmidt[2], Stefan Hepp[1], Ulrich Rengstl[1], Huiying Huang[3], Simone Luca Portalupi[1], Michael Jetter[1], Konstantin Illin[2], Michael Siegel[2], Armando Rastelli[3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Research Center SCoPE and IQST, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Institute of Micro- and Nanoelectronic Systems (IMS), Karlsruhe Institute of Technology (KIT), Hertzstrasse 16, 76131 Karlsruhe, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Altenbergerstraße 69, 4040 Linz, Austria

The scheme for linear optics quantum computing as proposed by Knill, Laflamme and Milburn requires sources of single and indistinguishable photons, which will non-classically interfere at beamsplitter structures, phase-shifters and single-photon detectors. Photonic integrated circuits (PICs) offer a scalable way to realize the scheme. Semiconductor quantum dots can serve as efficient on-demand sources of single photons in PICs, however when grown in Stranski-Krastanov mode they usually emit over a broad distribution of different wavelengths due to the statistical size-distribution of the dots.
Here, we present possibilities of tuning the emission wavelengths of metal-organic vapor-phase epitaxy (MOVPE) grown semiconductor quantum dots and show how these mechanisms can be implemented in PICs to enable two-photon interference in such a circuit.

HL 35.37 Wed 17:30 Poster E

Resonance fluorescence on plasmon-quantum dot hybrids — •Gerhard Johannes Schäfer[1], Armando Rastelli[2,3], and Markus Lippitz[1] — [1]Experimentalphysik III, Universität Bayreuth, Bayreuth, Germany — [2]Institute for Integrative Nanosciences, IWF Dresden, Dresden, Germany — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria

Resonance fluorescence spectroscopy is a well established tool to investigate single quantum dots in bulk experiments. I present simulations and experiments on single quantum dots which are coupled to plasmonic structures. We investigated GaAs quantum dots which are embedded in a membrane between two nanostructured gold layers.

HL 35.38 Wed 17:30 Poster E

Wet chemical etching of Gaussian shaped micro lenses in GaAs to enhance the extraction efficiency of QDs — •Lena Engel, Marc Sartison, Sascha Kolatschek, Fabian Olbrich, Cornelius Nawrath, Stefan Hepp, Michael Jetter, Peter Michler, and Simone Luca Portalupi — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Semiconductor quantum dots (QDs) are promising candidates for applications in quantum communication and quantum computing, as they show emission of single, indistinguishable photons. Since the QDs are embedded in a semiconductor environment, the extraction efficiency is firmly limited. As high brightness of the single photon source is crucial for the aforementioned applications, various mechanisms for enhancing the extraction efficiency of QDs are under current investigation, using either broadband approaches or narrow band cavity quantum electrodynamic systems. Due to their superior surface quality and variability in aspect ratio and size, wet chemically etched Gaussian shaped micro lenses have proven their applicability in broadband approaches and are auspicious suitors for more complex optical devices. We have placed them deterministically over pre-selected QDs emitting in the telecom O-band and have compared the enhancement factor and the fiber coupling efficiency for different lens geometries. FDTD simulations confirm the shaping of the emitted farfield.

HL 35.39 Wed 17:30 Poster E

Correlation of Auger Recombination in Self-Assembled InAs Quantum Dots with their Opto-Electrical Properties — •Nikolai Bart[1], Nikolai Spitzer[1], Martin Geller[2], Axel Lorke[2], Andreas D. Wieck[1], and Arne Ludwig[1] — [1]Ruhr-Universität Bochum — [2]Universität Duisburg-Essen

An Auger recombination is a usually undesired, non-radiative process in which the energy of an otherwise radiative exciton recombination gets absorbed by a secondary electron, thereby scattering it. By growing precisely tailored charge-tunable quantum dot devices, we aim to manipulate the conditions for Auger recombination to occur. For this, we make use of techniques such as indium-flushing and rapid thermal annealing to modify the QDs' size, shape and composition. In order to manipulate the coupling of the quantum dots to their surroundings, we predefine the tunnel barrier, which separates the QDs from an electron reservoir, suppress wettinglayer bound states or modify the QDs' capping layers. After characterization of the QDs' opto-electrical properties via photoluminescence and capacitance-voltage spectroscopy, Auger recombination rates are examined via two laser

resonance fluorescence. Correlating the QDs' characteristics to the occurrence of Auger recombination might give us crucial information to further decrease the decoherence and linewidth of photons from our devices and improve their quantum efficiency.

HL 35.40 Wed 17:30 Poster E

Occupation and Light Field Dynamics of a Quantum Dot in a Photonic Cavity — •Kevin Jürgens, Tilmann Kuhn, and Doris E. Reiter — Institut für Festkörpertheorie, Universität Münster, Münster

To enable the use of quantum dots (QDs) as efficient single photon emitters, the QDs are embedded in photonic structures. In such structures the light-matter interaction is enhanced due to the Purcell effect and the QD exciton and light field dynamics are strongly modified.

In this contribution we analyze these dynamics in a semi-classical model, where the QD is described as a two-level system and the light field is treated within the finite-difference time-domain (FDTD) method. The photonic cavity is realized as a defect between two Bragg mirrors. The electric field in this structure induces a polarization in the QD which again couples back in the Maxwell-equations, such that the QD modulates the electric field. This modified field propagates and scatters at the mirrors. Therefore the QD can interact with the self-generated fields resulting in interesting occupation dynamics.

We investigate the combined dynamics of the exciton occupation and the cavity mode induced by a Gaussian pulse and find a transition from exciton-polariton dynamics to Rabi oscillations for increased pulse intensities. These results help in understanding QDs in photonic structures.

HL 35.41 Wed 17:30 Poster E

Hot carrier cooling dynamics in PbS quantum dots - The influence of surface termination — •Emanuele Minutella[1,2], Nuri Yazdani[3], Vanessa Wood[3], and Holger Lange[1,2] — [1]Institute for Physical Chemistry, University of Hamburg — [2]The Hamburg Centre For Ultrafast Imaging, CUI — [3]Labratory for Nanoelectronics, Department of Information Technology and Electrical Engineering, ETH Zurich

Carrier multiplication (CM) in PbS quantum dots (QD) is an intriguing phenomenon with promises towards applications such as field-effect transistors, light-emitting diodes or solar cells due to their optical properties.(1) CM occurs in direct competition with carrier cooling via phonon emission or other relaxation channels.(2)In an experimental study, it was shown that halide-terminated PbS QDs feature an improved performance in solar energy conversion.(3) Our recent theoretical work showed that electron-phonon interactions are strongly suppressed in halide-terminated QDs due to reduction of the thermal displacement of the surface atoms.(4)

In our contribution we present an experimental study of the surface-termination impact. We observe the cooling of photo-induced hot carriers by femtosecond transient absorption spectroscopy in PbS QDs capped with different ligands. Our experimental results agree with the theoretical predictions and enable a tuning of the electron-phonon coupling in colloidal QDs.

(1) Adv. Mater. 2018, 30, 1800082 (2) ACS Nano 2017, 11, 6286-6294 (3) Nat. Mater. 2017, 16, 258-263 (4) Nano Lett. 2018, 18, 2233-2242

HL 35.42 Wed 17:30 Poster E

Optimized metamorphic buffer heterointerfaces for $\lambda = 1.55$ μm quantum dot growth — •Marcel Schmidt, Tim Bergmeier, Andreas D. Wieck, and Arne Ludwig — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Quantum dots emitting at the wavelength of 1550 nm are a key technology for future optical fibre transmitted quantum information exchange. At this wavelength, the attenuation in the optical fibre has an absolute minimum. Self assembled quantum dots (SAQDs) are very promising as nearly ideal sources for single indistinguishable photons or entgenled photon pairs which can be used for quantum information purposes like quantum key distribution or quantum repeaters. To shift the energy levels of SAQDs to an emission wavelength of 1550 nm, we investigate molecular beam epitaxy - grown InAs SAQDs on lattice-mismatch reduced InGaAs/InAlAs heterostructure layers with short period superlattices. We present first results of SAQDs already emitting at 1550 nm in photoluminescence spectroscopy at the temperature of T = 77 K.

HL 35.43 Wed 17:30 Poster E

The influence of the tunnel coupling to a charge reservoir on the Auger process in self-assembled quantum dots — •Pia Lochner[1], Annika Kurzmann[1], Jens Kerski[1], Rüdiger Schott[2], Andreas Dirk Wieck[2], Arne Ludwig[2], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Auger recombination is a non-radiative process, where the recombination energy of an electron hole pair is transferred to a third charge carrier. In colloidal quantum dots (QDs), this is a common effect which quenches the radiative emission with recombination times in the order of picoseconds [1]. In self-assembled QDs, it was speculated to be absent, and only recently, it has become possible to observe Auger recombination in these structures [2].

In this contribution, we investigate Auger recombination on a single self-assembled QD coupled to a charge reservoir with a small tunneling rate in the order of ms^{-1}. We observe in time-resolved resonance fluorescence measurements how the small tunneling rate of the sample structure influences the Auger rate and the quenching of the trion fluorescence intensity. Furthermore, we perform real-time measurements of the random telegraph signal which gives access to the statistics of the Auger process.

[1] R. Vaxenburg, et al., Nano Lett. 15, 2092 (2015).
[2] A. Kurzmann, et al., Nano Lett. 16, 3367 (2016).

HL 35.44 Wed 17:30 Poster E

Capacitance-voltage spectroscopy and temperature dependent photoluminescence spectroscopy on $\lambda = 1.55$ μm quantum dots — •Tim Bergmeier, Marcel Schmidt, Andreas Dirk Wieck, and Arne Ludwig — Institut für angewandte Festkörperphysik, Ruhr-Universität Bochum

Single λ=1.55 μm-wavelength photons are ideal for quantum communication, as fibre losses are minimal at this wavelength. Quantum dots can function as ideal single photon sources [Kuhlmann et al., Transform-limited single photons from a single quantum dot, Nat. Commun. 6, 8204 (2015)]. However, excellent photon quality is not yet achieved at the desired wavelength due to material issues accompanying needed metamorphic strain reduction layers, grown on GaAs substrates. We present temperature dependent photoluminescence spectroscopy and capacitance-voltage spectroscopy on molecular beam epitaxy-grown self-assembled InAs/InGaAs quantum dots emitting at λ=1.55 μm. We discuss the results in the framework of trap associated charge and non-radiative recombination processes.

HL 35.45 Wed 17:30 Poster E

Enhanced Biexciton Emission from single Quantum Dots encased in N-type Semiconductor — •Zhijie Li[1,2,3,4], Guofeng Zhang[3,4], Bin Li[3,4], Ruiyun Chen[3,4], Chengbing Qin[3,4], Yan Gao[3,4], Liantuan Xiao[3,4], and Suotang Jia[3,4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstraße 400, Dresden 01328, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]State Key Laboratory of Quantum Optics and Quantum Optics Devices, Institute of Laser Spectroscopy, Shanxi University, Taiyuan, 030006, China — [4]Collaborative Innovation Center of Extreme Optics, Shanxi University, Taiyuan, Shanxi, 030006, China

By encasing single near-infrared emitting CdSeTe/ZnS3ML core/multishell quantum dots (QDs) in N-type semiconductor indium tin oxide (ITO) nanoparticles, an enhanced biexciton emission can be realized. The ITO nanoparticles with a high electron density can increase the dielectric screening of single QDs to reduce the Coulomb interactions between carriers, thus suppressing the nonradiative Auger recombination of biexcitons. It is observed that an average g(2)(0)=0.57 in the second-order correlation function curves, which indicates the effective creation of biexciton and subsequent twophoton emission from single QDs encased in ITO nanoparticles. The fluorescence quantum yield ratio of the biexciton to single-exciton emission is increased to ~4.8 times, while the Auger recombination rate reduces by almost an order of magnitude.

HL 35.46 Wed 17:30 Poster E

Improving the Purcell-enhancement for InAs-QDs in Fabry-Perot fiber-microcavities — •Martin Fischer[1], Thomas Herzog[1], Sascha Böhrkircher[2], Steffen Both[2], Michael Jetter[1], Simone Luca Portalupi[1], Thomas Weiss[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technol-

ogy (IQ^{ST}) and SCoPE, University of Stuttgart, D-70569 Stuttgart, Germany — [2]4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70550, Stuttgart, Germany

Cavity quantum electrodynamics (cQED) deliver basic insight into fundamental principles of quantum-mechanics and its captivating nature. One specific phenomenon, for instance, can be the enhancement of a quantum system's spontaneous emission rate, the so-called Purcell effect. Recent studies of QDs in a Fabry-Perot-based fiber microcavity already presented clear Purcell enhancement of the investigated transitions[1]. Here scattering losses and cavity-to-fiber mode mismatching limit the full exploitation of the setup's potential.

We consequently present theoretical approaches which are leading to an optimized experimental setup.

We apply finite element methods (FEM) and mode-mixing in paraxial approximation to numerically determine the cavity modes. Furthermore, we investigate the influence of the curvature on the fiber in-coupling efficiency, hence paving the way for the pursuit of higher Purcell-enhancements.

[1] T. Herzog et al. , Quantum Sci. Technol. 3 (2018) 034009

HL 35.47 Wed 17:30 Poster E

A single quantum emitter in a Mach Zehnder interferometer — •Hendrik Mannel[1], Pia Lochner[1], Jens Kerski[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

A Mach-Zehnder interferometer can be used to measure the coherence of a photon stream by a two-path experiment. In the ultimate limit of a single photon in the interferometer, it is also a realization for the so-called *which-path experiment*. A measurement of the photon path will destroy the interference in the same way, as blocking one arm of the interferometer. *In this contribution, we place a single self-assembled quantum dot in one arm of the interferometer to answer the question if a single quantum emitter in the Heitler regime [1] acts as an optical block and, thus, destroys the interference pattern. A stabilized Mach*Zehnder interferometer has been built and a single quantum dot was placed in one arm of the interferometer. An applied gate voltage shifts the QD transition in resonance due to the quantum confined Stark effect. We analyzed the interference pattern with and without the quantum dot to answer the question if a resonantly excited quantum dot in one arm destroys or conserves interference.

*[1] C. Matthiesen et al., Phys. Rev. Lett. **108**, 093602 (2012)

HL 35.48 Wed 17:30 Poster E

Single hole storage and non-equilibrium tunneling dynamics of quantum dots — •Carsten Ebler, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Bochum, Germany

Approaching the goal of a memory, storing single charge quanta, especially in quantum dots are interesting. Therefore, we use epitaxially grown self-assembled InAs QDs (SAQD) as crystalline hosts compatible with coupling to photons. This is envisaged as a progress compared to amorphous indirect semiconductors used in today's flash memories [1]. We establish SAQDs in tunnel contact with a 2-dimensional electron gas (2DEG), manipulate the system with electronical and optical pulses and perform time resolved conductivity measurements of the 2DEG to readout the charge occupation of the QDs [2]. The structure is biased such, that the Fermi level is in electronic resonance with the X^0 state in the QD to store one single hole. This metastable hole state is read out over conductivity changes of the 2DEG. Thereby it is possible to resolve electron tunneling dynamics and furthermore the interaction with the holes trapped inside the QDs. We prove metastable hole storage for at least 10 s and successful readout. Further experimentation with different voltage pulses provide information about tunneling processes of the electron states and dynamics of non-equilibrium states. [1] A. Marent et al, Semiconductor Science and Technology 26, 014026 (2011) [2] B. Marquardt1, et al, Appl. Phys. Lett. 95, 022113 (2009)

HL 35.49 Wed 17:30 Poster E

High brightness quantum dot source of telecom O-band photons — •Jingzhong Yang[1], Cornelius Nawrath[2], Robert Keil[3], Michael Zopf[1], Xi Zhang[3], Yan Chen[4], Bianca Höfer[3], Simone Portalupi[2], Peter Michler[2], Fei Ding[1], and Oliver G. Schmidt[3] — [1]Institute for Solid State Physics, Leibniz University of Hannover, Hannover, Germany — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Stuttgart, Germany — [3]Institute for Integrative Nanosciences, Leibniz-Institut für Festkörper- und Werkstoffforschung Dresden, Dresden, Germany — [4]National University of Defense Technology, Changsha, Hunan,China

In order to realize long-distance quantum communication applications, the efficient single or entangled photon generation at telecommunication wavelengths is essential. Semiconductor quantum dots (QDs) are a very promising photon source for realizing quantum teleportation due to their non-Poissonian emission characteristics and compatibility with semiconductor technology. However, the extraction efficiency is restricted because of the significant total internal reflection caused by the high refractive index host material. Here we show high extraction efficiency from InAs/GaAs QDs emitting in the telecom O-band by using an optical antenna structure. Combining a nano-membrane containing QDs with gallium phosphide hemispherical lenses results in an increased photon extraction by two orders of magnitude. This versatile approach may therefore enable new developments for long-haul quantum communication technologies.

HL 35.50 Wed 17:30 Poster E

Factorial moments of photon-number states heralded from parametric down-conversion — •K. Laiho[1], M. Schmidt[1], G. Weihs[2], and S. Reitzenstein[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

Well-behaved twin beams from parametric down-conversion (PDC) are routinely used for preparing single photons or other quantum optical states with higher photon numbers [1,2]. However, experimental imperfections such as optical losses both in the herald and in the target state cause degradation and it is difficult to decouple their effect, especially if losses are high. We utilize the normalized factorial moments of photon number, which can be extracted independent of losses, to characterize heralded photon-number states. With this regard, the differences between heralding with a click-detector [1] and a true photon-number resolving detector [3] can easily be visualized. Additionally, the higher-order moments provide a direct loss-tolerant access to other photon-number properties, like the parity. We investigate the boundaries for the reliability of such a state reconstruction method.

[1] K. Laiho et al., Opt. Lett. 36, 1476 (2011).
[2] T. Guenthner et al., J. Opt. 17, 125201 (2015).
[3] M. Schmidt et al., J. Low Temp. Phys. 193, 1243 (2018).

HL 35.51 Wed 17:30 Poster E

Transport Properties of Self-Assembeld InAs Double Quantum Dots — •Felix Opiela, Jan. K Kühne, and Rolf. J Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, D-30167 Hannover, Germany

This work focuses on the analysis of transport measurements with variable parameters such as the magnetic field or the temperature, on self-assembeld InAs double quantum dots which are embedded in a GaAs/AlGaAs heterostructure. Due to the different size of the middle tunneling barrier (3/5/7nm), we were able to differentiate between a weak coupling and a strong coupling [1]. Likewise we examined a dependency of the thermal broadend fermi-edge with the expanded molecular resonant state of the coupled quantum dot[2].In the I/V measurements a decreasing amplitude and a thermal broadened peak width were observed. Thus leading to the analysis of a phononic contribution and a detailed examination of the thermal dependency at low temperatures. In addition to that we analyzed the different samples in a varying magnetic field in the range of 0 to 14 Tesla. Parallel as well as perpendicular magnetic field orientation were analyzed in respect to the current flow.

[1] W. G. van der Wiel et.al. Rev.Mod.Phys. 75,1 (2002)
[2] G. Kiesslich Phys. Rev. Lett. 99,206602 (2007)

HL 35.52 Wed 17:30 Poster E

Conductive nanorods generated by Cu exchange on contacted CdSe/CdS-rods — •Benedikt Brechtken[1], Franziska Lübkemann[2], Dirk Dorfs[2], Nadja Bigall[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover — [2]Institut für Physikalische Chemie und Elektrochemie, Leibniz Universität Hannover, 30167 Hannover

The classical fabrication procedures for electrical devices reaches their limits in miniaturization. The incorporation of chemical methods in the fabrication could be a way of surpassing those limits.

Chemical bottom up processes can create CdSe/CdS-nanorods with

5 nm diameter and 80 nm length. Single nanorods are individually contacted with electron beam lithography. To increase the measureable current in some cases a small number of rods are contacted in parallel by Cr/Au-contacts.

With the chemical cation exchange Cd can be replaced by Cu in these nanorods [1]. This transforms CdS with a resistivity around 10^12 Ωcm [2] to CuS which has a 15 orders of magnitude lower resistivity [3]. This method is applied to already contacted nanorods. These rods are electrically measured under ambient conditions. By measuring the same rods before and after the exchange, a drastic decrease in resistance is observed. The resulting resistance is stable for at least 14 days.

[1] B. Sadler et. al., J. AM. CHEM. SOC. 131, (2009)
[2] R. H. Bube, S.M.Thomsen, J. of Chemical Physics 23, (1955)
[3] M. Najdoski et al., J. of Solid State Chemistry 114, (1995)

HL 35.53 Wed 17:30 Poster E

Time-resolved reflectometry measurements on self-assembled quantum dots — •Jakob Penner[1], Kevin Eltrudis[1], Isabel Oppenberg[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Time-resolved transconductance measurements on the electron dynamics of self-assembled quantum dots (QDs) [1] can be used to access excited spin- and charge states in an all-electrical measurement [2], an important step towards quantum state manipulation and detection for future quantum information technologies. However, for fast and high-fidelity measurements, the signal-to-noise ratio of the read-out signal is of great importance. Combining transconductance with time-resolved reflectometry in a lock-in measurement scheme promises to significantly increase the signal-to-noise ratio. We use a high-mobility electron transistor (HEMT) with a layer of QDs that are coupled to a two-dimensional electron gas. This allows us to observe the tunneling dynamics between the 2DEG and the QDs in a reflectometry measurement setup. A high-frequency ac driving voltage in combination with a lock-in technique is set to an electrical resonance of an internal LC circuit. The reflected signal depends on the impedance of the sample, where the change in impedance is related the number of electron in the quantum dot layer, hence, to the tunneling dynamics.

[1] B. Marquardt. et al., Nature Commun. 2, 209 (2011).
[2] K. Eltrudis et al., Appl. Phys. Lett. 111, 092103 (2017).

HL 35.54 Wed 17:30 Poster E

Spatiotemporal Dynamics of correlated Carrier Wave Packets in Semiconductors — •Frank Lengers[1], Roberto Rosati[2], Tilmann Kuhn[1], and Doris E. Reiter[1] — [1]Westfälische Wilhelms-Universität Münster, Germany — [2]Chalmers University of Technology, Sweden

Highly focused optical excitation of semiconductors in real space results in strongly localized carrier distributions in the material. Subsequent transport of the excited carrier wave packets occurs on nanometer and picosecond scales and is influenced by the Coulomb interaction. Since the Coulomb interaction in heterostructures of low dimensionality is enhanced with respect to the bulk, we here study a one-dimensional quantum wire as an example system where strongly interacting electrons and holes can be excited. We treat a system of up to two photoexcited electron-hole pairs within a wave function approach and are thereby able to treat the carrier correlations exactly. The wave packet dynamics is analyzed as function of the excited density and excitation energy. We show that high densities can lead to travelling electron-hole wave packets or to enhanced wave packet broadening depending on the excitation conditions.

HL 35.55 Wed 17:30 Poster E

Charging dynamics of self-assembled InAs quantum dots in n-GaAs Schottky diodes — •Lars Kürten[1], Laurin Schnorr[1], Thomas Heinzel[1], Sven Scholz[2], Arne Ludwig[2], and Andreas D. Wieck[2] — [1]Lehrstuhl für Festkörperphysik, Heinrich-Heine-Universität Düsseldorf — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

We study the charge transfer dynamics between self-assembled InAs quantum dots (SAQD) embedded in n-GaAs Schottky diodes and the space charge region by Laplace deep level transient spectroscopy (LDLTS). The filling dynamics of the electronic SAQD states are investigated at liquid nitrogen temperature as a function of the applied bias voltage and modeled using band structure calculations. We find a non-trivial dependence of the apparent total charge transfer on the bias voltage and are able to quantitatively model our data by assuming a competing re-emission of electrons during the filling process via separately measured emission paths.

HL 35.56 Wed 17:30 Poster E

Simulation of mode competition phenomena in (Al,In)GaN laser diodes — •Eduard Kuhn, Lukas Uhlig, Matthias Wachs, Ulrich T. Schwarz, and Angela Thränhardt — Institut für Physik, Technische Universität Chemnitz

Experiments show interesting mode competition phenomena in laser diodes. For example streak camera measurements show cyclic mode hopping, where the currently active mode changes from lower to higher wavelengths. This can be explained by third order effects such as beating vibrations of the carrier density. In this work we describe these mode dynamics using a model based on the semiconductor Bloch equations and discuss the influence of the Hartree-Fock terms and different dephasing terms.

HL 35.57 Wed 17:30 Poster E

Blue InGaAs-VECSELs for Rydberg atom spectroscopy — •Ana Ćutuk[1], Marija Ćurčić[2], Marius Plach[3], Richard Hermann[3], Marius Grossmann[1], Roman Bek[1], Robert Löw[3], Harald Kübler[3], Michael Jetter[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart — [2]Photonics Center, Institute of Physics, Belgrade, Serbia — [3]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

The Rydberg state of atoms is very attractive for applications in quantum information due to its large dipole moment, lifetime and polarizability. For the excitation of the Rydberg states in rubidium and potassium, laser emission in the blue spectral range is necessary. The vertical external-cavity surface-emitting laser (VECSEL) turns out to be an excellent candidate due to its wavelength versatility and high output power combined with a near diffraction-limited beam profile and the flexibility to add optical components inside the cavity. Our focus is on the development of InGaAs-based VECSELs with the fundamental wavelength in the near-infrared spectral range. By inserting a BBO crystal in a v-shaped cavity, second harmonic generation at around 475 nm and 455 nm can be achieved. Further improvements will be made on reducing the laser linewidth to achieve single mode operation and with analog stabilization according to the Pound-Drever-Hall technique.

HL 35.58 Wed 17:30 Poster E

Characterization of mode competition phenomena in (Al,In)GaN laser diodes — •Lukas Uhlig, Eduard Kuhn, Matthias Wachs, Angela Thränhardt, and Ulrich T. Schwarz — Institute of Physics, Chemnitz University of Technology

(Al,In)GaN laser diodes have various recent applications, such as laser projection systems in augmented/virtual reality glasses, which require a modulation with frequencies ranging from 100 MHz to 1 GHz. Laser diodes show a rich dynamic behavior of the longitudinal modes on a nanosecond to microsecond time scale. We investigate the spectral-temporal dynamics of green InGaN laser diodes in high resolution using a streak camera setup combined with a monochromator. For interpretation we simulate the longitudinal mode dynamics using a multi-mode rate equation model.

The observed effects at pulse onset include the turn-on delay and relaxation oscillations as well as a fast red shift. In longer pulses, we investigate mode competition with mode hopping towards longer wavelengths, which repeats cyclically. Single shot measurements show significant variations between single pulses. Consequently, much of the dynamics cannot be observed in usual averaged / time-integrated characterization.

HL 35.59 Wed 17:30 Poster E

Towards mode locking with a membrane saturable absorber mirror — •Ana Ćutuk, Roman Bek, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Although providing several superior laser properties, the vertical

external-cavity surface-emitting laser (VECSEL) is limited to a certain range of laser wavelengths. An improvement can be made by removing the Bragg reflector and sandwiching the active region between heat spreaders and using another external dielectric mirror in the cavity instead. This membrane external-cavity surface-emitting laser (MECSEL) now allows for an extension of laser wavelengths and therefore new applications. A similar procedure can also be transferred to semiconductor saturable absorber mirrors (SESAMs) for mode-locked laser operation in order to extend the application range even further.

We present the concept of a membrane saturable absorber mirror (MESAM). Instead of a semiconductor DBR, a simple dielectric mirror is used as a cavity end mirror. The absorber active region containing two GaInP quantum wells is wet-chemically released from the substrate and then bonded onto the dielectric mirror in order to simulate a SESAM device. The MESAM is employed in a v-shaped VECSEL cavity to achieve pulsed laser emission in the red spectral range. Current investigations focus on achieving stable mode-locked operation and on the characterization of the MESAM nonlinear reflectivity.

HL 35.60 Wed 17:30 Poster E

Towards near-infrared emitting InP quantum dot VECSELs — •Marius Grossmann, Lea Stassen, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQ^{ST}) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

The near-infrared spectral range has various applications in atom spectroscopy as well as medicine. These benefit from a diffraction-limited beam profile and high output powers which can be obtained using e.g. vertical external-cavity surface-emitting lasers (VECSELs). Implementing quantum dots (QDs) as the active region provides advantages compared to quantum well (QW) VECSELs such as a decreased lasing threshold and temperature dependence, improved gain and tunability of emission wavelength. Especially the wavelength flexibility allows a target emission wavelength just above 700 nm, where GaInP and AlGaAs QWs suffer from high compressive strain and oxidation, respectively.

Our semiconductor structures comprise an InP QD/AlGaInP active region and VECSEL structures are fabricated including AlGaAs/AlAs based DBRs grown using metal-organic vapor-phase epitaxy.

Current research focuses on optimization of growth parameters of the individual active region layers in view of spectral and luminescence properties as well as interfacial morphology.

HL 35.61 Wed 17:30 Poster E

Monolithic quantum well mode-locked laser subject to short optical feedback with nanometric resolution — •Pascal Sauer[1], Dominik Auth[1], Christoph Weber[1], Andreas Klehr[2], Andrea Knigge[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

Self feedback by long external optical cavities significantly enhances the timing stability and repetition rate agility of optical pulse trains generated by monolithic passively mode-locked semiconductor lasers. The impact of very short feedback cavities with nanometric feedback delay control has recently been suggested and studied by simulations [Simos et al., Appl. Phys. B 123 (2017), 222]. In this contribution, the impact of a free-space external cavity configuration with macroscopic delay lengths ranging from 10 mm to 40 mm and nanometric resolution fine-delay control on the emission properties of a quantum-well passively mode-locked semiconductor laser emitting at 1070 nm at a free-running repetition rate of 13.6 GHz is studied experimentally. Wavelength scale dynamics of the center wavelength, the repetition rate and the optical output power are identified experimentally and discussed in the framework of recent long-cavity optical self feedback results [Auth et al., Electron. Lett. 54 (2018), 374].

HL 35.62 Wed 17:30 Poster E

Self mode-locked monolithic quantum dash lasers emitting at 1535 nm subject to optical self feedback by complex external cavity geometries — •Patrick Fiala[1], Dominik Auth[1], Christoph Weber[1], Klara Maria Neumann[1], Quentin Gaimard[2], Abderrahim Ramdane[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Centre de Nanosciences et Nanotechnologies (C2N), CNRS, Marcoussis 91460, France

The impact of optical self feedback onto self mode-locked quantum dash lasers emitting at 1535 nm is investigated in dependence of feedback cavity geometry and varying optical feedback strengths. The linear external cavity with a broadband reflecting mirror is compared to a ring geometry [Haji et al., Opt. Express 20 (2012), 3268-74] and a teardrop geometry [Liu et al., Appl. Phys. Lett. 113 (2018), 041108]. These complex feedback geometries deliver bi-directionally propagating feedback signals. The experimental results are compared to a mono-directional self feedback geometry. The obtained experimental results are validated by applying a stochastic time-domain model [Drzewietzki et al., Opt. Express 21 (2013), 16142].

HL 35.63 Wed 17:30 Poster E

Response of passively mode-locked quantum-well and quantum dot lasers subject to optical self feedback — •Dominik Auth[1], Christoph Weber[1], Igor Krestnikov[2], Andreas Klehr[3], Andrea Knigge[3], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Innolume GmbH, Konrad-Adenauer-Allee 11, 44263 Dortmund, Germany — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

In this conference contribution the response of two monolithic passively mode-locked semiconductor lasers are compared whereby one laser has a quantum-well gain material and the other laser consists of a quantum dot gain material. Both as-cleaved lasers are 3 mm long with a saturable absorber section length of 10%. The two lasers are studied in an optical self feedback set-up with an optical feedback cavity length of 5.9 m and are compared by adapting a stochastic time-domain model [Drzewietzki et al., Opt. Express 21 (2013), 16142] to predict the repetition rate tuning trends, timing jitter reduction and response to optical self feedback.

HL 35.64 Wed 17:30 Poster E

Optical frequency comb quantum dash semiconductor lasers subject to optical self feedback — •Patrick Fiala[1], Dominik Auth[1], Christoph Weber[1], Quentin Gaimard[2], Abderrahim Ramdane[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Centre de Nanosciences et Nanotechnologies (C2N), CNRS, Marcoussis 91460, France

Self mode-locked quantum dash lasers emitting at 1535 nm are compact photonic sources for broadband optical frequency comb generation. They find application as super-channel sources in datacom. Their mode comb spacing can be dynamically controlled by optical self feedback [Fiala et al, DPG Spring Meeting Berlin (2018), DY 69.18]. In this work, the impact of different optical feedback delays and strengths on the radio-frequency line width, the repetitions rate and thus the comb mode spacing are investigated experimentally. Feedback cavity lengths range from 6 m to 73 m. A dynamic mode spacing control from 2 to 22.5 MHz is demonstrated. A considerable reduction in RF line width from 20 kHz (free-running) to 2.5 kHz is reported. The experimental results are confirmed by a simple stochastic time-domain model [Drzewietzki et al., Opt. Express 21 (2013) 16142; Auth et al., Electron. Lett. 54 (2018), 374].

HL 35.65 Wed 17:30 Poster E

Synchronization of two mutually optically injected passively mode-locked quantum dot lasers — •Christoph Weber[1], Dominik Auth[1], Iraklis Hercules Simos[2], Christos Simos[3], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Electrical and Electronics Engineering, University of West Attica, Athens, Greece — [3]Department of Electronic Engineering, Technological Educational Institute of Sterea Ellada, 35100 Lamia, Greece

All-optical mutual injection is proposed to be a new technique for synchronization of two or more mode-locked semiconductor lasers with applications for example in novel secure communication schemes or optical clock synchronization, as initially theoretically predicted in [Simos et al., IEEE J.Quantum Electron. 54 (2018), 2001106]. In this contribution, two passively mode-locked quantum dot semiconductor lasers emitting at 1250 nm are mutually injected by a free-space all-optical experimental configuration. Pulse train repetition

rate and laser emission wavelength synchronization are experimentally demonstrated across a broad operating regime. Emission dynamics are analysed as a function of optical delay time and laser biasing conditions. A broad synchronization regime spanning 150 mA is reported. Simulations are in good agreement with the experimental results.

HL 35.66 Wed 17:30 Poster E

Ultrafast pulse generation and pulse train stability of an InP generic foundry platform passively mode-locked symmetric ring laser with dual saturable absorbers — •Christoph Weber[1], Mu-Chieh Lo[2], Dominik Auth[1], Patrick Fiala[1], Pascal Sauer[1], Guillermo Carpintero[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Departamento de Tecnología Electrónica, Universidad Carlos III de Madrid, Av de la Universidad, 30. 28911 Leganés, Madrid, Spain

Passively mode-locked semiconductor lasers in photonic integrated circuits are promising compact sources for generating coherent optical frequency combs and ultrashort optical pulse trains for metrology, spectroscopy and millimeter wave/terahertz applications. An InP foundry-fabricated semiconductor ring laser emitting at 1570 nm with two saturable absorbers is experimentally investigated. A symmetry geometry allows the circulating optical pulses to collide in the two reverse-biased saturable absorbers placed opposite to each other enhancing the pulse shortening. Stable optical pulse trains with repetition rates at 23.3 GHz, spectral bandwidth exceeding 10 nm, a radio-frequency line width of 80 kHz corresponding to a pulse-to-pulse timing jitter of 31.7 fs and optical pulses as short as 1.2 ps at a time-bandwidth-product of 0.7 are experimentally reported.

