Semiconductor Physics Division
Fachverband Halbleiterphysik (HL)

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Overview of Invited Talks and Sessions

(Lecture rooms A151, EW015, EW201, EW202, and EW203; Posters B (H Galeria) and F (tent))

Invited Talks

HL 12.1	Mon	16:45–17:15	EW 201	**III-Nitride Quantum Dots as Single Photon Emitters** — •Mark Holmes, Kang Gao, Florian Le Roux, Kihyun Choi, Satoshi Kako, Munetaka Arita, Yasuhiko Arakawa
HL 16.1	Tue	9:30–10:00	EW 201	**Exploring the limits of position measurement with optomechanics** — Sergey A. Fedorov, Vivishek Sudhir, Nils J. Engelsen, Ryan Schilling, Hendrik Schütz, Amir H. Ghadimi, Mohammad J. Bereyhi, Dalziel J. Wilson, •Tobias J. Kippenberg
HL 16.2	Tue	10:00–10:30	EW 201	**On-chip integration of superconducting single photon detectors** — •Wolfram Pernice
HL 16.5	Tue	11:15–11:45	EW 201	**Integrated III-V nonlinear quantum optical devices** — •Gregor Weihs
HL 16.12	Tue	14:00–14:30	EW 201	**Hybrid waveguide platforms for quantum optics** — •Michal Bajcsy
HL 17.1	Tue	9:30–10:00	EW 202	**Quantitative Electron Microscopy for III/V on Silicon integration** — •Kerstin Volz
HL 17.2	Tue	10:00–10:30	EW 202	**Total Tomography of Nonplanar Heterostructures: Doping and Confinement Pontentials** — •Lincoln Lauhon
HL 17.6	Tue	11:30–12:00	EW 202	**Modulating electron beams in space and time to probe for genuine structures and function at the atomic scale** — •Christian Kisielowski
HL 17.7	Tue	12:00–12:30	EW 202	**Advanced Nano-scale Characterization of Nitrides using Helium Temperature Scanning Transmission Electron Microscopy Cathodoluminescence** — •Gordon Schmidt
HL 17.8	Tue	12:30–13:00	EW 202	**Tip-enhanced Raman spectroscopy in semiconductor nanostructures and graphene** — Emanuele Poliani, •Janina Maultzsch
HL 25.1	Wed	9:30–10:00	EW 201	**The quantum knitting machine: a quantum dot as device for deterministic production of cluster states of many entangled photons** — •David Gershoni
HL 25.7	Wed	11:30–12:00	EW 201	**Exploiting the Bright and the Dark Side of Deterministic Solid-State Quantum-Light Sources** — •Tobias Heindel
HL 29.1	Wed	15:00–15:30	EW 201	**Device Applications of Metafilms and Metasurfaces** — •Mark Brongersma

HL 29.2	Wed	15:30–16:00	EW 201	**Harmonic generation and photon management at the nanoscale in AlGaAs nanoantennas** — •Costantino De Angelis, Dragomir Neshev, Luca Carletti, Lavinia Ghirardini, Davide Rocco, Valerio Gili, Giovanni Pellegrini, Marco Finazzi, Andrea Locatelli, Ivan Favero, Giuseppe Marino, Michele Celebrano, Giuseppe Leo
HL 29.5	Wed	17:00–17:30	EW 201	**Meta-optics and functional metasurfaces driven by Mie resonances** — •Yuri Kivshar
HL 29.6	Wed	17:30–18:00	EW 201	**Nonlinear Metasurface Holography** — •Thomas Zentgraf
HL 36.1	Thu	9:30–10:00	EW 202	**Semiconductor laser diodes: applications, trends and their technological challenges** — •Werner Bergbauer, Andre Somers, Teresa Wurm, Matthias Peter, Christoph Eichler, Sven Gerhard, Georg Bruederl, Soenke Tautz, Bernhard Stojetz, Andreas Loeffler, Martin Mueller, Harald Koenig, Uwe Strauss
HL 36.2	Thu	10:00–10:30	EW 202	**Recent progress on VCSELs for the near- to mid-infrared spectral region** — •Markus Amann
HL 36.6	Thu	11:30–12:00	EW 202	**Simplicity VCSELs** — •James A. Lott, Nasibeh Haghighi, Gunter Larisch, Ricardo Rosales, Martin Zorn
HL 41.1	Thu	12:30–13:00	EW 201	**Industrial Aspects of 2D Nanomaterials** — •Michael Heuken, Annika Grundmann, Matthias Marx, Holger Kalisch, Andrei Vescan
HL 44.1	Thu	15:00–15:30	EW 202	**Development of AlGaN based UV Laser Diodes** — •Ronny Kirste, Biplab Sarkar, Seiji Mita, Will Mecouch, James Tweedie, Qiang Guo, Andrew Klump, Ramon Collazo, Zlatko Sitar
HL 44.2	Thu	15:30–16:00	EW 202	**Semiconductor Nanolasers Based on 2D Monolayer of Transition Metal Dichalcogenides** — •Cun-Zheng Ning

Invited talks of the joint symposium SYID

See SYID for the full program of the symposium.

SYID 1.1	Mon	9:30–10:00	H 0105	**Data driven R&D for Materials: Cognitive Discovery** — •Alessandro Curioni
SYID 1.2	Mon	10:00–10:30	H 0105	**Rational design and synthesis of Pt-based catalysts for fuel cell applications** — •Younan Xia
SYID 1.3	Mon	10:30–11:00	H 0105	**2D, or not 2D? Materials discovery, data provenance, and workflow reproducibility.** — •Nicola Marzari
SYID 1.4	Mon	11:00–11:30	H 0105	**Generating and assessing data from combinatorial and high-throughput experiments for the design of new materials** — •Alfred Ludwig
SYID 1.5	Mon	11:30–12:00	H 0105	**Novel materials discovery: big-data-analytics methods and infrastructure for building maps of materials** — •Luca Ghiringhelli

Invited talks of the joint symposium SYTO

See SYTO for the full program of the symposium.

SYTO 1.1	Wed	9:30–10:00	H 0105	**Beyond Topologically Ordered States: Insights from Entanglement** — •B. Andrei Bernevig
SYTO 1.2	Wed	10:00–10:30	H 0105	**Topological Magnon Materials** — Alexander Mook, Jürgen Henk, •Ingrid Mertig
SYTO 1.3	Wed	10:30–11:00	H 0105	**Topological Order of Interacting Polymers on a Substrate** — •Vincenzo Vitelli
SYTO 1.4	Wed	11:15–11:45	H 0105	**Quantization of Heat Flow in Fractional Quantum Hall States** — •Moty Heiblum
SYTO 1.5	Wed	11:45–12:15	H 0105	**Currents and Phases in Quantum Rings** — •Kathryn Moler

Invited talks of the joint symposium SYTH

See SYTH for the full program of the symposium.

SYTH 1.1	Thu	9:30–10:00	H 0105	**Extracting the electrical properties of metal halide perovskite semiconductors using transient terahertz spectroscopy** — •Michael B. Johnston
SYTH 1.2	Thu	10:00–10:30	H 0105	**THz nanophotonics with 2D materials** — •Miriam SERENA Vitiello
SYTH 1.3	Thu	10:30–11:00	H 0105	**Nonlinear responses and 2D spectroscopy using THz electric and magnetic fields** — •Keith A Nelson
SYTH 1.4	Thu	11:15–11:45	H 0105	**Low energy electrodynamics of correlated spin systems.** — •N. Peter Armitage
SYTH 1.5	Thu	11:45–12:15	H 0105	**Lightwave scanning tunneling microscopy of single molecules** — Dominik Peller, Tyler L. Cocker, Ping Yu, Rupert Huber, •Jascha Repp

Invited talks of the joint symposium SYDM

See SYDM for the full program of the symposium.

SYDM 1.1	Thu	15:00–15:30	H 0105	**Bending, pulling, and cutting wrinkled two-dimensional materials** — •Kirill Bolotin
SYDM 1.2	Thu	15:30–16:00	H 0105	**Ultrafast valley and spin dynamics in single-layer transition metal dichalcogenides** — •Alejandro Molina-Sanchez
SYDM 1.3	Thu	16:00–16:30	H 0105	**Interlayer excitons in layered semiconductor transition metal dichalcogenides** — •Steffen Michaelis de Vasconcellos
SYDM 1.4	Thu	16:45–17:15	H 0105	**Exploring exciton physics in liquid-exfoliated 2D materials** — •Claudia Backes
SYDM 1.5	Thu	17:15–17:45	H 0105	**A Progress Report on Electron Transport in MXenes; A New Family of 2D Materials** — •Michel Barsoum

Sessions

HL 1.1–1.4	Sun	16:00–18:25	H 0105	**Quantum Technologies (joint session HL/TT/TUT)**
HL 2.1–2.3	Sun	16:00–18:25	H 1058	**Semiconductor Optics (joint session HL/TUT)**
HL 3.1–3.14	Mon	9:30–13:15	H 2032	**2D Materials: Session I (joint session DS/CPP/HL)**
HL 4.1–4.13	Mon	9:30–13:00	EW 201	**Quantum dots and wires: Optical properties I**
HL 5.1–5.11	Mon	9:30–12:30	EW 202	**Semiconductor Lasers**
HL 6.1–6.13	Mon	9:30–13:00	EW 203	**Photovoltaics I**
HL 7.1–7.13	Mon	9:30–13:00	A 151	**Topological insulators I (joint session HL/TT)**
HL 8.1–8.6	Mon	15:00–16:30	EW 201	**2D materials (joint session HL/DS)**
HL 9.1–9.9	Mon	15:00–17:30	EW 202	**III-V semiconductors (other than nitrides)**
HL 10.1–10.9	Mon	15:00–17:30	EW 203	**Nitrides: Devices**
HL 11.1–11.9	Mon	15:00–17:30	A 151	**Topological insulators II (joint session HL/TT)**
HL 12.1–12.1	Mon	16:45–17:15	EW 201	**Invited Talk: Mark Holmes**
HL 13.1–13.87	Mon	17:30–19:30	Poster B	**Poster Session I**
HL 14.1–14.14	Tue	9:30–13:15	H 2032	**2D Materials: Session II (joint session DS/CPP/HL)**
HL 15.1–15.12	Tue	9:30–13:15	EW 015	**Focussed Session: Geometry- and Topology-Controlled Nanoarchitectures I**
HL 16.1–16.17	Tue	9:30–15:45	EW 201	**Focussed Session: Quantum Nanophotonics in Solid State Systems: Status, Challenges and Perspectives I (joint session HL/TT)**
HL 17.1–17.8	Tue	9:30–13:00	EW 202	**Focussed Session: Atomic Scale Characterization**
HL 18.1–18.12	Tue	9:30–12:45	EW 203	**Perovskite and Hybrid Photovolatics**
HL 19.1–19.14	Tue	9:30–13:15	A 151	**Quantum dots and wires: Transport properties**
HL 20.1–20.6	Tue	14:00–15:45	EW 015	**Focussed Session: Geometry- and Topology-Controlled Nanoarchitectures II**
HL 21.1–21.5	Tue	14:00–15:15	EW 202	**Photo-voltaics II**
HL 22.1–22.6	Tue	14:00–15:30	EW 203	**Nitrides: Preparation and characterization I**
HL 23.1–23.7	Tue	14:00–15:45	A 151	**2D materials: Graphene and BN (joint session HL/DS)**
HL 24.1–24.38	Tue	18:30–20:30	Poster F	**Poster Session II**
HL 25.1–25.12	Wed	9:30–13:15	EW 201	**Focussed Session: Quantum Nanophotonics in Solid State Systems: Status, Challenges and Perspectives II (joint session HL/TT)**