HL 35.67 Wed 17:30 Poster E

External optical self feedback stabilization of an InP generic foundry platform based passively mode-locked ring laser — •Dominik Auth[1], Mu-Chieh Lo[2], Christoph Weber[1], Patrick Fiala[1], Pascal Sauer[1], Guillermo Carpintero[2], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Departamento de Tecnología Electrónica, Universidad Carlos III de Madrid, Av de la Universidad, 30, 28911 Leganés, Madrid, Spain

Passively mode-locked semiconductor ring lasers in photonic integrated circuits (PIC) platforms are promising compact sources for generating ultrashort optical pulse trains for telecommunication applications at 1550 nm. To allow for a dynamic mode spacing or pulse train repetition rate control, in this contribution, the impact of optical self feedback on a PIC ring laser is demonstrated experimentally. A stochastic time-domain model [Drzewietzki et al., Opt. Expr. 21 (2013), 16142] is applied to confirm the repetition rate tuning trends and pulse timing jitter reduction. A considerable improvement of the pulse train stability is reported. Thereby, the impact of the optical feedback strength and the macroscopic and microscopic optical feedback length on the stability of the emitted pulse train is studied experimentally and by modelling.

HL 35.68 Wed 17:30 Poster E

Optical pulse train stability of monolithic passively mode-locked quantum dot lasers on silicon emitting at 1310 nm — Dominik Auth[1], Songtao Liu[2], •Stefan Breuer[1], and John Bowers[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106-9560, USA

Passively mode-locked InAs/InGaAs quantum dot lasers directly grown on silicon and emitting at 1310 nm are promising sources for high-speed, high-capacity communication applications. Their ultrafast carrier dynamics, broadband gain spectra and easily saturated gain and absorption allow for the generation of ultra-short optical pulses [Liu et al., Appl. Phys. Lett. 113 (2018), 041108]. In this contribution, the pulse train stability of monolithic passively mode-locked quantum dot lasers consisting of InAs/InGaAs dots-in-a-well structures and directly grown on on-axis (001) Si is experimentally studied. Pulse train stability is quantified by relative amplitude jitter and pulse-to-pulse timing jitter in the radio-frequency domain and is complemented by temporal and spectral domain analysis. Stable mode-locking with a pulse-to-pulse timing jitter well below 100 fs, ultra-low relative amplitude jitter and optical spectra widths exceeding 5 nm are experimentally demonstrated.

HL 35.69 Wed 17:30 Poster E

Experimental studies on modal gain, absorption and dispersion of nanostructured edge-emitting monolithic semiconductor lasers — Felix Wilke[1], Stefan Heppe[1], •Christoph Weber[1], Dominik Auth[1], Quentin Gaimard[2], Abderrahim Ramdane[2], Andreas Klehr[3], Andrea Knigge[3], Igor Krestnikov[4], Thomas Walther[1], Jérôme Faist[5], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Centre de Nanosciences et Nanotechnologies (C2N), CNRS, Marcoussis 91460, France — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany — [4]Innolume GmbH, Konrad-Adenauer-Allee 11, 44263 Dortmund, Germany — [5]Institute for Quantum Electronics, ETH Zürich, Auguste-Piccard-Hof 1, 8093 Zürich, Switzerland

The generation of stable and ultrafast optical pulse trains by edge-emitting monolithic passive mode-locked and self mode-locked semiconductor lasers in the near-infrared wavelength range requires a delicate balance of differential gain, absorption and dispersion. Spectrally resolved modal gain, absorption and group delay dispersion properties of monolithic cavity single-section and two-section semiconductor lasers with quantum well and nanostructured active regions are studied experimentally. The laser structures include quantum well lasers emitting at 1070 nm, quantum dot lasers emitting at 1250 nm and quantum dash lasers emitting at 1550 nm.

HL 35.70 Wed 17:30 Poster E

Emission dynamics of monolithic broad-area InAs/InGaAs quantum dot lasers — •Dominik Auth[1], Christoph Weber[1], Stefan Breuer[1], Vladimir V. Korenev[2], Artem V. Savelyev[2], Mikhail V. Maximov[2], and Alexey E. Zhukov[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]St. Petersburg Academic University RAS, ul. Khlopina 8/3, 194021 St. Petersburg, Russia

Monolithic mode-locked edge-emitting semiconductor quantum dot lasers emitting at 1.31 micrometer are ideal sources for the generation of broad optical frequency combs for short-reach inter and intra data-center links. In this contribution, the emission dynamics of InAs/InGaAs quantum dot lasers with broad-ridge waveguide are studied experimentally. Our analysis focuses on spectral, radio-frequency and time-domain analysis as well as initial spectro-temporal emission properties. This work is supported by the Russian Foundation for Basic Research (project #18-502-12081).

HL 35.71 Wed 17:30 Poster E

Modal gain and dispersion of monolithic broad-area InAs/InGaAs quantum dot lasers — •Dominik Auth[1], Christoph Weber[1], Stefan Breuer[1], Vladimir V. Korenev[2], Artem V. Savelyev[2], Mikhail V. Maximov[2], and Alexey E. Zhukov[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]St. Petersburg Academic University RAS, ul. Khlopina 8/3, 194021 St. Petersburg, Russia

Monolithic mode-locked edge-emitting semiconductor quantum dot lasers emitting at 1.31 micrometer are ideal sources for the generation of broad optical frequency combs for short-reach inter- and intra data-center links. The modal dispersion and gain properties determine their suitability for ultrashort optical pulse generation by mode-locking. In this contribution, the modal gain and dispersion properties of InAs/InGaAs quantum dot lasers with broad-ridge waveguide are studied experimentally. Our analysis focuses on spectrally-resolved gain and group delay dispersion analysis. This work is supported by the Russian Foundation for Basic Research (project #18-502-12081).

HL 35.72 Wed 17:30 Poster E

Optical frequency comb splitting of nanostructured semiconductor lasers — •Christoph Weber[1], Lorenzo L. Columbo[2], Paolo Bardella[2], Luke F. Lester[3], Stefan Breuer[1], and Mariangela Gioannini[2] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Electronics and Telecommunications, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy — [3]Bradley Department of Electrical and Computer Engineering, Virginia Tech, Blacksburg, Virginia 24061, USA

Self mode-locked semiconductor lasers with nanostructured active regions based on quantum wells, quantum dashes, quantum dots or quan-

tum cascade lasers are promising optical frequency comb sources in crucial wavelength ranges for e.g. optical communication or spectroscopy applications. We experimentally investigate and study by simulations the spectral emission of a single-section InAs/InGaAs quantum dot laser emitting at near infrared wavelengths. We recently identified a temperature dependent mode-locking threshold [Bardella et al., Proc. SPIE 10682 (2018), 1068223], where unlocked multimodal emission switches to mode-locked emission. At this threshold, a splitting in the optical comb is detected and further analyzed in dependence of applied gain current and device temperature. We discuss the obtained results in the framework of published results on nanostructured semiconductor lasers within a broad emission wavelengths range.

HL 36: II-VI- and III-V-semiconductors

Time: Thursday 9:30–13:00 Location: H31

HL 36.1 Thu 9:30 H31

Optical properties of ZnSe-based microcavities — •Wilken Seemann[1], Alexander Kothe[1], Gesa Schmidt[2], Alexander Pawlis[2], and Jürgen Gutowski[1] — [1]Institute of Solid State Physics, Semiconductor Optics, University of Bremen, 28359 Bremen, Germany — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany

In the past years microcavities and microdisks have been shown to be a well-suited platform for the realization of low-threshold and thresholdless lasers since a small volume of the gain medium and strong containment of light can be achieved [1]. Particular interest has been directed towards whispering gallery modes (WGM) in microdisks which propagate along the border of the disk by total reflection and are therefore strongly contained. Such lasing modes were also realized in VCSEL-micropillar structures with quantum dots as gain medium [2].

Here, we analyse II-VI micropillar-microcavities and microdisks by means of micro-photoluminescence (μPL) and time-resolved μPL studies. The micropillar-microcavities were manufactured by cutting vertical 1λ-cavities with three quantum wells situated between distributed Bragg reflectors (DBRs) through focused ion beam (FIB) etching. Both the micropillar-microcavities and the microdisks exhibit diameters of a few micrometers. The results obtained from microdisk and micropillar structures are compared and their influence on the containment and the modes is discussed.

[1] L. He et al.: Laser & Photonics reviews 7(1), 2013, 60.

[2] V. N. Astratov et al.: Applied Physics Letters 91(7), 2007, 071115.

HL 36.2 Thu 9:45 H31

Photoluminescence Excitation Spectroscopy with Two-Photon Absorption on Excitons in Cu_2O — •Andreas Farenbruch, Johannes Mund, Dietmar Fröhlich, Dmitri R. Yakovlev, and Manfred Bayer — Technische Universität Dortmund, Germany

Exciton states in Cu_2O semiconductor are investigated by means of the photoluminescence excitation spectroscopy with two photon absorption (2P-PLE). Picosecond laser pulses are used to address the excitons with principal quantum numbers of 2, 3 and 4 in three different crystal directions. Comparison with second harmonic generation (SHG) spectra shows, that 2P-PLE can be allowed in SHG forbidden directions. Rotational anisotropy diagrams of the 2P-PLE signal in linear polarizations are measured and compared to model calculations based on group theory. The studies are also performed for magneto-excitons in magnetic fields up to 10 Tesla.

HL 36.3 Thu 10:00 H31

Second Harmonic Generation from the yellow 1S exciton in Cu_2O in symmetry forbidden geometries — •Johannes Mund, Christoph Uihlein, Dietmar Fröhlich, Dmitri R. Yakovlev, and Manfred Bayer — Experimentelle Physik 2, Technische Universität Dortmund, Germany

We observe second harmonic generation (SHG) from the 1S exciton resonance of the yellow exciton series in Cu_2O in four crystal orientations. For the light k-vector orientation parallel to [001] and [$\bar{1}$10] SHG should be symmetry forbidden [1]. The observed signals are explained by a band structure induced splitting of the 1S components and their mixing by residual strain in the samples. Measurements at the higher exciton resonances and a microscopic theory confirm that this effect can only be observed at the 1S exciton of relatively long lifetime, while the SHG of higher excited excitons is properly described by group theory.

[1] J. Mund et al., PRB 98, 085203 (2018)

HL 36.4 Thu 10:15 H31

Proof of principle experimental proposal for orbital control of exchange interactions between dopants in silicon — •Eleanor Crane[1], Alexander Schuckert[2], Nguyen Le[3], and Andrew Fisher[1] — [1]London Centre for Nanotechnology, University College London, London WC1H 0AH, United Kingdom — [2]5 Department of Physics, Technical University of Munich, 85748 Garching, Germany — [3]Advanced Technology Institute and Department of Physics, University of Surrey, Guildford GU2 7XH, United Kingdom

Randomly-doped silicon has many competitive advantages in the context of quantum computation; not only is it fast to fabricate but it could naturally contain high numbers of qubits and logic gates. One such logic gate relies on Heisenberg interactions between donor orbital states of two different dopant species. We use the Moving Average Cluster Expansion technique to make predictions for a proof of principle experiment demonstrating the control of one species by the orbital excitation of another.

15 min break

HL 36.5 Thu 10:45 H31

Molecular Beam Epitaxy Growth and Temperature-Dependent Electrical Characterization of Carbon-Doped GaAs on GaAs(111)B — •Tobias Henksmeier, Alexander Trapp, Stepan Shvarkov, and Dirk Reuter — Department of Physics, University of Paderborn, Warburger Straße 100, Germany

Molecular beam epitaxy (MBE) of III-V semiconductors on (111)-oriented surfaces has gained much interest in recent years due to the high symmetry of this surface. Carbon serves as a suitable p-type dopant on such surfaces.

We present a study of carbon doping of GaAs layers on (111)B semi-insulating 3" GaAs substrates with a 1° miscut towards (211) employing a heated graphite filament carbon source. GaAs(111)B samples of different carbon concentrations up to $N = 3 \times 10^{20}$ cm^{-3} were fabricated. Atomic force microscopy revealed smooth surfaces up to the highest carbon concentration. The overall carbon concentration was determined by SIMS and Hall measurements in van-der-Pauw geometry revealed p-type conductivity for all samples. Carrier freeze out was observed for low carbon concentrations at low temperatures while an almost temperature-independent conductivity and hole concentration is observed above $N = 1 \times 10^{19}$ cm^{-3} which indicates degeneracy. Almost 100 % of the carbon is incorporated as an acceptor up to $N = 1 \times 10^{19}$ cm^{-3}. For higher concentrations, compensation sets in. The carbon activation energy in the GaAs(111)B oriented sample is determined by photoluminescence measurements to 26.3 meV and is verified by a hole density Arrhenius plot.

HL 36.6 Thu 11:00 H31

XPS and Disorder Analysis of Quaternary Ga1-xInxAs1-yBiy Semiconductor Alloys — •Julian Veletas[1], Thilo Hepp[2], Kerstin Volz[2], and Sangam Chatterjee[1] — [1]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-University Giessen, D-35392 Giessen — [2]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, D-35032 Marburg

The incorporation of small fractions of bismuth atoms in III-V semiconductors such as Ga1-xInxAs1-yBiy leads to a decrease of the band gap energies and increase of the spin-orbit splitting energies of the alloy. This is attributed to an anti-crossing between the Bi-level with the valence bands of the matrix. Eventually the band gap energies may even get smaller than the spin-orbit splitting energy beyond certain fractions of bismuth incorporation into Ga1-xInxAs1-yBiy alloys. This is expected to lead to a suppression of non-radiative Auger recombination. However, growth of such materials remains challenging due to the required low growth temperatures. Furthermore, characteriza-

tion is challenging due to similar influences of In and Bi incorporation on major electronic and structural properties, such as the band gap energy and the lattice constant.

In this study, we complement standard characterization techniques with XPS. We show the influence of different partial pressures of the MOVPE growth on the bismuth segregation process as well, as on the alloy elemental composition. Using the VBAC model, the optical spectroscopy data reassemble the determined composition and a connection between disorder signatures and growth conditions is made.

HL 36.7 Thu 11:15 H31

Role of Bismuth in the Bandstructure of Ga(As,Bi) studied by Photomodulated Reflectance Spectroscopy — •Frederik Otto[1], Julian Veletas[1], Lukas Nattermann[2], Kerstin Volz[2], and Sangam Chatterjee[1] — [1]Institute of Experimental Physics I, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany — [2]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Hans-Meerwein-Str., D-35032 Marburg, Germany

Dilute bismuth-containing III-V semiconductor alloys exhibit several novel electronic properties, such as a rapidly reducing band gap with increasing bismuth concentration. This allows for a wide scope of band gap engineering in the near infrared (NIR) region. This is of significant interest for optimizing the efficiency of semiconductor lasers in the NIR. In particular, the incorporation of bismuth increases the spin-orbit split-off energy. This, in turn, potentially suppresses nonradiative Auger recombination. In addition, the incorporation of bismuth causes a heavy-hole (hh) and light-hole (lh) splitting at the Γ-point due to a reduction in tetrahedral symmetry of the zinc-blende structure. We conducted photomodulated reflectance and photoluminescence spectroscopy on a series of MOVPE grown Ga(As,Bi)-samples with varying bismuth concentration in order to get detailed information about the bismuth-induced change in band gap energy and the optical properties connected to the lifting of the hh-lh degeneracy at the Γ-point.

HL 36.8 Thu 11:30 H31

Tunable plasmonics in heavily doped GaAs via ion implantation and sub-second annealing — •juanmei duan[1,2], mao wang[1,2], manfred helm[1], wolfgang skorupa[1], shengqiang zhou[1], and slawomir prucnal[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, D-01328 Dresden, Germany — [2]Technische Universität Dresden, D-01062 Dresden, Germany

Semiconductors with ultra-high doping level are attractive for the near- and mid-infrared plasmonics. The III-V compound semiconductors are characterized by high electron mobility and low effective mass, where the plasma edge can be tuned by tailoring the doping level. In this work, we present the formation of heavily doped p- and n-type GaAs utilizing ion implantation of Te, S and Zn, followed by sub-second annealing. We demonstrate that either the millisecond range flash lamp annealing (solid phase epitaxy) or nanosecond range pulsed laser annealing (liquid phase epitaxy) is able to recrystallized the implanted layers and electrically activate the dopants.The carrier concentration in the heavily doped p- and n-type GaAs with sub-second annealing treatment is in the range of 1019~1020 cm-3. The plasmonic properties of implanted and annealed GaAs samples were investigated by Fourier transform infrared spectroscopy (FTIR) and Raman spectroscopy. The obtained ultra-highly GaAs films display a room-temperature plasma frequency above 2200 cm-1, which enables to exploit the plasmonic properties of GaAs for sensing in the mid-infrared spectral range.

HL 36.9 Thu 11:45 H31

Zeeman splitting features of novel III-V wurtzite materials — •Paulo E. Faria Junior[1], Davide Tedeschi[2], Marta De Luca[2,3], Benedikt Scharf[1,4], Antonio Polimeni[2], and Jaroslav Fabian[1] — [1]University of Regensburg — [2]Sapienza Università di Roma — [3]University of Basel — [4]University of Würzburg

The behavior of semiconductors under external magnetic fields provides valuable insight into their spin-dependent properties. Here, we investigate the Zeeman splitting features of novel III-V wurtzite materials, namely InP, InAs, and GaAs[1]. First, we present the values of the effective g-factors highlighting the important contribution of spin-orbit coupling effects. Moving to the Landau level picture, we discuss the intrinsic common features that give rise to the nonlinear Zeeman splitting, recently explained in magneto photoluminescence experiments for InP nanowires[2]. Focusing on the important Landau level coupling we derive an analytical model to fit the experimental nonlinear Zeeman splitting, applying it to InP and GaAs. We show that our analytical model correctly describes the physics of the nonlinear features and extrapolating our results, we predict the Zeeman splitting to reach a maximum value at magnetic fields larger than 30 T. [1] Faria Junior et al., arXiv:1811.09288 (2018). [2] Tedeschi et al., arXiv:1811.04922 (2018). Supported by: Alexander von Humboldt Foundation, Capes (grant No. 99999.000420/2016-06), SFB 1277 (B05), SFB 1170 'ToCoTronics', the ENB Graduate School on Topological Insulators, Awards2014 and Avvio alla Ricerca (Sapienza Università di Roma).

HL 36.10 Thu 12:00 H31

1D photonic bandgap structures for high-power GaN/InGaN laser devices — •Prabha Sana[1], Christoph Berger[1], Marc Peter Schmidt[2], Gordon Schmidt[1], Armin Dadgar[1], Jürgen Bläsing[1], Martin Deckert[2], Hartmut Witte[1], Jürgen Christen[1], and André Strittmatter[1] — [1]Institut für Physik, Otto-von-Guericke Universität, Universitätsplatz 2, 39106 Magdeburg, Germany — [2]Fakultät für Elektrotechnik und Informationstechnik, Otto-von-Guericke Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

Work reports the development of InGaN/GaN edge emitting laser with single mode 400-460 nm emission using the concept of photonic band gap crystals (PBC) to achieve vertical fundamental mode operation up to maximum power injection and reduction in vertical far field divergence. The laser structure consists of three InGaN/GaN quantum wells (QWs) as active region grown on a PBC superlattice of 35-pairs of lattice-matched GaN (220 nm)/InAlN (30 nm). The PBC periodically modulates the refractive index in the lower n-doped waveguide section, which helps to discriminate the higher order modes to obtain single mode lasing action. Basic PBC optimization parameters i.e. number of PBC pairs and layer thicknesses are obtained by CAMFR simulation. Investigations on doping of the PBC with Si or Ge were performed in order to achieve low optical losses and reduce the series resistance. Furthermore, the InGaN/GaN multi quantum well region and design of the Mg-doped AlGaN electron blocking layer were studied to achieve a reduced penetration of the optical mode into the p-doped cladding.

HL 36.11 Thu 12:15 H31

Colloidal InP-based Quantum Dot Emitters: Limiting Factors for Color Purity — •Michael Binder[1], Alexander F. Richter[1], Alexander S. Urban[2], Itai Lieberman[3], Thomas Eberle[3], and Jochen Feldmann[1] — [1]Chair for Photonics and Optoelectronics, LMU München — [2]Nanospectroscopy Group, LMU München — [3]Merck KGaA, Darmstadt

Colloidal quantum dots (cQDs) with an InP-based core/shell structure are promising for light emitting applications as non-toxic alternatives to colloidal cadmium-based QDs. Up to now it is still a challenge to compete with the narrower emission bandwidth of Cd-cQDs which is needed for high color purity in applications such as displays. Here, we investigate the nature of photoluminescence (PL) peak broadening by means of single cQD spectroscopy. It turns out that the PL bandwidth of individual InP-based cQDs is comparable to their Cd-based counterparts. Therefore broadening of the ensemble emission bandwidth can only be attributed to larger size-inhomogeneity. The latter is also responsible for non-radiative energy transfer between closely-spaced cQDs which red-shifts the ensemble PL peak. This effect can be dynamically followed in the spectrally resolved PL-decay. Altogether we conclude that there are no intrinsic drawbacks for InP cQDs regarding color purity of a light emitting device as compared to Cd-based cQDs.

HL 36.12 Thu 12:30 H31

Tunneling in coupled co-directional polariton waveguides — •Johannes Beierlein[1], Martin Klaas[1], Holger Suchomel[1], Tristan H. Harder[1], Karol Winkler[1], Monika Emmerling[1], Oleg Egorov[1], Hugo Flayac[2], Christian Schneider[1], Sebastian Klembt[1], and Sven Höfling[1,3] — [1]Technische Physik, Universität Würzburg, Germany — [2]Institute of Theoretical Physics, EPFL,Lausanne, Switzerland — [3]School of Physics and Astronomy, University of St. Andrews, United Kingdom

We investigate the coupling of waveguides supporting exciton-polariton condensates. A relevant and most simple device to study is the codirectional coupling device, where two waveguides are connected by a half-etched section which facilitates tunable coupling of the adjacent channels. This evanescent coupling of the two macroscopic wavefunc-

tions in each waveguide reveals itself in oscillations of the condensate. By designing gap width and channel length, the exit port of the polariton flow can be chosen. Continuing from here, we show numerical simulations, sample designs and first experimental results for waveguide-arrays with the goal of observing Bloch oscillations and realizing a topologically protected mode in a Su-Schrieffer-Heeger framework with polariton waveguides.

HL 36.13 Thu 12:45 H31

Laser-assisted local metalorganic vapor phase epitaxy — •Max Trippel, Matthias Wieneke, Armin Dadgar, and André Strittmatter — Institut für Physik, Otto-von-Guericke Universität Magdeburg- Universitätsplatz 2, 39106 Magdeburg Germany

Up to now, an unsolved problem of integration between Si and III/V semiconductor materials is the misfit between optimum III/V growth conditions and Si electronics. We propose laser-assisted local III/V epitaxy based on metalorganic vapor phase epitaxy (MOVPE) to resolve the growth-temperature related incompatibility of both worlds. GaAs-on-Si has been chosen as the first epitaxial system to study due to its well-known behavior in MOVPE.

In order to identify conditions where local epitaxial GaAs growth proceeds similar to full wafer growth, finite element multi-physics simulations were performed. We therefore calculated temperature profiles, distribution of species, and resulting reaction rates within the heated area. A reduced lateral extension of the growth area with respect to the heated area is found which correlates with the pyrolithic decomposition of the metalorganics.

Accordingly, we have developed our own MOVPE tool. Our epitaxy system comprises a conventional gas mixing cabinet, a stainless-steel vertical growth reactor, a xyz-movable substrate holder, and a temperature-controlled laser-heater. The substrate is clamped vacuum-tight against a non-rotating susceptor plate and can be cooled with helium. Pyrometric temperature measurement is done in the center of the laser spot being as small as 150 m in diameter.

HL 37: Focus Session: Growth, Properties and Application of Epitaxial Graphene (joint session DS/O/HL)

Graphene is the only 2D material, which up to now can be grown almost defect-free on large scales. The application of epitaxial concepts has turned out as a breakthrough in graphene research, because it provides control over the interface and surface structure of epitaxial graphene (EG) layers with atom-scale precision and in an efficient and technologically compatible way. A wide variety of physical phenomena have been observed in graphene-based structures, including topologically protected states, high charge carrier mobility, electron correlation or superconductivity. This versatility makes EG an ideal platform for the integration of graphene-based structures into electronic applications.

This Focus Session aims at fostering the cooperation between groups working in the field of the synthesis, characterization and integration of systems based on large, structurally well-ordered graphene layers. For this purpose it collects state-of-the-art contributions to all involved aspects of EG research, from the growth, functionalization and characterization to the integration of EG-based materials.

Organizers:

- Sibylle Gemming, Institut für Physik, TU Chemnitz, D-09107 Chemnitz
- Christoph Tegenkamp, Institut für Physik, TU Chemnitz, D-09107 Chemnitz

Time: Thursday 9:30–12:45 Location: H32

Invited Talk HL 37.1 Thu 9:30 H32

Epitaxial graphene on SiC(0001) studied by electron spectroscopy and microscopy — •Florian Speck — Professur für Technische Physik, TU Chemnitz, Reichenhainer Str. 70, D-09126 Chemnitz, Germany

The growth of epitaxial graphene (EG) on silicon carbide (SiC) by sublimation of silicon in an inert atmosphere has received considerable attention due to its scalability up to wafer size, and over the past years, the homogeneity of the graphene films could be significantly enhanced by a polymer assisted growth process [1]. Intricate transfer procedures can be dispensed with when semi-insulating SiC substrates are used, facilitating the use of EG in electronics. Yet, interfaces to other materials and the presence of a substrate can affect the graphene layers, e.g. with respect to their structural and electronic properties. As will be shown in this talk, EG grown on SiC(0001) constitutes an intriguing model system to study such interactions due to diverse possibilities of manipulating its properties for instance by intercalation of different elements at the interface to the substrate. To this end, we employ mainly surface science methods such as electron spectroscopies, low-energy electron diffraction and microscopy. Discussed topics include doping of EG induced by hexagonal SiC polytypes, interface modification by means of intercalation, dislocations in EG and investigations of graphene prepared by polymer assisted growth.
[1] M. Kruskopf et al., 2D Mater. **3**, 041002 (2016).

HL 37.2 Thu 10:00 H32

Uniform large-scale quasi-freestanding monolayer and bilayer graphene on SiC — Davood Momeni Pakdehi[1], •Klaus Pierz[1], Stefan Wundrack[1], Johannes Aprojanz[2], T.T. Nhung Nguyen[3], Thorsten Dziomba[1], Frank Hohls[1], Andrey Bakin[4,5], Rainer Stosch[1], Christoph Tegenkamp[2,3], Franz J Ahlers[1], and Hans. W. Schumacher[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]Institut für Festkörperphysik, LU Hannover, Appelstraße 2, 30167 Hannover — [3]Institut für Physik, TU Chemnitz, Reichenhainer Straße 70, 09126 Chemnitz — [4]Institut für Halbleitertechnik, TU Braunschweig, 38106 Braunschweig, — [5]Laboratory of Emerging Nanometrology, TU Braunschweig, 38106 Braunschweig

Epitaxial graphene growth is often accompanied by step bunching of the underlying SiC substrate and graphene bilayer formation which can deteriorate the quality of graphene-based devices, e.g., the resistance quantization of the quantum Hall effect. We show AFM, STM, Raman and electronic transport data which indicate that improved buffer layer growth is the key to obtain homogenous large-area monolayer graphene. Particularly, the substantial impact of the so-far less regarded Ar flow rate on the graphene quality is investigated in this study and explained by a quasi-equilibrium model at the growing surface. The quality of our ultra-smooth graphene layers is proven by the high uniformity of quasi-freestanding graphene sheets obtained by hydrogen intercalation which is underlined by the very small resistance anisotropy of such samples on um and mm scales.

HL 37.3 Thu 10:15 H32

Influence of minivalleys and Berry curvature on electrostatically induced nanostructures in gapped bilayer graphene — •Angelika Knothe and Vladimir Fal'ko — National Graphene Institute, University of Manchester, United Kingdom

We theoretically investigate the properties electrostatically confined nanostructures in gapped bilayer graphene (BLG). We show how the spectrum of subbands in a quantum wire in gapped BLG, and the energy levels in a quantum dot, manifest the minivalley structure and Berry curvature via the associated magnetic moment of the states in

the low-energy bands. These features determine the degeneracies of the low-energy minibands / -levels and their valley splitting, which develops linearly in a weak magnetic field. In a quantum point contact, magneto-conductance reflects such degeneracies in the heights of the first conductance steps which develop upon the increase of the channel doping: $8e^2/h$ steps in a wide channel in BLG with a large gap, $4e^2/h$ steps in narrow channels, all splitting into a staircase of $2e^2/h$ steps upon lifting valley degeneracy by a magnetic field B. For quantum dots, we investigate how optical selection rules are influenced by the minivalleys and the orbital magnetic moment, as well as by shapes of the confinement.

References: A. Knothe and V. Fal'ko, Phys. Rev. B 98, 155435 (2018); H. Overweg, A. Knothe, V. I. Fal'ko, K. Ensslin, T. Ihn, et al., arXiv:1809.01920; R. Kraft, I.V. Krainov, V. Gall, A.P. Dmitriev, R. Krupke, I.V. Gornyi, R. Danneau, arXiv:1809.02458

HL 37.4 Thu 10:30 H32

Tuning the doping level of graphene near the Van Hove singularity via ytterbium intercalation — •Hrag Karakachian, Philipp Rosenzweig, Stefan Link, Kathrin Müller, and Ulrich Starke — Max-Planck-Institut für Festkörperforschung, Heisenbergstr. 1, 70569 Stuttgart, Germany

At extremely high doping levels, when pushing the Fermi level to the vicinity of graphene's Van Hove singularity (VHs), exotic electronic ground states are expected to occur driven by many-body interactions. These competing electronic phases such as chiral superconductivity, charge or spin density waves, find their stability based on the amount of doping induced in the graphene layer [1]. In this work, we present a method for effectively tuning graphene's doping level near its VHs. Epitaxially grown graphene on SiC(0001) is decoupled from the SiC substrate and strongly n-doped up to its VHs via ytterbium intercalation. By annealing the graphene/Yb system at different temperatures, a topological transition at the Fermi level is observed and a continuous shift in Dirac point energy is measured, indicating a change in carrier density. The Yb atoms go through different order patterns at different heating stages, and their concentration is modified as a function of temperature. These variations significantly affect the amount of charge transferred to the graphene layer and allow the systematic control of graphene's doping level near its VHs. Thus, the Yb intercalation technique can provide a reliable way of accessing and switching between different possible ordered electronic ground states in graphene.

[1] A.M. Black-Schaffer et al., J. Phys. CM **26**, 423201 (2014).

HL 37.5 Thu 10:45 H32

Substrate induced nanoscale resistance variation in epitaxial graphene — •Anna Sinterhauf[1], Georg A. Traeger[1], Davood Momeni Pakdehi[2], Philip Schädlich[3], Florian Speck[3], Philip Willke[4,5], Thomas Seyller[3], Christoph Tegenkamp[3], Klaus Pierz[2], Hans Werner Schumacher[2], and Martin Wenderoth[1] — [1]IV. Physikalisches Institut, Universität Göttingen, 37077 Göttingen, Germany — [2]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [3]Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany — [4]Center for Quantum Nanoscience, Institute for Basic Science (IBS), Seoul 03760, Republic of Korea — [5]Department of Physics, Ewha Womans University, Seoul 03760, Republic of Korea

Electron transport in graphene is often crucially influenced by the underlying substrate which induces scattering mechanisms on a local scale. Using scanning tunneling potentiometry we investigate the transport properties of graphene on 6H-silicon carbide (0001) grown by polymer-assisted sublimation growth (PASG) down to the nanometer scale. We find a significant variation in the sheet resistance of up to 195% on neighboring terraces directly related to the stacking of the 6H-SiC substrate. Thus, our data clearly shows the strong influence of the substrate below the graphene layer on its local transport properties. In addition, we performed temperature dependent measurements to gain insight into the dominant scattering mechanism. This work is financially supported by the DFG through the SFB1073.

15 min. break.

Invited Talk HL 37.6 Thu 11:15 H32

Patternable non-polar epigraphene for nanoelectronics and Dirac point physics — Vladimir Prudkovskiy[1,3], Yiran Hu[1], Hue Hu[1], Lei Ma[2], Claire Berger[1,3], and •Walt de Heer[1,2] — [1]Georgia Institute of Technology, Atlanta USA — [2]TICNN, Tianjin China — [3]Neel Institute, CNRS, Grenoble, France

Recently reported measurements of epitaxial graphene nanoribbons grown on sidewalls etched in the 0001 face of h-SiC, Nature,506, 349, (2014) indicate that both spin and valley degeneracies are lifted, resulting in the observed 10 micron scale, temperature independent, single channel transport. These highly unusual properties were further investigated in SiC wavers that were cut at an angle to the 0001 face were prepared at the Tianjin International Center for Nanoparticles and Nanostructures. The wafers were graphitized and 10 micron scale top gated Hall bar structures were patterned using standard lithography methods. Magnetotransport measurements revealed striking transport properties. Single channel ballistic transport is observed even at the Dirac point. Moreover, an anomalous quantum Hall plateau is observed. Its anomalous value is caused by a quantized current that does not have a Hall effect, and that is in parallel with an equal current that does have a Hall effect. These properties are likely to be caused by edge currents, with energies that are pinned at the Dirac point. The ballistic transport is essentially temperature independent and consistent with that observed in sidewall ribbons. These results indicate that nonpolar epigraphene is a promising candidate for epigraphene nanoelectonics and important for Dirac point physics.

HL 37.7 Thu 11:45 H32

Epitaxial growth of ferromagnetic semiconducting $CrBr_3$ monolayer — •Weijiong Chen[1], Zeyuan Sun[1], Lehua Gu[1], Shiwei Wu[1,2], and Chunlei Gao[1,2] — [1]State Key Laboratory of Surface Physics, Key Laboratory of Micro and Nano Photonic Structures (MOE), Department of Physics, and Institute for Nanoelectronic Devices and Quantum Computing, Fudan University, Shanghai 200433, China — [2]Collaborative Innovation Center of Advanced Microstructures, Nanjing 210093, China

Recent discovery of two-dimensional (2D) ferromagnetic semiconducting materials greatly expands the family of 2D materials and invokes tremendous interests in novel magnetic related applications in 2D limit. Similar to most 2D materials, ferromagnetic 2D semiconductor is also firstly found in the mechanically exfoliated micrometer sized flakes, which hinders its further application. Here, we report the successful growth of ferromagnetic semiconducting monolayer $CrBr_3$ by compound source molecular beam epitaxy (CS-MBE). $CrBr_3$ compounds are directly evaporated onto the Highly Oriented Pyrolytic Graphite (HOPG) substrate and form $CrBr_3$ thin films with a precise thickness control. The atomic, electronic and magnetic properties were characterized by in-situ spin-polarized scanning tunneling microscopy. This growth method can be applied to other layered transition metal trihalides (LTMTs) as well, which provides a simple way of growing LTMTs for exploring their electronic and magnetic properties to the monolayer limit.