HL 26.1–26.13	Wed	9:30–13:00	EW 202	**Ultra-fast phenomena**
HL 27.1–27.13	Wed	9:30–13:00	EW 203	**Nitrides: Preparation and characterization II**
HL 28.1–28.14	Wed	9:30–13:15	A 151	**2D materials: Chalcogenides I (joint session HL/DS)**
HL 29.1–29.8	Wed	15:00–18:30	EW 201	**Focussed Session: Metasurfaces I**
HL 30.1–30.9	Wed	15:00–17:30	EW 202	**Heterostructures, interfaces, and surfaces**
HL 31.1–31.9	Wed	15:00–17:30	EW 203	**Quantum information systems (joint session HL/TT)**
HL 32.1–32.9	Wed	15:00–17:30	A 151	**Quantum dots and wires: Optical properties II**
HL 33.1–33.38	Wed	17:30–19:30	Poster F	**Poster Session III**
HL 34.1–34.4	Thu	9:30–10:30	EW 015	**Carbon: Diamond, nanotubes, Buckyballs**
HL 35.1–35.5	Thu	9:30–10:45	EW 201	**Focussed Session: Metasurfaces II**
HL 36.1–36.10	Thu	9:30–13:00	EW 202	**Focussed Session: Frontiers in Laser Diode Physics I**
HL 37.1–37.13	Thu	9:30–13:00	EW 203	**Oxide Semiconductors**
HL 38.1–38.14	Thu	9:30–13:15	A 151	**2D materials: Chalcogenides II (joint session HL/DS)**
HL 39.1–39.8	Thu	11:00–13:00	EW 015	**Group IV (other than C): Si/Ge/SiC**
HL 40.1–40.5	Thu	11:00–12:15	EW 201	**II-VI semiconductors**
HL 41.1–41.1	Thu	12:30–13:00	EW 201	**Invited Talk: Michael Heuken (joint session HL/DS)**
HL 42.1–42.7	Thu	15:00–16:45	EW 015	**Transport**
HL 43.1–43.9	Thu	15:00–17:30	EW 201	**Spintronics (joint session HL/TT)**
HL 44.1–44.2	Thu	15:00–16:00	EW 202	**Focussed Session: Frontiers in Laser Diode Physics II**
HL 45.1–45.10	Thu	15:00–17:45	EW 203	**Organic photovoltaics and electronics**
HL 46.1–46.10	Thu	15:00–17:45	A 151	**Quantum dots and wires: Optical properties III**
HL 47.1–47.5	Thu	16:15–17:30	EW 202	**Theory of electronic structure**
HL 48.1–48.4	Thu	17:00–18:00	EW 015	**Thermoelectricity**
HL 49	Thu	18:00–19:00	EW 201	**Annual General Meeting of theSemiconductor Physics division**
HL 50.1–50.57	Thu	19:00–21:00	Poster B	**HL Poster IV**
HL 51.1–51.10	Fri	9:30–12:30	H 2032	**2D Materials: Session III (joint session DS/CPP/HL)**
HL 52.1–52.12	Fri	9:30–12:45	EW 201	**Optical properties & Photonic crystals**
HL 53.1–53.6	Fri	9:30–11:00	EW 202	**Energy materials (other than photovoltaics)**
HL 54.1–54.10	Fri	9:30–12:15	EW 203	**Organic semiconductors**
HL 55.1–55.12	Fri	9:30–12:45	A 151	**Quantum dots and wires: Preparation and characterization**
HL 56.1–56.5	Fri	11:15–12:30	EW 202	**New materials and concepts**

Annual General Meeting of the Semiconductor Physics Division

Donnerstag, 18:00–19:00 Uhr, Raum EW201

- Bericht
- Verschiedenes

HL 1: Quantum Technologies (joint session HL/TT/TUT)

This tutorial features both the high hopes in Europe regarding quantum technologies and the underlying physics of several promising routes towards economically relevant quantum information science as well as the physics of a whole range of novel quantum devices.

Organized by Christian Enss (Heidelberg) and Erich Runge (Ilmenau) on behalf of the divisions TT and HL.

Time: Sunday 16:00–18:25 Location: H 0105

Tutorial HL 1.1 Sun 16:00 H 0105

Quantum Technology - how is research funded? — •Gerd Leuchs — Max Planck Institute for the Science of Light, Erlangen, Germany

Quantum technology is a field in physics which experienced considerable growth recently and is about to generate real world applications with significant economic potential. Scientists and research oriented companies succeeded raising the awareness of politicians in Germany and Europe.
As a consequence, the European Quantum Flagship, which will be supported by national initiatives (in Germany, QUTEGA, a BMBF funded project), is currently in the process of being established. The goal is to provide infrastructural and financial support to projects associated to Quantum Technologies. The major focus is on connecting scientific groups with players from industry who are interested in investing into emerging quantum technologies such as quantum communication, quantum metrology, quantum simulation and quantum computing.
For younger scientists, the structure and the political initiation process of such funding initiatives is often lacking transparency. As the national coordinator of the quantum initiative in Germany, I will try to shed some light on this topic by reporting about the currently ongoing foundation of the Quantum Flagship and the associated national initiatives. Since the final structure of the Flagship is not yet fully established, I will also share my experience with similar projects from the past.

5 min. break

Tutorial HL 1.2 Sun 16:40 H 0105

Superconducting Quantum Circuits — •Rudolf Gross — Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — Physik-Department, TU-München, Garching, Germany — Nanosystems Initiative Munich, München, Germany

Superconducting quantum circuits, consisting of inductors, capacitors and Josephson junctions, can be flexibly engineered using modern thin film and micro/nano-fabrication techniques. These quantum electronic circuits behave quantum coherently with coherence times approaching the millisecond regime. They are successfully used to study fundamental quantum effects and develop components for applications in quantum technology. Examples are the tailoring of light-matter interaction, the development of sources and detectors for quantum light, or the implementation of quantum information processing, quantum metrology and quantum simulation systems. Meanwhile, several companies such as Google, IBM or Intel have started the race towards a universal quantum computer based on a superconducting hardware platform.

Superconducting quantum circuits can also be successfully coupled to nano-mechanical and magnetic systems. In the resulting hybrid quantum systems different quantum degrees of freedom can be strongly coupled, allowing for the coherent exchange of elementary excitations such as pho-tons, phonons and magnons on a single quantum level.

I will give an introduction into the field of superconducting quantum circuits and address recent advancements in the rapidly growing field of superconducting quantum technology.

Tutorial HL 1.3 Sun 17:15 H 0105

Josephson junction based interferometers and amplifiers — •Sebastian Kempf — Kirchhoff-Institute for Physics, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany.

Advances in science, health care or other areas of everyday life are often accompanied by progress in physical instrumentation. The development of ultra-sensitive detectors and sensors is therefore of great importance and will not only influence our understanding of nature but also future examination methods in medical care or search strategies for natural resources. Quantum technology plays an important role in these developments as superconducting quantum devices (SQDs) are among the most sensitive measurement instruments presently existing and enabling fascinating investigations of tiniest signals.

Josephson junction based interferometers and amplifiers are a special class of SQDs which are very well suited for measuring variations of tiny magnetic fields or any other physical quantity that can be naturally converted into magnetic flux. They are based on the Josephson effects as well as magnetic flux conservation and are used not only for measuring biogmagnetic signals as induced for instance by the electrical currents within the human brain but also to read out cryogenic particle detectors, to explore mineral deposits within geoscience or for magnetic sensing at nanoscale level.

I will give an introduction into this fascinating field, discuss different kinds of devices such as the well-known superconducting quantum interference device and highlight several applications for which Josephson junction based interferometers and amplifiers are a key technology.

Tutorial HL 1.4 Sun 17:50 H 0105

Manipulation of quantum bits based on defect centres in diamond — •Oliver Benson — Institut für Physik der Humboldt-Universität zu Berlin, Newtonstrasse 15, 12489 Berlin

Quantum information processing relies on initialisation, manipulation, read-out and transmission of individual quantum bits. Defect centres in diamond are an example of stable, optically addressable single quantum systems in a solid-state matrix [1-4]. Their electronic states couple efficiently to light, and their energy level structure allows for long spin coherence time in the ground state. Moreover, coupling to nuclear spins in the diamond host provides storage of quantum bits for seconds. With this all ingredients for a full quantum information processing (QIP) architecture are present in one material platform. In this presentation, we introduce the fundamental concepts of QIP in diamond. We then describe recent breakthroughs, such as stationary to flying quantum bit conversion and entanglement of distant quantum bits [5]. Other applications of defect centres in diamond for quantum sensing [6] will be discussed as well.

[1] F. Jelezko and J. Wrachtrup, Phys. Status Solidi A, 203, 3207 (2006). [2] V. Acosta, P. Hemmer, MRS Bull. 38, 127 (2013). [3] J. R. Weber, et al., PNAS 107, 8513 (2010). [4] I. Aharonovich, et al., Rep. Prog. Phys. 74, 076501 (2011). [5] H. Bernien, et al., Nature 497, 86 (2013) [6] S. Hong, et al., MRS Bull. 38, 155 (2013).

HL 2: Semiconductor Optics (joint session HL/TUT)

The field of semiconductors optics explores the interaction of semiconductors and their nanostructures with light. This includes on the one hand the optical control of semiconductors via light fields. On the other hand, semiconductors can act as light sources like lasers or single and entangled photon sources. In particular the latter plays a decisive role for applications in photonic quantum technology and often a quantum description of the semiconductor and the light field is required to describe the underlying physics. In the tutorial "Semiconductor Optics" various aspects of light-matter interaction in nanostructures will be discussed from both the experimental and theoretical point of view.

Organizers: Doris Reiter (U Münster) and Stephan Reitzenstein (TU Berlin)

Time: Sunday 16:00–18:25 Location: H 1058

Tutorial HL 2.1 Sun 16:00 H 1058

Quantum dots for photonic quantum technologies — •Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

This tutorial aims to provide a general introduction to the physics of quantum dots and an overview of recent exciting developments in the field of semiconductor quantum optics with quantum dots (QDs). Semiconductor QDs have been identified as promising hardware for implementing the basic building blocks of novel quantum technologies, such as quantum computing, quantum communication, quantum metrology and quantum sensing. This is because individual charge carriers in QDs can be generated, manipulated, and coherently controlled. Moreover, miniaturized and integrated solutions with existing semiconductor technology are foreseeable. The topics addressed in this tutorial are two-photon interference with remote QDs, quantum dots in photonic integrated circuits, quantum sensing with QD photons, and hybrid atom-quantum dot systems.

5 min. break

Tutorial HL 2.2 Sun 16:50 H 1058

Non-classical light emission and superradiant emitter coupling in semiconductor nanolasers — •Frank Jahnke — Institute for Theoretical Physics, University of Bremen, 28334 Bremen, Germany

Quantum effects of the light-matter interaction in nanolasers can lead to highly unusual effects not known in conventional lasers, such as a strongly reduced laser threshold and non-classical light emission. The emission properties can be characterized using the second-order photon correlation function $g^{(2)}$. Lasers usually exhibit a change from $g^{(2)} = 2$ for thermal light to $g^{(2)} = 1$ for coherent emission. For a nanolaser with a small number of atom-like quantum-dot emitters in an optical cavity we demonstrate that radiative coupling of the emitters via the cavity field can establish a superradiant state of the active material, which reveals itself via a giant photon bunching with $g^{(2)} >> 2$ in the emitted radiation. Furthermore, superradiant pulse emission and excitation trapping are demonstrated for quantum-dot based nanolasers.