HL 37.8 Thu 12:00 H32

Tuning the electronic properties of PbPb molecules by epitaxial graphene — •T.T.Nhung Nguyen[1], U. Gerstmann[2], T.N.Ha Nguyen[1], and C. Tegenkamp[1,3] — [1]TU Chemnitz, Germany — [2]Universität Paderborn, Germany — [3]Leibniz Universität Hannover, Germany

Functionalization of graphene aimed for its application in nanoelectronics is an important step. Among a variety of surface tailoring methods, molecular self-assembly gives rise to precisely control their interface by choosing appropriate molecules, e.g. non-planar lead-phthalocyanine (PbPc). By means of scanning tunneling microscopy and density functional theory (DFT) we studied in detail the adsorption of PbPc on graphene/SiC(0001). Thereby, we used as template both n-doped monolayer (MLG) and neutral quasi-free monolayer graphene (QFML). On both surfaces PbPc forms almost identical monolayer structures, in agreement with DFT. Upon adsorption of the molecules, where the central atom points away from the surface, the benzene rings undergo pronounced distortions, where adjacent rings rotate and bend in opposite directions giving rise to a chiral single domain structure. Despite the same adsorption geometry, the molecular states of PbPc on these two surfaces are strongly shifted with respect to each other. First DFT results show that the negatively charged MLG is responsible for this effect.

Invited Talk HL 37.9 Thu 12:15 H32

Intrinsic stacking domains in graphene on silicon carbide: A pathway for intercalation — Tobias A de Jong[1], Eugene E Krasovskii[2], Christian Ott[3], Rudolf M Tromp[4,1], Sense Jan van der Molen[1], and •Johannes Jobst[1] — [1]Leiden Institute of Physics, Leiden, The Netherlands — [2]Universidad del Pais Vasco, San

Sebastián/Donostia, Spain — [3]Lehrstuhl für Angewandte Physik, Universität Erlangen-Nürnberg, Erlangen, Germany — [4]IBM T. J. Watson Research Center, Yorktown Heights, USA

Graphene on silicon carbide (SiC) bears great potential for future graphene electronic applications because it is available on the wafer scale and its properties can be custom tailored by inserting various atoms into the graphene/SiC interface. It remains unclear, however, how atoms can cross the impermeable graphene layer during this widely used intercalation process. Here we demonstrate that in contrast to the current consensus, graphene layers grown in argon atmosphere on SiC are not homogeneous, but instead are composed of domains of different crystallographic stacking as they have been observed in other systems. We show that these domains are the AB and AC versions of Bernal stacking, that they are intrinsically formed during growth and that dislocations between domains dominate the (de)intercalation dynamics of hydrogen. Tailoring the resulting dislocation networks, e.g., through substrate engineering, will increase the control over the intercalation process and could open a playground for topological and correlated electron phenomena on the wafer scale.

HL 38: Organic semiconductors

Time: Thursday 9:30–11:15 Location: H33

HL 38.1 Thu 9:30 H33

Quantitative Analysis of the Density of Trap States in Organic Semiconductors by Electrical Transport Measurements on Low-Voltage Thin-Film Transistors — •Michael Geiger[1], Lukas Schwarz[1], Thomas Ferschke[2], Ute Zschieschang[1], Dirk Manske[1], Jens Pflaum[2,3], Jürgen Weis[1], Hagen Klauk[1], and Ralf Thomas Weitz[4,5] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Experimental Physics VI, Julius-Maximilian University, Würzburg, Germany — [3]ZAE Bayern, Würzburg, Germany — [4]Faculty of Physics, Ludwig Maximilians University, München, Germany — [5]NanoSystems Initiative Munich (NIM) and Center for NanoScience (CeNS), Ludwig Maximilians University, München, Germany

We present an extension to an existing method to convert a measured transfer curve of a field-effect transistor to the underlying density-of-trap-states (trap DOS) function [1]. A comparison between thin-film transistors (TFTs) with high- and low-voltage operation confirms the validity of the original method for high-voltage transistors, but also the need for the extended method for the reliable extraction of the trap DOS in low-voltage transistors. Furthermore, we developed a method to systematically control the surface roughness of the gate dielectric in our TFTs and then used our extended method to investigate the correlation between the surface roughness of the gate dielectric and the trap DOS in the organic semiconductor layer and the implications of the surface roughness for the TFT performance.

[1] M. Grünewald et al., Phys. Stat. Sol. B 100, K139 (1980).

HL 38.2 Thu 9:45 H33

Fabrication and electrical properties of Rubrene/F6-TCNNQ charge transfer interfaces — •Bipasha Debnath, Daniel Waas, Martin Knupfer, Bernd Büchner, and Yulia Krupskaya — Leibniz Institute for Solid State and Materials Research Dresden, 01069 Dresden Germany

Although charge-transfer interfaces are widely used in organic electronics, the mechanism of the charge transfer remains unexplored. One of the very promising approaches to study the charge transfer is organic single-crystal based interfaces, where an enhanced electrical conductivity at the interface of two initially insulating materials can be observed [1]. In this research work, we build a charge-transfer interface based on high quality Rubrene single crystals as a donor material. As an acceptor, we choose F6-TCNNQ -a molecule with very high electron affinity (EA = 5.6 eV) [2]. Rubrene single crystals are grown using physical vapor transport (PVT) and characterized with the optical and atomic force microscopy. Additionally, field-effect transistor (FET) measurements are performed to ensure the highest quality of the crystals. To fabricate the charge-transfer interface, F6-TCNNQ is evaporated on top of the Rubrene crystals. Strongly increased electrical conductivity along the interface is observed by electrical measurement. The acquired results well complement the previous studies of Rubrene/Fx-TCNQ interfaces [1] and widen the possibility for further systematic investigations of the charge transfer mechanisms. Financial support: DFG KR 4364/4-1. [1] Y. Krupskaya et al., Adv. Funct. Mater. 26, 2334 (2016) [2] A. Kahn et al., Adv. Funct. Mater. 28, 1703780 (2018)

HL 38.3 Thu 10:00 H33

Charge transport properties of highly ordered solution processed films of C8-BTBT — •Michael Bretschneider[1], Katherina Haase[2], Stefan C.B. Mannsfeld[2], Bernd Büchner[1], and Yulia Krupskaya[1] — [1]IFW Dresden, Germany — [2]CFAED, TU Dresden,Germany

In the field of organic electronics one has to improve device sizes and structures and find new, more efficient materials. On the other hand it is intended to enhance the device performance. For all of these tasks one needs to understand the specific material properties of organic semiconductors. In terms of device performance it is important to investigate the charge carrier mobility and find a way to increase its value. The family of [1]Benzothieno[3,2-b]benzothiophene (BTBT) is a new type of high hole mobility organic semiconductor. In this family C8-BTBT is investigated the most in the past years. Solution based fabrication methods like shear coating allow for a large area growth of highly ordered films of C8-BTBT. Recently a new record value of mobility in field-effect transistors based on that method was published (1). Beside that there are still open questions concerning charge carrier properties. For further improvement one has to understand the transport mechanisms in these organic semiconductor devices. Here we present our results based on temperature dependent field-effect and Hall-effect measurements. These measurements allow to get a closer look into the transport behaviors of solution processed C8-BTBT films.

(1)K. Haase, C. Teixeira da Rocha, C. Hauenstein, Y. Zheng, M. Hambsch, S. C. B. Mannsfeld, Adv. Electron. Mater. 2018, 4, 1800076.

HL 38.4 Thu 10:15 H33

Optical and Electrical Investigations of an Organic Microcavity — •Stefan Meister, Robert Brückner, Markas Sudzius, Hartmut Fröb, and Karl Leo — IAPP, TU Dresden, Dresden, Germany

Organic materials are widely used in opto-electronic devices such as the OLED or the organic solar cell. The properties are also very interesting for laser applications. Whereas different types of laser, with an organic active medium, were presented optically pumped, so far, it is not possible to realize an electrically driven organic solid-state laser. There are several obstacles, e.g. potentially high current densities or accumulation of triplet states, which need to be addressed before the more convenient electrical pump process can be realized.

We investigated different kinds of electrically active structures and their potential for laser applications. The results are compared to optically pumped devices to better rate and understand the device performance.

Due to expected current densities in the range of kA/cm^2, the use of metal contacts seems to be inevitable. Therefore, optimizing the contacts plays a key role to prevent a decrease in device functionality due to the metals. We realized metal contacts which did not increase the optical lasing threshold and still supply a conductivity of $1.9x10^5$ $(\Omega cm)^{-1}$.

HL 38.5 Thu 10:30 H33

Electron paramagnetic resonance detected in a metal-free fluorescence-phosphorescence dual-emitter OLED — •Tobias Grünbaum, Wolfram Ratzke, Sebastian Milster, Sebastian Bange, and John M. Lupton — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Universitätsstraße 31, 93053 Regensburg, Germany

Organic light-emitting diodes (OLEDs) constitute an ideal model system for investigating spin-dependent phenomena in condensed matter physics. A tool for direct access to the spin symmetry of charge carrier pairs in OLEDs is electron paramagnetic resonance (EPR) [1].

We performed EPR measurements on OLEDs comprising the dual emitting host-guest system CBP:DMDB-PZ [2]. This allows us to simultaneously detect the effect of both static as well as high frequency

magnetic fields on the ratio of singlet and triplet charge-carrier pairs. We find the anticipated anti-correlation of singlet and triplet light emission in magneto-electroluminescence as well as under EPR. Due to the precise control of molecular design, spin-orbit as well as hyperfine interaction can be selectively tuned and investigated. We anticipate that the EPR technique can be applied to identify the region of the device where formation of charge-carrier pairs takes place, since differing distributions of the hyperfine fields are expected in different molecular scaffolds.

[1]: Baker, W. J. et al., Nat. Commun. 3, 898 (2012)
[2]: Ratzke, W. et al., Phys. Rev. Appl. 9, 054038 (2018)

HL 38.6 Thu 10:45 H33

Photoemission Spectroscopy Studies of Charge Transfer Interfaces — •Robert Kuhrt, Martin Hantusch, Martin Knupfer, and Bernd Büchner — IFW Dresden, Helmholtzstraße 20, 01069 Dresden

Charge transfer plays an important role in the field of organic molecular materials. Prominent examples are so-called two dimensional metals and superconductors as well as the doping of organic semiconductors that are used in devices like solar cells, OLEDs and organic transistors. Charge transfer at the interface of two organic semiconductors can lead to electronic properties that differ significantly from those of the individual materials which makes a deeper understanding of this process a matter of scientific interest. In principle, charge transfer is expected at interfaces where the ionization potential of one material is located in the same region as the electron affinity of the other material.

In this contribution we present a photoemission spectroscopy (PES) study of interfaces between the acceptor molecule hexafluorotetracyanonaphthoquinodimethane (F_6TCNNQ) and the donor molecules pentacene and di-benzo-pentacene. The electronic states in the valence band region are probed with ultraviolet photoemission spectroscopy (UPS) and an x-ray source (XPS) is used to measure the core levels. It is revealed that the highest occupied molecular orbitals of the donor molecules are shifted when they are in contact with the F_6TCNNQ-molecules. Also, the identification of additional nitrogen and carbon species indicate the presence of reduced F_6TCNNQ molecules and therefore a full localized charge transfer at the interface.

HL 38.7 Thu 11:00 H33

Electronic excitations in phthalocyanine mixed films — •Lukas Graf[1], Louis Doctor[1], Nikolay Kovbasa[1], Marco Naumann[1], Martin Knupfer[1], Katrin Ortstein[2], and Karl Leo[2] — [1]IFW Dresden — [2]IAPP Dresden

This contribution will present optical and electron spectroscopy experiments on mixed films of phthalocyanines. Phthalocyanines (PC's) are organic semiconductors which are well suited for fundamental studies as well as applications. Band structure tuning, such as size and position of the bandgap, is common in inorganic semiconductors. In organic semiconductors it was first reported in 2016 for mixtures of ZnPC with fluorinated ZnPC (M. Schwarze et al, Science, 2016). We investigate mixed films of ZnPC and its fluorinated partner F_8ZnPC with a particular focus on the electronic excitations. In different ratios they are evaporated in thin films on a KBr substrate. These films are measured by optical spectroscopy (UV,IR, VIS) and with electron energy loss spectroscopy (EELS), a method where the energy-loss of the transmitted electrons through the film can be measured momentum dependently. This unique technique allows us to measure the exciton disperson of the materials and to see how the mixed films' disperson is just a superposition of the pure molecules or if they are building new properties by being stacked next to each other. This is supported by the DFG (KN393/25, KN293/26).

HL 39: Quantum dots and wires: Optical properties I

Time: Thursday 9:30–12:45 Location: H34

HL 39.1 Thu 9:30 H34

Full photon statistics for superradiant quantum-dot-microcavity lasers via the Monte Carlo wave-function method — •Sergej Neumeier and Jan Wiersig — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Postfach 4120, D-39016 Magdeburg, Germany

Superradiance, the enhancement of spontaneous emission, appears due to radiative coupling between emitters. Using this effect highly efficient quantum-dot nanolasers can be build [1]. It has been experimentally observed that this coupling also leads to an enhanced photon bunching [2]. These inter-emitter coupling effects have been described by simulating open systems in quantum optics [3,4] using the Monte Carlo wave-function method [5,6,7]. The method gives access to the full photon statistics. Experimentally the full photon statistics, e.g. auto-correlation functions ($g^{(2)}(0)$ etc.) and the photon-number distribution p_n, can be measured using a transition edge sensor [8].

We use the Monte Carlo wave-function method to study a continuously driven (cw) quantum-dot ensemble interacting with a single-mode light field in a microcavity.

[1] H. A. M. Leymann et al., Phys. Rev. Appl. 4, 044018 (2015). [2] F. Jahnke et al., Nat. Comm. 7, 11540 (2016). [3] V. V. Temnov et al., Phys. Rev. Lett. 95, 243602 (2005). [4] V. V. Temnov et al., Opt. Express 17, 5774 (2009). [5] K. Mølmer et al., J. Opt. Soc. Am. B 10, 524 (1993). [6] J. Dalibard et al., Phys. Rev. Lett. 68, 580 (1992). [7] N. Gisin, Helvetica Physica Acta 62, 363 (1989). [8] E. Schlottmann et al., Phys. Rev. Appl. 9, 064030 (2018).

HL 39.2 Thu 9:45 H34

An information theoretical approach to the many-particle hierarchy problem: application to quantum dot microcavity lasers — •Boris Melcher, Boris Gulyak, and Jan Wiersig — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Postfach 4120, D-39016 Magdeburg, Germany

Using the maximum entropy principle [E. T. Jaynes, Phys. Rev. 106, 620 (1957), Phys. Rev. 108, 171 (1957)], we develop a stand-alone approach to numerically determine the full density matrix of open quantum systems. By doing so, the many-particle hierarchy problem that arises in conventional equation of motion techniques and makes it necessary to utilize factorization and truncation schemes such as the cluster expansion method [H. A. M. Leymann et al., Phys. Rev. B 89, 085308 (2014)], is completely avoided. Instead, a finite set of input information is used to calculate the least biased density matrix self-consistently, and thus making all relevant expectation values and correlation functions as well as the full statistics directly accessible.

As a benchmark, we compare the maximum entropy method results for a four-level single quantum dot microcavity laser where the full density matrix is still available by numerically solving the von Neumann-Lindblad equation and demonstrate excellent agreement in terms of entropy, mean photon number, autocorrelation function, and photon statistics. Finally, we show that our approach can be used as a tool for learning about the relevant processes of quantum systems.

HL 39.3 Thu 10:00 H34

Carrier dynamics and modulation properties in tunnel-injection based quantum-dot structures — •Michael Lorke[1], Stephan Michael[1], Igor Khanonkin[2], Gadi Eisenstein[2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Germany — [2]Andrew and Erna Viterbi Department of Electrical Engineering, Technion, Haifa, Israel

For tunnel-injection (TI) quantum-dot (QD) lasers record high small signal modulation bandwidth and improved performance of 1.55μm InAs QDs on InP-based hetero-structures (1) were reported, which underscores their application potential for high-speed optical communication networks. However, large signal modulation, which really is the fingerprint of applicability in optical communication, is much less investigated. We present a theoretical analysis of TI laser and amplifier devices by combining material realistic electronic structure calculations with a detailed description of the carrier dynamics. Based on these investigations, we can give design guidelines to optimize the modulation bandwidth and turn-on delay.

HL 39.4 Thu 10:15 H34

Exploring excited electronic states in QDs by spatially structured laser beams - a theoretical investigation — •Matthias Holtkemper, Doris E. Reiter, and Tilmann Kuhn — Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

In many experiments an optically driven self-assembled quantum dot (QD) is excited at some high energy. The created "hot" exciton relaxes via short-living intermediate levels into the exciton ground state which then decays radiatively. A detailed knowledge of the intermediate single and multiexciton levels is crucial to understand different relaxation channels as well as time-resolved nonlinear optical signals. However, many of the intermediate excitons are not optically accessible by standard Gaussian beams and, thus, difficult to study.

We theoretically explore the possibilities that arise by excitations with spatially structured light fields, such as higher modes in optical cavities or freely propagating Bessel or Hermite-Gaussian beams. We show that many of the intermediate states become accessible by such light fields. Furthermore, we show that the spatial degree of freedom of these laser fields can be used to excite different excitonic levels selectively. With this we propose a generalized polarization measurement, where not just the orientation of the dipole moments, but also the spatial orientation of the excitonic states can be measured.

HL 39.5 Thu 10:30 H34

Influence of lattice mismatch on direct and indirect electronic states in $In_{1-x}Ga_xAs_ySb_{1-y}$ quantum dots grown on GaP or GaAs — •Petr Klenovsky[1,2], Andrei Schliwa[3], and Dieter Bimberg[3,4] — [1]Masaryk University, Department of Condensed Matter Physics, Brno, Czech Republic — [2]Czech Metrology Institute, Brno, Czech Republic — [3]Technical University Berlin, Inst Solid State Physics, Berlin, Germany — [4]Chinese Acad Sci, Chinese German Ctr Green Photon, Changchun, Jilin, Peoples R China

We study the electronic structure of $In_{1-x}Ga_xAs_ySb_{1-y}$/GaAs/GaP quantum dots as an example of system exhibiting concurrently direct and indirect transitions both in real and momentum space. We show that this system provides a unique combination of physical properties currently studied in the physics of low-dimensional systems and potentially provides much easier access to applications in quantum information technology than the currently studied (In,Ga)As/GaAs dots. We inspect the confinement potentials for $\mathbf{k} \neq 0$ and $\mathbf{k} = 0$ conduction and $\mathbf{k} = 0$ valence bands, formulate the method of $\mathbf{k} \cdot \mathbf{p}$ calculations for **k**-indirect transitions, and we discuss the excitonic structure of Γ-transitions in this system. Throughout this process we compare the results obtained for dots on both GaP and GaAs substrates revealing the influence of the large hydrostatic stress for the former and, moreover, enabling us to make a direct comparison with the (In,Ga)As/GaAs quantum dot system.

HL 39.6 Thu 10:45 H34

Interpreting ensemble photoluminescence of InAs quantum dots coupled to a Fermi reservoir — •Alexander Rolf Korsch[1], Giang Nam Nguyen[1], Marcel Schmidt[1], Carsten Ebler[1], Sascha René Valentin[1], Pia Lochner[1,2], Charlotte Rothfuchs[1], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

Self-assembled InAs quantum dots in semiconductor heterostructures enabled the realization of new technologies such as quantum dot lasers or single photon sources. For many applications, temperature stability of the emission properties is desired and tunability of energy levels by an applied voltage is required [1].

We present anomalous behavior of temperature-dependent photoluminescence (PL) measurements on InAs quantum dot ensembles coupled to an electron reservoir. When negative gate voltages are applied to the sample, an anomalous initial increase of the integrated PL signal intensity with rising temperature is observed for the ground state and first excited state emission peaks. The anomalous temperature-dependence is caused by electrons tunneling from the electron reservoir to the quantum dots enhancing the PL signal. This effect can be accounted for by a modified Arrhenius model. PL measurements at 77 K are further compared to capacitance-voltage spectroscopy measurements on the same sample supporting the proposed interpretation.

[1] Ediger et al., Nature Physics 3, 774 (2007).

15 min. break

HL 39.7 Thu 11:15 H34

Interpreting ensemble photoluminescence of InAs quantum dots coupled to a Fermi reservoir — •Alexander Rolf Korsch[1], Giang Nam Nguyen[1], Marcel Schmidt[1], Carsten Ebler[1], Sascha René Valentin[1], Pia Lochner[1,2], Charlotte Rothfuchs[1], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

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[1] Ediger et al., Nature Physics 3, 774 (2007).

HL 39.8 Thu 11:30 H34

Ultrasensitive, high spectral resolution photocurrent detection of QDs excitons — •Sebastian Krehs, Alex Widhalm, Björn Jonas, Nand Lal Sharma, Dirk Reuter, and Artur Zrenner — Physics Department, University of Paderborn, Warburger Str. 100, Paderborn

In optical experiments on single quantum dots the exciton ground state transition appears as a two-level system with a lifetime limited linewidth of a few μeV. In contrast to resonance fluorescence, photocurrent (PC) spectroscopy is a quantitative method to read out the occupancy of the QD. In the past PC detection was limited to a regime with high tunneling rates and elevated excitation powers, which results in PC in the pA-range. Therefore the linewidth of QD excitons, as observed in the PC measurements suffered from lifetime and power broadening. Refined PC detection enabled us to improve its sensitivity down to the fA-range. This allows us to investigate the linewidth of QDs at exceptionally low tunneling rates and at very low excitation powers.

For this work we have fabricated Schottky photodiodes with embedded high quality MBE grown QDs. We have been able to demonstrate exciton ground state linewidths as low as 1.62 μeV in the low tunneling regime. Our results are close to the Fourier transform limit of InAs/GaAs QD systems, as shown by Kuhlmann et al. using resonance fluorescence [1].

[1] A.V. Kuhlmann et al. Nature Physics 9, 570-575 (2013).

HL 39.9 Thu 11:45 H34

Hot carrier cooling dynamics in PbS quantum dots - The influence of surface termination — •Emanuele Minutella[1,2], Nuri Yazdani[3], Vanessa Wood[3], and Holger Lange[1,2] — [1]Institute for Physical Chemistry, University of Hamburg — [2]The Hamburg Centre For Ultrafast Imaging, CUI — [3]Labratory for Nanoelectronics, Department of Information Technology and Electrical Engineering, ETH Zurich

Carrier multiplication (CM) in PbS quantum dots (QD) is an intriguing phenomenon with promises towards applications such as field-effect transistors, light-emitting diodes or solar cells due to their optical properties.(1) CM occurs in direct competition with carrier cooling via phonon emission or other relaxation channels.(2)In an experimental study, it was shown that halide-terminated PbS QDs feature an improved performance in solar energy conversion.(3) Our recent theoretical work showed that electron-phonon interactions are strongly suppressed in halide-terminated QDs due to reduction of the thermal displacement of the surface atoms.(4)

In our contribution we present an experimental study of the surface-termination impact. We observe the cooling of photo-induced hot carriers by femtosecond transient absorption spectroscopy in PbS QDs capped with different ligands. Our experimental results agree with the theoretical predictions and enable a tuning of the electron-phonon coupling in colloidal QDs.

(1) Adv. Mater. 2018, 30, 1800082 (2) ACS Nano 2017, 11, 6286-6294 (3) Nat. Mater. 2017, 16, 258-263 (4) Nano Lett. 2018, 18, 2233-2242

HL 39.10 Thu 12:00 H34

Capacitance-Voltage spectroscopy on Quantum Dots as sensor for trap charge density — •Giang Nam Nguyen[1], Alexander Rolf Korsch[1], Carsten Ebler[1], Marcel Schmidt[1], Pia Lochner[1,2], Fabian Brinks[1,2], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

Self assembled quantum dots (QDs) act as major candidates for many future quantum devices for which much higher material quality are needed. While disadvantages of non-radiative recombination centers are obvious for optoelectronic devices, fluctuating charges in the environment of QDs lead to spectral wandering or blinking, as the electric field varies randomly and changes the emitter's energy levels by quantum confined Stark effect [1].

A trap charge density sensor using capacitance-voltage (C-V) spectroscopy on QDs embedded in a diode structure is demonstrated. After optically exciting our device at different biases and wavelengths, we find a strongly electric field and photon energy dependent persistent shift of the QDs' charging resonances. We propose a Franz-Keldysh or k-space indirect type of excitation of trap states within the diode. To quantify the according charge trap density, we model the band bending by 1D band structure simulation. For low trap densities we find an excellent agreement with a simple linear dependence, making our device an efficient charge trap density monitor.

[1] J. Houel et al, Phys. Rev. Lett. 108, 107401 (2012)

HL 39.11 Thu 12:15 H34

Interpreting ensemble photoluminescence of InAs quantum dots coupled to a Fermi reservoir — •Alexander Rolf Korsch[1], Giang Nam Nguyen[1], Marcel Schmidt[1], Carsten Ebler[1], Sascha René Valentin[1], Pia Lochner[1,2], Charlotte Rothfuchs[1], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

Self-assembled InAs quantum dots in semiconductor heterostructures enabled the realization of new technologies such as quantum dot lasers or single photon sources. For many applications, temperature stability of the emission properties is desired and tunability of energy levels by an applied voltage is required [1].

We present anomalous behavior of temperature-dependent photoluminescence (PL) measurements on InAs quantum dot ensembles coupled to an electron reservoir. When negative gate voltages are applied to the sample, an anomalous initial increase of the integrated PL signal intensity with rising temperature is observed for the ground state and first excited state emission peaks. The anomalous temperature-dependence is caused by electrons tunneling from the electron reservoir to the quantum dots enhancing the PL signal. This effect can be accounted for by a modified Arrhenius model. PL measurements at 77 K are further compared to capacitance-voltage spectroscopy measurements on the same sample supporting the proposed interpretation.

[1] Ediger et al., Nature Physics 3, 774 (2007).

HL 39.12 Thu 12:30 H34

Interpreting ensemble photoluminescence of InAs quantum dots coupled to a Fermi reservoir — •Alexander Rolf Korsch[1], Giang Nam Nguyen[1], Marcel Schmidt[1], Carsten Ebler[1], Sascha René Valentin[1], Pia Lochner[1,2], Charlotte Rothfuchs[1], Andreas Dirk Wieck[1], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [2]Fakultät für Physik and CENIDE, Universität Duisburg-Essen, Germany

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[1] Ediger et al., Nature Physics 3, 774 (2007).

HL 40: Perovskite and Hybrid Photovolatics I (joint session HL/CPP)

Time: Thursday 9:30–13:00 Location: H36

HL 40.1 Thu 9:30 H36

Effects of Masking on Open-Circuit Voltage and Fill Factor in Solar Cells — •Kristofer Tvingstedt[1], David Kiermasch[1], Lidón Gil-Escrig[2], and Henk J. Bolink[2] — [1]Experimentelle Physik VI Julius Maximilians Universität Wûrzburg — [2]Instituto de Ciencia Molecular, Universidad de Valencia, C/Catedrático J. Beltrán 2, 46980 Paterna, Spain

Guidelines for the correct measurement protocol of novel photovoltaic technologies such as perovskites are now becoming more frequent in literature. This because, as will be confirmed in this talk, it is not straightforward to correctly measure the true efficiency parameters of these and many other novel solar cells. This is particularly the case for small area research devices which are prone to overestimate the short circuit current density, due to edge effects of various types. To reduce the inaccuracy of current density determination, the common recommended practice is to utilize masks with well-defined apertures, often smaller than the device active area. Herein we show both experimentally and theoretically that this common practice, however, leads to erroneous determination of both open-circuit voltage and fill factor, which are figures of merit of equal importance to the short-circuit current density. Although the errors induced in voltage and fill factor by using a mask are generally smaller than what the errors in current can amount to when not using a mask, they are on the other hand omnipresent and can be quite well described.

HL 40.2 Thu 9:45 H36

Enhanced stability and optical properties of perovskite nanocrystals encapsulated in block copolymer micelles — •Hyowon Jeong, Carola Lampe, Moritz Gramlich, and Alexander S. Urban — Nanospectroscopy Group, Department of Physics, Ludwig-Maximilians-Universität München (LMU), Amalienstraße 54, 80799, Munich, Germany

Recently, lead halide perovskites in the form of colloidal nanocrystals (NCs) have emerged as promising candidates for use in light-emitting and photovoltaic devices. High photoluminescence quantum yields as well as size- and consequently band gap- tuning are enabled by a facile synthesis and the natural defect tolerance of the material. However, to exploit these fascinating properties, long-term stability of the NCs under different conditions is necessary. Here, a novel synthesis is introduced, where methylammonium lead iodide (MAPbI3) NCs are grown inside of micelles formed by block copolymers, which protect the NCs from the environment and greatly enhance their lifetime. In addition, the optoelectronic properties of the encapsulated NCs will be discussed based on single NC spectroscopy results.

HL 40.3 Thu 10:00 H36

Energy transfer in films of thickness-tunable CsPbBr3 nanoplatelets — •Andreas Singldinger, Moritz Gramlich, Carola Lampe, and Alexander S. Urban — Nanospectroscopy Group, Department of Physics, Ludwig-Maximilians-Universität München (LMU), Amalienstrasse 54, 80799 Munich, Germany

In recent years, lead halide perovskites have rapidly attracted attention not only in their bulk but also in their nanocrystal form. Various synthetic routes yield highly luminescent nanocrystals of different shapes and sizes and consequently enable band gap tuning through quantum confinement effects. A novel synthesis now allows the growth of quantum-confined CsPbBr3 nanoplatelets (NPLs) with an adjustable thickness ranging from two to six unit cells. These NPLs show strong blue emission induced by a fast radiative decay of excitons. For ef-

ficient electroluminescence, however, insight into energy and charge transfer between these NPLs is crucial. Here, we look at two energy transfer processes in perovskite nanocrystal films. Firstly we study energy transfer between NPLs of different bandgaps, via time-resolved photoluminescence-spectroscopy. Secondly we investigate diffusion of photo-excited excitons in films comprising NPLs of a single thickness.

HL 40.4 Thu 10:15 H36

Ultrafast phonon dynamics in lead halide perovskite — •Hong-Guang Duan[1,2,3], Vandana Tiwari[1], Ajay Jha[1], Pabitra Nayak[4], Michael Thorwart[2,3], Henry Snaith[4], and R. J. Dwayne Miller[1,3,5] — [1]MPSD, Hamburg, Germany — [2]I. Institut für Theoretische Physik, UH, Germany — [3]CUI, Hamburg, Germany — [4]University of Oxford, UK — [5]University of Toronto, Canada

Hybrid organic-inorganic perovskites has gathered much attention owing to their unprecedented success in photovoltaics. To unravel the secrets to this success, we have studied the ultrafast dynamics of lead halide perovskites using heterodyne-detected transient grating and two-dimensional spectroscopy in thin films at room temperature. We distinctly observe the ground and excited state vibrational modes corresponding to organic and inorganic sub-lattices. The interplay of strongly coupled dominant vibrational modes to ultrafast carrier generation process will be discussed. Our experiments also unravel the role of organic cations in the ultrafast dynamics after photoexcitation.

HL 40.5 Thu 10:30 H36

Effect of the organic cation in halide perovskites on vibrations in the far-infrared region: a combined theoretical-experimental study — •Christian Gehrmann[1], Michael Sendner[2,3], Sebastian Beck[2,3,4], Robert Lovrincic[2,4], and David A. Egger[1] — [1]Institute of Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]InnovationLab, 69115 Heidelberg, Germany — [3]Kirchhoff Institute for Physics, Heidelberg University, 69120 Heidelberg, Germany — [4]Institute for High Frequency Technology, TU Braunschweig, 38106 Braunschweig, Germany

Halide perovskites (HaPs) are intriguing optoelectronic materials. In particular, hybrid organic-inorganic HaPs have attracted much interest as possible solar-cell materials. Since phonons might be the dominant source of scattering for charge carriers at room temperature, special efforts should be made to understand lattice dynamics in HaPs. While the internal vibrations of the organic cation are mainly in the mid-infrared region, we study the impact of the cation on vibrations in the far-infrared region by comparing the hybrid MAPbBr3 to the all-inorganic CsPbBr3. To this end, we present lattice dynamics calculations, based on density functional theory. The theoretical results are compared to experimental data obtained from far-infrared spectroscopy. Using reflectance measurements, we can even present experimental results related to the LO phonons which are not infrared active, but inherently contained in our calculations.

HL 40.6 Thu 10:45 H36

Density-functional-theory modeling of point defects in halide-perovskite alloys — •Li Jingrui and Patrick Rinke — Department of Applied Physics, Aalto University, Finland

Perovskite solar cells (PSCs) are a promising emergent technology, because their photo-conversion-efficiency has been increasing rapidly in recent years. In these cells, the photoabsorbing material is a hybrid (organic-inorganic) halide perovskites (ABX_3), that is usually grown with low-temperature solution-based synthesis. This synthesis method introduces many point defects, that may critically affect the electronic and structural properties of the PSCs. To gain microscopic insight, we used density-functional-theory to study a series of point defects of halide-perovskite alloys with ion-mixing at A (methylammonium, Cs and Rb), B (Pb and Sn) and X (I, Br and Cl) sites. The considered defects include A- and X-site vacancies and native interstitials in different charge states, as well as K and H impurities. For each model system, a $4 \times 4 \times 4$ perovskite supercell was relaxed using the PBEsol exchange-correlation functional. Then the electronic structure and defect formation energy were calculated using the hybrid HSE06 functional. Our results indicate that the defect formation energy sensitively depends on the phase and composition of halide perovskites. For halogen vacancies, the +1 state that has very small impact on the electronic structure is the most stable in a large Fermi-energy range. Only within the strongly n-type doped region, neutral or negatively-charged halogen vacancies will be formed, which introduce states in the band gap and significantly limit the PSC efficiency.

15 min. break

HL 40.7 Thu 11:15 H36

Calculating structural properties of halide perovskites: Influence of the computational approach — •Hubert Beck, Christian Gehrmann, and David A. Egger — Institute of Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany

Hybrid organic-inorganic halide perovskites (HaPs) have shown promising results in the development of new optoelectronic devices. Density functional theory (DFT) based first-principles calculations can address several of the open questions for these systems. For many of those calculations it is of vital importance to understand, which of the various microscopic effects in different DFT-related approximations play an important role. Here, we present an investigation of the importance of various theoretical aspects in the DFT calculations of the structural properties for the prototypical case of $MAPbI_3$. The main focus is on a comparison of calculations varying the DFT functional, the account of dispersion forces as well as the inclusion of spin-orbit coupling. The relative effect for the calculations of structural properties of $MAPbI_3$ is evaluated by comparing our computed unit-cell volumes and bulk moduli to results of experiments. Finally, we also present results on the impact of temperature-induced structural fluctuations on calculating the structural properties of $MAPbI_3$.