[1] J. Wiersig, C. Gies, F. Jahnke, M. Aßmann, T. Berstermann, M. Bayer, C. Kistner, S. Reitzenstein, C. Schneider, S. Höfling, A. Forchel, C. Kruse, J. Kalden, and D. Hommel, Nature 460, 245 (2009).

[2] F. Jahnke, C. Gies, M. Aßmann, M. Bayer, H.A.M. Leymann, A. Foerster, J. Wiersig, C. Schneider, M. Kamp, and S. Höfling, Nature Communications 7, 11540 (2016).

5 min. break

Tutorial HL 2.3 Sun 17:40 H 1058

Semiconductor spin-photon interfaces for quantum repeaters and cluster state generation — •Ruth Oulton — QET Labs, School of Physics and Department of Electrical and Electronic Engineering, University of Bristol, Tyndall Avenue, Bristol, BS8 1FD, UK

In this tutorial I will describe how one may use the spin of carriers in semiconductor quantum dots to store quantum information, and transfer or entangle that information with the polarization state of a photon. With efficient photonic structure surrounding the quantum dot, one may efficiently entangle a photon input into the structure with the QD a spin-photon interface. This is the basic building block of many functionalities, including a means to achieve a quantum repeater in quantum communication networks, and to generate entire strings of photons, all of which are entangled with each other after interacting with a mediating spin.

HL 3: 2D Materials: Session I (joint session DS/CPP/HL)

Time: Monday 9:30–13:15 Location: H 2032

HL 3.1 Mon 9:30 H 2032

Graphene nanoribbon: electronic band structure, doping and Raman fingerprints — •Boris Senkovskiy[1], Dmitry Usachov[2], Alexander Fedorov[2,3], Gianni Profeta[4], Danny Haberer[5], Felix Fischer[5], and Alexander Grüneis[1] — [1]II. Institute of Physics, University of Cologne, Cologne, Germany — [2]St. Petersburg State University, St. Petersburg,Russia — [3]IFW-Dresden, Dresden, Germany — [4]Department of Physical and Chemical Sciences and SPIN-CNR, University of L'Aquila , Coppito, Italy — [5]Department of Chemistry, University of California at Berkeley, Berkeley, USA

We present the state-of-the-art studies of atomically precise graphene nanoribbons (GNRs) synthesized using on-surface assisted molecular assembly. Using angle-resolved photoemission spectroscopy (ARPES), we obtain the band structure of pristine and boron-doped armchair GNRs of N=7 carbon atoms width. ARPES maps in the full 2D momentum space visualize each sub-band of quasi-1D GNRs and allow to extract effective masses, charge carrier velocities and sub-band energy offsets. Vibration properties of GNRs are probed in-situ by ultra-high vacuum Raman setup. We show how the periodically incorporated boron atoms affect the band structure and the Raman-active modes of GNRs. Particularly, in doped nanoribbons the effective mass of charge carriers is ∼2 times smaller and the peculiar Raman modes are red-shifted and doubled regarding to the pristine system.

[1] Senkovskiy et al. Adv. Electron. Mater. 2017.
[2] Senkovskiy et al. Nano Lett., 2017.
[3] Senkovskiy et al. Phys. Status Solidi RRL, 2017.

HL 3.2 Mon 9:45 H 2032

Valley spin lifetimes reaching 100 ns in monolayer $MoSe_2$ at room temperature — •Maximilian Heithoff, Manfred Ersfeld, Frank Volmer, Robin de Winter, Christoph Stampfer, and Bernd Beschoten — 2nd Institute of Physics and JARA-FIT, RWTH Aachen University, 52074 Aachen, Germany

We present time-resolved Kerr-rotation measurements on a monolayer of $MoSe_2$ revealing spin lifetimes up to 100 ns at room temperature. This extraordinary long-lived spin signal only weakly depends on temperature between 60 K and 300 K. At lower temperatures, it gets masked by an additional spin signal with significantly larger amplitude but shorter spin lifetimes reaching 8 ns. The latter spin signal exhibits a Kerr resonance which coincides with the photoluminescence spectrum from neutral and charged excitons showing that the spin dynamics at low temperatures are dominated by excitonic effects. In contrast, the long-lived spin signal at higher temperatures shows no resonance in the energy regime of the excitons. The absence of such resonance combined with the long spin lifetimes at room temperature is expected if the spin dynamics at elevated temperatures are not domi-

nated by excitonic effects but by a polarization of resident holes, which is protected even at room temperature due to the large spin splitting in the valence bands of transition metal dichalcogenides.

HL 3.3 Mon 10:00 H 2032

Ultra-high vacuum Raman spectroscopy of Cs doped monolayer graphene — •Martin Hell, Boris Senkovskiy, Joshua Hall, Thomas Michely, and Alexander Grüneis — II. Physikalische Institut, Universität zu Köln

We show that ultra-high vacuum (UHV) Raman spectroscopy is a valuable tool for in-situ characterization of epitaxial graphene on Ir(111) regarding strain, defects and doping level. We study the Cs doping induced changes in the Raman spectrum of epitaxial monolayer graphene for 2x2 and $\sqrt{3}$x$\sqrt{3}$ Cs adsorption geometries for exciting laser energies in a wide range (325nm to 633nm). The combined effects of lattice expansion and dynamic effects lead to characteristic changes in the Raman spectrum that allow us to identify the charge transfer and the electron-phonon coupling strength from the position, width and asymmetry of the G band Raman line. The electronic and structural characterization of Cs doped graphene is complemented by angle-resolved photoemission measurements and scanning tunneling microscopy on identically prepared samples. The high energy resolution of Raman (∼1 wavenumber) allows for a precise determination of temperature induced strain of epitaxial graphene. Finally, we will show new results regarding the UHV Raman and luminescence characterization of transition metal dichalcogenides grown on graphene/Ir(111).

HL 3.4 Mon 10:15 H 2032

Raman spectroscopy of misfit layer compound nanotubes from CrS_2 and TaS_2 — •Felix Kampmann[1,2], Dalit Stolovas[3], Leela S. Panchakarla[3], Gal Radovsky[3], Christian Thomsen[2], Reshef Tenne[3], and Janina Maultzsch[2] — [1]Institut für Festkörperphysik, TU Berlin, Berlin, Germany — [2]Institut für Physik der Kondensierten Materie, FAU Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Department of Materials and Interfaces, Weizmann Institute of Science, Rehovot, Israel

Misfit layer compounds (MLC) offer an interesting approach towards synthesis of novel one-dimensional nanostructures and two-dimensional materials. Understanding their structure and their physical properties has been subject to intense scientific research. The MLCs described by the formula MX-TX_2 consist of a transition metal dichalcogenide (TMD) layer TX_2 and an intercalation layer MX with distorted rock-salt structure. Here M denotes a metal, X is one of the elements S or Se, and T is of the group of transition metals.

In our study the TMD layer CrS_2 or TaS_2 is intercalated by either LaS-, CeS- or GdS- layers. Upon formation of the MLC charge transfer between the sublayers and deformation of the intercalation layer stabilize the otherwise metastable CrS_2. Due to the misfit between the sublayers in at least one direction and the seaming of dangling bonds at the rim atoms, the synthesis of nanotubes and -scrolls is favored. We investigate the vibrational properties of MLC nanotubes via Raman spectroscopy and discuss the results regarding previously published TEM methods.

HL 3.5 Mon 10:30 H 2032

Photoluminescence study of MoS_2 monolayers integrated with photonic nanostructures — •Rajeshkumar Mupparapu[1], Tobias Bucher[1], Antony George[2], Frank Setzpfandt[1], Thomas Pertsch[1], Andrey Turchanin[2], and Isabelle Staude[1] — [1]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany — [2]Institute of Physical Chemistry, Friedrich Schiller University Jena, 07743 Jena, Germany

Interaction of light with MoS_2 monolayers can be enhanced by integrating them with resonant nanostructures [1], and such interaction allows to manipulate their photoluminescence (PL) directionality and polarization. Here, we investigated the PL properties of MoS_2 monolayers integrated with resonant Silicon nanostructures [2] to explore the behavior of PL and valley polarization. Experiments performed on MoS_2-nanostructures reveal a significant PL enhancement [3], dominantly due to the local strain rather than Purcell enhancement. We further studied the valley polarization of MoS_2 flakes under different locally modified environments.

References:
[1]. S. Butun, *et al.*, Nano Lett., 2015, 15, 2700-2704.
[2]. M. Decker, I. Staude, J. Opt. 18, 103001 (2016).
[3]. T. Bucher, *et al.*, CLEO/Europe-EQEC 2017, Munich, EI-4.5, (2017).

HL 3.6 Mon 10:45 H 2032

luminescence at defects in h-BN : excitons at stacking faults and single photon emitters — •Alberto Zobelli, Romain Bourrellier, Sophie Meuret, Michele Amato, Odile Stéphan, Luiz Tizei, and Mathieu Kociak — Laboratoire de Physique des Solides, University of Paris-Sud, CNRS, Orsay, France

h-BN is a promising material for optical application due to a strong exciton in the far UV and bright and stable defect emissions. Here we investigate the spatial localization at the nanometric scale of defects lines in this rich emission spectrum by employing an original cathodoluminescence system (nano-CL) integrated within a scanning transmission electron microscope. We show that high energy emissions are related to crystal folds leading to local changes of the layer stacking order which promote additional excitons. Furthermore, middle band gap emissions present a high spatial localization (˜80 nm) and a typical zero-phonon line plus phonon replica spectroscopic signature, indicating a point defect origin. Finally, by combining our nano-CL system with an Hanbury Brown and Twiss (HBT) interferometer we identify a new bright and stable single photon emitter in the far UV.

HL 3.7 Mon 11:00 H 2032

Density-functional perturbation theory for gated 2D heterostructures — •Thibault Sohier[1], Marco Gibertini[1], Nicola Marzari[1], Matteo Calandra[2], and Francesco Mauri[3] — [1]THEOS and MARVEL, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland — [2]IMPMC, CNRS, Université Pierre et Marie Curie, Paris, France — [3]Departimento di Fisica, Università di Roma La Sapienza, Roma, Italy

The ability to perform first-principles calculations of phonons and electron-phonon interactions in gated 2D heterostructures is crucial to the understanding and design of next-generation devices. Yet, standard methods relying on 3D periodic-boundary conditions fail to properly account for the consequences of dimensionality and the field-effect on electron-phonon physics. Here we present an implementation of density-functional perturbation theory using open boundary conditions adequate to the simulation of 2D systems, and with the possibility to add charged planes to emulate the doping of the slab via field-effect. We first illustrate the importance of working in the correct 2D framework with the study of long-wavelength phonons in polar materials, focusing on two mechanisms relevant for the performances of electronic devices: the Fröhlich interaction and the LO-TO splitting. Second, we address the consequences of the field-effect setup by looking at flexural phonons and their coupling to electrons in gated graphene. We observe that unlike isolated graphene, the coupling with flexural phonons in gated graphene is not forbidden by symmetry, but it is strongly suppressed by electronic screening.

15 min. break.

HL 3.8 Mon 11:30 H 2032

Spectroscopic characterization of the silicene multi-layer phase on Ag(111) — •Dmytro Solonenko[1], Sandhya Chandola[2], Eugen Speiser[2], Norbert Esser[2], Dietrich R.T. Zahn[1], and Patrick Vogt[1] — [1]Semiconductor Physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany — [2]Leibniz-Institut für Analytische Wissenschaften-ISAS-e.V., 12489 Berlin, Germany

The formation of so-called "multi-layer silicene" has been suggested to form for supramonolayer Si coverages on Ag(111)[1], but its nature is still controversially discussed including silicene multi-layers, bilayers or Ag-mediated growth of bulk Si with a Ag-terminated $(\sqrt{3}\times\sqrt{3})$R30° reconstruction[2]. However, the experimental results which were shown so far do not allow an unequivocal assignment of this phase to any of the suggested structures. In order to retrieve the structural properties of this $(\sqrt{3}\times\sqrt{3})$R30° structure, we carried out an *in situ* Raman spectroscopy study varying the Si coverage (up to 10 monolayers). Our results show a unique spectral signature, which does not bear any resemblance to monolayer epitaxial silicene[3]. We compare the Raman results to those for the $(\sqrt{3}\times\sqrt{3})$R30° Ag/Si(111) system, yielding the similarities in terms of the overall number of spectral bands and their positions but also suggests fundamental differences, hinting towards the formation of a Si bilayer.

[1] Vogt, P., *et al.*, *Appl. Phys. Lett.* **104**, 021602 (2014). [2] Borensztein, Y., *et al.*, *Phys. Rev. B* **92**, 155407 (2015). [3] Solonenko, D., *et al.*, *2D Mat.* **4**, 015008 (2017).

HL 3.9 Mon 11:45 H 2032

Frictional anisotropy of MoS2 studied with molecular dynamics simulations — •Victor Claerbout[1], Tomas Polcar[1,2], and Paolo Nicolini[1] — [1]Czech Technical University in Prague, Prague, Czech Republic — [2]nCATS, University of Southampton, Southampton, United Kingdom

Transition metal dichalcogenides are considered to be among the best solid lubricants due to their lamellar structure. Tribological research focused upon molybdenum disulfide has revealed its super low friction behavior [1]. However, a full understanding of the mechanism behind this behavior remains lacking. In this contribution we aim to elucidate the phenomena taking place at the nanoscale when two commensurate layers of molybdenum disulfide slide one atop of another. In particular, by means of molecular dynamics simulations, we studied the effect of sliding anisotropy [2] (i.e., the changing frictional behavior upon varying the sliding angle of two commensurate layers) on the energy dissipation due to friction. We simulated different sliding conditions (varying e.g. normal load, sliding speed and system temperature) in order to highlight their effect on the lubricating properties. These results will help on the one hand to identify the fundamental mechanisms that govern friction at an atomistic level, as well as providing guidelines for the design of novel layered materials with improved tribological properties.

[1] J.M. Martin et al., Phys. Rev. B, 48, 10583(R) (1993). [2] Onodera et al., J. Phys. Chem. B, 114, 15832 (2010).

HL 3.10 Mon 12:00 H 2032

Structural changes and phase stability of Ti doped MoS_2 monolayers — •Andrea Silva, Tomas Polcar, Ondrej Hovorka, and Denis Kramer — Faculty of Engineering and Environment, University of Southampton, SO17 1BJ Southampton, United Kingdom

The discovery of graphene and its remarkable properties has renewed interest in inorganic materials and drawn attention to two-dimensional systems. Transition metal dichalcogenides (TMDs) have been known for decades in industry, but only recently their graphite-like layered structure has renewed academic interest. Quantum confinement in the monolayers yields different electronic properties compared to bulk counterparts. Moreover, TMDs are more chemically versatile than graphene, allowing easy functionalization of the layers [1]. Understanding the doping possibilities for TMDs is a key step in exploiting their potential.

In this study, we focus on the Ti doped MoS_2 TMD, a recently proposed new material with enhanced tribological properties [2].

In order to address the challenging task of determining the phase-stability of a new compound, we map energy landscapes obtained with DFT onto a cluster-expansion hamiltonian and iteratively search for low energy orderings of the atoms inside the given host. This methodology allows us to explore the Ti-Mo-S phase space and determine doping possibilities leading to stable phases of the form $Ti_xMo_{1-x}S_2$, quantify miscibility gaps and thermodynamic competition with ternary oxides.

[1] M. Chhowalla *et al.*, Nat. Chem. 5, 263 (2013).
[2] A. Cammarata and T. Polcar, Inorg. Chem. 54, 5739 (2015).

HL 3.11 Mon 12:15 H 2032

Resonance profiles of valley polarization in single-layer MoS_2 and $MoSe_2$ — •Hans Tornatzky[1], Roland Gillen[1,2], Anne-Marie Kaulitz[1], and Janina Maultzsch[1,2] — [1]Institut für Festkörperphysik, TU Berlin, Germany — [2]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

Transition metal dichalcogenides (TMDCs) attract a lot of interest due to their unique properties, such as the repeatedly investigated strong photoluminescence from the direct gap in few layered samples. Furthermore, TMDCs have recently become promising materials for spin- and valleytronics as circular polarized excitation leads to the generation of electron-hole-pairs with distinct spin at either K or K^* points in the Brillouin zone. However, questions remain unanswered about the mechanisms of the scattering processes.

In this talk we present photoluminescence measurements with different excitation energies on single-layer MoS_2 and $MoSe_2$ in order to examine the resonance behavior of the conservation of circular polarization in these TMDCs. We find that the circular polarization of the emitted light is conserved to 100 % in MoS_2 and 84 %/79 % (A/A^- peaks) in $MoSe_2$ close to resonance. The values for $MoSe_2$ surpass any previously reported value. However, in contrast to previous predictions, the degree of circular polarization decreases clearly at energies less than the 2 LA phonon energy above the resonance.

Our findings indicate that at least two competing processes underly the depolarization of the emission in single-layer transition metal dichalcogenides.

HL 3.12 Mon 12:30 H 2032

Defect mediated phase transformation of two-dimensional 2H-MoTe2 to the distorted 1T'-MoTe2 — •Tibor Lehnert[1], Mahdi Ghorbani-Asl[2], Janis Köster[1], Hannu-Pekka Komsa[3], Arkady Krasheninnikov[2,3], and Ute Kaiser[1] — [1]Electron Microscopy Group of Materials Science, University of Ulm, Ulm 89081, Germany — [2]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden 01328, Germany — [3]Department of Applied Physics, Aalto University, P.O. Box 11100, 00076 Aalto, Finland

We applied the newly developed Cc-and Cs-corrected SALVE (Sub-Angstrom Low-Voltage Electron Microscopy)[1] instrument, to study the dynamics of extended defects in single-layer 2H-MoTe2. In particular we report atom by atom on the transformation of an area in single-layer MoTe2 from the semiconducting 2H to the distorted and metallic 1T* phase, starting with a single vacancy line of missing Te atoms. We find that the size of the transformed area is defined by the length of the single vacancy line. First-principles calculations are performed to understand the transformation's driving forces.

[1] www.salve-project.de

HL 3.13 Mon 12:45 H 2032

Excitonic transitions in heterostructured Mo and W transition metal dichalcogenides from first principles — •Roland Gillen and Janina Maultzsch — Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Novel two-dimensional materials from the group of layered transition metal dichalcogenides (TMDC) attract scientific interest for their unusual physical properties, such as their strong optical response. Two ways to tailor the electronic and optical properties are (i) the combination of different TMDCs to form lateral and stacked heterostructures and (ii) creation of alloys containing different metal or chalcogen atoms. Recent experiments have suggested long-lived interlayer excitons in stacked heterostructures, with spatial separation of electrons and holes across the layers, allowing for exploitation in solar cells.

Based on recent work [1,2], we show the theoretical absorption spectra of bilayer $MoSe_2$-WSe_2 and MoS_2-WSe_2 heterostructures from solution of the excitonic Bethe-Salpeter equation with GW quasiparticle corrections and inclusion of spin-orbit-coupling. In accordance with experimental observations, we find contributions related to interlayer excitons below the absorption onset of the monolayer materials. Our calculations allow us to estimate the binding energy of these electron-hole pairs to be on the order of 0.2 eV for both studied heterostructures. We will further show recent calculations of the absorption spectra of alloyed $MoWS_2$ materials.

[1] Gillen et al., IEEE JSTQE 23, 1 (2017), [2] Gillen et al., in preparation

HL 3.14 Mon 13:00 H 2032

Suppression of inhomogeneous broadening of excitons and trions in encapsulated $MoSe_2$ monolayers — •Max Waldherr[1], Jacob Goddard[1], Nils Lundt[1], Sefaattin Tongay[2], Kenji Watanabe[3], Takashi Taniguchi[3], Sven Höfling[1,4], and Christian Schneider[1] — [1]Technische Physik, Physikalisches Institut and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]School for Engineering of Matter, Transport, and Energy, Arizona State University, Tempe, Arizona 85287, USA — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan — [4]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, KY16 9SS, United Kingdom

Two-dimensional transition metal dichalcogenides offer a rich platform for the investigation of light-matter coupling effects due to unique effects such as spin-valley locking. In the monolayer limit the optical properties of these materials are highly sensitive to surface effects, hence the exciton and trion resonances undergo inhomogeneous broadening by surface impurities. We present a method to reduce the linewidth of these resonances involving encapsulation between two ultra-thin hexagonal boron nitride layers and thermal annealing in an argon-hydrogen atmosphere. With this technique inhomogeneous broadening is suppressed effectively which manifests in a Lorentzian line shape and improved optical quality. Moreover, the spectral weight of the exciton increases and the linewidths of the exciton and trion reduce to 2.9 and 2.4 meV, respectively.

HL 4: Quantum dots and wires: Optical properties I

Time: Monday 9:30–13:00 Location: EW 201

HL 4.1 Mon 9:30 EW 201

Temperature-dependent investigations of the emission properties of InAs/InGaAs quantum dots in the telecom C-band — •Cornelius Nawrath, Fabian Olbrich, Matthias Paul, 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

Over the last decades quantum dots (QDs) have proven to be promising candidates as single-photon emitters for applications like quantum computing and quantum communication. The prerequisites for this perspective, namely entangled photon generation and high indistinguishability have been shown to be feasible.

In the past, research has focused on QDs emitting around 900nm. For long-distance applications, however, emission around 1550nm (telecom C-band) is preferable, due to the global absorption minimum of the existing fiber network.

This talk presents recent progress for InAs QDs on a GaAs substrate using a metamorphic buffer. Their temperature stability is investigated by means of ensemble photoluminescence (PL) and μPL measurements. The thermal activation of charge carriers of the QD ensemble and the single dots is monitored. Furthermore, the individual behaviour of certain transitions is explored, pointing towards the presence of charge carrier traps in the vincinity of the QDs. Ultimately the single-photon nature of the emission is shown up to 77K and the different emission lines are identified.

HL 4.2 Mon 9:45 EW 201

InP-based coupled quantum well - quantum dot structures for 1.55 μm high speed laser applications — •Sven Bauer[1], Vitalii Sichkovskyi[1], Wojciech Rudno-Rudziński[2], Grzegorz Sek[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]Institute of Physics, Wrocław University of Technology, Wybrzeze Wyspiańskiego 27, 50-370 Wrocław, Poland

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. In order to get a better understanding of the involved mechanisms, coupled QW-QD structures have been grown on Fe-doped InP substrates. These consist of a InGaAs QW, a thin InAlGaAs barrier, both lattice matched to InP, and InAs QDs. Samples with varying QW and barrier thicknesses were grown, in order to determine the best TI structure candidate to implement into a high speed QD laser design. These were investigated with photoluminescence and photoreflectance spectroscopy. Atomic force microscopy was used to determine the influence of the QD morphology on their emission behavior. The influence of the band alignment and coupling strength on the emission behavior could be shown. An incorporation of the optimum TI structure into an actual laser design showed promising properties.