HL 40.8 Thu 11:30 H36

Identification of trap states by photo-induced transient spectroscopy in metal halide perovskites — •Mathias Fischer[1], Andreas Baumann[2], and Vladimir Dyakonov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Defects in perovskite solar cells ar often related to a reduced device performance. A common method for the characterization of defects in conventional semiconductors is the deep level transient spectroscopy (DLTS). This technique is based on a modulation of the depletion layer width by injecting charge carriers, mostly by applying voltage pulses. Due to electrical field screening in the device, redistribution of mobile ions and relatively low conductivity of organic transport layers, particularly when studying the device at low temperatures, charge carrier injection via voltage pulses is often difficult. This limitation can be mostly overcome by charge carrier injection charges via optical pulses, which enables us to record a rich trap spectrum over the broad temperature range down to 30 K. We apply this technique, which is also known as photo induced-transient spectroscopy (PITS), to perovskites of various compositions and compare the results with complementary techniques, such as thermal admittance spectroscopy and TSC. We show that multiple additional trap states can be observed when optical pulses instead of voltage pulses are used for injection of charges into the device.

HL 40.9 Thu 11:45 H36

Identifying recombination dynamics in efficient perovskite solar cells with transient optoelectrical techniques via active layer thickness alteration — •David Kiermasch[1], Lidón Gil-Escrig[2,3], Andreas Baumann[4], Henk J. Bolink[2], Kristofer Tvingstedt[1], and Vladimir Dyakonov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Instituto de Ciencia Molecular, Universidad de Valencia, 46980, Paterna, Spain — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, 12489 Berlin — [4]Bavarian Center for Applied Energy Research (ZAE Bayern) Bayern, 97074 Würzburg

Quantifying charge carrier recombination processes leading to energy losses in perovskite solar cells is of crucial importance for further improvements. Usually time-resolved photoluminescence (PL) is used to study charge carrier recombination, since electrical techniques are often limited by large capacitance values due to thin film layers and mostly short charge carrier lifetimes. By optimizing both the active layer thickness and the surrounding transport layers, we identified bulk dynamics using the combination of Transient Photovoltage (TPV) and Charge Extraction (CE) in $MAPbI_3$ solar cells with V_{oc}'s above 1.1 V and efficiencies up to 18 %. This allows us to assign loss processes to be mainly of Shockley-Read-Hall and free-carrier recombination type in line with PL studies on pure films. Our work also shows that increasing the perovskite thickness, advantageous to achieve high photocurrents, does not affect the recombination dynamics significantly confirming the high quality of the vacuum processed solar cells studied herein.

HL 40.10 Thu 12:00 H36

Describing the Optoelectronic Properties of Halide Perovskites with a Tight Binding Approach — •Maximilian J. Schilcher[1], Matthew Z. Mayers[2], Liang Z. Tan[3], David R. Reichman[2], and David A. Egger[1] — [1]Institute of Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Department of Chemistry, Columbia University, New York, NY 10027, USA — [3]Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

The intriguing optoelectronic properties of halide perovskites (HaPs) have invoked the development of new solar cells with enormous power conversion efficiencies. However, it is still not understood how these optoelectronic properties can emerge despite the remarkably soft lattice of HaPs. Theoretical calculations reveal important structure-function relations, yet are often limited by computational costs. We aim for developing theoretical tools that enable the simulation of HaPs with low computational costs, since for the calculation of realistic properties large super cells are often required. Their simulation via more conventional theoretical tools, such as density functional theory (DFT), can be challenging or even impossible. An efficient approach to model large-scale system sizes is the tight binding (TB) formalism. Here, we develop a TB parametrization for the HaP methylammonium lead bromide by projecting the Bloch wave functions on the basis functions corresponding to specific orbital sites of the atoms. This allows us to examine the impact of ionic composition and the effect of dynamical structural distortions on the optoelectronic properties of HaPs.

HL 40.11 Thu 12:15 H36

A completely solvent free route for hybrid perovskite film processing based on pressure treatment of perovskite powders - decoupling material synthesis and film formation — Nico Leupold[2], Maximilian Schulz[1], Konstantin Schötz[1], Ralf Moos[2], and •Fabian Panzer[1] — [1]Soft Matter Optoelectronics — [2]Department of Functional Materials, all University of Bayreuth, Bayreuth, 95440, Germany

Even though hybrid perovskites have undergone a remarkable development within the last years, state of the art processing approaches such as solution processing or evaporation suffer from an intrinsically high complexity, as the perovskite crystallization and its film processing happen simultaneously and are inextricably interconnected. Here we present an alternative, entirely dry processing approach, decoupling perovskite crystallization and film formation, by using readily prepared perovskite powders and produce films by appropriate mechanical pressure treatment. We show how a mechanochemical synthesis by ball milling allows to produce a wide range of phase pure and highly stable perovskite powders with a high flexibility in processing and we address the impact of milling parameters on the powder properties. Using these powders, we demonstrate how the used pressure and the powder microstructure, i.e. particle size and stoichiometry affect the mechanical stability, compactness and surface roughness of the pressed layers. We further address how specific temperature treatment during the pressing step can improve the properties of the pressed layer, and show their capability to be used in perovskite based optoelectronic devices.

HL 40.12 Thu 12:30 H36

Ultrafast two-dimensional electronic spectroscopy of CsPbBr3 perovskite crystals — •Xuan Trung Nguyen[1], Daniel Timmer[1], Yevgeny Rakita[2], David Cahen[2], Antonietta De Sio[1] und Chirstoph Lienau[1] — [1]Institut für Physik, Carl von Ossietzky Universität Oldenburg, Germany — [2]Weizmann Institute of Science, Israel

Halide perovskites are attractive as cost-effective materials for developing highly efficient solar cells. Many research discussed about generation of excitons and free charges in halide perovskites under optical excitation. However, the role of excitons and their interplay with free charges for the optoelectronic and transport properties is not yet clear. Here we use two-dimensional electronic spectroscopy (2DES), with 10-fs-time resolution, to study the initial dynamics of optical excitations in single crystals of CsPbBr3. Upon excitation, we observe bleaching of the exciton resonance as diagonal peak and a cross-peak suggesting their interaction with free charges. Interestingly, the exciton peak vanishes within only ~20 fs and an intense elongated cross-peak persists for several ps. These results suggest efficient screening of exciton by free charges and highlight the importance of many-body interactions in the ultrafast dynamics of halide perovskites crystals.

HL 40.13 Thu 12:45 H36

Exploring the stability of halide perovskite alloys by combining density-functional theory and machine learning — •Guo-Xu Zhang[1,2], Lauri Himanen[1], Jingrui Li[1], and Patrick Rinke[1] — [1]Department of Applied Physics, Aalto University, Finland — [2]School of Chemistry and Chemical Engineering, Harbin Institute of Technology, China

Halide perovskites (ABX_3) have attracted considerable attention in recent years due to their breakthrough performance as photovoltaic materials in perovskite solar cells (PSCs). We here consider the materials space of perovskites spanned by A = Cs and Rb, B = Sn and Pb, and X = Cl, Br, and I. Since this space is too large to peruse with density-functional theory (DFT) alone, we combine DFT with machine learning. We use the recently proposed many-body tensor representation (MBTR) [1] as structural descriptor. We then train a kernel ridge regression (KRR) model for fast energy prediction with DFT energies for 2×2×2 and 4×4×4 perovskite supercell models of varying composition. We analyse the effect of MBTR parameters on the KRR learning quality and then use KRR to explore the vast alloy space. We compute the convex-hull of several binary alloy series, for example $Cs_xRb_{1-x}PbI_3$, $CsPb_xSn_{1-x}I_3$, and $Cs_xRb_{1-x}Pb_ySn_{1-y}Cl_{z_1}Br_{z_2}I_{3-z_1-z_2}$. Our prediction accuracy for the cohesive energy of different alloys is as low as few meV/atom. This suggests that KRR in combination with the MBTR can be used to speed up the discovery of stable halide perovskite alloys.

[1] Huo and Rupp, arXiv 1704.06439.

HL 41: Heterostructures, interfaces, and surfaces

Time: Thursday 15:00–17:15 Location: H31

HL 41.1 Thu 15:00 H31

Electronic properties of hybrid organic/inorganic semiconductor pn-junctions — Moritz Futscher[1,3], •Thorsten Schultz[1], Johannes Frisch[2], Maryline Ralaiarisoa[1], Ezzeldin Metwalli[3], Marco Nardi[1], Peter Müller-Buschbaum[3], and Norbert Koch[1,2] — [1]Institut für Physik & IRIS Adlershof, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH-BESSY II, 12489 Berlin, Germany — [3]Physik-Department, Lehrstuhl für Funktionelle Materialien, Technische Universität München, 85748 Garching, Germany

Hybrid inorganic/organic semiconductor heterojunctions are candidates to expand the scope of purely organic or inorganic junctions. Comprehensive understanding of bulk and interface doping on the junction's electronic properties is therefore desirable. In this work, we elucidate the energy level alignment and its mechanisms at a prototypical hybrid pn-junction comprising ZnO (n-type) and p-doped α-NPD, using photoelectron spectroscopy. The level alignment can be quantitatively described by the interplay of contact-induced band and energy level bending in the inorganic and organic component away from the interface, and the formation of an interface dipole. By adjusting the dopant concentration in α-NPD, the position of the frontier energy levels of ZnO can be varied by over 0.5 eV and that of α-NPD by over 1 eV. The tunability of this pn-junction's energy levels evidences the substantial potential of the hybrid approach for enhancing device functionality.

HL 41.2 Thu 15:15 H31

Orientation of antiphase boundaries in GaP on Si(001) — •Pascal Farin, Mario Dähne, Holger Eisele, and Andrea Lenz — TU Berlin, Berlin, Deutschland

Monolithic integration of III-V semiconductors on Si would dramatically lower the cost of optoelectronic devices as well as improve their performance. Due to its small lattice mismatch with Si, GaP is par-

ticularly suited. However, locally charged defects called antiphase boundaries strongly deteriorate the optoelectronic device performance. While growth conditions that limit the antiphase-domain size and density have already been found, the exact crystalline orientation of the two-dimensional antiphase boundaries remains unclear. Their orientation is related to the net doping introduced into the crystal.

In this work, antiphase boundaries are investigated in detail by means of cross-sectional scanning tunneling microscopy (XSTM) on two perpendicular cleavage surfaces of the same sample. It is shown, how it is thereby possible to determine the exact orientation of the antiphase boundaries and their shares of the entire antiphase domain surface in order to finally estimate the net doping caused by the antiphase boundaries.

We thank Prof. K. Volz *et al.* for providing the sample and we acknowledge support by the DFG, project LE 3317/1-2.

HL 41.3 Thu 15:30 H31

Strain study of piezotronic ZnO microstructures utilising X-ray nanodiffraction techniques — Philipp Jordt[1], Stjepan Hrkac[2], Niklas Wolff[3], Mona Mintken[3], •Christina Krywka[4], Rainer Adelung[3], Lorenz Kienle[3], Olaf Magnussen[1], and Bridget Murphy[1] — [1]Institut für Experimentelle und Angewandte Physik, Kiel University, Germany — [2]UC San Diego, CA, USA — [3]Technische Fakultät, Kiel University, Germany — [4]Zentrum für Material- und Küstenforschung, Helmholtz-Zentrum Geesthacht, Germany

Combining piezoelectric/piezotronic and magnetostrictive materials is one promising approach to design bio magnetic field sensors to detect magnetic signals from the human body. To achieve the extreme sensitivity of less than 100 pT required for medical applications, is a challenge. Piezotronic readout is possibility to increase the limit of detection. For piezotronic, the strain induced piezoelectric potential causes additional charges at the metal-semiconductor interface resulting in a change of height and width of the Schottky barrier. The charge carrier transport across the metal-semiconductor contact is therefore dependent on the piezoelectric charges, which can be controlled by the applied strain or vice versa. For this experiment we used ZnO micro wires with diameters between one and 100 microns. During the experiment we collected the current voltage curves of the sample and simultaneous applied a mechanical stress while observing key Bragg reflections. This nanofocus diffraction experiment provided unique spatially resolved lattice deformation during piezotronic measurements.

HL 41.4 Thu 15:45 H31

Non-percolatve dilectric films based on conductor-insulator hybrid material systems — •Markus Wiesinger, Till Welzel, Aylin Gelle, and Martin Stutzmann — Walter Schottky Institut and Physics Departement, TUM, Am Coulombwall 4, 85748 Garching b. München, Germany

The application of new hybrid materials for e.g. small floating gate MOSFETs or high power devices is motivated by novel properties of hybrid dielectric layers such as enhanced and tunable dielectric constants, the capability to store and retain charge for long time or the ability to screen high electric fields. In this study, we explore approaches to produce a polyimide-nanoparticle-based hybrid thin film, which has a tunable dielectric constant. We put our focus on suppressing percolation effects in the films and enhance interface polarization at the internal boundaries. This is achieved by carefully choosing different materials and systematically changing the processing conditions. The dielectric and electrical properties of our films are investigated using impedance spectroscopy and DC-conductivity measurements. The results will be discussed in terms of the nanoparticles utilized, the processing conditions and the resulting structure of the material.

HL 41.5 Thu 16:00 H31

In-Situ Patterning of IBC SHJ Solar Cells with Efficiencies Exceeding 20 % — •Philipp Wagner[1,2], Dimitri Belostotski[1], Johann-Christoph Stang[1], Bernd Stannowski[3], Bert Stegemann[2], and Lars Korte[1] — [1]HZB, Institute Silicon Photovoltaics, Kekuléstraße 5, D-12489 Berlin — [2]HTW Berlin, Wilhelminenhofstraße 75a, D-12459 Berlin — [3]HZB, Institute PVcomB, Schwarzschildstraße 3, D-12489 Berlin

Silicon represents the predominant material for solar cell fabrication owing to its excellent electrical properties and abundance. Its predicted theoretical efficiency potential is 29.4 % [1]. Within Silicon-based technologies, the interdigitated back contacted silicon heterojunction (IBC SHJ) solar cell represents the recently most successful approach with an efficiency record of 26.7 %[2], almost entirely exploiting the abovementioned potential. However, hitherto established contact preparation of such solar cells by photolithography is elaborate, time-consuming, and cost-intensive, rendering their implementation in industrially fabrication challenging. Here, we report on our recent progress in developing an easy and potentially industrially viable fabrication process for IBC SHJ solar cells using in-situ shadow masks during PECVD, yielding efficiencies exceeding 20 %. Detailed device characterisation as well as strategies to further improve passivation quality and reduce resistive losses are presented to close the yet present performance gap between these devices and their photolithography-based counterpart.

[1] A. Richter et al. IEEE J. Photovoltaics 3(4), 1184-1191 (2013).
[2] M. A. Green et al. Prog. Photovolt. Res. Appl. 25, 668-676 (2017).

15 min. break

HL 41.6 Thu 16:30 H31

Cubic tin sulfide nanocrystals: growth mechanism unfolded by organic ligands adsorption — •Elad Segev[1,2], Ran Eitan Abutbul[1,2], Uri Argaman[1], Yuval Golan[1,2], and Guy Makov[1,2] — [1]Department of Materials Engineering, Ben-Gurion University of the Negev, Beer-Sheva 84105, Israe — [2]Ilse Katz institute for Nanoscale science and Technology, Ben-Gurion University of the Negev, Beer-Sheva 84105m Israel

Novel metastable cubic phase was recently discovered in tin monosulfide and monoselenide systems. Surface energy calculations and experimental studies indicate that this cubic phase is stabilized by specific ligands adsorption on the surface. The ab-initio computations with adsorbed ligands show lower surface energies for the cubic phase and for the orthorhombic phase than for the pristine surfaces. It is shown that Cl bonds are replacing the missing Sn-S bonds on the surface in the cubic structure. We observe that high ligand concentration reaching a full surface coverage enables the cubic nanoparticles to stabilize while for the same concentration the ORT nanoparticles collapse.

HL 41.7 Thu 16:45 H31

Optical *in situ* spectroscopy during MOCVD-preparation of $GaAs_{1-x}P_x$ surfaces — •Ammar Tummalieh, Agnieszka Paszuk, Oliver Supplie, Alexander Heinisch, Peter Kleinschmidt, and Thomas Hannappel — Institute for Physics, University of Technology, Ilmenau, Germany

Multi-junction solar cells comprising GaAsP top absorbers with Si bottom cells enable photovoltaic conversion efficiencies above 40%. However, monolithic epitaxial integration of GaAsP with As contents between 50%-75% on Si requires to overcome a significant lattice mismatch. Commonly, this is achieved with GaAsP graded buffers where the As/P ratio increases step-wise. Here, such $GaAs_{1-x}P_x$ buffers ($x \leq 0.5$) were grown on GaP(100) substrates by metalorganic chemical vapor deposition. The entire process was monitored *in situ* with reflection anisotropy spectroscopy (RAS), an optical surface sensitive technique, in order to yield a better understanding of the interface preparation. To further resolve the origin of the RA spectra and the atomic structure of the surfaces, selected samples were transferred to ultra-high vacuum surface-sensitive tools. The atomic structure depends on processing routes: While GaAsP surfaces annealed under H_2 at 500°C exhibit (2x4) surface reconstruction and are V-rich, annealing at 700°C leads to Ga-rich surfaces. We also find that the $GaAs_{1-x}P_x$ stoichiometry can be quantified empirically during growth via the stoichiometry-depending energy shift of the E_1 interband transition of GaAsP.

HL 41.8 Thu 17:00 H31

Single atomic layer removal via mechanochemical reactions — •Lei Chen[1], Seong H. Kim[2], and Linmao Qian[1] — [1]Southwest Jiaotong University, No. 111, Erhuan Road, Chengdu, Sichuan, China — [2]N349, MSC, Pollock Road, University Park, Pennsylvania, USA

Nanomanufacturing process with an ultra-high precision is of paramount importance for new development of nanoelectronics with unique functionalities. Here, we demonstrate a mask-less and chemical-free nanolithography process for regio-specific removal of atomic layers on 2D material and crystalline materials surfaces via shear-induced mechanochemical reactions. Since chemical reactions involve only the topmost atomic layer exposed at the interface, the removal of single atomic layer is possible and the crystalline lattice or structure beneath the processed area remains intact without subsurface structural dam-

ages. There are two mechanochemical wear processes depending on materials. For the materials which can react with the counterface, such as graphite or single crystalline silicon, the atom-by-atom removal process is that the first atomic layer is removed preferentially through the formation and dissociation of interfacial bridge bonds. Differently, for other material, like CaF2, the stress-enhanced chemical reaction with surrounding water results in the formation of softening layer on the outermost surface which can be preferentially removed under mechanical interaction. This study advances research toward nanofabrication with single atomic layer precision, opening new opportunities for advanced nanoelectronics with new functionalities.

HL 42: Quantum dots and wires: Preparation and characterization

Time: Thursday 15:00–17:15 Location: H34

HL 42.1 Thu 15:00 H34

Monolithic co-integration of III-V-based structures on silicon using multiple step relaxation technique — •Ramasubramanian Balasubramanian[1], Vitalii Sichkovskyi[1], Gadi Eisenstein[2], and Johann Peter Reithmaier[1] — [1]Institute of Nanostructure Technologies and Analytics (INA), Technische Physik, CINSaT, University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Andrew and Erna Viterbi Faculty of Electrical Engineering, Technion, Haifa 32000, Israel

Monolithic co-integration of group III-V materials on silicon (Si) aims at integrating advantages of both in a single chip. Si possesses excellent electronic, thermal and mechanical properties, whereas group III-V materials exhibit excellent photonic properties due to their direct band gap. Development of defects due to the difference in thermal expansion coefficient and lattice constants between III-V materials and Si could be overcome by the use of strain relaxation technique. Here we report on GaAs buffer layer followed by InGaAs/GaAs strained layer super lattices (SLS) directly grown on 5° off-cut Si wafers by MBE. The quality of grown structures is examined by transmission electron microscopy (TEM), atomic force microscopy and photo luminescence (PL). TEM studies have shown an efficient dislocation filtering by SLS layers. Optically active InGaAs quantum dots grown on top of such structures showed PL properties comparable to InGaAs quantum dots grown directly on GaAs substrates.

HL 42.2 Thu 15:15 H34

GaAs based quantum dot structures for VECSEL and MIXSEL applications — •Tanja Finke[1], Vitalii Sichkovskyi[1], Cesare Alfieri[2], Léonard Krüger[2], Jacob Nürnberg[2], Matthias Golling[2], Ursula Keller Keller[2], and Johann Peter Reithmaier[1] — [1]Institute of Nanostructure Technologies and Analytics (INA), Technische Physik, CINSaT, University of Kassel, Germany — [2]Institute for Quantum Electronics, Ultrafast Laser Physics Laboratory, ETH Zürich, Switzerland

By integration of a semiconductor saturable absorber mirror (SESAM) into a vertical external cavity surface emitting lasers (VECSEL), one can form a so-called mode-locked integrated external-cavity surface emitting laser (MIXSEL). With this approach, a very compact ultrashort high-power fs laser source for frequency comb generation can be realized. By using quantum dots (QDs) for the gain and absorber regions, the material properties can be tailored by geometrical parameters of the QDs. The QDs gain material was optimized by MBE towards high dot density and narrow photo luminescence (PL) emission. The influence of the growth parameters like growth temperature and In content on the optical and morphological properties of QDs was studied by PL and AFM, respectively. For SESAM structures QDs test samples with different designs were grown on DBR mirrors and characterized by reflectivity and pump-probe experiments. Fast recovery time of only 10 ps and good saturation parameters close to QW based SESAMs were achieved. Finally, all the sections, including high quality DBR mirrors were integrated into a single VECSEL structure.

HL 42.3 Thu 15:30 H34

Tuning the emission energy of self-assembled low density In(Ga)As quantum dots — •Timo Langer, Nandlal Sharma, and Dirk Reuter — Universität Paderborn, Department Physik, Warburger Str. 100, 33098 Paderborn

Self-assembled InAs and $In_xGa_{1-x}As$ quantum dots (QDs) were grown on GaAs(100) substrates by molecular beam epitaxy (MBE). The density can be controlled by modifying the growth conditions. Furthermore, the transition energies can be tuned by using the In-flush-technique or by ex-situ annealing.

Experiments using a gradient approach resulted in densities from 10^8 to $10^{10}\,cm^{-2}$. An alternative approach is the deposition of a subcritical amount of InAs with subsequent annealing. Using this approach, we were able to achieve a low density of $10^8\,cm^{-2}$ homogeneously over the whole wafer. The ground state transition energy at 4.2 K can be increased from 1.0 to 1.3 eV by using the In-flush-technique. Also, by growing $In_xGa_{1-x}As$ QDs we were able to increase the emission energy to 1.3 eV.

The QDs grown by different approaches have been investigated by photoluminescence spectroscopy and atomic force microscopy. The results are discussed in comparison.

HL 42.4 Thu 15:45 H34

Temperature controlled phase transition in single Ag2Se nanowires — •Maximilian Schwarz, August Dorn, and Alf Mews — Institute of Physical Chemistry, University of Hamburg, Germany

One-dimensional nanostructures grown via the solution-liquid-solid method (SLS) offer great application in electronic devices given the variety of materials and a well-established and low-cost synthetic route. Fine-tuning the characteristics of individual nanowires makes them suitable for numerous fields of interest. At this, silver selenide (Ag2Se) has gained the interest of many researchers for its temperature dependent change of conductivity, driven by a phase transition of the crystal lattice.

Here we show the fabrication of single nanowire transistor devices by growing cadmium selenide (CdSe) nanowires directly on substrates [1]. These act as a template to obtain silver selenide nanowires through a simple cation exchange reaction, leading to conductivities in the order of 10E5 S/m. The n-type character of the semiconductor is confirmed by field-effect transport measurements. Heating the device to 100 °C leads to a transformation of the crystal structure from monoclinic to body-centered cubic, resulting in a conductivity enhancement of 50 %. Adjusting the degree of cation exchange and the operating temperature allows for precise control of the electronic properties of single nanowire devices. Hereby, the system can be adapted to the desired application.

[1] A. Dorn et al., Advanced Materials, 2009, 21 (34), pp 3479-3482

15 min. break

HL 42.5 Thu 16:15 H34

Heterointegration of III-V materials on silicon substrates using quantum dot strain relaxation layers — •Cedric Corley, Vitalii Sichkovskyi, and Johann Peter Reithmaier — Institute of Nanostructure Technologies and Analytics (INA), Technische Physik, CINSaT, University of Kassel, Germany

The heterointegration of III-V materials and Silicon is of significant interest, e.g. for telecommunication technology, but faces challenges due to threading defect generation at the GaAs/Si interface. Photoluminsecent emission (PL) from optically active Quantum Dots (QDs) embedded in a GaAs buffer layer grown on a Silicon substrate by Molecular Beam Epitaxy (MBE) is deteriorated by these dislocations. Peach-Koehler forces exerted from highly strained QDs grown in between the interface and the optically active layers can redirect the dislocations and thus compensate their impact on the optical properties. In the past, defect filtering by structures encompassing multiple (five or more) highly strained QD layers seperated by GaAs spacer layers has been shown. This contribution compares defect filtering in structures grown by MBE incorporating a various number of InAs QD layers. An efficient defect filtering can already be achieved by as few as two layers. The material quality is monitored by the optical emission properties of an $In_{0.5}Ga_{0.5}As$ QD layer grown on top of the relaxation layer structure. The results are compared with a similar QD layer grown directly

on a GaAs substrate showing similar PL properties in intensity and linewidth.

HL 42.6 Thu 16:30 H34

Multi-probe electrical characterization of axial pn-junction in GaAs nanowires — •Andreas Nägelein, Juliane Koch, Cornelia Timm, Matthias Steidl, Peter Kleinschmidt, and Thomas Hannappel — Institute of Physics, TU Ilmenau, 98693 Ilmenau, Germany

Charge separating contacts in nanowires (NWs) are crucial for all future optoelectronic devices. To receive high efficiencies, suitable doping profiles as well as abrupt junctions are required. In this work, multi-probe electrical characterizations were conducted on GaAs-NWs with axial pn-junction. By the utilization of a multi-tip scanning tunneling microscope (MT-STM), which is equipped with a scanning electron microscope (SEM), four tips can be controlled via nanopositioners at the nanoscale. With this setup it is possible to perform four-point probe measurement on single freestanding NWs.

Besides the non-linear IV-characteristic, we detected a threshold voltage, which correlates to the forward bias of the GaAs-pn-junction. Local ideality factors of the diode can be extracted from the IV-curves, which enable a classification of the quality of the diode. By performing four-point probe measurements axial resistance profiles were recorded, which are proportional to the axial doping profile of single NWs. The doping concentration of the p- and n-doped region was determined, as well as the position and width of the charge separating contact. The latter was also made visible with electron beam induced current (EBIC) images.

HL 42.7 Thu 16:45 H34

Short wavelength InGaAs quantum dots grown via droplet epitaxy — •David Fricker[1,3], Paola Atkinson[4], Mihail Lepsa[2,3], Detlev Grützmacher[1,2,3], and Beata Kardynal[1,3] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany — [2]Peter Grünberg Institute (PGI-10), Forschungszentrum Jülich, Germany — [3]JARA - Fundamentals of Future Information Technology, RWTH Aachen University, Germany — [4]Institut des NanoSciences de Paris, CNRS UMR 7588, Sorbonne Université, France

Epitaxial In(Ga)As quantum dots in GaAs, typically grown by the Stranski-Krastanov growth mode, have been used in solid state quantum optics experiments for over a decade, as the basic building block of single and entangled photon sources and as hosts for spin qubits. Here we investigate an alternative method of growing these dots based on low temperature droplet epitaxy, which may allow a higher degree of control over dot density and dot wavelength as well as allowing dots without an underlying wetting layer to be grown. The grown quantum dots are characterized structurally, mainly using atomic force microscopy and optically, using low temperature microphotoluminescence. We show the effect of substrate temperature and deposition amount of Ga and In on the droplet size and dot emission wavelength. The impact of the capping layer growth parameters on the dot emission intensity and linewidth is presented as well. Finally, we discuss the influence of these parameters on the physical presence of the wetting layer and the corresponding intensity of photoluminescence.

HL 42.8 Thu 17:00 H34

Quantum dot-microlenses and -mesas for single-photon sources operating at telecom wavelength — •Nicole Srocka[1], Jan Grosse[1], Pawel Mrowinski[1,2], Anna Musial[2], David Quandt[1], André Strittmatter[1,3], Grzegorz Sek[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin, Germany — [2]Laboratory for Optical Spectroscopy of Nanostructures, Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland — [3]Present address: Institute of Experimental Physics, Otto von Guericke University Magdeburg, D-39106 Magdeburg, Germany

Advanced quantum communication applications require single photon sources featuring i) high photon-extraction efficiency, ii) high flux rate, iii) high suppression of multi-photon emission and iv) high degree of photon indistinguishability. The concept of monolithic microlenses and -mesas aligned to self-assembled semiconductor-quantum-dots has been proven to be an efficient approach to satisfy all of these four requirements in a single device operating at $900-950$ nm [1]. We report on applying this approach to In(Ga)As/GaAs quantum dots emitting in the telecom O-band. We will sketch a full circuit from theory based design optimization to fabrication utilizing in situ three-dimensional electron-beam lithography and results of a final spectroscopic evaluation [2].

[1] M. Gschrey, A.Thoma *et al*, Nat. Commun., 6, 7662 (2015). [2] N. Srocka, *et al*, AIP Adv., 8, 085205 (2018).

HL 43: Perovskite and Hybrid Photovolatics II (joint session HL/CPP)

Time: Thursday 15:00–17:30 Location: H36

HL 43.1 Thu 15:00 H36

Valence band structure of $CsPbBr_3$ inorganic perovskite — •Janek Rieger[1], Daniel Niesner[1], Andrii Kanak[2], Petro Fochuk[2], Ievgen Levchuk[3], Christoph Brabec[3], and Thomas Fauster[1] — [1]Lehrstuhl für Festkörperphysik, University of Erlangen-Nürnberg, Staudtstr. 7, D-91058 Erlangen, Germany — [2]Department of General Chemistry and Material Science, Yuriy Fedkovych Chernivtsi National University, Kotsjubynskyi St. 2, Chernivtsi, 58012, Ukraine — [3]I-MEET, Department of Materials Science and Engineering, University of Erlangen-Nürnberg, Martensstr. 7, D-91058 Erlangen, Germany

The impact of the organic ion on the electronic properties of lead halide perovskites is matter of an ongoing debate. With angle-resolved photoelectron spectroscopy we investigated the properties of the valence bands of different perovskite single crystals cleaved in ultra-high vacuum. The talk focusses on recent results from the inorganic perovskite $CsPbBr_3$. Measurements were carried out in the temperature range from 87 K to 350 K, covering all bulk phase transitions of the material. The width of the valence band and the dispersion of the valence band maximum are discussed. Results are compared to the valence band structure of the organic-inorganic perovskite $(HC(NH_2)_2)PbBr_3$ as well as to $(CH_3NH_3)PbBr_3$, which was already investigated in detail by our group [1].

[1] D. Niesner et al., Phys. Rev. Lett. **117**, 126401 (2016).

HL 43.2 Thu 15:15 H36

Charge Recombination Dynamics in Defect-Engineered Hybrid Organic-Inorganic Halide Perovskites — •Wen-Yu Cheng, Chang-Ming Jiang, and Ian Sharp — Walter Schottky Institut and Physik Department, Technische Universität München, 85748 Garching, Germany

Organic-inorganic halide perovskites, with their ease of fabrication and bandgap-tunability, provide promising prospects in photovoltaic and light-emitting diode applications. While such materials are highly tolerant of defects, the presence of ionic, along with electronic, charge conduction can result in dynamic optoelectronic properties. In this work, we aim at understanding the charge recombination pathways in defect-engineered perovskites. Point defects are intentionally and controllably introduced into the lattice of methylammonium lead iodide (MAPbI3), and a series of thin films with tunable bandgaps from 1.60 to 1.95 eV are fabricated. The concentrations and energetic positions of defects are quantified by photothermal deflection spectroscopy. The effects of these defects on photoluminescence yield are studied by steady-state and time-resolved fluorescence techniques. In addition to shedding light on the interactions between organics cations and the inorganic lattice, the results provide insights into the factors that underlie defect tolerance in hybrid halide perovskite semiconductors.

HL 43.3 Thu 15:30 H36

Reversible Bandgap Instabilities in Multiple-Cation Mixed-Halide Perovskite Solar Cells — •Fabian Ruf[1], Pascal Rietz[1], Meltem F. Aygüler[2], Pablo Docampo[3], Heinz Kalt[1], and Michael Hetterich[1,4] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Department of Chemistry and CeNS, University of Munich (LMU), 81377 München, Germany — [3]Physics Department, School of Electrical and Electronic Engineering, Newcastle University, Newcastle upon

Tyne, NE1 7RU, United Kingdom — [4]Light Technology Institute, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany

Multiple-cation mixed-halide perovskites have demonstrated their great potential as promising candidates for next-generation thin-film photovoltaics due to further improved power-conversion efficiency and stability. In this contribution, we investigate the stability of the compositional and resulting electronic structure of $Cs_{0.05}(FA_{0.83}\ MA_{0.17})_{0.95}Pb(I_{0.83}Br_{0.17})_3$ solar cell absorbers using electroreflectance (ER) spectroscopy as sensitive and non-invasive measurement technique. Despite the enhanced compositional stability, these compounds show a decrease of the bandgap up to 70 meV under AM1.5 illumination and applied voltage. We attribute this to segregation of the intermixed perovskite into iodide-rich and bromide-rich domains which is also confirmed by in-situ X-ray diffraction. A detailed study under operation-relevant conditions (illumination and bias) is conducted in various environments (different oxygen contents and relative humidity) to evaluate the consequences for photovoltaic applications.

HL 43.4 Thu 15:45 H36

Exciton Spin Dynamics and Their Dependence on Monovalent Cation Dipole Moment in Layered 2D Metal-Halide Perovskites — •Sean Bourelle, Ravichandran Shivanna, and Felix Deschler — University of Cambridge

Strong spin-orbit coupling in metal-halide perovskites connects optical transitions to spin states via the conservation of total angular momentum. These self-assembled quantum well structures of high-performance, defect tolerant semiconductors are broadly tunable through chemical composition. Here, we use ultrafast circularly-polarised broadband transient absorption spectroscopy to study the effect of perovskite composition on the polarisation and dynamics of exciton spin-states in two-dimensional (2D) Ruddlesden-Popper perovskites. We spectrally resolve the dynamic circular dichroism from a photoinduced polarisation in the secondary total angular momentum quantum number. This dichroism is used to determine the impact of the monovalent cation's dipole moment on the exciton spin-state depolarisation time.

HL 43.5 Thu 16:00 H36

Vacuum-deposited Bismuth and 2D perovskites as absorber material for solar cells — •Martin Kroll — TU Dresden, IAPP, Dresden Deutschland

Organic-inorganic halide perovskites are a fast developing absorber material class for thin-film solar cells. The state of the art material combinations with record efficiencies all contain methyl-ammonium (MA) and lead as cations, which both display unfavorable properties. Cells with methyl-ammonium as organic cation all show rapid degradation due to its instability under exposure to light and moisture. Lead is known for its toxicity, which is bound to cause problems during cell marketing and legislation. In order to circumvent these issues, current research discusses less toxic material combinations like MA/Cesium-Bismuth-Iodide as well as self-layering 2D perovskites for better stability, which are formed by introducing large organic cations like butyl-ammonium (BA). So far, these approaches have only been shown using solution processing. We show the prospects of multi-source vacuum evaporation, which excels at material purity and film control. For MA/Cs3Bi2I9 as well as BA/MAPbI3, we present XRD and absorption data for thin-films as well as functional solar cells with efficiencies of $> 1\%$ and $> 10\%$, respectively.

15 min. break

HL 43.6 Thu 16:30 H36

The missing long range order in point-dipole based hybrid perovskite models — •Menno Bokdam and Jonathan Lahnsteiner — University of Vienna, Faculty of Physics and Center for Computational Materials Sciences, Vienna, Austria

The crystal structure of hybrid perovskites forms an intricate electrostatic puzzle. Using density functional theory (DFT) calculations we study the ordering of A={MA, Cs} cations in the APbI$_3$ perovskite framework. We show that previously proposed model Hamiltonians do not capture the long range structural order observed in large scale *ab-intio* molecular dynamics calculations. We attempt to improve on these models by applying an Ewald summation to sum the dipole-dipole interaction and by introducing a distance dependent screening function, however with only limited success. We envision that well-trained force fields would be able, and are likely necessary, to fully describe the finite temperature behaviour of hybrid perovskites.

HL 43.7 Thu 16:45 H36

Recent progress in the vapour deposition of organic-inorganic hybrid metal-halide perovskite solar cells — •Juliane Borchert[1], Ievgen Levchuk[2], Lavina C. Snoek[1], Mathias Uller Rothmann[1], Henry J. Snaith[1], Laura M. Herz[1], Christoph J. Brabec[2], and Michael B. Johnston[1] — [1]Clarendon Laboratory, Department of Physics, University of Oxford — [2]Materials for Electronics and Energy Technology (i-MEET), FAU Erlangen-Nürnberg, Erlangen, Germany

Hybrid metal-halide perovskite semiconductors are promising absorber materials for single junction and as well as for tandem solar cells. They have attracted a lot of research attention in recent years, due to the rapid rise of solar cell efficiencies for these materials. Record efficiencies have now reached to above 23%. Co-evaporation of perovskite thin-films for solar cells offers many advantages such as precise thickness control, pinhole free planar films and compatibility with a large range of different substrates. Efficient co-evaporated solar cells have been demonstrated with different perovskite materials, for example methylammonium lead iodide ($MAPbI_3$) and formamidinium lead iodide ($FAPbI_3$). Furthermore co-evaporation is a promising technique for the upscaling of perovskite solar cells to commercial scales. Some challenges remain, including problems with the process control and relatively small crystallites in the deposited films. Additionally, it is more challenging to achieve mixed compositions with co-evaporation than with solution processing. Here we present recent progress made towards solving these challenges.

HL 43.8 Thu 17:00 H36

Growth Monitoring and Evolution of Optoelectronic Properties during the Formation of CH3NH3PbI3-xClx — •Klara Suchan[1], Justus Just[1], Eva L. Unger[1,2], José Marquez Prieto[2], and Thomas Unold[2] — [1]Lund University, Paradisgatan 2, 22350 Lund, Sweden. — [2]Helmholtz-Zentrum Berlin, Hahn-Meitner-Platz 1, 14109 Berlin, Germany

We present a detailed investigation of the formation mechanism and the evolution of optoelectronic properties during annealing of chlorine derived methylammonium lead iodide (MAPIC). MAPIC layers are prepared by a one-step solution based process. While solution based processes do not need cost intensive vacuum technology and no high-temperature annealing steps, little is known about the exact mechanisms during synthesis. This prohibits identification and exact control of all relevant variables, leading to widely reported poor reproducibility. Using in-situ optical reflection we are able to monitor the evolution of the MAPIC phase as a function of time and processing temperature. The extracted formation kinetics are fitted using an altered Johnson-Mehl-Avrami-Kolmogorov model and show that the presence of Chlorine induces a delayed formation of MAPIC. This is verified by X-ray diffraction and X-ray fluorescence measurements. From absolute photoluminescence measurements we determine the quasi-Fermi level splitting during film formation. Correlating structural and electronic properties, we will present a detailed view on the reaction route during synthesis and specifically the influence of annealing conditions on the process and its intermediate states

HL 43.9 Thu 17:15 H36

The versatility of polyelemental perovskite compositions — •Michael Saliba — University of Fribourg, Switerland

Perovskite solar cells (PSCs) have created much excitement in the past years and attract spotlight attention from research groups all over the world with many thousands of publications every year. This talk will provide an overview on the reasons for this unique success story highlighting the historic development as well as the specific material properties that make perovskites so attractive for the research community.

The current challenges are exemplified using a high-performance model systems for PSCs (multication Rb, Cs, methylammonium (MA), formamidinium (FA) perovskites).(1,2) The triple cation (Cs, MA, FA) achieves power conversion efficiencies (PCEs) close to 21% due to suppressed phase impurities. This results in more robust materials enabling breakthrough reproducibility. Through multication engineering, the seemingly too small Rb can be integrated (unsuited as a single-cation perovskite).(2) This results in a stabilized efficiency of 21.6%with one of the smallest differences between band gap and voltage ever measured for any PV material. Polymer-coated cells maintained 95% of their initial performance at elevated temperature for 500

hours under working conditions, a crucial step towards industrialisation of PSCs. The last part elaborates on a roadmap on how to extend the multicatio to multicomponent engineering providing a series of new compounds that are highly relevant candidates for the coming years.

HL 44: Annual General Meeting of the Semiconductor Physics Division

Time: Thursday 17:30–18:30 Location: H34

Duration 60 min.

HL 45: HL Posters III

Time: Thursday 18:30–21:00 Location: Poster E

HL 45.1 Thu 18:30 Poster E

Deep Level Transient Spectroscopy on Perovskite Solar Cells — •Florian Schwarz[1], Mathias Fischer[1], Andreas Baumann[2], and Vladimir Dyakonov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

In thin-film perovskite solar cells (PSC) charge carriers can be captured by trap states located in the active layer or at the interface towards the transport layers, which often results in a reduced performance of the device. Therefore different techniques were established for the characterization of charge carrier trapping. One popular method is the so-called '-deep level transient spectroscopy-' (DLTS), which allows to determine the emission rate, capture cross-section and activation energy of such deep states close to the middle of the band gap. We use DLTS to investigate the defect formation in PSC with respect to the incorporation of different additives, which may play a role of dopants, to the methylamonium lead iodide (MAPI) layer. The knowledge about the impact of such additives on the defect formation in the PSC is an essential step towards a controlled doping of the perovskite absorber itself.

HL 45.2 Thu 18:30 Poster E

Investigation of organic/inorganic lead tribromide perovskite single crystals — •Julian Höcker[1], Melina Armer[1], Volker Drach[1], Vladimir Dyakonov[1], and Andreas Baumann[2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Lead halide perovskites (HaPs) are a hot topic in the field of optoelectronic materials due to their unprecedented performance as solution-processed layer, e.g. in photovoltaics and light emitting diodes. Nevertheless, further optimization of HaP solar cell devices is needed, but this requires a deeper understanding of the physical phenomena especially charge carrier transport processes. Here we investigate the fundamental transport mechanism in 3D HaP crystals. The so-called inverse temperature crystallization (ITC) growth technique was used, which is based on the substantial decrease of perovskite solubility, in certain solvents, at elevated temperatures. We focused on three different types of HaP, i.e. organo lead tribromide perovskite single crystals methylammonium lead tribromide ($MAPbBr_3$) and formamidinium lead tribromide ($FAPbBr_3$) comparing to a completely inorganic perovskite crystal caesium lead tribromide ($CsPbBr_3$). The grown crystals are studied by means of powder X-ray diffraction, atomic force microscopy (AFM) and scanning electron microscopy (SEM). The optical properties of the different crystals are characterized by steady-state and transient photoluminescence (PL) and the charge carrier dynamics by Time-of-flight measurements.

HL 45.3 Thu 18:30 Poster E

Influence of excitonic effects on charge carrier extraction in organic-inorganic perovskite solar cells — •Philip Lange[1], Fabian Ruf[1], Ihteaz M. Hossain[2,3], Ulrich W. Paetzold[2,3], Moritz Schultes[4], Erik Ahlswede[4], Heinz Kalt[1], and Michael Hetterich[1,2] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Light Technology Institute, KIT, 76131 Karlsruhe, Germany — [3]Institute of Microstructure Technology, KIT, 76344 Eggenstein-Leopoldshafen, Germany — [4]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany

Organic-inorganic perovskites are among the most promising absorber materials for thin-film solar cells with reported conversion efficiencies above 23 %. However, it is still not sufficiently clear, to which degree the relatively strong excitonic effects in this material system hamper the separation of optically generated electron-hole pairs and the subsequent collection of the charge carriers. In order to elaborate this, semi-transparent solar cells employing $(MA)PbI_3$ and $Cs_{0.1}(MA_{0.17}FA_{0.83})_{0.9}Pb(I_{0.83}Br_{0.17})_3$ as absorbers are investigated utilizing a combination of absorption and photocurrent measurements as a function of temperature. First results will be discussed in this contribution.

HL 45.4 Thu 18:30 Poster E

Identifying recombination mechanisms in perovskite solar cells — •Seth Niklas Schumann, Fabian Meier, Clemens Göhler, and Carsten Deibel — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Organic-inorganic perovskite solar cells yield high power conversion efficiencies above 20 % at low manufacturing cost. The recombination of charge carriers influences the performance. We studied recombination in $(FAPbI_3)_x(MAPbBr_3)_{1-x}$, processed with a one step approach. To identify the dominant loss mechanism we measured the open circuit voltage and time-resolved photoluminescence as a function of the incident light intensity. We compare the resulting ideality factor and recombination lifetime of the samples with different $FAPbI_3$ to $MAPbBr_3$ ratios and discuss them with respect to the solar cell parameters.

HL 45.5 Thu 18:30 Poster E

Reversible changes of the bandgap energy in multiple-cation mixed-halide perovskite solar cells under illumination and bias investigated by optical spectroscopy — •Eva Wirth[1], Fabian Ruf[1], Meltem F. Aygüler[2], Jonas Hanisch[3], Pablo Docampo[4], Erik Ahlswede[3], Heinz Kalt[1] und Michael Hetterich[1,5] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]Dept. of Chemistry and CeNS, LMU Munich, München, Germany — [3]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Stuttgart, Germany — [4]Physics Dept., School of Electrical and Electronic Engineering, Newcastle University, Newcastle upon Tyne, United Kingdom — [5]Light Technology Institute, KIT, Karlsruhe, Germany

One advantage of perovskite solar cells, with power conversion efficiencies of more than 23 %, is the wide tunability of the bandgap (by intermixing of different ions) which enables the fabrication of tandem cells. However, the stability of mixed perovskites is still problematic. We investigate compositional instabilities and resulting shifts of the bandgap energy of these compounds non-destructively using electroreflectance spectroscopy whereby the relative change of the reflectivity $\Delta R/R$ is analyzed. Under illumination with a solar simulator while varying relative humidity and applied voltage, shifts of the bandgap are observed. The latter are caused by segregation effects in the Br*I system, which are partly reversible. We compare perovskite solar cells with different absorber materials in order to reveal the influence of different architectures.

HL 45.6 Thu 18:30 Poster E

Reversible changes of the bandgap energy in multiple-cation mixed-halide perovskite solar cells under illumination and bias investigated by optical spectroscopy — •Eva Wirth[1], Fabian Ruf[1], Meltem F. Aygüler[2], Jonas Hanisch[3], Pablo Docampo[4],

Erik Ahlswede[3], Heinz Kalt[1] und Michael Hetterich[1,5] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany — [2]Dept. of Chemistry and CeNS, LMU Munich, München, Germany — [3]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Stuttgart, Germany — [4]Physics Dept., School of Electrical and Electronic Engineering, Newcastle University, Newcastle upon Tyne, United Kingdom — [5]Light Technology Institute, KIT, Karlsruhe, Germany

Perovskite solar cells (PSC) provide a wide-range bandgap tunability (by intermixing of different ions) enabling the fabrication of tandem cells. But the stability of mixed PSC is still problematic. We investigate compositional instabilities and resulting shifts of the bandgap energy of these compounds non-destructively using electroreflectance spectroscopy. Thereby the relative change of the reflectance $\Delta R/R$ is analyzed. Under illumination as well as varying relative humidity and applied voltage, shifts of the bandgap are observed. The latter are caused by segregation effects in the Br–I system, which are partly reversible. We compare PSC with different absorber materials in order to reveal the influence of different architectures. To study the halide segregation in more detail, we apply TOF-SIMS measurements.

HL 45.7 Thu 18:30 Poster E

π-extended phosphoniumfluorenes: a new type of hole blocking layer in p-i-n perovskite solar cells — •Qingzhi An[1,2], Qing Sun[1,2], Andreas Weu[1,2], Sebastian Amdt[3], A.Stephen K Hashmi[3,4], and Yana Vaynzof[1,2] — [1]Kirchhoff-Institut für Physik, Heidelberg, Germany — [2]Centre for Advanced Materials,Heidelberg,Germany — [3]Organisch-Chemisches Institut,Heidelberg,Germany — [4]Chemistry Department,Jeddah,Saudi Arabia

Hole blocking layer (HBL) is applied to p-i-n perovskite solar cells for avoiding charges recombination by blocking the holes transfer to the anode, leading to achieve a higher fill factor (FF) and power conversion efficiency (PCE). In this work, 7 different π-extended phosphoniumfluorene molecules were synthesized and applied as HBL to p-i-n planar heterojunction perovskite solar cells. A combination of characterization techniques was utilized to investigate HBL molecular crystallization and charge recombination kinetics in the solar cells. Our study shows that the HBL can also modify the open circuit voltage (Voc). A better coverage and faster extraction HBL leads to an increase of Voc and PCE to 1.05V and 18%, respectively. Though the in-depth mechanism between Voc and HBL is unclear so far, this work provides new guidelines for designing efficient HBL materials and demonstrates that open circuit voltage can be further improved by HBL.

HL 45.8 Thu 18:30 Poster E

Impact of precursor stoichiometry on the energetic trap landscape in methylammonium lead iodide perovskite solar cells — •Philipp Rieder[1], Andreas Baumann[2], and Vladimir Dyakonov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Hybrid organic inorganic perovskite has turned out to be the most promising candidate for highly efficient next generation thin film photovoltaics, amongst others due to its solution processability. Interestingly, the use of slightly non-stoichiometric precursors, typically with a slight excess of lead halide salt, has proven to be essential to achieve the highest efficiencies reported so far. On the contrary, lead halide is known to be the most prominent by-product of film decomposition. In fact, any initial presence of excess lead halide has been linked to an accelerated degradation of the photoactive layer. Here, we study the impact non-stoichiometry of the perovskite layer on the trap landscape of perovskite solar cells in p-i-n layout by means of Thermally Stimulated Current (TSC). We incorporated an increasing amount of lead halide salt in the phenotype of perovskite solar cell absorbers, methylammonium lead iodide. We found that unreacted lead iodide leads to an increase in the density of energetically shallow trap states with an activation energy of around 100 meV. Moreover, we found that the commonly known low temperature phase transition between the orthorhombic and tetragonal crystal phase shifts to even lower temperatures when excess lead iodide is incorporated in the film.

HL 45.9 Thu 18:30 Poster E

Stable hybrid organic-inorganic halide perovskites for photovoltaics from ab-initio high-throughput calculations — •Sabine Körbel[1], Miguel A. L. Marques[2], and Silvana Botti[1] — [1]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Germany

Hybrid perovskites, such as methylammonium lead iodide, have revolutionized research on solar cells in the past years. Well known instability and toxicity issues restrain however the large-scale application of these perovskites in commercial photovoltaic technology. It is therefore crucial to find chemical substitutions which stabilize these and other lead-free perovskites, preserving at the same time their excellent absorption and charge-transport properties. Using density-functional theory, we screened the periodic table of the elements for perovskites with the composition $A^+B^{2+}X_3^-$, where A is a molecular organic cation, B is a divalent element, and X is a halogen. For the molecular cation, we vary the molecule size from sulfonium (H_3S, very small) to tert-butylammonium (C_4NH_{12}, very large). All thermodynamically stable hybrid perovskites were then further characterized by calculating their band gaps and effective masses, to identify the most promising candidates for further experimental and theoretical characterization. We find that the substitution of the organic molecule is the most promising way to enhance thermodynamic stability, while there is no optimal replacement for lead or Sn, unless one considers partial substitution or alloying.

HL 45.10 Thu 18:30 Poster E

Perovskite-on-Quantum Dot solar cells — •Miguel Albaladejo-Siguan[1,2], David Backer-Koch[1,2], and Yana Vaynzof[1,2] — [1]Kirchhoff-Institut für Physik, Heidelberg — [2]Centre for Advanced Materials, Heidelberg

Nanometer-sized quantum dots offer the possibility to build flexible, low-cost, thin film photovoltaic devices. In recent years, device engineering and optimized architectures have contributed to a fast rise in performance, reaching a record power conversion efficiency of 13.4 %. At the same time, pervoskite based solar cells are showing promising results in device performance with open circuit voltage values surpassing 1.2 V, which motivates the option of combining both materials in one solar cell. In this study we focus on the growth of perovskite crystals on the surface of colloidal lead sulfide quantum dots by performing a ligand exchange in a solution containing the perovskite precursor, followed by thin film deposition and annealing. A succesful incorporation of the perovskite shell could be measured as well as an improved passivation and higher interdot coupling, which translates into an enhanced open circuit voltage.

HL 45.11 Thu 18:30 Poster E

Raman spectroscopy of hybrid perovskites and perovskite-like structures — •Sebastian Lotter[1], Felix Kampmann[1,2], Daniel Niesner[1], Mykhailo Sytnyk[3], Ievgen Levchuk[3], Wolfgang Heiss[3], Christoph J. Brabec[3], and Janina Maultzsch[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin — [3]Department of Materials Science and Engineering, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

In recent years organic-inorganic hybrid perovskites have been subject to intense research efforts in physics and materials science, due to their promising efficiency in solar cell applications [1]. Providing an organic cation and an inorganic frame, these materials have a rich vibrational spectrum. Understanding the phonon modes of these hybrid crystals and their effect on the electronic properties is key to future design of perovskites materials for applications.

In this work we present Raman scattering and photoluminescence (PL) spectra of different organic-inorganic perovskites, such as MAPbBr3 and of perovskite-like ferroelectrics. The experiments are performed at different temperature regimes between 5K and 300K and at different excitation wavelengths. Furthermore, we compare Raman spectra and PL between bulk crystals and thin-film samples.

[1] Y. Hou et al., A generic interface to reduce the efficiency-stability-cost gap of perovskite solar cells, Science 358, 1192 (2017).

HL 45.12 Thu 18:30 Poster E

Investigating the damaging effect of GCIB etching during XPS/UPS depth profiling on perovskite considering temperature dependence — •Joshua Kress and Yana Vaynzof — Universität Heidelberg

In order to properly evaluate gas cluster ion beam (GCIB) etching studies it is important to understand the physical processes taking place in the layer. Our studies focus on the effect of argon cluster beams on various perovskite layers, especially taking into account sub-

strate temperature dependence, in order to identify the ideal cluster etching conditions. The composition and energetics of the layers can be measured in situ, directly after etching via x-ray (ultraviolet) photoelectron spectroscopy (XPS/UPS). Additional studies of morphology (SEM), optical properties (UV-VIS, PDS) or vibronic properties (FTIR) have been performed.

HL 45.13 Thu 18:30 Poster E

Surface potential distribution studies on Cu(In,Ga)Se_2 solar cell cross sections with Kelvin Probe Force Microscopy — •Jonas Schundelmeier[1], Jasmin Seeger[1], Wolfram Witte[2], Dimitrios Hariskos[2], Oliver Kiowski[2], Heinz Kalt[1], and Michael Hetterich[1,3] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany — [3]Light Technology Institute, KIT, 76131 Karlsruhe, Germany

The efficiency of Cu(In,Ga)Se_2 (CIGS) thin-film solar cells might be further improved by the use of alternatives compared to the CdS buffer layer as well as by changing the gallium concentration within the CIGS absorber. In order to investigate the influence of these modifications on the potential distribution through all the layers of the devices, Kelvin Probe Force Microscopy (KPFM) on CIGS cross sections is employed. Potential distributions for three different Ga concentrations of the absorber and for different solution-grown buffer layer materials (CdS, Zn(O,S) and In_xS_y) are compared, enabling conclusions about the influence of the mentioned parameters on the diffusion voltage and the Fermi energy within the absorber.

HL 45.14 Thu 18:30 Poster E

A mathematical model for an InGaAs/GaAs based waveguide solar cell showing 36% efficiency — •Bhaskar Singh[1] and Daniel Schaadt[2] — [1]Institute of Energy Research and Physical Technologies, TU Clausthal, Leibnizstr. 4, 38678 Clausthal-Zellerfeld — [2]Institute of Energy Research and Physical Technologies, TU Clausthal, Leibnizstr. 4, 38678 Clausthal-Zellerfeld

The use of a waveguide structure in solar cell device to achieve full trapping of photons is of interest in the field photovoltaics. We designed an In0.2Ga0.8As/GaAs based quantum well solar cell structure, where the In0.2Ga0.8As layer is behaving as a quantum well in the confinement direction while acting as a waveguide in planer direction of the device and calculated the photovoltaic characteristics. The results show that the short-circuit current density of our device increases by 19% leading to an enhancement in the conversion efficiency by 13% with respect to a GaAs p-i-n solar cell without inserted quantum well. For the proposed waveguide solar cell, a total efficiency of 36% under AM1.5G solar illumination is achieved.

HL 45.15 Thu 18:30 Poster E

Simulation of electroreflectance spectra of CIGS solar cells — •Ellen Förstner[1], Alice Magin[1], Fabian Ruf[1], Christian Huber[1], Wolfram Witte[2], Dimitrios Hariskos[2], Oliver Kiowski[2], Heinz Kalt[1], and Michael Hetterich[1,3] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany — [3]Light Technology Institute, KIT, 76131 Karlsruhe, Germany

Thin-film solar cells such as Cu(In,Ga)Se_2 (CIGS) offer an alternative to the widely spread silicon technology. Electroreflectance (ER) spectroscopy is a non-destructive tool enabling the investigation of their electronic properties. For instance, both the bandgap energy of absorber and buffer layer can be determined.

In this contribution, we present a numerical procedure developed to calculate ER spectra based on the model described in [1]. Electronic effects are modelled by SCAPS [2] and subsequently the modulated reflection signal is calculated using a transfer-matrix method. We further improve the simulation to achieve quantitative agreement with measured ER spectra and show applications of the procedure. Comparison of simulations with measured ER spectra allow for a conclusive interpretation of the experimental results.

[1] C. Huber *et al.*, Phys. Rev. B **92**, 075201 (2015).
[2] M. Burgelman *et al.*, Thin Solid Films **361-362**, 527-532 (2000).

HL 45.16 Thu 18:30 Poster E

Electroreflectance studies of CdS buffers in CIGS solar cells: Influence of Ga content and thermal annealing on the CdS bandgap — •Nico Weber[1], Jasmin Seeger[1], Jonas Grutke[1], Wolfram Witte[2], Dimitrios Hariskos[2], Oliver Kiowski[2], Heinz Kalt[1], and Michael Hetterich[1,3] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany — [3]Light Technology Institute, KIT, 76131 Karlsruhe, Germany

Cu(In,Ga)Se_2 (CIGS) has proven to be ideally suited as absorber material for high efficiency thin-film solar cells due to its excellent optical and electrical properties. In order to further improve the CIGS solar cells, a detailed understanding of the absorber–buffer interface is required. For this purpose, CIGS solar cells with the commonly used CdS buffer layer are investigated utilizing angle-resolved electroreflectance (ARER) spectroscopy. This new approach enables an accurate and destruction-free bandgap energy determination of the buffer layer despite the occurring interference effects caused by the layer stack. Therefore, ARER can provide information about possible interdiffusion processes between buffer and absorber layers. In this contribution, we employ ARER to study the impact of different gallium contents of the absorber on the bandgap energy of the buffer layer. In addition, the influence of thermal annealing on the bandgap energy of the buffer layer is investigated.

HL 45.17 Thu 18:30 Poster E

Efficiency of an absorber with hot carrier harvesting — •Magdulin Dwedari, Björn Sothmann, and Dietrich E. Wolf — University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

A hot carrier solar cell consists of an absorber and energy filters that facilitate the separation of electrons and holes before they relax to the edges of the conduction or valence band, respectively, after having been created by optical excitation with an energy much larger than the band gap. In this way the efficiency of a solar cell might be enhanced beyond the Shockley-Queisser limit. In this work we present an absorber-load system, where the absorber is modulated by the time evolution of non-equilibrium distribution functions in the valence and the conduction band due to photo excitations as well as electron-electron and electron-phonon interactions. The photo-excited hot carriers separate via energy filters and flow to a load that extracts a certain power P out of the system. A detailed examination of the efficiency with respect to the excitation strength and extracted power is presented.

HL 45.18 Thu 18:30 Poster E

Properties of In_2S_3:V-Based Intermediate Band Solar Cells — •Tanja Jawinski[1,2], Rainer Pickenhain[1], Leonard Wägele[2], Michael Lorenz[1], Roland Scheer[2], Marius Grundmann[1], and Holger von Wenckstern[1] — [1]Universität Leipzig, Halbleiterphysik, Germany — [2]Universität Halle, Photovoltaik, Germany

To overcome the Shockley Queisser limit of single junction solar cells an intermediate band (IB) can be introduced in wide band gap materials in order to reduce thermalization [1]. Absorption of photon energies smaller than the band gap can generate transitions from the valence band to the IB and from the IB to the conduction band. Theoretical calculations suggest that In_2S_3 hyper-doped with vanadium is a suitable candidate for realization of such an IB solar cell.

Intrinsic V-doped and undoped In_2S_3 layers are grown by physical co-evaporation of the elements. Heterostructure *pin* solar cells are formed using *n*-ZnO:Al and *p*-ZnCo2O4 grown by radio-frequency sputtering and pulsed laser deposition, respectively [2]. Furthermore, we grew In_2S_3 and In_2S_3:V epitaxially on p-Si wafers to improve structural properties of the samples. The samples are investigated using a combination of tuneable IR and VIS lasers allowing simultaneous excitation with multiple photons of well defined sub-band gap energies for photocurrent measurements. We compare undoped and V-doped samples with varying doping concentrations and find a small increase in sub-band gap photocurrent for samples with highest doping concentrations of 1.1 at%. [1] Luque and Martí, Phys. Rev. Let., 78(26),1997 [2] Jawinski et al., Phys. Stat. Sol. A, 215(11), 2018

HL 45.19 Thu 18:30 Poster E

Intermediate band solar cells - Two photon excitation of transition metal doped indium sulfide — •R. Hildebrandt[1], T. Jawinski[1], L. Wägele[2], H. von Wenckstern[1], R. Scheer[2], and M. Grundmann[1] — [1]Universität Leipzig, Felix Bloch Institute for Solid State Physics, Linnéstraße 5, 04103 Leipzig, Germany — [2]Martin-Luther-Universität Halle-Wittenberg, Institute of Physics, Von-Dankelmann-Platz 3, 06120 Halle, Germany

The Shockley-Queisser limit for solar cell efficiency of 33.7% is based on a trade-off between generated photocurrent and photovoltage [1]. Intermediate band (IB) solar cells are proposed to overcome this trade-off by an additional two step photon absorption via states within the band gap [2]. Those states may be realized by quantum dots, band anti-crossing in highly mismatched alloys or deep level impurities.

In this work we pursue a deep level impurity approach for IB solar cells. The heterostructure consists of p-$ZnCo_2O_4$/i-In_2S_3/n-ZnO:Al [3]. The transition metal (V, Nb or Ti) doped In_2S_3 absorber material is deposited by thermal co-evaporation. $ZnCo_2O_4$ is deposited by pulsed laser deposition and ZnO:Al by HF-sputtering.

The devices were characterized with photocurrent measurements and with a two photon excitation setup provided by two UV/VIS and IR supercontinuum laser sources. Thermal admittance spectroscopy measurements revealed a sulfur vacancy at 400 meV depth.

[1] W. Shockley, H. J. Queisser: J. Appl. Phys., 32(3):510-519, 1961.
[2] A. Luque, A. Martí: Phys. Rev. Lett., 78(26):5014-5017, 1997.
[3] T. Jawinski et al.: pss (a), 215(1700827):1-6, 2018.

HL 45.20 Thu 18:30 Poster E

Organic nano-triode arrays based on self-assembled porous Al and PMMA — •Erjuan Guo, Shen Xing, Felix Dollinger, Hans Kleemann, and Karl Leo — Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and Institute for Applied Physics, Technische Universität Dresden, 01062 Dresden, Germany

We utilize the colloidal lithography method for solution processable electronics and demonstrate massively parallel organization of connected three terminal vertical organic transistors. The vertical transistor devices consist of connected organic nano-triode arrays obtained using nanoporous aluminum and PMMA as templates with pore density of about 10^9 pores/cm^2. In this structure, a collector-emitter diode gives rise to a space charge limited current, which can be controlled by a third intermediate porous base electrode to give transistor like characteristics. The transistors achieve a high on/off ratio greater than 10^5 at low operation voltage of -1.5 V. The output current density is 115 mA/cm^2 with current gain greater than 1000, thereby facilitating the development of cost-efficient organic power devices. This study provides a potential foundation for achieving cost-efficient colloidal lithography in real production environment.

HL 45.21 Thu 18:30 Poster E

Monte-Carlo-Simulation organischer Halbleiter für verschiedene Phthalocyanine — •Inga Fischer[1], Sreetama Banerjee[1], Tobias Rüffer[2], Georgeta Salvan[1] und Angela Thränhardt[1] — [1]Institut für Physik, Technische Universität Chemnitz — [2]Institut für Chemie, Technische Universität Chemnitz

Organische Materialien wie Phthalocyanine stehen seit etlichen Jahren im Fokus der Entwicklung neuer Halbleiteranwendungen. Wir berichten über die Simulation des Stromflusses mittels Hüpfleitungsprozess durch makroskopische Proben aus verschiedenen Phthalocyaninen, die sich hinsichtlich des Zentralatoms sowie der Substitution von Wasserstoffatomen durch Halogene unterscheiden. Die Ladungsträgerlaufzeiten und die hieraus ermittelten Stromstärken werden in Abhängigkeit von Spannung, Temperatur, räumlicher und energetischer Unordnung sowie dem Einfluss der Kontaktierungen unter Berücksichtigung verschiedener Kristallstrukturen untersucht. Die Simulationsergebnisse für bis zu 5 Mio. Moleküle bzw. 300 Mio. Atome werden experimentellen Befunden gleichgroßer Proben gegenübergestellt.

HL 45.22 Thu 18:30 Poster E

Tunable Polymer Photodetectors: Towards Low Dark Current and High Detectivity — •Shen Xing, Erjuan Guo, Hans Kleemann, and Karl Leo — Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and Institute for Applied Physics, Technische Universität Dresden, 01062 Dresden, Germany

Photodetectors with a high detectivity as well as a high spectral selectivity are essential for high-resolution image sensor arrays. Here, we introduce a method for tuning the polymer photodetector (PPD) spectra without an optical filter. The devices have a simple planar junction architecture with the photoactive layer being a sequentially solution-processed film of PC71BM onto the pre-deposited bottom layer of doped P3HT. We demonstrate a redshift of response peak of around 100 nm in the red light range (645-745 nm) by tuning the PTB7 doping ratio in P3HT layer. In addition, for optimized doping ratio in P3HT, the external quantum efficiency of the response peak is doubled and the dark current density is simultaneously reduced by two orders of magnitude, leading to a maximum detectivity over 10^{12} Jones. This design concept allows for response tuning and is generic for other spectral windows.

HL 45.23 Thu 18:30 Poster E

Investigating Oxygen Degradation in PCE-11 Solar Cells — •Andreas Weu and Joshua Kress — Centre for Advanced Materials, Heidelberg

Recently, the efficiency of organic solar cells was improved to over 13%, bringing organic photovoltaics one step closer to serious commercialisation. However, the environmental stability of such devices, which is an essential step towards further development, remains rather insufficiently understood. Here, we address the effect of oxygen on the operation of the high-efficiency material system PCE-11:PC71BM. By using ultra-fast transient absorption (TA) and ultra-sensitive photo-thermal deflection (PDS) techniques in combination with field-effect transistors, we show that oxygen-induced doping of the active layer is mainly responsible for the observed device degradation. We find that exposure to light is accelerating this effect without causing photo-oxidation of the materials.

HL 45.24 Thu 18:30 Poster E

Investigation of New Organic Acceptor Materials for Bulk-Heterojunction Solar Cells — •Julian Butscher[1,2], Sebastian Hahn[3], Uwe Bunz[3], and Yana Vaynzof[1,2] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg, Heidelberg, Germany — [2]Center for Advanced Materials (CAM), Heidelberg, Germany — [3]Organisch-Chemisches Institut, Universität Heidelberg, Heidelberg, Germany

Promising cost reductions and advantages in fabrication, organic photovoltaics attracted much research effort over the last years. In this context, the choice of new non-fullerene acceptor materials for the active layer plays a key role in increasing efficiency and stability of bulk-heterojunction (BHJ) solar cells.

We investigate bent phenanthrene-analogous N-heteroacenes as non-fullerene acceptor materials in organic solar cells. By means of different spectroscopic and microscopic techniques, we examine their photovoltaic properties. First experiments show promising power conversion efficiencies. In order to improve the solar cells' performance, we study different preparation parameters as for example annealing time, acceptor-donor stochiometry and additive concentration.

HL 45.25 Thu 18:30 Poster E

Growth of Na-doped SnSe single crystals — •Ali Scherzad, Yannik Bartlock, Kristin Kliemt, Marius Peters, Sebastian Witt, and Cornelius Krellner — Physikalisches Institut, Goethe Universität Frankfurt, 60438 Frankfurt am Main, Germany

Single crystalline tin-selenid has proven to be an excellent thermoelectric material, since new studies have shown that the figure of merit of hole doped SnSe is above 1 [1]. The large figure of merit arises mainly from a huge increase of the power factor, e.g. an increase of the electrical resistivity and the thermopower. This work presents the single crystal growth of tin-selenid and various Na-doped tin-selenid compounds via vertical Bridgman method. The samples were analyzed with x-ray diffraction and probed by van de Pauw measurements to investigate the influence of the Na-doping on the density and the mobility of the charge carriers. Furthermore a new setup is developed for future thermopower measurements.