HL 4.3 Mon 10:00 EW 201

Determination of the two-photon interference visibility of remote quantum emitters: The influence of temporal correlations — •J. H. Weber, J. Kettler, H. Vural, S. L. Portalupi, M. Jetter, and P. Michler — IHFG, IQST Center and SCoPE, Universität Stuttgart

Two-photon interference (TPI) with photons from remote quantum emitters is of key importance for upscaling of photonic quantum information schemes. On this respect, the photon indistinguishability of the overall emission is the key property which is typically measured via photon correlation exploiting the Hong-Ou-Mandel effect. However, temporal dynamics in emitter brightness and blinking of the emission result in unexpected correlation statistics. Such temporal correlations are frequently observed in several solid state sources being then fundamental to understand their effect on the measured statistics. In this study, we perform TPI with two remote semiconductor quantum dots and fully reproduce the resulting Hong-Ou-Mandel measurement not only via a developed analytical approach but also via Monte Carlo simulation. We show how both blinking and dynamic changes in brightness affect the temporal correlation. As it is then possible to predict the outcome, we show how to securely extract the TPI contrast from a single measurement. Moreover, a novel setup scheme is shown, which allows for blinking- and brightness-independent extraction of the TPI contrast. Even though, this report is based on semiconductor quantum dots as single-photon emitter, all findings can be directly transferred to any kind of quantum emitter.

HL 4.4 Mon 10:15 EW 201

Single photons from a quantum dot interacting with an atomic vapor: model and simulation — •Julian Maisch[1], Hüseyin Vural[1], Simone L. Portalupi[1], Simon Kern[1], Jonas Weber[1], Michael Jetter[1], Jörg Wrachtrup[2], Robert Löw[3], Ilja Gerhardt[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, IQST and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart — [2]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [3]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

For future quantum network applications, hybrid quantum systems provide promising capabilities. One example for such a system is the interface between single photons from a quantum dot (QD) and an alkali vapor as storage medium. In any application, it is essential to know the properties of the investigated photons.

Therefore, a detailed investigation of the photon-atom interaction is necessary. Beyond experimental results, numerical simulations embody a powerful tool for this task. The presented framework adapts the description of particle diffusion to take the effects of spectral diffusion in a QD into account. Moreover, the influence of the vapor is considered via the complex refractive index. Altogether, all realized experimental observations (time-correlated single-photon measurements and two-photon interference measurements) can be understood on one basis. Additionally, the simulations can be possibly extended for the description of photon propagation in other media.

HL 4.5 Mon 10:30 EW 201

Unusual transitions in a QD induced by spatially structured laser beams — •Matthias Holtkemper, Doris E. Reiter, and Tilmann Kuhn — Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

The discrete states in semiconductor quantum dots (QDs) can be used to implement proposals from quantum information processing. We show in this contribution, that the optical control of QDs can profit from the excitation using spatially structured laser beams, such as Bessel or Hermite-Gaussian beams, by enabling the optical access to otherwise geometry-forbidden transitions. To be specific, we study selection rules induced by Bessel beams of a topological charge up to two within an analytical QD model. Next, we expand our model by including Coulomb interactions and valence band mixing within a configuration interaction approach. A weakening of the strict selection rules and thereby an increased number of addressable exciton states is found. We discuss the influence of the beam shape by a comparisons between Hermite-Gaussian and Bessel beams, the influence of a positioning of the beam axis away from the QD center and differences in absorption for differently charged QDs. In summary, we present an overview about the new possibilities that arise from QD excitations with spatially structured laser beams.

HL 4.6 Mon 10:45 EW 201

High-Q micropillars with a controlled number of deterministically grown quantum dots — •Arsenty Kaganskiy, Fabian Gericke, Tobias Heuser, Tobias Heindel, Xavier Porte, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623

We report on the realization of micropillars with site-controlled quantum dots (SCQDs) in the active layer. The SCQDs are grown via the buried stressor approach which allows for the positioned growth and device integration of a countable number of QDs with high optical quality. This concept is very powerful as the number and the position of SCQDs in the cavity can be simultaneously controlled by the design of the buried stressor. The fabricated micropillars exhibit

high position control of the QD growth combined with Q-factors of up to 12000. The cavity Q-factor, Purcell factor and photon-extraction effciency are analyzed as a function of the aperture diameter demonstrating an additional oxid-aperture-induced mode confinement in the microcavity. Single-QD Purcell enhancement of the emission is investigated via temperature-induced resonance-tuning resulting in a Purcell factor of 4.3 ± 0.3. [1]

[1] A. Kaganskiy et al., arXiv:1711.09235 (2017)

15 min. break.

HL 4.7 Mon 11:15 EW 201

Spectroscopic Properties of Semiconductor Quantum Wires at Cryogenic Temperatures — •Svenja Patjens, Andreas Nielsen, Philip Harder, Tobias Kipp, and Alf Mews — Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Semiconductor quantum wires grown by the solution-liquid-solid (SLS) mechanism or similar methods typically consist of alternating segments of zinc blende and wurtzite phases. This effect results in potential variations, which in turn may influence the optical properties of these materials.[1] Here, we spectroscopically investigate phase-pure and polytypic cadmium telluride nanowires via confocal microscopy. The crystal phase distribution throughout single wires was analyzed by means of high resolution transmission electron microscopy (HRTEM). These single nanostructures revealed several distinct features and spectral shifts, when being spectroscopically analyzed at cryogenic temperatures. The fluorescence spectra were correlated to HRTEM images in order to get an insight into the effect of phase-alternations and domain sizes. We gratefully acknowledge financial support by the DFG via KI 1257/2 and ME 1380/16-3.

[1] D. Franz et al., Nano Lett., 2014, 14 (11), pp 6655-6659.

HL 4.8 Mon 11:30 EW 201

High Contrast Differential Reflection Measurements on a Single Quantum Dot — •Pia Eickelmann[1], Annika Kurzmann[1], Rüdiger Schott[2], Andreas D. Wieck[2], Arne Ludwig[2], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Lotharstraße 1, 47057 Duisburg — [2]Chair of Applied Solid State Physics, Ruhr-Universität Bochum, Universitätsstraße 150, 44780 Bochum, Germany

Excitons in semiconductor quantum dots (QDs) are promising candidates for the realization of quantum information technologies. Resonance fluorescence is a widely used possibility to address single excitons, where the laser background is suppressed by cross-polarization of two polarizers. Another possibility is differential reflection, where the ratio between the signal of a single QD and the reflected laser light is determined by lock-in technique. However, this technique was limited to low contrasts between QD photons and back-scattered laser light in the order of 10 % [A. N. Vamivakas, et al., Nano Lett. 7, 2892 (2007)].

In this talk we present an optimized sample structure which significantly increases the collection efficiency of the QD photons. A distributed Bragg reflector and an epitaxially grown gate allows us to measure contrasts up to more than 80 %, in confocal rejection even exceeding 800 %. It enables us to perform measurements on a single dot without the modulation of the lock-in technique. These findings open up the possibility to obtain optical measurements on single QDs without the need of suppressing the backscattered laser light.

HL 4.9 Mon 11:45 EW 201

Fully On-Chip Hanbury-Brown and Twiss Experiment with Semiconductor Quantum Dots — •Florian Hornung[1], Mario Schwartz[1], Ekkehart Schmidt[2], Stefan Hepp[1], Ulrich Rengstl[1], Simone Luca Portalupi[1], Michael Jetter[1], Konstantin Ilin[2], Michael Siegel[2], 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

The generation, manipulation and detection of single photons on-chip is currently under strong investigation due to their large potential in quantum information processing. Up to now, experiments using laser excitation of quantum dots and on-chip detectors suffer from a high laser background on the detectors, which makes a temporal filtering of the detected signal necessary. [1] Here, we present a fully integrated circuit, consisting of an InGaAs/GaAs quantum dot which is resonantly pumped, two single mode GaAs/AlGaAs waveguides forming a 50/50 beamsplitter structure and two NbN superconducting nanowire single photon detectors. With this system we perform on-chip second order correlation measurements on a single photon level without temporal filtering.

[1] G. Reithmaier et al. *Nano Lett.*, **2015**, *15* (8), pp 5208-5213.

HL 4.10 Mon 12:00 EW 201

Strain-dependent optical spectra of carbon nanotubes — •Christian Wagner[1], Jörg Schuster[2], and André Schleife[3] — [1]Center for Microtechnologies, TU Chemnitz, Germany — [2]Fraunhofer Institute ENAS, Chemnitz, Germany — [3]Department for Materials Science, UIUC, USA

Optical transitions in carbon nanotubes (CNTs) show a strong strain sensitivity, which makes them suitable for optical strain sensing at the nano-scale and for strain-tunable emitters. The origin of this effect is the dependence of the CNT band-gap on strain and chirality, which is well explored. However, there is no quantitative model for the strain dependence of optical transitions — which are subject to strong excitonic effects due to the quasi one-dimensional structure of CNTs.

One approach towards such a model is a parametrized description of the quasiparticle gap as well as the scaling relation of the exciton binding energy in CNTs given by Perebeinos *et al* [1]. However, the description of screening in the scaling relation is insufficient, since for CNTs, a one-dimensional wave-vector dependent dielectric function $\epsilon(q)$ is required instead of an effective-medium dielectric constant ϵ_0.

We improve the approach by Perebeinos *et al* [1] by relating the screening physics in CNTs to the electronic transitions. The resulting model is fitted to electronic-structure calculations within many-body perturbation theory. This enables us to quantitatively predict the strain dependence of optical transitions for any CNT.

[1] V. Perebeinos et al., Phys. Rev. Lett. 92, 257402 (2004).

HL 4.11 Mon 12:15 EW 201

Theoretical evaluation of two-photon transitions in wurtzite III-nitride quantum dots — •Stefan Thomas Jagsch, Ludwig Albrecht Thorsten Greif, Stephan Reitzenstein, and Andrei Schliwa — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, D-10623 Berlin

Experiencing both, strong carrier confinement and large exciton binding energies, nitride quantum dots (QDs) are predestined for single-photon emitter-based quantum optics at elevated temperatures. When grown along the (0001) crystallographic axis, wurtzite III-nitride systems exhibit strong internal pyro- and piezoelectric fields of the order of MV/cm. We explore the influence of these internal fields on two-photon transitions in wurtzite III-nitride quantum dots, via the mediation of parity selection rules, in the framework of 8-band k.p-theory [1]. We highlight possible routes to employ III-nitride QDs for frequency conversion on a single-emitter level. [1] Winkelnkemper, M., Schliwa, A. et al. PRB 74 (2006)

HL 4.12 Mon 12:30 EW 201

1550 nm wavelength emitting quantum dots, grown on a strain reduced InGaAs matrix — •Marcel Schmidt, Tim Bergmeier, Arne Ludwig, and Andreas D. Wieck — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

An important milestone to quantum information transfer are single photon sources emitting at a wavelength of 1550 nm for low losses in optical fibres. To achieve an emission at 1550 nm, self assembled quantum dots (SAQDs) as nearly ideal single photon sources are very promising. With the tempting prospect to tune the energy levels of QDs to an emission wavelength of 1550 nm, we investigate molecular beam epitaxy grown InAs SAQDs on lattice mismatch reduced, relaxed 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 4.13 Mon 12:45 EW 201

Nonlinear Frequency Generation by Rabi Oscillations in Quantum-Dot Semiconductor Amplifiers — •Benjamin Lingnau and Kathy Lüdge — Institut für Theoretische Physik, TU Berlin

We investigate the nonlinear light propagation in InAs/InGaAs quantum-dot-in-a-well semiconductor optical amplifiers in the limit of strong optical excitation where Rabi oscillations are excited in the

active medium. The amplifier is analyzed in a degenerate four-wave-mixing setup and characterized by its frequency conversion and creation performance. Our simulations show that the interplay between the nonlinear four-wave-mixing process and the coherent Rabi oscillations greatly influences the frequency conversion process. Rabi oscillations can be resonantly excited by the correct choice of the frequency detuning between pump and probe signals, which greatly enhances the nonlinear frequency conversion efficiency at frequencies up to several THz. We furthermore show that the coherent pulse shaping of ultrashort optical pulses in the quantum-dot medium can greatly enhance their spectral bandwidth, potentially allowing for ultra-broadband wavelength conversion and frequency comb generation.