[1] L.-D. Zhao et al., Science **351**, 141 (2016)

HL 45.26 Thu 18:30 Poster E

Mesoporous silicon filled with functionalized molecules as novel thermoelectric hybrids — •Natalia Gostkowska, Klaus Habicht, and Tommy Hofmann — Helmholtz-Zentrum Berlin für Materialien und Energie Hahn-Meitner-Platz 1 14109 Berlin

This contribution presents objectives and first results of the DFG project 'Hybrid thermoelectric materials based on porous silicon: Linking macroscopic transport phenomena to microscopic structure and elementary excitations'. The approach to associate mesoporous semiconductors and functionalized molecules in novel thermoelectric materials is thoroughly motivated. We discuss in detail the synthesis of the mesoporous silicon by means of electrochemical etching in a newly designed etching cell. Nitrogen sorption isotherms and scanning electron microscopy studies reveal comprehensively the morphology of the synthesized porous membranes. To complete the thermoelectric characterization the Hall effect, Seebeck coefficient, thermal conductivity and electrical conductivity measurements are performed to elucidate

the interplay of morphology and thermoelectric transport. The presentation finally discusses the P3HT, PEDOT:PSS, polypyrrole and other functionalized molecules as potential candidates for the envisioned hybrids and provides an outlook on synthesis routes.

HL 45.27 Thu 18:30 Poster E

Influence of defect and impurities in tin telluride nanowires: a theoretical study — Tainá Matendal de Souza, Maicon Luan Stefan, Fellipe de Souza Reis, and •Ernesto Osvaldo Wrasse — Universidade Tecnológica Federal do Paraná, Toledo, Brazil

A crescent demand of energy, and the necessity of renawable sources of energy, has increased the interess of materials that present a high thermoelectric efficiency, defined by the figure of merit ZT. Tin telluride (SnTe) is one of the most promissing materials for apllications in thermoelectricity. Recent works suggest that SnTe nanowires have a greather thermoelectric efficiency when compared to the bulk, and n-type doping can improve significantly the value of ZT. In this contribution, quantum mechanical calculations in the framework of the Density Functional Theory (DFT)as implemented in the VASP code, were employed to describe SnTe nanowires. The influence of intrinsic defects (vacancies and antisites) and group III impurities (Al, Ga, In, and Tl) in the structural and electronic properties were analised. Similar as obtained in SnTe bulk phase, Sn vacancie has the lowest formation energy among all the defects in SnTe nanowires. Due defect levels, the system became a p-type semiconductor. For the impurities, Ga and Tl substitutional to Sn atoms have the lowest formation energy, and give rise to a n-type semiconductor character in the SnTe nanowires. As a resume, by combining quantum confinement and doping, our results show that SnTe nanowires are good candidates for applications in efficient thermoelectric devices.

HL 45.28 Thu 18:30 Poster E

Construction and Application of an Apparatus to Measure the Seebeck-Effect in Modulation Doped Semiconductors — •Timo Kruck, Arne Ludwig, and Andreas D. Wieck — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

Most processes (for instance information processing, power generation and power conversion) don't perform at maximum possible efficiency. The resulting waste heat can be converted into electric energy using thermoelectric generators even from a very small temperature gradient. This is called Seebeck-Effect. Today they only offer a small efficiency, that is represented by the "Figure of Merit", $ZT = S^2\sigma T/\kappa$, but offer a wide range of other benefits, like reliability and scalability. S is the Seebeck-coefficient, σ is the electrical conductivity and κ the thermal conductivity. For this work an apparatus to measure the Seebeck-Effect in semiconductors was constructed and with that the influence of a few parameters (for instance the type of doping, the charge-carrier mobility and density, and the specific heterostructure) on the Seebeck-Coefficient S will be analyzed. Experimentally we use a single thermocouple to locally heat the sample, measure the local temperature and the resulting thermovoltage in the sample.

HL 45.29 Thu 18:30 Poster E

Enhancing potassium-ion battery performance by defect and interlayer engineering — •Yuhan Wu[1], Yang Xu[1], Farzaneh Bahmani[2], Chenglin Zhang[1], and Yong Lei[1] — [1]Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau — [2]Department of Chemistry, Institute for Advanced Studies in Basic Sciences

Defect and interlayer engineering is applied to exploit the large van der Waals gaps of transition metal dichalcogenides for potassium ion batteries. As a demonstrator, MoS2 nanoflowers with expanded interlayer spacing and defects in the basal planes are used as KIB anodes in the voltage range of 0.5 to 2.5 V, where an intercalation reaction rather than a conversion reaction takes place to store K-ions in the van der Waals gaps. The nanoflowers show enhanced K-storage performance compared to the defect-free counterpart that has a pristine interlayer spacing. Kinetic analysis verifies that the K-ion diffusion coefficient and surface charge storage are both enhanced in the applied voltage range of the intercalation reaction. The collective effects of expanded interlayer spacing and additionally exposed edges induced by the in-plane defects enable facile K-ion intercalation, rapid K-ion transport and promoted surface K-ion adsorption simultaneously.

HL 45.30 Thu 18:30 Poster E

Photoinduced transient spin polarization in the semiconducting lead halide perovskite $(CH_3NH_3)PbI_3$ above the orthorhombic-tetragonal phase transition — •Oskar Schuster[1], Daniel Niesner[1], Thomas Fauster[1], Shreetu Shrestha[2], Ievgen Levchuk[2], Miroslaw Batentschuk[2], and Christoph Brabec[2] — [1]Lehrstuhl für Festkörperphysik, Univ. of Erlangen–Nürnberg, Staudtstr. 7, D-91058 Erlangen — [2]I-MEET, Univ. of Erlangen–Nürnberg, Martensstr. 7, D-91058 Erlangen

$(CH_3NH_3)PbI_3$ belongs to a class of semiconducting lead halide perovskites with singly degenerate valence and conduction band, playing an important role in current solar cell research. At 160 K the material undergoes a transition from a centrosymmetric orthorhombic phase to a tetragonal phase which is centrosymmetric on average, exhibiting local disorder. The concept of a "dynamical Rashba effect" induced by the local electric fields in the disordered structure has been proposed by theoretical models and by measurements of optically induced spin currents [1]. For the disordered, high–temperature phase a transient magneto–optical Kerr effect (MOKE) is induced by pumping the fundamental optical transition with circularly polarized light. A clear MOKE signal is absent in the ordered, low-temperature phase. This further supports the idea of a "dynamical Rashba effect". We discuss the picosecond spin dynamics and the possible spin scattering mechanisms in this new class of Rashba semiconductors.

[1] D. Niesner et al., Proc. Natl. Acad. Sci. **115**, 9505 (2018)

HL 45.31 Thu 18:30 Poster E

Optical amplification of spin noise spectroscopy via homodyne detection — •Pavel Sterin, Julia Wiegand, Jens Hübner, and Michael Oestreich — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany

Spin noise (SN) spectroscopy measurements on delicate semiconductor spin systems, like single InGaAs quantum dots, are currently limited by electrical noise of the detection system rather than by optical shot noise[1]. Here, we report a realization of homodyne SN spectroscopy enabling shot noise limited SN measurements. The proof-of-principle measurements on impurities in an isotopically enriched rubidium atom vapor show that homodyne SN spectroscopy can be utilized even in the low frequency spectrum which facilitates advanced semiconductor spin research like higher order SN measurements on spin qubits.

HL 45.32 Thu 18:30 Poster E

Electron spin polarization in singly charged (In,Ga)As/GaAs quantum dots: Spin inertia and extended pump-probe — •Eiko Evers[1], Vasilii V. Belykh[1,2], Alex Greilich[1], Dmitri R. Yakovlev[1,3], Dirk Reuter[4], Andreas D. Wieck[5], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, TU Dortmund University, 44221 Dortmund, Germany — [2]P.N. Lebedev Physical Institute of the Russian Academy of Sciences, 119991 Moscow, Russia — [3]Ioffe Institute, Russian Academy of Sciences, 194021 Saint Petersburg, Russia — [4]Optoelectronic Materials and Devices, Paderborn University, 33098 Paderborn, Germany — [5]Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum, Germany

The electron spin in n-type, singly charged (In,Ga)As/GaAs quantum dots offers μs long transversal and longitudinal relaxation times, a timescale too long for optical pump-probe measurements using a mechanical delay. We determine characteristic timescales of the longitudinal electron spin relaxation using the spin inertia [1],[2] and the extended pump-probe technique [3]. While the spin-inertia technique is based on the inability of the electron spin polarization to follow excitation with high frequency, the extended pump-probe technique adds an electronically controlled delay between pump and probe pulses. We compare the extracted time scales and show differences between the techniques.

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HL 45.33 Thu 18:30 Poster E

NV-centers, embedded in a diamond transistor structure — •Dennis Oing[1], Martin Geller[1], Stefan Borgsdorf[2], Ulrich Köhler[2], Nicolas Wöhrl[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany — [2]Institut für Experimentalphysik IV - AG Oberflächen, Ruhr-Universität Bochum, 44780 Bochum

Nitrogen-vacancy-centers (NV-centers) in diamond are promising candidates for applications in quantum information technology.
So far, mostly optical spectroscopy and read-out of NV-centers in di-

amond have been performed and three different charge states were observed. However, electrical control and read-out of the charge states has been proven to be difficult.
In this contribution, we present a transistor-like structure in diamond that allows us to electrically control the charge state of the NV-centers and which could have the potential for electrical read-out and manipulation.
The sample consists of bulk diamond with NV-centers, where a hydrogen termination on the surface induces a two-dimensional hole gas as a conductive surface layer. Reactive ion etching was used to define a mesa and two different ion implantation steps to form a graphite electrode 95 nm and the NV-centers 10 nm below the surface. After implantation the sample is coated with a thin aluminium oxide layer and annealed in high vacuum. We show device characterization like IV-characteristics, Raman spectroscopy and gate dependent photoluminescence.

HL 45.34 Thu 18:30 Poster E

Laser writing of scalable single spin in SiC — •Yu-Chen Chen[1], Patrick Salter[2], Matthias Niethammer[1], Matthias Widmann[1], Klorian Kaiser[1], Roland Nagy[1], Naoya Morioka[1], Charles Bbin[1], Patrick Berwian[3], Jürgen Erlekampf[2], Martin Booth[3], and Jörg Wrachtrup[1,4] — [1]3.Physikalisches Institut, Universitaet Stuttgart, Germany — [2]Department of Engineering Science, University of Oxford, Oxford, UK — [3]Fraunhofer IISB, D-91058 Erlangen, Germany — [4]Max-Planck Institute for Solid State Research, Stuttgart, Germany

Single photon emitters in silicon carbide (SiC) have attracted widespread attention as photonic systems, applied on quantum applications [1-2]. However, to achieve scalable devices it is essential to generate the single photon emitters at desired location on demand. Here we report the controlled creation of single silicon vacancy (V_{Si}) centres in 4H SiC using laser writing and without annealing. Due to the aberration correction in the writing apparatus and the non-annealing process, the generation of single V_{Si} centres with yield up to 30%, located within about 80 nm of the desired position in the transverse plane. We also investigated the mechanism of the laser writing V_{Si} centres and there are 15.5 photons involved in the laser writing V_{Si} centres process. The results demonstrate a new tool to fabricate single V_{Si} centres in SiC for quantum technologies and provide some insight into the laser writing defects in dielectric materials.

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HL 45.35 Thu 18:30 Poster E

Taking OLEDs for a Spin — •Nikolai Bunzmann[1], Sebastian Weissenseel[1], Jeannine Grüne[1], Christoph Boehme[2], Vladimir Dyakonov[1], and Andreas Sperlich[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg — [2]University of Utah, Salt Lake City, USA

Organic light emitting diodes (OLEDs) based on thermally activated delayed fluorescence (TADF) exhibit a high upconversion rate from non-emissive triplet to emissive singlet states due to a a small energy splitting ΔE_{ST} between the respective states. Electroluminescence and electrically detected magnetic resonance (ELDMR, EDMR) are suitable methods to investigate such devices as they connect spin-dependent processes with optical and electrical properties. Both techniques were previously used by us to reveal excitation pathways of intermediate excited states in donor:acceptor based TADF OLEDs. However continous wave (cw) experiments do not always allow to fully explain the origin of the observed magnetic resonance effects since different spin- and time-dependent processes may result in indistinguishable spectra. Therefore, we apply pulsed EDMR (pEDMR) to donor:acceptor based TADF OLEDs and by varying the parameters of these experiments such as pulse intensity and length we explore the genesis of TADF emission with respect to interspin coupling and spin relaxation time (T1).

HL 45.36 Thu 18:30 Poster E

Multifrequency Spin-Resonance Experiments on organic LEDs based on Triplet-Singlet Conversion — •Rebecca Bönnighausen, Sebastian Weissenseel, Sebastian Lulei, Vladimir Dyakonov, and Andreas Sperlich — Experimental Physics VI, Julius Maximilian University of Würzburg

In organic light emitting diodes (OLEDs), which are based on thermally activated delayed fluorescence (TADF), the small energy splitting ΔE_{ST} between singlet and triplet states is utilized to achieve an increased light output. The so called exciplexes (weakly bound e-h pairs) in the triplet state can upconvert from the triplet state to the singlet state via reverse intersystem crossing (RISC). This process can be investigated by spin sensitive techniques such as electroluminescence detected magnetic resonance (ELDMR). The triplet states split in an external magnetic field and transitions between those states can be induced by resonant microwaves, which results in a detectable change in the luminescence. We investigate the change to this ELDMR spectrum if an additional microwave frequency is applied to the sample. It saturates the spin transition, which is seen as a spectral hole burning. We discuss the mechanism responsible for such "hole burning" and its practical use to enhance the sensitivity of ELDMR due to the inhomogeneous linewidth to probe the interspin coupling in OLEDs for TADF and the involved mechanisms of RISC and interspin coupling.

HL 45.37 Thu 18:30 Poster E

Engineering and Resonant Excitation of Highly Coherent Spin Defects in Silicon Carbide — •C. Kasper[1], A. Sperlich[1], T. Ohshima[2], V. Soltamov[1], G. V. Astakhov[1,3], and V. Dyakonov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg — [2]National Institutes for Quantum and Radiological Science and Technology, Takasaki — [3]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf

Quantum centers in silicon carbide (SiC) have been demonstrated to be more than just the hampering defects for device performance. With their long spin coherence times [1] and the possibility of downscaling to single-photon source level [2], they have proven themselves to be promising candidates for a multitude of quantum information applications. By using the pulsed-ODMR technique we compare the two main spin-coherence parameters (T1 and T2) of silicon vacancies in SiC created with neutron, electron and proton irradiation in a broad range of silicon vacancy densities. Additionally we examine the influence of sample annealing and tuning of the laser excitation-wavelength on the ODMR contrast and the coherence properties in several potentially interesting SiC polytypes, 4H, 6H and 15R. Our results give an insight into the effects of irradiation method, sample annealing and excitation wavelength on the spin-coherence properties of silicon vacancies in SiC and hence allow their optimization for a concrete task.

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[2] F. Fuchs et al., Nature Commun. 6, 7578 (2015)

HL 45.38 Thu 18:30 Poster E

Sensing Weak Microwave Signals by Quantum Control — •Timo Joas, Andreas M. Waeber, Georg Braunbeck, and Friedemann Reinhard — Walter Schottky Institut und Physik-Department, Technische Universität München

Solid state qubits, such as the Nitrogen-Vacancy (NV) center in diamond, are attractive sensors for nanoscale magnetic and electric fields, owing to their atomically small size. A major key to their success have been dynamical decoupling protocols (DD), which enhance sensitivity to weak AC signals such as the field of nuclear spins from a single protein. However, those methods are currently limited to signal frequencies up to several MHz.

Here we harness a quantum-optical effect, the Mollow triplet splitting of a strongly driven two-level system, to overcome this limitation. We microscopically understand this effect as a pulsed DD protocol and find that it enables sensitive detection of fields close to the driven transition. To this end, we create a pair of photon-dressed qubit states which support a new transition with narrow linewidth. Generally, our scheme is applicable to any qubit but we consider sensitive detection of signals close to the NV's transition frequency (≈ 2 GHz). As a result, we demonstrate slow Rabi oscillations with a period up to $\Omega_{Rabi}^{-1} \sim T_2$ driven by a weak signal field. The corresponding sensitivity could enable various applications. Specifically, we consider single microwave photon detection, as well as fundamental research on spin-phonon coupling.

HL 45.39 Thu 18:30 Poster E

An Optical Interface to Spin Qubits in GaAs — •Zheng Zeng[1], Arne Ludwig[2], Eva Gross[1], Detlev Grützmacher[1], Hendrik Bluhm[3], and Beata Kardynał[1] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [3]JARA-Institute for Quantum Information, RWTH Aachen University, D-52074 Aachen, Germany

Connecting quantum information processors over long distances using

photons as qubits would enable more complex quantum computing architectures and quantum networks. Spin qubits in GaAs/AlGaAs gate-defined quantum dots (GDQDs) have been demonstrated to be promising scalable qubits. Since GaAs is a direct band gap material, a coherent transfer of information between a spin qubit and a photon qubit is in principle possible but cannot be achieved directly using GDQDs. Here we investigate a possibility of using InAs self-assembled quantum dots (SAQDs) to facilitate a coherent transfer of an energy encoded photon qubit into a spin qubit. We discuss the protocol of the spin qubit transfer between the two quantum dots of the device and show the results of fabrication and characterization of a hybrid device with a gate-defined double quantum dot (GDDD) tunnel coupled to a SAQD. We show an optical method that enables alignment of the two component quantum dots with an accuracy of 20 nm and analyze the proximity effect of the two components of the device on each other.

HL 45.40 Thu 18:30 Poster E

Defect-affected Current in Silicon Carbide: Towards Photoelectric Spin Readout — •M. Hollenbach[1,2,3], C. Kasper[3], A. Sperlich[3], M. Takahiro[4], T. Ohshima[4], V. Dyakonov[3], and G.V. Astakhov[1,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam and Materials Research, Dresden — [2]Technische Universität Dresden, Dresden — [3]Experimental Physics VI, Julius-Maximilians-Universität Würzburg, Würzburg — [4]National Institutes for Quantum and Radiological Science and Technology (QST, formerly Japan Atomic Energy Agency), Takasaki, Japan

Silicon carbide (SiC) is a technologically advanced wide bandgap semiconductor for high-power and high-temperature electronics and is envisioned to be a viable candidate for solid-state quantum information applications. At present, laser excitation as well as optical readout of the atomic-scale defects, localized within the bandgap, are typically based on confocal microscopy. In this study, we implemented a hybrid detection method, allowing the direct light induced photoelectric readout of the silicon defects (V_{Si}) in SiC. Here, we characterize particularly 4H-SiC diodes with varying spatial distribution introduced by electron irradiation with regard to their optical and electrical properties. By analyzing I-V-characteristics, photoluminescence spectra as well as optically and electrically detected magnetic resonance (ODMR, EDMR) of active V_{Si} centers, we identify an irradiation threshold to boost diodes with sufficient quantity of V_{Si} for nanotesla magnetic field sensing applications.

HL 45.41 Thu 18:30 Poster E

Electrical readout of NV$^-$ centres — •Manuel Schiefer, Julius Röwe, David Vogl, and Martin S. Brandt — Walter Schottky Institut and Physik-Department, Technische Universität München, Garching, Germany

Recently, the readout of the spin state of NV$^-$ centres in diamond has been demonstrated monitoring conductivity rather than luminescence. This approach carries the potential to significantly simplify the realisation of integrated devices for, e.g., quantum information processing or metrology. In this contribution, we study the elementary processes leading to the photoionisation of the NV$^-$ centre to further understand and improve the electrical spin readout.

HL 45.42 Thu 18:30 Poster E

Calculation of Emitter-Photon Waveguide Dynamics Using Binary Tensor Networks — •Oliver Kästle, Sandra Kuhn, and Marten Richter — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik von Halbleitern, Technische Universität Berlin, 10623 Berlin, Germany

We investigate the radiation dynamics of semiconductor quantum dots within a one-dimensional waveguide, where spontaneous radiative decay is caused by electron-photon interactions. Typically the coupling elements are approximated by a constant coupling rate to avoid the numerical demand for non-Markovian calculations. We utilize tensor networks to act as a data compression scheme for high dimensional tensors, yielding the possibility to calculate the dynamics of even large quantum many-body systems [1]. The proposed method allows for the use of millions of grid points for photonic wave numbers and their corresponding coupling elements, enabling investigations of non-Markovian dynamics of several quantum dots and multiple photons inside the waveguide. The density matrix elements are decomposed into matrix product states (MPS) using a bit decomposition scheme. System operators are constructed from binary logic gates, imposing the system dynamics on the bit-encoded MPS.

[1] S. Kuhn and M. Richter, arXiv:1807.09036v1 (2018).

HL 45.43 Thu 18:30 Poster E

Hybrid Assembly of Elements for Quantum Networks — •Andreas W. Schell — Quantum Optical Technology Group, CEITEC, Brno, Czech Republic

Bringing quantum technology from the laboratory to real world applications is a complex, but very rewarding, task. It will enable society to exploit the new opportunities the laws of quantum mechanics offer compared to purely classical physics. However, before the new quantum technology can be deployed, platforms to implement such a technology need to be discovered and developed. Here, we will show our ongoing efforts to implement such a platform using the so called hybrid approach for the assembly of quantum photonic elements. In the hybrid assembly approach, structures and emitters from different materials are combined in order to exploit the specific strength of the individual material while avoiding possible disadvantages by use of complementary other materials. This approach is highly flexible and can be adapted to many different material systems and structures. In particular, we will introduce techniques based on scanning probe microscopy and three-dimensional laser writing. Assembled systems include emitter coupled to on-chip resonators and waveguides, different kinds of fiber integrated cavities, and incorporate a variety of emitter such as NV centers, quantum dots, and defects in two-dimensional materials, such as hexagonal boron nitride. From these examples it can be seen that photonics elements assembled using hybrid techniques might help to facilitate the transition of quantum photonic networks out of lab to real-world applications.

HL 45.44 Thu 18:30 Poster E

Optical properties of implanted transition-metal impurities in SiC — •Zhen Shang[1,2], Yonder Berencén[1], Shengqiang Zhou[1], and Georgy Astakhov[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Technische Universität Dresden, Dresden, Germany

Atomic-scale defects in silicon carbide, such as silicon vacancy (Vsi), are attracting worldwide attention because of their potential application in quantum technology. These defects can be used as optically addressable single photon emitters at room temperature. They are also considered as stable solid-state spin qubits because its spin state can be easily manipulated. Generally, these defects can be divided into two categories, the intrinsic defects such as Vsi and the transition-metal impurities-related defects such as titanium or vanadium related defects. For the intrinsic defects, the optical and spin properties as well as the fabrication method have been well investigated. However, the investigation of the transition-metal impurities in silicon carbide still remains elusive. Here we introduce transition-metal impurities into SiC by ion implantation and subsequent annealing. We use irradiation fluence of vanadium and titanium up to 1e17 and thermal annealing up to 1700°C. We investigate the optical properties of the created defects, and compare the relative intensities of the zero-phonon lines to those in reference samples, where titanium- and vanadium-related defects are incorporated during growth. This work is the first step for the realization of single photon emission and spin manipulation from vanadium- and titanium-related defects in SiC.

HL 45.45 Thu 18:30 Poster E

Line shapes in Raman spectroscopy of amorphous semiconductors — •priyanka Yogi[1], priyanka yogi[1], and Rajesh Kumar[2] — [1]Institut für Festkörperphysik, ATMOS, Leibniz Universität Hannover Appelstr. 2, D-30167 Hannover, Germany — [2]Material Research Laboratory, Discipline of Physics & MEMS, Indian Institute of Technology Indore, Simrol-453552, India

The theoretical analysis of line shapes of Raman scattering data from amorphous semiconductors like silicon, germanium etc. turned out to contain important information about short range order correlations and size distributions of local nanocrystals formed. For that purpose, an existing modified phonon confinement model (MPCM) is used to analyze the Raman scattering data of amorphous semiconducting materials. A MPCM includes two main conventions namely phonon momentum conservation and shift in zone centre phonon frequency. These two factors were amalgamated to generate the theoretical Raman lineshape that was fitted to experimentally observed Raman spectra of amorphous materials. Experimentally observed Raman scattering data of amorphous materials which are prepared by different techniques are well fitted, and has been used to quantify the distance of short-range order. It can be established that the Raman line-shape obtained within the framework of MPCM is a close representative Raman line-shape of

amorphous semiconducting materials. The quantification of the degree of order may prove to be scientifically and technologically important to enhance the efficiency of solar cells of amorphous materials such as amorphous silicon solar cells etc.

HL 45.46 Thu 18:30 Poster E

Nonequilibrium Resonance in Quantum Dots without Electronic Wetting Layer States — •Ibrahim A. Engin, Ismail Bölükbasi, Sven Scholz, Andreas D. Wieck, and Arne Ludwig — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Self assambled InAs quantum dots (SAQD) proved promising semiconductor structures as single photon sources.

We investigate electronic resonances in illuminated InAs SAQDs by using C(V)-spectroscopy. With constant illumination of SAQDs metastable hole states can be created [1]. Furthermore, nonequilibrium states have been observed by increased illumination or tunnel barrier length [2].

SAQDs are grown inevitably with a wetting layer (WL), which interferes with the SAQD observation by affecting the photon emission spectrum of quantum dots. Here we modify the growth of SAQDs by adding a monolayer of AlAs on the quantum dots to suppress electronic WL-states [3] by more than 30dB and study non-equilibrium electron resonances.

[1] Labud, P. et al., "Direct Quantitative Electrical Measurement of Many-Body Interactions in Exciton Complexes in InAs Quantum Dots", Phys. Rev. Lett. 112 (2014), 046803

[2] Valentin, S. et al., "Illumination-induced nonequilibrium charge states in self-assembled quantum dots", Phys. Rev. B 97 (2018), 045416

[3] Löbl, M. et al., "Excitons in InGaAs Quantum Dots without Electron Wetting Layer States", eprint arXiv:1810.00891 (2018)

HL 45.47 Thu 18:30 Poster E

Pseudomorphic strain in corundum-phase Al-rich (Al,Ga)$_2$O$_3$ thin films grown on R-plane sapphire — •Marius Grundmann, Michael Lorenz, Stefan Hohenberger, and Eduard Rose — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstr. 5, 04103 Leipzig

We present the theory of pseudomorphic elastic continuum strain for heterostructures for rhombohedral/trigonal materials for arbitrary orientation of the epitaxial plane [1]. For $C_{14} = 0$ it degenerates to the theory for hexagonal (wurtzite) materials. We test the theory for atomically smooth, pseudomorphic α-$(Al_{1-x}Ga_x)_2O_3$ ($0 \leq x < 0.08$) thin films grown on R-plane sapphire (01.2) by pulsed laser deposition at growth temperatures up to 1,000°C. A careful analysis of lattice constants and tilt from 13 symmetric, skew-symmetric and asymmetric X-ray peaks agrees quite well with the strain theory [2]. The Ga-contents x and weak deviations from the expected ratio of rhombohedral/hexagonal c/a lattice constants are obtained from best fits of the spacing of the (02.4), (04.8), and (00.6), (00.12) film and substrate reflections, in reasonable agreement with chemical EDX analyses.

[1] M. Grundmann, J. Appl. Phys. 124(18), 185302:1-10 (2018).
[2] M. Lorenz, S. Hohenberger, E. Rose, M. Grundmann, Appl. Phys. Lett., accepted (2018).

HL 45.48 Thu 18:30 Poster E

Optical phonon modes and dielectric function of orthorhombic κ-Ga_2O_3 thin films — •Andreas Müller, Chris Sturm, Max Kneiss, Vitaly Zviagin, and Marius Grundmann — Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig, Linnéstraße 5, 04103 Leipzig

The large band gap energy of about 4.8 eV [1] makes Ga_2O_3 interesting as transparent conductive oxide. Of special interest is the orthorhombic κ-phase, due to its large predicted spontaneous electric polarization, which can be utilized for polarization doping to create high carrier densities at heterointerfaces [2]. However, the optical and phonon properties have not been explored in detail yet.

We determined the dielectric function of κ-Ga_2O_3 thin films, deposited by pulsed laser deposition on Al_2O_3, MgO and STO substrates [3], by means of spectroscopic ellipsometry from the infrared up to the ultraviolet spectral range (0.04 eV − 8.50 eV). By means of a parametric model dielectric function approximation, the nature and the properties of the electronic band-to-band transitions as well as of the phonon modes were examined. Complementary to the investigations done by spectroscopic ellipsometry, we investigated the phonon modes by Raman spectroscopy and 8 phonon modes were identified.

[1] Chris Sturm *et al.*, Phys. Rev. B **94**, 035148 (2016)
[2] Maria B. Maccioni *et al.*, Appl. Phys. Expr. **9**, 041102 (2016)
[3] Max Kneiß *et al.*, APL Materials, Accepted (2018)

HL 45.49 Thu 18:30 Poster E

Growth of MoO_3 Microfakes by Thermal Evaporation — •Sophie Müller, Daniel Splith, Holger von Wenckstern, and Marius Grundmann — Felix-Bloch-Institut, Universität Leipzig

The discovery of graphene as a 2-dimensional material had great impact on current research. Nevertheless, a 2-dimensional material with semiconducting properties, especially a band gap, would be desirable for the realization of 2-dimensional electronic devices. Molybdenum oxide is a semiconductive metal oxide with numerous interesting properties, like its wide band gap of more than 2.7 eV [1]. Balendhran *et al.* investigated 2-dimensional molybdenum oxide and reported a high room temperature electron mobility of 1160 $cm^2\ V^{-1}\ s^{-1}$ [2].
In order to realize electronic devices like field-effect transistors based on 2-dimensional MoO_3, a reproducible fabrication of thin molybdenum oxide nano- or microflakes is necessary. In this contribution, we investigated the growth of preferably thin molybdenum oxide microflakes via thermal evaporation. The influence of the major growth parameters temperature and argon gas flow were determined. Furthermore, the separation and thinning of the microflakes into nanoflakes was investigated. With this, nanoflakes with lateral dimensions of several 10 μm and thicknesses between 20 and 30 monolayers were realized.

[1] de Castro *et al.*, Advanced Materials, 29, 1701619 (2017)
[2] Balendhran *et al.*, Advanced Materials, 25.1, 109-114 (2013)

HL 45.50 Thu 18:30 Poster E

Structural, electrical and optical properties of $W_xMo_{1-x}O_3$ thin films fabricated by pulsed laser deposition — •Peter Schlupp, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Leipzig, Germany

To reduce the energy consumption of buildings, controlled reduction of the energy flow through the glazing is a promising option. Electrochromic coatings on the windows can be used to switch the light flow within minutes blocking light from outside (summer) or repelling light from inside the building (winter). Today, oxide based materials, especially tungsten oxide thin films, are often used [1]. Alloying WO_3 with MoO_3 can enhance the electrochromic properties [2]. Using pulsed laser deposition (PLD), it is possible to fabricate material libraries using a segmented target [3].

We present $W_xMo_{1-x}O_3$ thin films with a continuous composition spread grown by PLD. Crystalline structure investigated by X-ray diffraction, electrical properties determined by Hall-effect measurements and optical properties from transmission and reflection measurements in dependence on the cation ratio will be presented. The properties of an electrochromic cell, with $W_xMo_{1-x}O_3$ as cathodic and NiO as anodic material will be discussed.

References

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[3] von Wenckstern *et al.*, CrystEngComm **15**, 10020 (2013)

HL 45.51 Thu 18:30 Poster E

Tuning of material properties of ZnMgON by cationic substitution — •Antonia Welk[1], Anna Reinhardt[1], Holger von Wenckstern[1], Marius Grundmann[1], Thorsten Schultz[2], and Norbert Koch[2] — [1]Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany — [2]Institut für Physik, Humboldt-Universität zu Berlin, Brook-Taylor-Straße 6, 12489 Berlin, Germany

Amorphous zinc oxynitride (a-ZnON) with Hall mobilities up to 100 $cm^2V^{-1}s^{-1}$ [1][2] is a promising low-temperature deposition channel material for thin film transistors (TFTs). In order to fabricate transparent devices we suggested to add magnesium as an additional cation to a-ZnON to increase the mobility gap of 1.3 eV and to reduce the charge carrier concentration to 10^{17} cm^{-3} or below.
We deposited ZnMgON thin films by reactive magnetron co-sputtering. In general, an increased magnesium content leads to a profound decrease in charge carrier concentration, an absorption edge shift to higher energies and a decrease in Hall mobility. However, some films do not show a systematic decrease of the charge carrier concentration. XPS and temperature dependent Hall measurements were applied to correlate differences in chemical bonding configuration with different electrical transport properties.

[1] H. Kim *et al.*: *Sci. Rep.* **3**, 1459 (2013)
[2] A. Reinhardt *et al.*, Phys. Status Solidi A 213 (7), 1767 (2016)

HL 45.52 Thu 18:30 Poster E

Growth and functionalisation of ZnO nanowires for H_2S detection in the low ppb region for medical purpose — •Angelika Kaiser[1], Yujia Liu[1], Florian Huber[1], Klaus Thonke[1], and Ulrich Herr[2] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University — [2]Institue of Functional Nanosystems, Ulm University

Over the past few years, the medical role of hydrogen sulfide (H_2S) in the human body was extensively investigated. Revealing numerous medical applications, e.g. H_2S acting as a biomarker for asthma or as a moderator in the glucose metabolism, a reliable H_2S detection mechanism for target gas concentrations in the parts per billion range (ppb range) is needed. In our research we focus on resistive gas detection using nanostructured metal oxide grown by chemical-vapor-deposition (CVD). Different types of ZnO nanowires (ZnO NW) were grown either by the vapor-liquid-solid (VLS) method with gold catalyst on silicon, or by the vapor-solid (VS) method without catalyst on sapphire. To overcome the poor stability or selectivity of metal oxides towards gases, we investigate the impact of various post growth treatments on the H_2S detection by ZnO. Possible treatments are the annealing in O_2 rich and O_2 poor atmosphere, or ZnO NW surface functionalistation with gold (Au) and copper (Cu) nanoparticles. Because the planar sensor design used is effectively a ChemFET formed by the ZnO NWs with gas sensitive open gate, the suitability of these is tested by electrical measurements. Here, H_2S sensing is performed at room temperature and in synthetic air to mimic the characteristic of the human breath.

HL 45.53 Thu 18:30 Poster E

Structural and magnetic properties of MBE-grown NiO thin films studied by Raman spectroscopy — •Johannes Feldl, Melanie Budde, Carsten Tschammer, Oliver Bierwagen, and Manfred Ramsteiner — Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institute of the Forschungsverbund Berlin e. V., Hausvogteiplatz 5–7, 10117 Berlin, Germany

NiO is an antiferromagnetic oxide and a transparent p-type semiconductor making this material interesting for applications in the fields of spintronics and transparent electronics. The physical properties of NiO thin films often depend on the strain state and existence of grain boundaries. Using Raman spectroscopy, the structural and magnetic properties of NiO films grown on MgO(100) by plasma-assisted molecular beam epitaxy at different substrate temperatures were investigated. The structural properties of the NiO films are studied by the analysis of second-order phonon scattering. The respective frequencies reflect the strain state in the NiO films. In addition, the phonon confinement due to the formation of grains and the diffusion of Mg into the NiO films possibly affect the actual values of the phonon frequencies. The magnetic characteristics of the NiO films is investigated by temperature-dependent second-order Raman scattering originating from magnons. As a result, a clear dependence of the Néel temperature on the growth conditions is found. The analysis of our results allows for the identification of structural effects on the antiferromagnetic superexchange interaction in the NiO films.

HL 45.54 Thu 18:30 Poster E

Herstellung und Charakterisierung von LuftfeuchteMikrosensoren auf TiO_2-Basis — •Felix Gross, Beate Horn-Cosfeld und Thomas Heinzel — Lehrstuhl für Festkörperphysik, HHU Düsseldorf,

Es wurden Titandioxidstrukturen mit verschiedenen Herrstellungsverfahren auf ihre Funktion als Luftfeuchtesensor getestet. Das physikalische Grundprinzip der Luftfeuchtedetektion basiert auf der Änderung der Permittivität ϵ_r durch die Adsorption von H_2O auf der TiO_2 Oberfläche, sodass $\epsilon_r = \epsilon_r(c_{H_2O})$.

Der Imaginärteil der Impedanz weist eine qualitative Abhängigkeit von der relativen Luftfeuchte im Bereich 5-100% r.H. auf. Wir konnten durch die Änderung des Realteils der Impedanz zudem die Bildung der ersten chemisorbierten Monolage H_2O an TiO_2 nach dem Prinzip der Grothusskette identifizieren.

HL 45.55 Thu 18:30 Poster E

Structural, Optical and Electrical Properties of Si- and Zr-Doped κ-$(In_xGa_{1-x})_2O_3$ Thin Films — •Catharina Krömmelbein, Anna Hassa, Daniel Splith, Max Kneiss, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstraße 5, 04103 Leipzig, Germany

The orthorhombic polymorph of the wide band-gap semiconductor Ga_2O_3 has a predicted large spontaneous polarization of $23\,\mu C/cm^2$ [1]. At the interface of κ-Ga_2O_3-based, ternary heterostructures occurs a discontinuous change of the polarization leading to a charge accumulation that can potentially be exploited in high-electron mobility transistors. Therefore, it is crucial to determine deposition conditions allowing growth of ternary layers with tailored material properties.
In this study, we present κ-$(In_xGa_{1-x})_2O_3$ thin films prepared on c-sapphire substrates by pulsed laser deposition doped with Si or Zr to improve electrical conductivity. We added tin to induce the growth of the orthorhombic phase [2]. Resulting thin films were investigated by means of energy-dispersive X-ray spectroscopy, X-ray diffraction, atomic force microscopy, transmission, and Hall effect measurements. Further, Schottky barrier diodes were studied at room temperature by current-voltage measurements.
[1] M. Orita *et al.*, Thin Solid Films **411**, 134-139 (2002)
[2] M. Kracht *et al.*, Phys. Rev. Appl. **8**, 054002 (2017)

HL 45.56 Thu 18:30 Poster E

Finite element simulation and experimental characterization of field-effect transistors based on amorphous zinc tin oxide — •Michael Bar, Daniel Splith, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Leipzig, Germany

Within the quest for field-effect transistors (FETs) with high frequency switching capability various designs have been proposed, including vertical layouts [1,2]. Cost effective production of transparent, flexible FETs also requires a naturally abundant material such as zinc tin oxide (ZTO), a transparent amorphous oxide semiconductor which can be deposited at room temperature [3].
Simple lateral device designs, however, are not optimal for achieving high frequency switching for which vertical layouts are well suited due to the strongly reduced channel length, avoiding the need for submicrometer lithography.
In this contribution, a finite element approach was used to simulate lateral and vertical thin-film field-effect transistors in order to determine the influence of device geometry on static and dynamic properties such as transfer characteristics, cut-off frequency and on-resistance. The obtained data is then compared with experimental results obtained from transistors fabricated on sputtered ZTO thin films [4].
[1] A. N. Morgan *et al.*, Proc. IEEE, **59**(5), 805-807, (1971).
[2] B. J. Baliga, J. Appl. Phys., **53**(3), 1759-1764, (1982).
[3] H. Frenzel *et al.*, Phys. Status Solidi (a), **212**(7), 1482-1486, (2015).
[4] S. Vogt *et al.*, Appl. Phys. Lett., **113**(13), 133501, (2018).

HL 45.57 Thu 18:30 Poster E

Characterization of κ-$(Al,Ga)_2O_3$ Thin Films grown by VCCS PLD — •P. Storm, M. Kneiss, D. Splith, H. von Wenckstern, M. Lorenz, and M. Grundmann — Universität Leipzig, Felix-Bloch Institut für Festkörperphysik

Ga_2O_3 is a wide band gap semiconductor with $E_g = 4.4 - 5.3$ eV depending on the respective polymorph [1]. Compared to the monoclinic β-phase, the orthorhombic κ-phase exhibits promising features like ferroelectic properties with high spontaneous polarization, possibly leading to the formation of 2DEGs with high electron densities at heterointerfaces. Alloying with Al allows band gap engineering, which is substantial for optoelectronic devices utilizing heterostructures, such as quantum well infrared photodetectors or modulation doped FETs and has therefore been investigated in this study. To achieve this, VCCS-PLD, a novel PLD method allowing the realization of vertical continuous composition spread (VCCS), has been utilized [2]. It enables direct control of the particle flux composition in the PLD plasma and the corresponding thin film compositions using a single radially-segmented target. Employing this technique, we have grown $(Al,Ga)_2O_3$ thin films (on c-sapphire substrates and MgO(111) buffer layers) with varying flux of tin in the PLD plasma to determine the critical content of this catalyst for κ-phase growth. Using the same technique, we varied the Al-content to investigate the structural and morphological impacts of Al in κ-phase Ga_2O_3.
[1] D. Tahara *et al.* : Appl. Phys. Lett. 112, 152102 (2018)
[2] M. Kneiß *et al.* : ACS Comb. Sci. 20 (11), pp 643-652 (2018)

HL 45.58 Thu 18:30 Poster E

PLD-growth of epitaxial κ-$(In_x,Ga_{1-x})_2O_3$/κ-Ga_2O_3 heterostructures — •Max Kneiss, Anna Hassa, Daniel Splith, Holger von Wenckstern, Michael Lorenz, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Leipzig, Germany

Ga_2O_3 in the metastable κ-phase has recently gained remarkable interest. Like the monoclinic β-modification, it features a high E_g of ≈5 eV [1] and the possibility of alloying with Al_2O_3 or In_2O_3 for bandgap engineering. However, κ-Ga_2O_3 is additionally expected to possess a high spontaneous electric polarization along its c-direction [2]. Polarization differences at heterointerfaces can be utilized to achieve high electron densities in a 2DEG located at the interface. For high quality heterostructures, epitaxial growth of e.g. κ-$(In_x,Ga_{1-x})_2O_3$ on κ-Ga_2O_3 templates and vice versa is necessary. We demonstrate epitaxial growth of (001)-oriented κ-$(In_x,Ga_{1-x})_2O_3$ layers with various In-concentrations x on κ-Ga_2O_3 thin film templates fabricated by pulsed laser deposition (PLD) employing elliptically-segmented and Sn-doped $(In_x,Ga_{1-x})_2O_3$/Ga_2O_3 targets (VCCS-PLD [3]). Additionally, a κ-Ga_2O_3/κ-$(In_x,Ga_{1-x})_2O_3$/κ-Ga_2O_3 double heterostructure was investigated. Epitaxial growth on the κ-Ga_2O_3 template and its epitaxial relationship with various substrates were determined by XRD; AFM measurements reveal smooth surfaces.

[1] J. Furthmüller *et al.*, Phys. Rev. B **93**, 115204 (2016)
[2] M. B. Maccioni *et al.*, Appl. Phys. Expr. **9**, 041102 (2016)
[3] M. Kneiß *et al.*, ACS Comb. Sc. **20**, 643 (2018)

HL 45.59 Thu 18:30 Poster E

Gasadsorbtion of epitaxial thin β-Ga_2O_3 layers — •Martin Handwerg[1], Robin Ahrling[1], Rüdiger Mitdank[1], Günter Wagner[2], Zbigniew Galazka[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Leibniz Institute for Crystal Growth, 12489 Berlin, Germany

The transparent conductive oxide β-Ga_2O_3 is of huge interest for high power electronics and optoelectronics because of its high band gap ($E_G \approx 4.8eV$) and breakthrough voltage. Due to the surface electron accumulation layer β-Ga_2O_3 has possible gas sensing application as well. To date only gas sensing mechanics at high temperatures several hundred degree above room temperature could be found.
Here, we investigate the dependence of the conductivity from the atmospheric conditions at room temperature. We used thin homoepitaxially MOCVD grown films of β-Ga_2O_3 which are silicon doped. We show, that pressure and atmospheric composition have influence on the conductivity of very thin films with a thickness $t < 30$ nm. Vander-Pauw and Hall-measurements in relation to nitrogen and oxygen content and pressure of the atmosphere were used. Additionally, the time dependence and the recovery rate of the conductivity change is investigated and discussed.

HL 45.60 Thu 18:30 Poster E

Optimizing the sputter deposition process of amorphous zinc oxynitride thin films — Anna Reinhardt[1], •Antonia Welk[1], Holger von Wenckstern[1], Marius Grundmann[1], Thorsten Schultz[2], and Norbert Koch[2] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Semiconductor Physics Group — [2]Humboldt-Universität zu Berlin, Institut für Physik

Amorphous zinc oxynitride (a-ZnON) was demonstrated to be a promising high-mobility semiconductor for low-temperature fabricated, high-performance thin-film transistors, whereby reactive sputtering with two reactive gases (O_2 and N_2) either in RF or DC mode is the method of choice for thin film deposition [1–3]. However, the reported electron mobility values for a-ZnON span a wide range of $20-120\ cm^2V^{-1}s^{-1}$. Due to the complexity of the reactive sputtering process a profound knowledge of the relations between sputter parameters and film properties is nescessary to optimize the latter. We investigated in detail the influence of the sputtering mode and parameters on the electrical properties of a-ZnON thin films. We found that the achievable electron mobility is directly linked to the discharge voltage which can be tuned by applying an additional negative substrate bias. Furthermore, the effect of N_2-plasma-assistence during sputtering process was analyzed regarding the chemical bonding states by means of depth-profiling XPS measurements.

[1] Y. Ye *et al.*, J. Appl. Phys. 106, 074512 (2009)
[2] H.-S. Kim *et al.*, Sci. rep. 3, 1459 (2013)
[3] A. Reinhardt *et al.*, Phys. Status Solidi A 213 (7), 1767 (2016)

HL 45.61 Thu 18:30 Poster E

X-ray Photoelectron Spectroscopy of Gallium-Sesquioxide — •Sebastian L. Benz[1], Martin Becker[1], Philipp Schurig[1], Max Kracht[1], Fabian Michel[1], Alexander Karg[2], Martin Eickhoff[2], and Angelika Polity[1] — [1]Institute for Exp. Physics I and Center for Materials Research (LaMa), Justus Liebig University Giessen, Germany — [2]Institute of Solid State Physics - Semiconductor Epitaxy - University of Bremen, Germany

X-ray Photoelectron Spectroscopy is used to characterize Ga_2O_3 thin films (β- and ϵ-phase) grown by different synthesis methods. Particularly, the provided thin films were prepared by plasma-assisted molecular beam epitaxy, an adapted pulsed sputtering method and ion-beam sputter deposition. All thin films share a gallium excess independent of the specific growth method. However, for a stoichiometric template, grown by edge-defined film-fed growth, it is found that the characterization with X-ray Photoelectron Spectroscopy leads to an overestimation of the Ga concentration of about 6 at%. It is believed that this result can be explained by the effect of preferential sputtering. A correction factor is determined to adjust the data of Ga_2O_3 thin films. As a consequence, all mentioned growth methods are capable to produce stoichiometric Ga_2O_3.

HL 45.62 Thu 18:30 Poster E

Modifying GaAs-Heterostructures with laser-annealing — •Hans-Georg Babin, Julian Ritzmann, Marcel Schmidt, Arne Ludwig, and Andreas D. Wieck — Ruhr-Universität Bochum, D-44780 Bochum, Germany

Ex-situ modification of semiconductors is crucial for sample preparation and further experiments. For example the fabrication of ohmic contacts to the relevant structure can be decisive for the success of the conducted transport experiment.

Our goal is to use laser radiation to locally thermal anneal our samples. Due to the high power density and low spot size, it is possible to confine the thermal effects to a small area. Another benefit is the fast heating and cooling ramp when processing the sample, especially when compared to other methods like Rapid-Thermal-Annealing (RTA).

The main focus is to provide low resistance ohmic contacts to two-dimensional-electron gases (2DEG). This can be achieved by combining laser-annealing with focused-ion-beam (FIB) implantation. It is possible to produce stronger and more homogenous doping profiles compared to thermally diffused alloy contacts. Another benefit is a much lower use of thermal budget, which can be achieved by only locally heating the samples for a shorter time. This minimizes unwanted diffusion processes in the functional semiconductor structure.

HL 45.63 Thu 18:30 Poster E

Optimization of the Contact Resistance for Conductance Spectroscopy — •Mario Werner Farny, Carsten Ebler, Andreas Dirk Wieck, and Arne Ludwig — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

The development of time resolved conductance spectroscopy enhanced the possibilities to investigate two-dimensional electron gases (2DEG) coupled to Quantum Dots [1]. It allows time resolved observation of Quantum Dot charging dynamics. For this, modulation doped field effect transistor structures are made and measured at cryogenic temperatures. The success of the measurements depends on the highest possible response current of the 2DEG and a good signal to noise ratio. To ensure this, the source and drain contact resistance should be low.

We present results of the influence of various device processing steps. In particular, the influence of wet-chemical etching to reduce the distance to the 2DEG, as well as the necessity of wet-chemical surface passivation will be presented.

[1] Marquardt B. et al. Using a two-dimensional electron gas to study nonequilibrium tunnelling dynamics and charge storage in self-assembled quantum dots. Appl. Phys. Lett. 95, 022113 (2009).

HL 45.64 Thu 18:30 Poster E

Investigation of the effect of FIB processing on the surface recombination velocity of semiconductor TEM lamellas — •Christopher Wendeln, Arne Ahrens, and Michael Seibt — IV. Physical Institute of Georg-August University, Göttingen, Germany

'Dead layers' are electrically damaged regions occurring at the surfaces of processed samples and are considered as recombination centers for electrons and holes. The effect of a dead layer on the properties of a material increases with decreasing size since surface-near regions make up a significant proportion of the sample. Thus, electrical measure-

ments on the nanoscale are affected due to the position of the dead layers at the surfaces. Examples are electron beam induced current (EBIC) measurements [1] and electron holography [2] in transmission electron microscopes (TEM). The preparation of TEM lamellas with a focused ion beam (FIB) can cause dead layers to emerge and to disturb the EBIC measurements on that system. Unfortunately, the influence of sample preparation on the formation and thickness of dead layers is not well understood. In this work EBIC investigations of differently FIB-prepared cross sections of an Au/n-Si Schottky contact were conducted to provide insights about the existence and formation of dead layers.

[1] P. Peretzki et al. *Phys. Status Solidi RRL* **2017**, *11(1)*, 1600358.
[2] M. Gribelyuk et al. *Phys. Rev. Lett.* **2002**, *89(2)*, 025502.

HL 45.65 Thu 18:30 Poster E

Contactless Measurement of the Sheet Resistance of two-dimensional Electron Gases — •Timo A. Kurschat and Andreas D. Wieck — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

The aim of this work is to measure the sheet resistance of two-dimensional electron gases in GaAs without the need for built-in contacts. Such a method could be used to measure whole wafers in order to evaluate quality and homogeneity of the samples before further processing.

Therefore two electrodes (small metal plates) are placed close to the wafer so that they form capacitances C with the conducting layer. If an alternating voltage is applied, the transmitted signal can be measured, from which the sheet resistance can be calculated. The reactance of the capacitance is proportional to $\frac{1}{\omega C}$. To minimize the influence of the capacitance, either the frequency can be set high, or the capacitance can be determined from the phase or from the signal amplitude at multiple frequencies.

The lateral resolution depends on the size of the electrodes, which in turn determines the capacitance and frequency. In this work, circular electrodes with 3 mm diameter, 3 mm distance (6 mm distance center-to-center) and frequencies of some 100 MHz up to about 10 GHz are used. We expect an effective sensitivity footprint of about 5 mm diameter which is then the lateral resolution of this technique.

HL 45.66 Thu 18:30 Poster E

Triangular nanoperforation and band engineering of InGaAs quantum wells: a lithographic route towards Dirac cones in III-V semiconductors — •Christiaan Post[1], Tao Xu[2,3], Nathali Franchina Vergel[2], Yannick Lambert[2], Francois Vaurette[2], Ludovic Desplanque[2], Xavier Wallart[2], Didier Stiévenard[2], Bruno Grandidier[2], Christophe Delerue[2], and Daniel Vanmaekelbergh[1] — [1]Debye Institute for Nanomaterials Science, Utrecht, The Netherlands — [2]Institute of Electronics, Microelectronics and Nanotechnology (IEMN), Lille, France — [3]Key Laboratory of Advanced Display and System Applications, Shanghai, China

The design of two-dimensional periodic structures at the nanoscale has renewed attention for band structure engineering. In case of a nano scale honeycomb geometry, and entirely new band structure emerges in which the highest valence and lowest conduction bands become Dirac cones at the K-points, while the semiconductor quantum well band gap remains nearly unaltered.

In this research we report on the fabrication of a 10 nm thick InGaAs quantum well (QW) on a p-type InP substrate with a honeycomb symmetry structure by creating a triangular anti-lattice inside the QW using high-resolution electron beam lithography. The morphology of the samples is intensively studied, and the quality of the lattice is characterized, which is used for an extensive statistical analysis to determine the disorder inside the lattices. The results are supported by theoretical simulations on the band structure and density of states (DOS).

HL 45.67 Thu 18:30 Poster E

Reduction reflection for silicon wafer with maskless plasma etching by CHF3 and H2 — •Alena Okhorzina[1,2], Jens Hirsch[1,2], and Norbert Bernhard[1] — [1]Hochschule Anhalt, 06366, Köthen, Deutschland — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Otto-Eißfeldt-Straße 12, 06120 Halle (Saale)

The main goal is the development of a basic fluorocarbon plasma etching process for the structuring of silicon surfaces and its compounds. Plasma texturing of glass surface allows getting a moth-eye surface which has a light trapping effect. This will increase the efficiency of solar modules The main problem with the use of CHF3 and H2 gases is the determination of the parameters of the etching process for the predominance of the etching over the deposition. In this work, prescanning experiments were obtained for a maskless plasma texturing of silicon by CHF3/H2 within a design of experiments. Results of this investigation were the main impact parameters of the plasma etching according to the wafer reflection. The main impact parameters are (I) the CHF3/H2 fraction, (II) the value of capacitive and inductive coupled power, and (III) the pressure in the plasma chamber. The reflection of silicon samples after CHF3/H2 plasma texturing was investigated in this work. Sample one shows a reflection of 3-5 % in the short wavelength region ($<$ 500 nm) and a reflection of 10-20 % in the long wavelength region ($>$ 500 nm). The second investigated sample shows similar results but has a reflection of approx. 20 % in the short wavelength region.

HL 46: Ultra-fast phenomena

Time: Friday 9:30–12:45 Location: H31

HL 46.1 Fri 9:30 H31

Ultrafast x-ray scattering from laser-driven electronic systems — •Darya Gorelova[1,2], David A. Reis[3,4,5], and Robin Santra[1,2,6] — [1]Center for Free-Electron Laser Science, DESY, Notkestrasse 85, D-22607 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany — [3]PULSE Institute, SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA — [4]Department of Applied Physics, Stanford University, Stanford, California 94305, USA — [5]Department of Photon Science, Stanford University, Stanford, California 94305, USA — [6]Department of Physics, University of Hamburg, Jungiusstrasse 9, D-20355 Hamburg, Germany

We theoretically study x-ray scattering from an electronic system in the presence of a laser field driving electron dynamics in this system [1]. We apply Floquet theory to describe a laser-driven electronic system, and then obtain the scattering probability of an arbitrary nonresonant x-ray pulse from such a system employing the framework of quantum electrodynamics. We apply our theory for a calculation of a diffraction signal from a driven crystal in the regime of high harmonic generation. We connect the properties of the energy- and time-resolved diffraction signals to the properties of electron dynamics driven by the pump pulse.

[1] Daria Popova-Gorelova, David A. Reis and Robin Santra, accepted to Phys. Rev. B, arXiv:1811.02246.

HL 46.2 Fri 9:45 H31

Transient birefringence and dichroism of ZnO studied by femtosecond time-resolved spectroscopic ellipsometry — •Oliver Herrfurth[1], Steffen Richter[2], Mateusz Rębarz[2], Shirly Espinoza[2], Joshua A. Leveillee[3], André Schleife[3], Jakob Andreasson[2,4], Marius Grundmann[1], and Rüdiger Schmidt-Grund[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Leipzig — [2]ELI Beamlines, Institute of Physics, Czech Academy of Science, Prague, Czech Republic — [3]Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, USA — [4]Condensed Matter Physics, Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

We report on UV-pump-induced transient birefringence and dichroism of an *m*-plane oriented ZnO thin film measured by femtosecond pump-probe spectroscopic ellipsometry in the spectral range from 340 nm to 690 nm (1.8 eV to 3.6 eV) with approximately 100 fs time-resolution. The pump-induced density of electron-hole pairs is estimated as $3 \times 10^{19}\mathrm{cm}^{-3}$. We determine the complex dielectric function tensor from measurements parallel and perpendicular to the crystal's optic axis using a transfer matrix algorithm. Comparison to the ZnO

bandstructure and first-principles dielectric function (DF) calculations provides evidence for inter-valence-band transitions of "hot" charge carriers near the M point in the Brillouin zone. They are governed by selection rules for dipole transitions for perpendicular and parallel light polarization which cause the transient optical anisotropy.

HL 46.3 Fri 10:00 H31

Diffuse scattering in a laser controlled state above the melting threshold — •Tobias Zier, Sabrina Schuster, Eeuwe S. Zijstra, and Martin E. Garcia — Theoretische Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

With recent time-resolved x-ray diffraction techniques it became possible to measure, besides Bragg diffraction peaks, time-dependent diffuse scattering signals. Within these signals important information about the atomic motion after a femtosecond-laser excitation are included, which are mandatory to distinguish, e.g., coherent phonon motion from thermally squeezed one. Here, we analyze the diffuse scattering of bulk silicon in a laser-controlled state in the nonthermal melting region, by performing ab initio dynamics simulations using CHIVES (Code for Highly excIted Valence Electron Systems). Even though, nonthermal melting is a stochastic process we developed a control mechanism that enables us to drive the system above the nonthermal melting threshold into a stable state. Characteristic for this new state are different electronic properties compared to the ground state. Our results will give new insights into the atomic configuration within the control mechanism.

HL 46.4 Fri 10:15 H31

Transient absorption and population dynamics of laser-excited conjugated molecules from RT-TDDFT — •Jannis Krumland[1], Ana Valencia[1], Stefano Pittalis[2], Carlo Andrea Rozzi[2], and Caterina Cocchi[1] — [1]Physics Dept. and IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]CNR NANO, Modena, Italy

Pump-probe spectroscopy is a powerful tool to study the electronic and optical properties of materials. In transient absorption spectroscopy, the system is illuminated by two femtosecond laser pulses with the first one exciting the system and the second one probing its response at a given time delay. Real-time time-dependent density functional theory (RT-TDDFT) can be adopted for ab- initio simulations of these experiments [1]. In RT-TDDFT, the electron density is propagated in time, enabling the calculation of optical properties in the linear regime and beyond. We apply this method to investigate ethylene, benzene and thiophene molecules representing the building blocks of a variety of organic compounds. By applying laser pulses of increasing intensity in resonance with the gap transition, we analyze the dynamics of photo-excited electrons. From the transient absorption spectra, we identify the signatures of excitations due to the laser-induced population of initially unoccupied states. The underlying mechanisms of excited-state absorption are discussed in relation with benchmark calculations unraveling their excitations in the linear response [2].

[1] U. de Giovannini et al., ChemPhysChem 14 1363 (2013)
[2] J. Krumland et al., in preparation (2019)

HL 46.5 Fri 10:30 H31

Externally Controlled Lotka-Volterra Dynamics in a Linearly Polarized Polariton Fluid — •Matthias Pukrop and Stefan Schumacher — Department of Physics and CeOPP, Paderborn University, 33098 Paderborn, Germany

Coherent polariton fluids in semiconductor microcavities provide a platform for optical pattern formation and all-optical switching of patterns induced by a weak control beam. Recently, reversible on-demand switching was studied for a linearly polarized polariton system. Switching times and achievable gain were discussed based on detailed numerical simulations of the coupled light-field exciton dynamics obtained within a microscopic semiconductor theory [1]. Here we derive a simplified population competition model to gain more detailed insight into the switching mechanisms based on dynamical systems theory. The model we derived leads to an extended generalized Lotka-Volterra system for two competing populations controlled by an external source term. We will give an overview of both the existence and stability properties of possible steady states in the relevant parameter space, spanned by the strength of anisotropy and external control. We construct phase boundaries in representative regions of the non-trivial parameter space and characterize relevant bifurcations. The population competition model reproduces all key features of the switching processes observed in the full numerical simulations of the rather complex system and at the same time is simple enough for a fully analytical understanding of the underlying system dynamics.

[1] P. Lewandowski et al., Opt. Express 25, 31056-31063 (2017).

HL 46.6 Fri 10:45 H31

Ultrafast coherent 2D fluorescence micro-spectroscopy on semiconducting carbon nanotubes at room temperature — •Matthias Nuss, Alexandru Badalan, Jan-Hagen Krohn, Kerstin Müller, Donghai Li, Friedrich Schöppler, Tobias Hertel, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie I, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Further developments in nano- and molecular electronics would benefit strongly from the possibility of the spatio-temporal evolution of molecular processes. Non-linear ultrafast techniques provide insights into energy transfer pathways, e.g., mediated via electronic coupling. A comprehensive way to observe these dynamics is ultrafast coherent 2D fluorescence micro-spectroscopy [1]. This method is a generalization of transient absorption spectroscopy with frequency resolution both for the pump and the probe step, combined with spatial resolution in an optical microscope. This provides the capability to observe, e.g., inhomogeneous line broading as well as the formation and annihilation dynamics of excitons on the femtosecond timescale. Here, we utilize the third-order 2D signal for monitoring electronic coupling and energy transfer processes in semiconducting single-walled carbon nanotubes. To this end, an LCD-shaped four pulse sequence with 13 fs temporal encoding of each puls is focused through an NA = 1.4 objective and the fluorescence is detected as a function of inter-pulse time delays and phases.

[1] S. Goetz, et al., *Optics Express* 26, Nr. 4: 3915-25 (2018)

15 min. break

HL 46.7 Fri 11:15 H31

Non-equilibrium (Transient) Experiments on Zinc Oxide — •Shirly Espinoza[1], Steffen Richter[1], Oliver Herrfurth[2], Mateusz Rebarz[1], Stefan Zollner[3], Marius Grundman[2], Jakob Andreasson[1,4], and Rüdiger Schmidt-Grund[2] — [1]ELI Beamlines, Institute of Physics, Czech Academy of Sciences, Czech Republic — [2]Semiconductor Physics Group, Felix Bloch Institute for Solid State Physics, Leipzig, Germany — [3]New Mexico State University, Department of Physics, Las Cruces, NM, USA — [4]Condensed Matter Physics, Department of Physics, Chalmers University of Technology, Göteborg, Sweden

Zinc Oxide is a wide bandgap semiconductor considered for applications in electronics and optoelectronics devices. Its wide bandgap allows high power operation at high temperature; therefore, studies about its electron distribution at non-equilibrium values are crucial for the design of such device. Our work was done by pump-probe ellipsometry, a technique that allows the distinction between real and imaginary part of the dielectric function. We observed bleaching of the excitonic absorption at the band edge, and occurrence of intra-valence-band absorption during the very first picoseconds. Electron-phonon scattering causes thermalization, which creates non-thermal phonon distributions delaying the charge relaxation to tens of picosecond. The final heat dissipation happens in the scale of nanoseconds.

HL 46.8 Fri 11:30 H31

Ultrafast lattice dynamics in thin film black phosphorus — •Patrick-Nigel Hildebrandt[1,2], Daniela Zahn[1], Thomas Vasileiadis[1], Helene Seiler[1], Yingpeng Qi[1], and Ralph Ernstorfer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, Berlin, Germany — [2]Humboldt-Universität zu Berlin, Germany

We study the ultrafast lattice dynamics of thesemiconductor black phosphorus after photoexitation. Using femtosecond electron diffraction, we obtain a time-resolved picture of the electron-lattice equilibration and the subsequent relaxation of a non-thermal phonon population in an anisotropic material. Along the in-plane directions, *armchair* and *zigzag*, we measure an anisotropic Debye-Waller-Factor. The time-dependence of the average mean-square displacement reveals anisotropic phonon relaxation. This shows that the structural anisotropy of black phosphorus leads to anisotropic lattice dynamics, which is tentatively explained by different phonon density of states with *armchair*- or *zigzag*-polarization.

HL 46.9 Fri 11:45 H31

Ultrafast photo-induced spin polarized currents in nanostructers — •Michael Kraus, Dominik Schulze, Anna Dyrdal, and Jamal Berakdar — Martin-Luther Universität Halle-Wittenberg

We present theoretical predictions on the ultrafast generation of spin-polarized currents and pure spin currents by an appropriate nanostructuring of the sample and/or by modulating local fields produced by nearby plasmonic elements. It is shown how spin currents are steered by spatio-temporal tailoring of the driving photonic fields.

HL 46.10 Fri 12:00 H31

Modeling white light coherent 2D-spectroscopy on electrically pumped semiconductor nanostructures — •Aris Koulas-Simos[1,2], Mirco Kolarczik[1], Benjamin Lingnau[2], Bastian Herzog[1], Sophia Helmrich[1], Ulrike Woggon[1], Nina Owschimikow[1], and Kathy Lüdge[2] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin — [2]Institut für Theoretische Physik, Technische Universität Berlin

We investigate the coherent coupling mechanisms of an electrically pumped InAs/InGaAs quantum dot-in-a-well semiconductor optical amplifier. We track the phase evolution of the system using white light coherent 2D spectroscopy with collinear pulses and electronic frequency filtering. In the experiment, we observe signatures of the quantum dot ground and excited state and a coupling between them. Interestingly, we also observe the existence of crossed excitons, i.e. coupling of states with different dimensionality. Our observations can be described using a theoretical model based on the Maxwell Bloch equations, where we incorporate the local charge carrier and polarisation dynamics microscopically. Similar to a heterodyne experiment, we vary the phase of both the pump and probe pulse, which allows us to distinguish the different bands of the outcoming signal and to extract a 2D spectrum corresponding to the rephasing sideband.

HL 46.11 Fri 12:15 H31

Higher-order contributions and non-perturbative effects in the nonlinear optical absorption of direct-gap semiconductors — •Wolf-Rüdiger Hannes and Torsten Meier — Department of Physics and CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany

The semiconductor Bloch equations including the intraband acceleration [1] are used to study the nonlinear absorption of single or multiple light pulses by direct-gap semiconductors. The steady state response can be described analytically by multi-photon absorption coefficients, which are shown to agree well with numerical results for short pulses and/or finite dephasing and relaxation times. The dependencies on the light frequencies, band gap energy, initial populations, and the time delay between the pulses are analyzed. In third order we confirm some previously described aspects [2] such as the strong enhancement of two-photon absorption for non-degenerate light frequencies. In higher orders we discuss both multi-photon absorption and dispersive corrections to lower orders. Beyond the perturbative treatment of the Bloch equations we investigate the intensity-dependent optical absorption for a single incident pulse and in a pump-probe setup.

[1] H. T. Duc, T. Meier, and S. W. Koch, Phys. Rev. Lett. **95**, 086606 (2005).
[2] C. Aversa *et al.*, Phys. Rev. B **50**, 18073 (1994).

HL 46.12 Fri 12:30 H31

Bringing nonlinear stimulated emission to the infrared: From sapphire and fused silica to perovskites — •Thomas Winkler[1], Sean Bourelle[1], Thomas Baumert[2], and Felix Deschler[1] — [1]Cavendish Laboratory, University of Cambridge, United Kingdom — [2]Institut für Physik und CINSaT, Universität Kassel, Deutschland

While the stimulated emission of light was postulated over more than a hundred years ago and the laser has found its way into every laboratory, its nonlinear counterpart (i.e. two-photon stimulated emission) has only been observed in a handful of experiments so far. Therefore it was very surprising when we recently discovered the nonlinear amplification of an ultraviolet femtosecond laser pulse in a piece of optically excited sapphire (LADIE effect [1]). The effect holds high promises for laser technology, nonlinear microscopy and laser-spectroscopy as it provides e.g. a different set of selection rules. Here, we present extended studies showing the possibility of switching between two nonlinear amplification processes in fused silica, one being related to free carriers, whereas the other is related to the characteristic and self-trapped excitons. Furthermore, we discuss our recent studies to expand the nonlinear stimulated emission from the ultraviolet into the infrared regime. To that extend we utilize novel 2D and 3D perovskite materials, which showed great properties for optoelectronic devices. Having band gaps in visible spectrum and long carrier lifetimes, they are an ideal sample system to probe the two-photon stimulated emission in an ultrafast pump-probe experiment with tunable- and broadband infrared probe pulses. [1]T.Winkler *et al.* Nature Physics **14**, 74-79 (2018)

HL 47: Quantum dots and wires: Optical properties II

Time: Friday 9:30–13:00 Location: H34

HL 47.1 Fri 9:30 H34

Investigation of spectral diffusion by slow-light photon correlation — •Julian Maisch[1], Hüseyin Vural[1], Simon Kern[1], Jonas H. Weber[1], Jörg Wrachtrup[2], Ilja Gerhardt[2], Michael Jetter[1], Simone L. Portalupi[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]3. Institute of Physics, University of Stuttgart, IQST and SCoPE

Highly complex quantum applications require single coherent photons. One promising type of sources are semiconductor quantum dots (QDs). Due to the fact that they are embedded in a solid-state matrix, the emission is generally influenced by the environment e.g. fluctuating electrical and magnetic fields. These fluctuations cause random shifts of the emission frequency resulting in a broadened spectrum.

This so-called spectral diffusion is well known. Still, the charactersitic time scales are of interest. This talk presents a method to use a slow-light medium (here: cesium vapor) to make the effect of spectral wandering visible in a typical second-order correlation measurement. The dispersion of the atomic medium transfers spectral differences into the time signal of the photons. Therefore, the correlation reveals diffusion dynamics. Both experimental and supporting simulation results are presented.