HL 5: Semiconductor Lasers

Time: Monday 9:30–12:30 Location: EW 202

HL 5.1 Mon 9:30 EW 202

Emitter-emitter correlation mediated by collective modes in coupled cavity arrays — •Mawussey Segnon[1], Isa Grothe[1], Paul Gartner[2], and Christopher Gies[1] — [1]Institute for Theoretical Physics, University of Bremen, P.O. Box 330 440, 28334 Bremen, Germany — [2]National Institute of Materials Physics, P.O. Box MG-7, Bucharest-Magurele, Romania

Coupled cavity arrays are an interesting physical architecture, in which the optical coupling between their building blocks allows one to explore some exotic states of photons including the Mott insulator and the fractional quantum Hall effect. In the present work, we numerically investigate the physics of superradiance in coupled cavity systems. To this end, we use the Jaynes-Cummings-Hubbard Hamiltonian, where each cavity contains a single two-level quantum dot interacting with the confined local mode and contiguous cavities are mutually coupled by photon hopping. A diagonalization of the photonic part of the system Hamiltonian yields collective modes. We find parameter regimes, in which the exchange of photons via each of these collective modes leads to a radiactive coupling of the intercavity emitters.

HL 5.2 Mon 9:45 EW 202

Influence of spontaneous emission on the coherence properties of high-β semiconductor nanolasers — •Frederik Lohof[1], Roy Barzel[1], Paul Gartner[2], and Christopher Gies[1] — [1]Institute for Theoretical Physics, University of Bremen, Bremen, Germany — [2]National Institute of Material Physics, Bucharest-Magurele, Romania

Nanolasers, often operating in the high-β regime, are one of the prime applications of cavity-QED promising ultra-low thresholds and driving research in the field of green photonics. However, in such lasers spontaneous emission can play a central role even above the threshold, thereby influencing the coherence properties of the emitted light. In this context, we revisit the lasing criterion in terms of the degree of coherence of the emission inprinted in the two photon correlation function $g^{(2)}$. Using theoretical models we demonstrate that there are new regimes of cavity-QED lasing, realized e.g. in nanolasers with extended gain material, for which the coherence is reached at higher pump powers than required to observe the laser intensity jump, normally associated with the laser threshold. We present results from a photonic crystal nanobeam cavity laser with nitride-based quantum well gain material, operating in the mentioned new regime where $g^{(2)}$ becomes essential to identify lasing in the system.

HL 5.3 Mon 10:00 EW 202

Beam Analysis of Semiconductor Lasers by their Wavefront Structure — •Inga-Maria Eichentopf and Martin Reufer — Hochschule Ruhr West, Institut Naturwissenschaften, Mülheim an der Ruhr, Germany

For many applications of semiconductor lasers like high precision engraving, cutting and additive manufacturing a constant beam quality during processing is essential. But even if the intensity distribution is perfectly Gaussian for a certain set of laser parameters, blur effects can occur due to a slight shift of working conditions during the process. To forecast a loss of beam quality the analysis of the wavefront structure of the processing laser over the typical diode current range can be a helpful tool to choose a suitable parameter window or to correct the beam parameters using optical elements like deformable mirrors. In our research we use a Shack-Hartmann Sensor to record the wavefront and intensity distribution of single and multimode semiconductor lasers based on GaAs composites emitting at wavelengths in the near infrared. Over the parameter range electrical as well as thermal effects inside the laser resonator strongly influence the modal composition of the intensity distribution causing a deformation of the wavefront. To determine the impact of these effects a Gaussian telescope setup is used to detect the wavefront structure during the spatial and current depending evolution of the beam. This approach shall be used to forecast the beam stability.

HL 5.4 Mon 10:15 EW 202

Carrier dynamics and modulation properties in tunnel-injection based quantum-dot structures — •Michael Lorke, Stephan Michael, and Frank Jahnke — Institute für theoretische Physik, Universität Bremen

For tunnel-injection (TI) quantum-dot (QD) lasers record high small signal modulation bandwidth and improved performance of 1.55 μm InAs QDs on InP-based hetero-structures (1) were reported, which underscores their application potential for high-speed optical communication networks. We present a theoretical analysis of TI laser devices by combining material realistic electronic structure calculations with a many-body description of the carrier dynamics and the modulation properties. Based on these investigations, we give design guidelines to optimize the modulation bandwidth and turn-on delay.

(1) S. Bhowmick, M. Z. Baten, T. Frost, B. S. Ooi, and P. Bhattacharya, IEEE JQE 50, NO. 1 7-14 (2014)

HL 5.5 Mon 10:30 EW 202

Switching behaviour of bimodal micro lasers with optical injection — •David Schicke[1], Christoph Redlich[1], Benjamin Lingnau[1], Elisabeth Schlottmann[2], Felix Krüger[2], Xavier Porte[2], Sören Kreinberg[2], Kathy Lüdge[1], and Stephan Reitzenstein[2] — [1]Institut für Theoretische Physik, Technische Universität Berlin — [2]Institut für Festkörperphysik, Technische Universität Berlin

The dynamics of micropillar laser devices have been a topic of increased interest in the semiconductor laser community over the last years. Because of unavoidable structural asymmetries in such a micro laser, the device can emit in two possible orthogonal linearly polarized modes. Far from the threshold pump current, one of these modes becomes the dominant mode and suppresses the other, weak, mode. However, because of the high noise level present in the laser temporal switching is possible, i.e. the weaker mode becomes the strong, lasing, mode.

We present numerical simulations using a semiclassical rate equation approach to describe the emission dynamics of a bimodal laser subject to external optical injection and compare to recent experimental results. We find that the switching dynamics can be controlled by a proper choice of the injection parameters and investigate the underlying bifurcation scenarios by modeling the noise as a deterministic variable.

HL 5.6 Mon 10:45 EW 202

Repetition rate transitions and timing stability improvement in monolithic multi-section semiconductor lasers — •Martin Birkholz[1], Julien Javaloyes[2], Oleg Nikiforov[1], Christoph Weber[1], Luke F. Lester[3], and Stefan Breuer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Departamento de Física, Universitat de les Illes Balears, 07122 Palma de Mallorca, Spain — [3]Bradley Department of Electrical and Computer Engineer- ing, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA

Passively mode-locked lasers (PMLLs) are compact photonic sources delivering high repetition rate (RR) pulse trains and picosecond short optical pulses. An excellent stability of the generated optical pulse train is crucially important towards their application in optical sampling, in optical time division multiplexing or as photonic clocks. In this contribution, we study numerically the optical pulse train stability improvement and transitions to higher harmonic RRs in a monolithic

semiconductor laser with interdigitated absorber placement by the simulation tool FreeTWM (http://onl.uib.eu/softwares). The laser under investigation is 4 mm long, corresponding to a fundamental RR of 10 GHz, and consists of 2 gain and 2 absorber sections. By using numerical continuation transitions from fundamental mode locking to higher harmonic mode locking occur. Associated with these transitions is an improved timing stability. Experimental studies on timing stability and RR transitions confirm the simulated results.

15 min. break.

HL 5.7 Mon 11:15 EW 202

Nonlinear lensing in a vertical-external-cavity surface-emitting laser — •Christian Kriso, Tasnim Munshi, Sascha Kress, Mohib Alvi, Wolfgang Stolz, Martin Koch, and Arash Rahimi-Iman — Philipps-Universität Marburg, 35032 Marburg, Germany

Passively mode-locked semiconductor disk lasers (SDLs), also known as vertical-external-cavity surface-emitting lasers (VECSELs), present a cost-efficient and wavelength-flexible alternative to conventional solid-state lasers. However, most mode-locked SDLs rely on the use of an additional saturable absorber element setting constraints on compactness and peak powers. Recently, a new, saturable-absorber-free mode-locking technique has shown promising results in terms of pulse duration and peak power. The underlying mechanism is assumed to be Kerr-lens mode-locking but the observation of self-mode-locking behavior is still not well understood. In order to gain a deeper understanding of nonlinear lensing in a VECSEL chip, we investigate the influence of optical pumping and the operation wavelength on the measured nonlinear refractive index via z-scan measurements close to real operation conditions.

HL 5.8 Mon 11:30 EW 202

Remarkable laser emission around 630nm via a vertical cavity surface emitting laser (VCSEL) based on InP quantum dot layers — •Isabel Reis, Mona Stadler, 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

VCSELs in the AlGaInP material system are ideal candidates to realize a miniaturized optical device for laser emission around 630 nm capable to integrate. Such a development will be a suitable alternative to the best-known and successful emitter at 633nm, the HeNe laser. Furthermore, the realization of single-mode VCSELs comes with the ability of easy fiber coupling and array fabrication. We have carried out devices with an emission wavelength at 630 nm by combining structural design and adjusted growth parameters. Particular attention was devoted to the active region, which consists either of stacked InP quantum dot (QD) layers or quantum wells (QW) within a barrier and cladding layer of Al0.33GaInP and Al0.55GaInP, respectively. The advantage of QD based VCSEL compared to QW based devices is the decreased threshold current with less temperature dependency, an improved gain and tunability of the emission wavelength. The results of specific examples emitting around 630 nm will be presented, in both their designs and experimental behavior. Especially, the output power in the continuous wave and pulsed operation, the lasing characteristics and spectra of our processed VCSEL are measured and evaluated.

HL 5.9 Mon 11:45 EW 202

Controlling switching dynamics in quantum-dot micropillar lasers with time-delayed optical feedback — •Steffen Holzinger[1], Christoph Redlich[2], Benjamin Lingnau[2], Marco Schmidt[1], Martin von Helversen[1], Jörn Beyer[3], Christian Schneider[4], Martin Kamp[4], Sven Höfling[4,5], Kathy Lüdge[2], Xavier Porte[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Germany — [3]Physikalisch-Technische Bundesanstalt, Berlin, Germany — [4]Technische Physik, Julius-Maximilians-Universität Würzburg, Germany — [5]School of Physics and Astronomy, University of St Andrews, Scotland

Electrically pumped quantum-dot micropillar lasers provide a platform for the realization of delay-coupled experiments in the field of quantum optics, where single emitter effects and high spontaneous emission noise become prominent. In these structures two linear, orthogonally polarized lasing modes compete for a common gain medium, resulting in characteristic switching dynamics above the lasing threshold. We experimentally and theoretically investigate the influence of the feedback on the optical spectrum as well as the switching dynamics of the lasing modes. By directly measuring the photon number distribution with a transition edge sensor detector, we characterize the effects of feedback on the stability of the modes.

HL 5.10 Mon 12:00 EW 202

Injection forced Polarization Switching in Bimodal Quantum Dot Micropillar Lasers — •Elisabeth Schlottmann[1], Felix Krüger[1], Benjamin Lingnau[2], David Schicke[2], Steffen Holzinger[1], Christian Schneider[3], Martin Kamp[3], Sven Höfling[3], Xavier Porte[1], Kathy Lüdge[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Germany — [3]Technische Physik, Julius-Maximilians-Universität Würzburg, Germany

Quantum Dot Micropillar lasers are fascinating devices that show an enhanced spontaneous emission in the lasing mode (high β-factor) and a correspondingly low laser threshold. Moreover, the fundamental laser mode is splitted into two orthogonally polarized modes. As they share the gain medium, gain competition leads to stable laser emission in either one of the modes or stochastic polarization switching (C. Redlich et al. New J. Phys. 18, 63011 (2016)).

Here, we tailor polarization switching in a QD-micropillar laser via optical injection into the non-lasing mode. For low injection powers, a non-switching micropillar laser strongly fluctuates. Increased injection power stabilizes the intrinsically non-lasing mode and pushes it to lasing with simultaneous suppression of the other mode. These effects are characterized with high-resolution spectral and correlation measurements.

HL 5.11 Mon 12:15 EW 202

Fabrication of spectrally homogeneous microlaser arrays as a nanophotonic hardware for reservoir computing — •Tobias Heuser[1], Jan Grosse[1], Arsenty Kaganskiy[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), Campus Universitat de les Illes Balear, 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, called the reservoir, 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 developements of our fabrication process to realize large 2D arrays of microlasers, namely quantum dot micropillars and VCSELs, which 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, which are related to the material growth, are compensated by electrical tuning or by precisely adjusting the radius of the fabricated micropillars [2].

References:

[1]D.Brunner, I.Fischer, Opt. Lett. 40, 3854-3857 (2015).

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

HL 6: Photovoltaics I

Time: Monday 9:30–13:00 Location: EW 203

HL 6.1 Mon 9:30 EW 203

Formation process of the CIGSe absorber layers in a two stage sequential process — •Sven Schönherr, Philipp Schöppe, Michael Oertel, Udo Reislöhner, and Carsten Ronning — Institut für Festkörperphysik, Friedrich Schiller Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

A sequential process is often used to produce $Cu(In,Ga)Se_2$ (CIGSe) solar cells, which show high efficiencies of light conversion. In our process, the metallic precursor on top of a molybdenum back contact was reactively annealed in a selenium vapour atmosphere where it is typically converted to an about 2 μm thick CIGSe absorber layer. The selenization was spilt in two stages to get a better control of the absorber formation process. Completing the solar cell, a CdS buffer layer was grown via chemical bath deposition and as front contact a ZnO layer was sputtered on top. For a more homogeneous CIGSe absorber layer we varied the substrate temperature and the selenization time in the second stage. Current-voltage and capacitance-voltage measurements were used for a first electrical characterization. X-ray diffraction were taken to investigate the phase formation in the final absorber and in the molybdenum diselenide layer at the back contact. Furthermore, thin cross section lamellas of the complete solar cell were prepared via a focused ion beam system to measure the gallium gradient via energy dispersive X-ray spectroscopy. Additionally, photoluminescence measurements at low temperatures were performed to characterize the defect structure and to get information about the ratio of group III elements.

HL 6.2 Mon 9:45 EW 203

The beneficial effect of Rubidium in $Cu(In,Ga)Se_2$ solar cells — •Philipp Schöppe[1], Sven Schönherr[1], Roland Wuerz[2], Wolfgang Wisniewski[3], Gema Martínez-Criado[4,5], Maurizio Ritzer[1], Konrad Ritter[1], Carsten Ronning[1], and Claudia Sarah Schnohr[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg, Stuttgart, Germany — [3]Otto-Schott-Institut, Friedrich-Schiller-Universität Jena, Germany — [4]Instituto de Ciencia de Materiales de Madrid, Spain — [5]European Synchrotron Radiation Facility, Grenoble, France

$Cu(In,Ga)Se_2$ solar cells are the most efficient ones among all thin film photovoltaics. The current world record efficiency was realized by applying a RbF post deposition treatment (PDT) to the absorber. However, it is not clear why the introduced Rb improves the solar cell performance. In order to investigate the beneficial effect of Rb, a $Cu(In,Ga)Se_2$ absorber was grown on a Mo coated alkali free substrate and subjected to a RbF PDT. This pure RbF PDT leads to a significantly higher efficiency. A thin cross sectional lamella was cut out of the layer stack and investigated via a combination of electron microscopy and synchrotron based x-ray fluorescence analysis. This approach provides clear indications of the origin of the beneficial effect of Rb. It is evident that Rb segregates at random grain boundaries and dislocation cores, where it likely passivates defects. In contrast, Rb does not segregate at $\Sigma 3$ twin boundaries. Additionally, Rb agglomerates at the interface between the absorber and the $MoSe_2$ layer.

HL 6.3 Mon 10:00 EW 203

Computational investigation of quantum well superlattice solar cells — Urs Aeberhard[1] and •Jose Maria Ulloa[2] — [1]IEK-5 Photovoltaik, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Institute for Systems based on Optoelectronics and Microtechnology (ISOM), Universidad Politécnica de Madrid, Ciudad Universitaria s/n, E-28040 Madrid, Spain

Quantum well superlattices (QWSL) are widely considered as tunable absorbers in high-efficiency multi-junction solar cells. In conventional models for the photovoltaic properties of QWSL, the latter is treated as an effective bulk medium with modified material parameters derived from a perfectly periodic structure, where transport is assumed to proceed in band-like fashion via extended superlattice Bloch states. In realistic implementations, deviations from this flat-band bulk picture are induced by the presence of built-in fields, scattering and disorder, as well as the finite number of periods.

We quantify these deviations using a comprehensive non-equilibrium quantum statistical mechanics approach to the computation of charge carrier dynamics in non-idealized QWSL. By consideration of the spectral information on density of states, scattering rates and current flow, we specifically address the transition from QWSL to multi-quantum-well behavior with increasing period thickness, type-I vs type-II band alignment, the effect of the number of SL periods, as well as the impact of electron-phonon scattering, built-in fields and disorder in the heterostructure potential. The findings are related to experimental data from type-I GaAs/GaAsNSb and type-II GaAsN/GaAsSb QWSL.

HL 6.4 Mon 10:15 EW 203

Band-gap tuning of $Cu_2ZnSn(S,Se)_4$ solar cell absorbers via defined adjustment of the chalcogenide ratio using a post-sulphurization process — •Markus Neuwirth[1], Elisabeth Seydel[1], Jasmin Seeger[1], Alexander Welle[2,3], Heinz Kalt[1], and Michael Hetterich[4] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Institute of Functional Interfaces, Karlsruhe Institute of Technology (KIT), 76344 Eggenstein-Leopoldshafen — [3]Karlsruhe Nano Micro Facility, Karlsruhe Institute of Technology (KIT), 76344 Eggenstein-Leopoldshafen — [4]Light Technology Institute, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe

Kesterite $Cu_2ZnSn(S,Se)_4$ (CZTSSe) thin-film solar cells are promising candidates for the future photovoltaic market. One of their very interesting and useful features is the tunability of their absorber band gap. In our work we achieve this by tuning the chalcogenide ratio x = [S]/([S]+[Se]) from close to 0 up to 1, which corresponds to a band-gap range of about 1.0 eV up to 1.5 eV. Experimentally this is done by post-annealing selenium-rich ($x = 0.1$) absorbers in a sulphur atmosphere. By varying the temperature and process hold time during this post-sulphurization step, we are able to accurately adjust x. Studies of the elemental composition give insight into the sulphur incorporation process which seems to be strongly correlated with the absorber's morphology before post-sulphurization. Further morphology studies and current-voltage characteristics of the solar cells show a clear trend for the dependency of the device performance on process parameters.

HL 6.5 Mon 10:30 EW 203

Element-specific atomic-scale structure of $Cu_2(Zn,Fe)SnS_4$ kesterite-stannite alloys — •Cora Preiss[1], Konrad Ritter[1], Stefanie Eckner[1], Philipp Schöppe[1], Susan Schorr[2], and Claudia S. Schnohr[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin & Institut für Geologische Wissenschaften, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany

The chalcogenides Cu_2ZnSnS_4 (kesterite) and Cu_2FeSnS_4 (stannite) are interesting as potential photovoltaic absorbers being non-toxic and earth-abundant. In $Cu_2(Zn,Fe)SnS_4$, the S anions are surrounded by different local cation configurations. Therefore, Cu_2ZnSnS_4, Cu_2FeSnS_4, and their solid solutions with different Zn/(Zn+Fe) ratios were investigated with extended X-ray absorption fine structure spectroscopy. The absorption was measured at the K-edges of Cu, Zn, Sn, and Fe thus revealing the element-specific bond lengths of the material. All bond lengths are nearly independent of composition, yet they differ substantially for the different elements. While the Cu-S and Fe-S bond lengths are identical, the Zn-S and Sn-S bond lengths are larger by about $\sim$0.03 and 0.12 Å, respectively. Based on these experimental results, the S anion position is modelled for two possible cation nearest neighbour configurations. The S position is clearly different in the Zn and the Fe containing environment, leading to an intrinsic structural inhomogeneity on the submicrometer scale.

HL 6.6 Mon 10:45 EW 203

CZTSe solar cells prepared by co-evaporation of Cu-Sn/CZTSe/ZnSe/CZTSe layer stacks — •Lwitiko Mwakyusa[1,3], Markus Neuwirth[1], Ulrich Paetzold[3], Bryce Richards[2,3], Heinz Kalt[1], and Michael Hetterich[2] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe — [2]Light Technology Institute, (KIT), 76131 Karlsruhe — [3]Institute of Microstructure Technology, (KIT), 76344 Karlsruhe

CZTSe solar cells are a promising alternative for CIGS- and CdTe-

based technologies because they only comprise non-toxic and earth-abundant elements. However, the main concern of this approach is the low conversion efficiency compared to CIGS and CdTe. Essentially, CZTSe device performance is limited by a high open-circuit voltage ($\boldsymbol{V}$oc) deficit and a low fill factor ($\boldsymbol{FF}$). It is often assumed that this is related to a high recombination rate at the heterojunction and Mo/CZTSe interface. It is has been proven that, the reaction of Mo and CZTSe promotes the formation of a thicker $MoSe_2$ layer as well as unwanted phases and defects at the interface. The latter could harm solar cell performance, especially $\boldsymbol{V}$oc, series resistance ($\boldsymbol{R}$s) and $\boldsymbol{FF}$. To suppress this challenge, alloyed precursors with a configuration of Mo/Cu-Sn/CZTSe/ZnSe/CZTSe are employed in this work and compared to single-layered co-evaporated CZTSe precursors with respect to material growth and device performance. The presence of an alloyed Cu-Sn seed layer prevents earlier interaction of the CZTSe absorber with the Mo back-contact. In addition the influence of annealing of each stacked layer on the growth and device performance is examined.