HL 47.2 Fri 9:45 H34

High-resolution measurement of quantum dot emission spectra after resonant excitation — •Tim Strobel, Stephan Simmler, Simon Kern, Jonas H. Weber, Hüseyin Vural, Simone L. Portalupi, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Photonic quantum information technologies rely on two-photon inteference (TPI) as their key building block. Actual quantum applications highly depend on the indistinguishability of single photons. In this respect single semiconductor quantum dots (QDs) are well-established quantum emitters of high interest. They can be used as on-demand single sources of indistinguishable photons. This property is inevitable to successfully carry out two-photon inteference (TPI) experiments with the perspective of scaling up the complexity. To reach high indistinguishability, Fourier-limited emission spectra are desired. However, dephasing such as charge and spin noise broaden the linewidth of such single photon emitters drastically. Therefore, it is crucial to have knowledge about the influence of these effects on the emission spectrum. Here, we present a monolithic Fabry-Pérot interferometer which can be used to capture high-resolution spectra of semiconductor quantum dots. The inteferometer has a resolution even below the bandwith of the single Fourier-limited photons.

HL 47.3 Fri 10:00 H34

Determination of doping profiles in axial GaAs Nanowires by 4-point-probe and Luminescence Measurements — Andreas Nägelein[1], •Peter Kleinschmidt[1], Cornelia Timm[1], Matthias Steidl[1], Klaus Schwarzburg[2], and Thomas Hannappel[1] — [1]TU Ilmenau, Institut für Physik, 98693 Ilmenau, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany

Semiconductor devices depend crucially on the controlled incorporation of dopants and their spatial distribution. In the case of III-V nanowires (NWs), a number of techniques have been developed to analyze this property, but precise, rapid and non-destructive doping profiling is still challenging. Here, we investigate axial pn-junctions in GaAs-NWs, on the one hand electrically by a multi-tip scanning tunneling microscope (MT-STM) operated as a four-point nanoprober and on the other hand optically by room-temperature photoluminescence (PL) and cathodoluminescence (CL) microscopy spectroscopy. We fabricate the NWs by metalorganic vapor phase epitaxy in the vapor liquid solid growth mode. The MT-STM is accessible via a contamination-free UHV transfer, while optical characterization is performed in ambient air. Both approaches provide complementary information on doping distribution. Analysis of the MT-STM measurements involves a transport model, whereas analyzing the PL and CL data relies on semi-empirical equations taking the Burstein-Moss shift and the bandgap narrowing into account. Combining these results reveals a constant hole concentration in the p-dope base of the NWs and an axial variation in the electron concentration in the n-doped top part of the NWs.

HL 47.4 Fri 10:15 H34

Generation of single-photon and two-photon pulses from a quantum two-level system — •Katarina Boos[1], Lukas Hanschke[1], Kevin Andrew Fischer[2], Jakob Wierzbowski[1], Stefan Appel[1], Daniil Lukin[2], Shuo Sun[2], Rahul Trivedi[2], Malte Kremser[1], Tobias Simmet[1], Constantin Dory[2], Jelena Vuckovic[2], Jonathan Finley[1], and Kai Müller[1] — [1]Walter Schottky Institut and Physik Department, Technische Universität München, 85748 Garching, Germany — [2]E.L. Ginzton Laboratory, Stanford University, Stanford, CA 94306, USA

Resonantly driven quantum two-level transitions in quantum dots are promising single-photon sources [1]. Here, we demonstrate that they can surprisingly also operate in a two-photon bundling regime. Specifically, when exciting with a 2pi pulse emission of a photon during the presence of the laser pulse restarts the Rabi oscillation and leads to a second emission of a photon with near-unity probability [2,3]. Finally, we demonstrate single-photon generation from self-assembled quantum dots with ultra-low multi-photon probability. Using two-photon excitation of the bi-exciton suppresses the re-excitation and improves the single photon purity by several orders of magnitude for short pulses [4].

[1] K. A. Fischer, et al., New J. Phys. 18, 113053 (2016)
[2] K. A. Fischer, et al., Nature Physics 13, 649-654 (2017)
[3] K. A. Fischer, et al., Quantum Sci. Technol. 3, 014006 (2017)
[4] L. Hanschke, et al., npj Quantum Information 4, 43 (2018)

HL 47.5 Fri 10:30 H34

Optical spectroscopy of type-II semiconductor ZnSe/CdS dot-in-rod nanostructures — •Hans Werners, Sven Lohmann, Christian Strelow, Alf Mews, and Tobias Kipp — Institut für Physikalische Chemie, Universität Hamburg, Germany

In type-II semiconductor heterostructures the band offset leads to a spatial separation of electrons and holes. This charge separation makes type-II systems particularly useful, e. g., as light-harvesting materials in photovoltaic devices. Nanoparticles consisting of a spherical ZnSe core surrounded by a rod-shaped CdS shell, so-called dot-in-rods (DRs), represent a quantum system with an intrinsic type-II band alignment at the core/shell interface. This should allow for an efficient manipulation of exciton properties by, e.g., external fields.

We use time-, energy-, and space-resolved confocal fluorescence spectroscopy at room and cryogenic temperatures to investigate individual ZnSe/CdS DRs. The DRs show a high photostability while emitting linearly polarized light at about 2.16 eV, with quantum yields above 35%. Compared to the more conventional type-I CdSe/CdS DR system [1], ZnSe/CdS DRs exhibit increased fluorescence lifetimes. At 8 K, the lifetime is decreased compared to room temperature measurements. Furthermore, at low temperature, we observe abrupt spectral shiftings of the emission line over time, superimposed on smoother spectral diffusion processes. The spectral diffusion covers a larger range in energy than for type-I CdSe/CdS DRs, indicating the larger susceptibility of type-II structures to external stimuli, like surface charges.

[1] S. Lohmann et al., ACS Nano 11, 12185-12192 (2017).

HL 47.6 Fri 10:45 H34

Quantum dots as charge detectors for nanoscale defect tomography — •Jens Kerski[1], Pia Lochner[1], Arne Ludwig[2], Andreas D. Wieck[2], Annika Kurzmann[1], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Self-assembled semiconductor quantum dots (QDs) can be used as single-photon sources in visionary applications in quantum information technologies. However, spin and charge noise in the vicinity destroy the needed fourier-transform limited linewidth [1].

In this contribution, we use a single quantum dot as nanoscale electrometer to investigate the charging process of individual defects by the nearby n-doped back contact. Spectral and time-resolved resonance fluorescence measurements allowed us to identify four nearby defect states by small shifts of the resonance energy of the exciton transition [2]. From the occupation probability of the individual states, the position of these defects in the growth direction, as well as their binding energy were determined. Their position allowed to identify the states as defects.

Our results give rise to further investigations, e.g. triangulation of individual defects by using multiple QDs, optical transport measurements at a single QD and nanoscale deep level transient spectroscopy.

[1] A. V. Kuhlmann et al., Nature Physics 9, 570-575 (2013).
[2] J. Houel et al., Phys. Rev. Lett. 108, 107401 (2012).

15 min. break

HL 47.7 Fri 11:15 H34

Distributed Bragg Reflectors in Nanowires towards Impurity Nanolasers — •Maximilian Zapf[1], Oscar Kennedy[2], Robert Röder[1], Robert Buschlinger[3], Ulf Peschel[3], Paul Warburton[2], and Carsten Ronning[2] — [1]Institute of Solid State Physics, Friedrich Schiller Universität Jena — [2]London Centre for Nanotechnology, University College London — [3]Institute for Solid State Theory and -Optics, Friedrich-Schiller-Universität Jena

Nanoscale coherent light sources are key components in novel photonic concepts for integrated photonic circuits and lab-on-a-chip devices. Optically one-dimensional nanolasers are currently realized using semiconductor nanowires (NWs) under intense optical excitation. Distributed Bragg reflectors (DBRs), where the nanowire is periodically cut, have higher reflectivity than a single end facet at wavelengths pre-determined by the spacing of cuts. These wavelength-selective mirrors can be combined with gain from the semiconductor material or from dopants ion implanted into the NW to shift laser emission within a broad spectral range. Finite-difference time-domain calculations were performed to simulate the wavelength-dependent reflections occurring at an air - ZnO DBR structure. Such DBR structures were milled into ZnO nanowires using inert-gas focused ion beam providing the high refractive index contrast between the ZnO material and air. Subsequently, reflection and transmission properties of the DBR structures have been studied. Enhanced wavelength-dependent end facet reflections allow reducing laser thresholds in nanowire lasers as well as tailorable nanoscale wavelength filtering, and spectral emission tuning.

HL 47.8 Fri 11:30 H34

Cutting of halide perovskite nanowires into single photon emissive low-aspect-ratio CsPbX3 (X=Cl, Br I) perovskite nanorods — •Philipp Konrad, Aurora Manzi, Yu Tong, Ming Fu, Eva Bladt, He Huang, Alexander Richter, Kun Wang, Peter Müller-Buschbaum, Sara Bals, Philippe Tamarat, Brahim Lounis, Jochen Feldmann, and Lakshminarayana Polavarapu — Chair for Photonics and Optoelectronics, Ludwig-Maximilians-Universität, München, Deutschland

Colloidal perovskite nanocrystals (NCs) have been highly investigated within the past few years due to their unique optical properties which make them favorable for LED and lasing applications. Their optical properties are strongly dependent on their dimensions. Despite rapid advances in the shape-control of perovskite NCs ranging from nanocubes to nanowires and nanoplatelets, it is hardly possible to obtain colloidal perovskite nanorods (NRs).

In this presentation, we will present our finding about the ligand-induced cutting of CsPbBr3 perovskite nanowires (NWs) into low aspect-ratio CsPbBr3 (X=Cl, Br and I) NRs. The shape transformation of Nws to NRs resulted in an increase of photoluminescence efficiency and longer exciton lifetimes compared to that of NWs. This indicates that the defect parts of the NWs gets separated during their breaking into NRs, otherwise the excitons are more likely to find a trap owing to large exciton diffusion lengths in perovskites. Interestingly, those NRs exhibit single photon emission as revealed by photon anti-

bunching measurements, which is not detected in their parent NWs.

HL 47.9 Fri 11:45 H34

Effect of Methyl Viologen on Electronic and Vibrational Spectra of Glutathione-stabilized Ag-In-S and Ag-In-S/ZnS Core-shell Quantum Dots — •Oleksandr Selyshchev[1], Volodymyr Dzhagan[1,2], and Dietrich R.T. Zahn[1] — [1]Semiconductor Physics, TU Chemnitz, Chemnitz D-09107, Germany — [2]V. Lashkaryov Institute of Semiconductor Physics, Nat. Acad. Sci. of Ukraine, 03028 Kyiv, Ukraine

One of the challenges on the way to the application of colloidal quantum dots (QDs) in electronic devices, such as solar cells and field effect transistors, is their low electrical conductivity hindered by dielectric organic ligands. The idea of the current study is to modify the surface of colloidally synthesized QDs by another organic ligand, methyl viologen that possesses electron accepting properties and could act as an electrical linker. Here we investigate the effect of methyl viologen on the spectral characteristics of nonstoichiometric Ag-In-S and Ag-In-S/ZnS core-shell QDs stabilized by glutathione as the native ligand. Methyl viologen results in strong quenching of the QD photoluminescence (PL), while the QD absorption spectra remain without changes. This behaviour indicates photoinduced electron transfer from QDs (donor) to methyl viologen (acceptor). A decrease of the average lifetime of the PL additionally confirms the interaction via photoexcited states. Raman and FTIR spectroscopies show that glutathione ligands are still present on the QD surface, therefore the interaction of the methyl viologen (cations) with the QDs is realized via electrostatic bonding to negatively charged functional groups of glutathione.

HL 47.10 Fri 12:00 H34

Highly luminescent halide perovskite Supercrystals: Toward Filling the Green Gap — •Maximilian Feil, Aurora Manzi, Yu Tong, Julius Feucht, En-Ping Yao, Markus Döblinger, Lakshminarayana Polavarapu, Alexander Urban, and Jochen Feldmann — Ludwig-Maximilians-Universität München, Munich, Germany

Self-assembly of nanoscale building blocks into ordered nanoarchitectures has emerged as a powerful approach for tailoring the nanoscale optical properties and using them for the development of novel optical devices [1, 2]. In our studies, we aim to uncover the optical properties of $CsPbX_3$ (X= Cl, Br, I) perovskite nanocubes (NCs) assembling into 3D superlattices commonly referred to as supercrystals (SCs). In this presentation, we will show a new one-pot synthesis method to obtain colloidal $CsPbX_3$ perovskite SCs by spontaneous self-assembly of individual NCs. The SCs retain the high photoluminescence efficiency of their NC subunits, however also exhibit a redshifted emission compared to that of the individual NCs due to miniband formation via electronic coupling between the NC subunits [1]. This redshift makes the SCs pure green emitters filling the so-called Green Gap, while the individual NCs emit a cyan-green color.

[1] Y. Tong, E.-P. Yao, A. Manzi, E. Bladt, K. Wang, M. Doblinger, S. Bals, P. M. Buschbaum, A. S. Urban, L. Polavarapu, J. Feldmann, Adv. Mater. 30, 1801117 (2018) [2] A. Manzi, Y. Tong, J. Feucht, E.-P. Yao, L. Polavarapu, A. S. Urban, J. Feldmann, Nat. Commun. 9 (1), 1518 (2018)

HL 47.11 Fri 12:15 H34

Dephasing dynamics of optically active hole spin qubits in self-assembled quantum dots — •Friedrich Sbresny[1], Tobias Simmet[1], William Rauhaus[1], Malte Kremser[1], Fuxiang Li[2], Nikolai Sinitsyn[2], Kai Müller[1], and Jonathan Finley[1] — [1]Walter Schottky Institut and Physik Department, Technische Universität München, 85748 Garching, Germany — [2]Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico, 87545 USA

Single spins in self-assembled InGaAs quantum dots (QDs) are promising candidates for spin-photon interfaces with applications in quantum technologies. While an electron spin in a QD rapidly dephases within $T_2^* = 2$ns [1], it was predicted that a single heavy hole spin would exhibit two orders of magnitude longer dephasing times. At zero magnetic field, through time-domain measurements of the net hole spin projection we find a hole spin dephasing time of 300ns. This largely reduced dephasing rate can be explained by the much weaker hyperfine contact interaction of a valence band hole with the nuclei. Measurements of T_2^* through time-resolved Ramsey interference show faster dephasing rates with increasing magnetic field. We attribute this to electronic noise, which broadens the distribution of Zeeman frequencies via the linear coupling of the hole g-tensor to the local electric field. Strategies to counteract this noise source as well as spin-echo measurements to obtain the single spin coherence time T_2 are discussed [2].

[1] A. Bechtold et al., Nature Physics 11, 1005-1008 (2015)
[2] T. Simmet et al, in preparation

HL 47.12 Fri 12:30 H34

Antenna-Controlled Antibunching in the Photoluminescence of Single Carbon Nanotubes — •Lucas Lange, Frank Schäfer, Alexander Biewald, Richard Ciesielski, and Achim Hartschuh — Department of Chemistry and CeNS, LMU Munich, Germany

Photon antibunching in the photoluminescence (PL) from semiconducting single-walled carbon nanotubes (SWCNTs) attracted considerable attention because of potential applications of SWCNTs as single-photon-sources [1]. Known for single point-like quantum systems, the observed antibunching from a 1D nano material also raised fundamental questions regarding the underlying mechanism. In general, antibunching is thought to require the efficient localization of the excited state energy at local minima in the exciton energy landscape or at chemical dopant sites and was reported for different nanotube materials and configurations upon optical as well as electrical excitation [2]. We performed photon-correlation experiments in a Hanbury-Brown-Twiss setup. A sharp laser-illuminated metal tip operated in a scanning probe scheme acted as optical antenna providing near-field PL enhancement with a spatial range around 20 nm [3]. In the near-field of the tip, the second order correlation at zero delay $g^{(2)}(0)$ was found to be substantially reduced. We discuss possible mechanisms of antenna-controlled antibunching including localized exciton-exciton annihilation [3] and applications to other low-dimensional materials.

[1] A. Högele, et al., PRL 100, 217401 (2008).
[2] A. Ishii, et al., PRA 8, 054039 (2017).
[3] N. Mauser, et al., Chem. Soc. Rev. 42, 1248 (2014).

HL 47.13 Fri 12:45 H34

Synthesis and Characterization of Lead Chalcogenide Nanocrystals for Short-Wavelength Infrared Photodetectors — •Martin Sarott[1,2], Tianshuo Zhao[2], and Cherie Kagan[2] — [1]Laboratory of Multifunctional Ferroic Materials (M. Fiebig), ETH Zurich, Switzerland — [2]Department of Materials Science and Engineering, University of Pennsylvania, USA

Recent advances in the characterization and synthesis of solution-processable semiconductor nanocrystals (NCs) have increased the interest in this class of materials for optoelectronic device applications including solar cells, light-emitting diodes, and photodetectors. In particular, lead chalcogenide NCs are promising candidates with a broadly tuneable spectral response from visible (VIS) to infrared (IR) depending on the NC size. In this study, we prepare PbS, PbSe, and PbTe NCs with a first excitonic absorption peak in the short-wavelength infrared range at 1.55um. For a variety of ligand chemistries, charge transport and doping properties of NC films are measured on a field-effect transistor (FET) geometry. Vertically stacked p-n and p-i-n heterojunction photodiodes are fabricated using an n-type ZnO film as electron transport layer. Current-voltage characteristics reveal that the degree of rectification, noise, and dark current level strongly depend on the choice of ligand, air-exposure, and electron blocking layers (MoO3) within the diode stack.

HL 48: Two-dimensional Materials IV (joint session HL/CPP)

Time: Friday 9:30–13:00 Location: H36

HL 48.1 Fri 9:30 H36

Optical Valleytronic Properties of CVD-grown Tungsten Disulfide AA' and AB Bilayers — •Lorenz Maximilian Schneider[1], Jan Kuhnert[1], Simon Schmitt[1], Ulrich Huttner[1], Lars Meckbach[1], Tineke Strouken[1], Stepan W. Koch[1], Wolfram Heimbrodt[1], Shichen Fu[2], Xiaotian Wang[2], Kyung Nam Kang[2], and Arash Rahimi-Iman[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, D-35032 Marburg, Germany — [2]Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, New Jersey, 07030, USA

Two-dimensional semiconductors such as transition-metal dichalcogenides have attracted considerable attention due to their strong light-matter interaction as well as "valleytronic" properties. The valley-dependent polarization properties are of potential interest for future devices and, both, homojunctions as well as heterostructures of monolayer materials promise considerable valley-polarization degrees and valley coherence.

In this work, chemical-vapour-deposition-grown AA' and AB stacked tungsten-disulfide bilayers are investigated. The differences between AA' and AB stacked bilayers are characterized optically and attributed to the distinct interlayer coupling between k-space valleys. Our spectroscopic investigations are supported by calculations focusing on the difference in symmetry and interlayer electronic coupling for these bilayers. A comparably high valley polarization and valley coherence is found for the AB stacked case in contrast to the AA' case, which is in good agreement with the expectations.

HL 48.2 Fri 9:45 H36

Exciton-lattice coupling in monolayer WSe2 investigated by femtosecond electron diffraction — •Shuo Dong[1], Daniela Zahn[1], Robert Schneider[2], Thomas Vasileiadis[1], Helene Seiler[1], Yingpeng Qi[1], Rudolf Bratschitsch[2], and Ralph Ernstorfer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Institute of Physics and Center for Nanotechnology, University of Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany

Exciton-phonon coupling as the essential exciton relaxation mechanism plays a crucial role in transition metal dichalcogenides (TMDC). Besides the bright exciton dynamics, the formation of dark excitons greatly impacts the optoelectronic properties of atomically thin TMDC, which requires spin flip-scattering or phonon-assisted momentum transfer. Here, we investigate the incoherent lattice excitation associated with exciton relaxation in monolayer WSe2 by femtosecond electron diffraction. We discuss the observed structural dynamics in terms of the intra- and inter-valley exciton scattering towards the lower-lying dark states. The direct measurement of lattice motion provides important complementary insights to exciton dynamics.

HL 48.3 Fri 10:00 H36

Towards an Atomistic Understanding of Defects in 2D Materials - Correlating Defects, Band Structure and Excitons — •Christoph Kastl[1], Roland Koch[1], Chris Chen[1], Bruno Schuler[1], Johanna Eichhorn[1], Soren Ulstrup[2], Aaron Bostwick[1], Chris Jozwiak[1], Nicholas Borys[3], Francesca Toma[1], Shaul Aloni[1], Alexander Weber-Bargioni[1], Eli Rotenberg[1], and Adam Schwartzberg[1] — [1]Lawrence Berkeley National Laboratory, Berkeley, United States — [2]Aarhus University, Denmark — [3]Montana State University, Bozeman, United States

Despite their importance, a detailed understanding of defects in 2D materials and their impact on excitonic and electronic properties is lacking. We use spatially resolved, angle resolved photoemission spectroscopy (nano-ARPES) to map the variations in band structure and defect density of monolayer WS_2 down to a resolution of 150 nm. [1] By correlating nano-ARPES with photoluminescence, we reveal the interplay between local defect density, band structure, and excitons. We compare this to atomic force and scanning tunneling microscopy, where we unambiguously identify defects at the atomic level. Surprisingly, the chalcogen vacancy is not present in as-grown monolayers, although it is commonly inferred to be the dominant point defect.[2] Instead, we find that substitutional oxygen effectively passivates chalcogen vacancies, which removes the electronic in-gap state and renders correct assignment of the defect challenging.

[1] C. Kastl et al., 2D Mater. 5, 045010, 2018. [2] arXiv:1810.02896, arXiv:1810.03364.

HL 48.4 Fri 10:15 H36

Magnetic Anisotropic Behavior in Two-Dimensional Layered $Cr_2Ge_2Te_6$ Crystals — •Sebastian Selter[1,2], Gaël Bastien[1], Anja U. B. Wolter[1], Saicharan Aswartham[1], and Bernd Büchner[1,2] — [1]IFW Dresden, Dresden, Germany — [2]TU Dresden, Dresden, Germany

$Cr_2Ge_2Te_6$ is one of the few known examples of two-dimensional layered ferromagnetic insulators. Ferromagnetic order was observed down to the bilayer, while theoretical calculations even suggest stable ferromagnetic order on the monolayer. This finding makes this compound interesting in terms of both fundamental understanding as well as for novel spintronic applications.
Thus, to entangle the physics behind possible monolayer ferromagnetism it is essential to understand the bulk magnetism which will enable us for the future applications. Here, we present a comprehensive synthesis, magnetic and thermodynamic investigation on $Cr_2Ge_2Te_6$. Bulk $Cr_2Ge_2Te_6$ becomes ferromagnetic below 64 K with the magnetic easy axis parallel to the crystallographic c-axis. A magnetic anomaly has been observed for low external fields applied perpendicular to the easy axis. An investigation of the field dependency of this anomaly hints towards a field driven nature.

HL 48.5 Fri 10:30 H36

Nanoscale Mapping of Charge Transfer at SnS/MoS_2 2D-2D p-n Junctions Created via Low-Temperature Epitaxy — •Alex Henning[1,2], Jack N. Olding[1,3], Michael J. Moody[1], Jason Dong[1], Emily A. Weiss[3], and Lincoln J. Lauhon[1] — [1]Department of Materials Science and Engineering, Northwestern University, USA — [2]Walter Schottky Institute and Physics Department, Technische Universität München — [3]Department of Chemistry, Northwestern University, USA

Many novel two-dimensional (2D) van der Waals (vdW) heterostructures with intriguing properties for optical and electronic applications have been created by mechanical exfoliation and stacking. The ability to directly grow vdW heterostructures over large areas would create new opportunities for large-scale integration. Here, p-type tin sulfide (SnS) is grown on n-type molybdenum disulfide (MoS_2) in an atomic layer deposition (ALD) reactor at low temperatures (180 °C) to form vertical p-n 2D-2D heterojunctions (HJs). X-ray diffraction and electron backscatter diffraction establish an axiotaxial relationship between the two crystals. Kelvin probe force microscopy (KPFM) combined with a tunable illumination source is used to characterize the topography, potential landscape and photoresponse of the MoS_2/SnS HJs with a lateral resolution < 50 nm. The gained structural and electronic properties were used to optimize the parameters for the growth of electronically active SnS of controlled thickness. The built-in potential difference of 0.9 eV, measured between MoS_2 and SnS, is significantly larger than those previously reported for 2D HJs.

HL 48.6 Fri 10:45 H36

Controlling band alignment at heterointerfaces using atomically thin Janus structures with built-in dipoles — •Simone Manti — Technical University of Denmark, Kongens Lyngby, Denmark

Recently Janus MoSSe monolayers have been synthesized by replacing S by Se on one side of MoS2. This material is an example of an atomically thin Janus structure, in which the inversion symmetry in the plane is broken leading to a finite out of plane dipole moment. Here we demonstrate that by inserting a MoSSe layer between two semiconductors, or between a semiconductor and a metal, it is possible to control the band alignment, or Schottky barrier, at the interface in a highly predictable manner. Using high-throughput density functional theory (DFT) calculations we screen for new, stable 2D Janus structures. This leads to a library of potentially synthesizable 2D materials with out-of-plane dipoles of varying strength corresponding to potential shifts between 0 and 2 eV. Our work opens new directions for rational design of band alignment at heterointerfaces.

15 min. break

HL 48.7 Fri 11:15 H36

Theory of electron-exciton scattering in atomically thin semiconductors — Christian Fey[1], Peter Schmelcher[1], Atac Imamoglu[2], and •Richard Schmidt[3] — [1]Universität Hamburg, Germany — [2]ETH Zürich, Switzerland — [3]MPI of Quantum Optics, Garching, Germany

Excitons interacting with charge carriers in van-der-Waals materials represent a new venue to study the many-body physics of strongly interacting Bose-Fermi mixtures. In order to derive an effective low-energy model for such systems we develop an exact diagonalization approach that predicts the bound and scattering properties of electron, excitons, and trions in two-dimensional semiconductors. By solving the quantum mechanical three-body problem of interacting charge carriers we obtain binding energies of excitons and trions that are in excellent agreement with quantum Monte Carlo predictions. Importantly, in our approach also excited states are accessible. This allows us to study exotic excited trion states as well as to predict the scattering phase shifts of electrons and excitons. From these results we derive an effective low-energy model of exciton-electron scattering that can serve as an input to advanced many-body techniques. As a demonstration we study the recently observed exciton Fermi polarons, and we show that effective range corrections predicted by our model have a substantial impact on the optical absorption spectrum of charge-doped transition-metal dichalcogenides. Our approach can be applied to a plethora of many-body phenomena realizable in atomically thin semiconductors ranging from exciton lattices and localization to induced superconductivity.

HL 48.8 Fri 11:30 H36

Computational characterization of novel 2d-materials for applications in energy and electronics — •Davide Campi[1], Thibault Sohier[1], Cedric Klinkert[2], Simran Kumari[1], Marco Gibertini[1], Nicolas Mounet[1], Mathieu Luisier[2], and Nicola Marzari[1] — [1]École polytechnique fédérale de Lausanne, Lausanne, Switzerland — [2]ETH Zurich, Zurich, Switzerland

Novel materials are crucial to future progress in information-and-communications technologies (ICT) and in energy harvesting, conversion, and storage. 2D materials provide an entire novel playground to discover novel properties and functionalities. The recent identification of many novel monolayers [1] has made available a large portfolio of materials to be explored. In this work we present an applications-oriented screenings aimed at the identification of the most promising candidates for photocatalytic water splitting, field-effect transistor channels and superconductivity.

HL 48.9 Fri 11:45 H36

Magnetic hallmarks of viscous electron flow in graphene — •Karina A. Guerrero-Becerra[1], Francesco M. D. Pellegrino[2,3], and Marco Polini[1,4] — [1]Istituto Italiano di Tecnologia, Via Morego 30, 16163 Genova, Italy — [2]Dipartimento di Fisica e Astronomia, Università di Catania, Via S. Sofia, 64, I-95123 Catania, Italy — [3]INFN, Sez. Catania, I-95123 Catania, Italy — [4]School of Physics & Astronomy, University of Manchester, Oxford Road, Manchester M13 9PL, United Kingdom

Electrical transport, thermal transport, and scanning gate spectroscopy measurements have been used to identify signatures of viscous electron flow in graphene, PdCoO2, and GaAs. In this regime of transport, viscosity determines electron whirlpools in the steady-state current pattern. So far, a direct experimental observation of electron whirlpools and associated backflow is still lacking. We predict that the profile of the magnetic field generated by hydrodynamic electron flow in confined geometries displays unambiguous features linked to whirlpools and backflow near current injectors. We also show that the same profiles shed light on the nature of the boundary conditions describing friction exerted on the electron fluid by the edges of the sample. Our predictions are within reach of vector magnetometry based on nitrogen-vacancy centers in diamond, a technique that access the details of 2D spatial flow patterns in graphene [1] and combines the benefits of high spatial resolution, competitive magnetic field resolution, and operability over a wide range of temperatures.

[1] J.-P. Tetienne et. al., Sci. Adv. **3**, e1602429 (2017).

HL 48.10 Fri 12:00 H36

Strain-induced localization of interlayer excitons in a van-der-Waals heterostructure — Malte Kremser, •Moritz Meyer, Janine Gückelhorn, Kai Müller, and Jonathan Finley — Walter Schottky Institut, Technische Universität München, München, Deutschland

The intricate potential landscape of interlayer excitons (IX) in heterobilayers (HBLs) of transition metal dichalcogenides is currently undergoing intense study. [1, 2] We show that strain can be utilized to locally modify the IX potential resulting in locally trapped states, similar to the strain-related emergence of quantum emitters in monolayer WSe2. [3, 4]

We locally strain a HBL composed of MoSe2 and WSe2 by placing it on top of lithographically defined nanopillars. The strain at the nanopillar positions creates localized states that appear as new peaks in low-temperature photoluminescence (PL) measurements, red-shifted by ~50-100 meV with respect to the IX main emission. We show that in excitation-power-dependent measurements the emission features a series of discrete peaks that suggests sequential charging of the trapping potential with multiple IXs.

[1] K. Tran et al., arXiv 1807.03771
[2] K. L. Seyler et al., arXiv 1809.04562
[3] A. Branny et al., Nat. Commun. 8, 15053 (2017)
[4] C. Palacios-Berraquero et al., Nat. Commun. 8, 15093 (2017)

HL 48.11 Fri 12:15 H36

Extreme Ultraviolet Core-Exciton Dynamics in Two-dimensional Molybdenum Disulfide — •Michael Zürch[1,8], Hung-Tzu Chang[1], Alexander Guggenmos[1], Diana Y. Qiu[2,3], Romain Geneaux[1], Yen-Chang Chen[4,5], Xuan Wei[5], Chang-Ming Jiang[6,7], Yufeng Liang[4], Felipe H da Jornada[2,3], Adam Schwartzberg[4], David Prendergast[4], Vincent C. Tung[5], Steven G. Louie[2,3], Daniel M. Neumark[1,6], and Stephen R. Leone[1,2,6] — [1]Department of Chemistry, University of California, Berkeley, USA — [2]Department of Physics, University of California, Berkeley, USA — [3]Materials Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, USA — [4]Molecular Foundry, Lawrence Berkeley National Laboratory, Berkeley, USA — [5]School of Engineering, University of California, Merced, USA — [6]Chemical Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, USA — [7]Joint Center of Artificial Photosynthesis, LBNL, Berkeley, USA — [8]Fritz Haber Institute of the Max Planck Society, Berlin, Germany

Novel tightly-bound core-excitons triggered by an XUV attosecond pulse are observed in two-dimensional transition-metal dichalcogenide molybdenum disulfide. State-of-the-art theory calculations confirm the observed features. The dynamics observed in the core-exciton states between the molybdenum 4p and 4d states indicate coherences, and population transfer between different states. The observation of strongly enhanced long-lived core excitons in two-dimensional semiconductors paves the way for further exploration into the properties of core excitons in two-dimensional materials and potential application of these.

HL 48.12 Fri 12:30 H36

One-Nanometer-Thin Carbon Nanomembranes: Combining High Water Permeance with High Selectivity — •Yang Yang, Petr Dementyev, Niklas Biere, Daniel Emmrich, Patrick Stohmann, Riko Korzetz, Xianghui Zhang, André Beyer, Sascha Koch, Dario Anselmetti, and Armin Gölzhäuser — Faculty of Physics, Bielefeld University, 33615 Bielefeld, Germany

Membrane-based separation provides an energy-efficient technology in producing clean water. Recent nanotechnology breakthroughs have led to the emergence of 2D membranes which promise minimal transport resistance and thus exceedingly high molecular flow rates. Carbon nanomembranes (CNMs) are a special class of 2D materials made by crosslinking of self-assembled monolayers. In this work, we will present the rapid and selective water permeation through a 1.2-nm thin CNM fabricated from terphenylthiol (TPT) precursors [1]. TPT CNMs consist of sub-nanometer channels with a high areal density of $10^{18}\,m^{-2}$. The membrane can block the passage of most gases and liquids, while permitting water and helium to pass through. In particular, water transits with a remarkably high permeance of 1.1×10^{-4} mol $m^{-2}\,s^{-1}\,Pa^{-1}$, 2,500 times faster than helium. The rapid water flow is ascribed to a hydrogen-bonded cooperative transport inside the CNM channels.

Reference

[1] Y. Yang, *et al*. Rapid Water Permeation Through Carbon Nanomembranes with Sub-Nanometer Channels. *ACS Nano* 2018, 12, 4695-4701.

HL 48.13 Fri 12:45 H36

Photoactive molecular nanosheets with 1 nm thickness

— •Maria Küllmer[1], Felix Herrmann-Westendorf[1,3], Stefan Götz[2], Christof Neumann[1], Patrick Endres[2], Andreas Winter[2], Ulrich Sigmar Schubert[2,4], Benjamin Dietzek[1,3,4], and Andrey Turchanin[1,4] — [1]Institute of Physical Chemistry, Friedrich Schiller University Jena, 07743 Jena — [2]Institute of Organic Chemistry and Makromolecular Chemistry (IOMC), Friedrich Schiller University Jena, 07743 Jena — [3]Leibniz Institute of Photonic Technology e. V., 07745 Jena — [4]Center for Energy and Environmental Chemistry Jena (CEEC Jena), 07743 Jena

Artificial photocatalytic systems play an important role in the development of novel energy sources. Functional incorporation of molecular catalysts into two-dimensional (2D) soft matter matrixes is a prerequisite towards the realization of the artificial leaf systems. Here we present 1 nm thick photoactive molecular nanosheets - Carbon Nanomembranes (CNMs) - generated by electron irradiation induced crosslinking of self-assembled photocatalytic ruthenium-(II)-complexes on gold substrates. We characterize the chemical and structural properties of these molecular 2D systems using high-resolution X-ray photoelectron and surface enhanced Raman spectroscopy in combination with atomic force and scanning electron microscopy. We employ photothermal deflection spectroscopy to characterize the adsorption band of the formed free-standing photoactive CNMs and to compare it with the characteristics of the pristine ruthenium-(II)-complexes