HL 6.7 Mon 11:00 EW 203

Atomic-scale structure of $Cu_2Zn(Sn,Ge)Se_4$ kesterite alloys — •Konrad Ritter[1], Cora Preiss[1], Galina Gurieva[2], René Gunder[2], Stefanie Eckner[1], Roman Chernikov[3], Edmund Welter[3], Susan Schorr[2,4], and Claudia S. Schnohr[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner Platz 1, 14109 Berlin, Germany — [3]Deutsches Elektronen Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany — [4]Institut für Geologische Wissenschaften, Freie Universität Berlin, Malteserstr. 74-100, 12249 Berlin, Germany

Kesterites offer a wide range of promising absorber materials for photovoltaics, but the record efficiency has not exceeded 12.6% yet. Alloying Sn with Ge or replacing it completely has been used in many different approaches in the literature. However, doing so might change the local structure of the material, which has been shown to influence macroscopic material properties such as the band gap energy. Extended X-ray Absorbtion Fine Structure Spectroscopy allows the local interatomic bond lengths to be probed and correlated with Ge content or off-stoichiometry of $Cu_2Zn(Sn,Ge)Se_4$ powder samples from solid state reactions. For the $Cu_2Zn(Sn,Ge)Se_4$ alloys it can be seen, that Ge uses the least space in the lattice and Sn the most. Furthermore, the nearest neighbour bond lengths do not change significantly with composition. This holds true for off-stoichiometric $Cu_2ZnGeSe_4$ samples as well.

15 min. break.

HL 6.8 Mon 11:30 EW 203

Compositional inhomogeneity in kesterite thin film solar cell absorbers — •Maurizio Ritzer[1], Sven Schönherr[1], Philipp Schöppe[1], Sergio Giraldo[2], Gerardo Larramona[3], Galina Gurieva[4], Konrad Ritter[1], Gema Martínez-Criado[5], Susan Schorr[4,6], Gilles Dennler[3], Edgardo Saucedo[2], Carsten Ronning[1], and Claudia S. Schnohr[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Germany — [2]Catalonia Institute for Energy Research, Spain — [3]IMRA Europe S.A.S., France — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, Germany — [5]Instituto de Ciencia de Materiales de Madrid, Spain — [6]Institut für Geologische Wissenschaften, Freie Universität Berlin, Germany

Kesterite $Cu_2ZnSnSe_4$ (CZTSe) is a promising absorber material for thin film solar cells. However, it often contains secondary phases that can limit their conversion efficiency. Moreover, the local kesterite composition may fluctuate on different length scales. High resolution, spatially resolved X-ray beam investigations enable insights into such compositional variations. Thin cross section lamellas were prepared out of complete solar cells using a focused ion beam system, in order to achieve high spatial resolution and to minimize averaging along the beam direction. Subsequently, the lamellas were scanned with the highly focused X-ray beam of 50 nm at the ID16B-NA station of the ESRF and by analyzing the emitted fluorescence (XRF) radiation we obtained elemental distribution maps. Thus, our approach easily allows to compare the composition within single grains and even grain boundaries.

HL 6.9 Mon 11:45 EW 203

Identification of transparent p-type conducting non-oxide materials from high-throughput calculations — •Ramya Kormath Madam, Thomas Kühne, and Hossein Mirhosseini — Department of Chemistry, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

Transparent conducting materials (TCMs) have attracted attention owing to their diverse applications. Materials having wide bang gap and low carrier effective mass have been considered as potential TCMs. Transparent conducting oxides (TCOs) have been largely commercialized as n-type TCMs in transistors, UV light emitting diodes, gas sensors, and tandem cells. However, the designing of efficient p-type TCOs are mainly hindered owing to the localized p character of their valence band which results in heavy holes. Hence, it is necessary to search for alternative potential p-type TCMs. In this work, high-throughput calculations were employed to determine the most promising p-type TCMs among chalcogenides. A large computational data set were investigated by data screening. Binary chalcogenides with band gaps $>$ 1.7 eV and hole effective masses $<$ 1 were considered for this study. Defect physics were investigated to probe the p-type performance of these semiconductors.

HL 6.10 Mon 12:00 EW 203

High-Throughput Computational Assessment of Previously Synthesized Semiconductors for Photovoltaic and Photoelectrochemical Devices — Korina Kuhar, •Mohnish Pandey, Kristian Thygesen, and Karsten Jacobsen — Technical University of Denmark (DTU), Lyngby - 2800, Denmark

We use computational screening to identify materials as light absorbers for photovoltaic (PV) and photoelectrochemical (PEC) devices. The screening is carried out on already synthesized compounds present in the ICSD database although yet unexplored for the PV and PEC applications. With thorough analyses of the properties like light absorption, charge carrier mobility, and defect tolerance we identify 74 materials including few already explored PV and PEC absorbers. Several recently investigated light absorbers such as $CsSnI_3$, $CsSnBr_3$, and $BaZrS_3$ also appear on the list.

HL 6.11 Mon 12:15 EW 203

Aluminum oxide passivation layers for Cu(In,Ga)Se2 thin-film solar cells — •Florian Werner[1], Conrad Spindler[1], Susanne Siebentritt[1], Dimitri Zielke[2], and Jan Schmidt[2] — [1]Laboratory for Photovoltaics, Physics and Materials Science Research Unit, University of Luxembourg, L-4422 Belvaux, Luxembourg — [2]Institute for Solar Energy Research Hamelin (ISFH), Am Ohrberg 1, D-31860 Emmerthal, Germany

We employ ac and dc electrical measurements and photoluminescence to investigate the growth and passivation performance of aluminum oxide layers deposited by plasma-assisted atomic layer deposition (ALD) on Cu(In,Ga)Se2. Already few monolayers of aluminum oxide hinder current flow through the device and result in non-linear current-voltage characteristics, which scale with the nominal thickness of the passivation layer. This indicates that a compact insulating layer is formed already after a few ALD cycles despite the larger surface roughness and different surface chemistry compared to standard single-crystalline silicon. Using plasma-assisted ALD, as-deposited aluminum oxide layers do not provide any meaningful surface passivation. Annealing for several minutes even at moderate temperatures of 350 °C results in a drastic improvement of the effective carrier lifetime, resulting in a level of surface passivation comparable to optimized CdS buffer layers. For such moderate annealing conditions we do not observe any indication of the formation of negative fixed charges, which would suppress interface recombination even further. A higher thermal budget, however, has so far led to a degradation of the passivated devices.

HL 6.12 Mon 12:30 EW 203

Insight into local fluctuations of net doping and lifetime in Cu(In,Ga)Se_2 solar cells — •Maximilian Krause[1], Aleksandra Nikolaeva[1], Jose Marquez[1], Charles Hages[1], Sergej Levcenko[1], Thomas Unold[1], Wolfram Witte[2], Dimitrios Hariskos[2], and Daniel Abou-Ras[1] — [1]Helmholtz-Zentrum Berlin, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Meitnerstr. 1, 70563 Stuttgart, Germany

It is known that local fluctuations in net doping and lifetime present in polycrystalline Cu(In,Ga)Se_2 (CIGS) thin films (with $\frac{[Ga]}{[In]+[Ga]} = 0.33$) can deteriorate the device performance of the corresponding solar cells via enhanced recombination. In order to investigate such fluctuations, electron-beam-induced current (EBIC) measurements were performed in a SEM on CIGS solar cells with different buffer lay-

ers: CdS, Zn(O,S), and In_2S_3 grown by chemical bath deposition. By fitting EBIC signals using appropriate models, the widths of the space-charge region, w_{SCR}, and also the diffusion lengths of the minority charge-carriers, L_D, were extracted. The order of magnitude of these values (400-500 nm and 1-2 μm) was verified by capacitance-voltage and quantum efficiency measurements. Although the values for w_{SCR} and therefore the average net doping of the CIGS layers were the same in the solar cells with the different buffer layers, substantial local variations of w_{SCR} were detected parallel to the p-n junction, which depend on the buffer/window stack applied. The present contribution discusses the impact of these fluctuations on the limitations of the device performance.

HL 6.13 Mon 12:45 EW 203

Inhomogeneities in wide-gap Cu(In,Ga)Se_2 solar cells — •Aleksandra Nikolaeva[1], Maximilian Krause[1], Jose Marquez[1], Charles Hages[1], Sergej Levcenko[1], Thomas Unold[1], Wolfram Witte[2], Dimitrios Hariskos[2], and Daniel Abou-Ras[1] — [1]Helmholtz-Zentrum Berlin, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Meitnerstr. 1, 70563 Stuttgart, Germany

Inhomogeneities in Cu(In,Ga)Se_2 solar cells related to the different net doping densities N_A in neighboring grains can limit the open-circuit voltage. The present work gives insight into local electrical and optoelectronic properties of wide-gap Cu(In,Ga)Se_2 solar cells ([Ga]/([In]+[Ga])=0.66) with different buffer layers by using electron-beam-induced current (EBIC) and cathodoluminescence measurements. Combining these techniques on the same identical position of cross-sectional specimens makes it possible to investigate the spatial distribution of inhomogeneities in the corresponding solar cells. From the EBIC profiles perpendicular to the substrate, values for the widths of the space-charge region w_{SCR}, which are proportional to $N_A^{-0.5}$, as well as for the diffusion lengths L_D of the charge carriers (related to the lifetime of the minority charge carriers) were extracted. It is shown that w_{SCR} and therefore N_A exhibits fluctuations depending on the buffer layer applied. The average values of w_{SCR} and L_D were confirmed by capacitance-voltage and quantum efficiency analysis of the solar cells.

HL 7: Topological insulators I (joint session HL/TT)

Time: Monday 9:30–13:00 Location: A 151

HL 7.1 Mon 9:30 A 151

Model for ferromagnetic Weyl and nodal line semimetals: topological invariants, surface states, anomalous and spin Hall effect — Tomáš Rauch[1,2], Huong Nguyen-Minh[1], •Jürgen Henk[1], and Ingrid Mertig[1,3] — [1]Institute of Physics, Martin Luther University Halle-Wittenberg, Halle, Germany — [2]Berc Materials Physics Center, Donostia–San Sebastián, Spain — [3]Max Planck Institute for Microstructure Physics, Halle, Germany

By adding a Zeeman term to the extended Dirac equation [1] we show that this equation describes not only topological insulators but also models the electronic properties of ferromagnetic Weyl and nodal line semimetals [2], both of which arise for specific parameter sets. We confirm the topological nontriviality of the nodal objects by calculating the topological invariants as well as by demonstrating the existence of characteristic topological surface states of the associated semi-infinite systems. Moreover, Weyl points and nodal lines produce notable features in the anomalous and in the spin Hall conductivity.

[1] S.-Q. Shen, W.-Y. Shan, and H.-Z. Lu, Spin **1**, 33 (2011).

[2] T. Rauch, H. Nguyen-Minh, J. Henk, and I. Mertig, Phys. Rev. B, submitted.

HL 7.2 Mon 9:45 A 151

Transport Spectroscopy of Induced Superconductivity in the three-dimensional Topological Insulator HgTe — •Jonas Wiedenmann — Experimentelle Physik III, Universität Würzburg, Am Hubland, 97074 Würzburg

Inducing superconducting pairing into the surface states of a topological insulator is predicted to lead to the emergence of mixed spin singlet/triplet superconducting correlations and Majorana bound state related physics. We studied the proximity-induced superconducting state into the topological surface states of strained bulk HgTe by Andreev reflection point-contact spectroscopy. By analyzing the conductance as a function of voltage for various temperatures, magnetic fields and gate-voltages, we find evidence, in equilibrium, for an induced order parameter in HgTe of 0.070 meV and an order parameter of the superconducting gap of niobium of 1.1 meV. To describe the full conductance curve we suggest that a charge imbalance suppresses the induced superconducting state. As a result the relevant scattering region changes depending on the applied bias voltage.

HL 7.3 Mon 10:00 A 151

Interplay between topology and disorder in a two-dimensional semi-Dirac material — P V Sriluckshmy, •Kush Saha, and Roderich Moessner — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We investigate the role of disorder in a two-dimensional semi-Dirac material characterized by a linear dispersion in one, and a parabolic dispersion in the orthogonal, direction. Using the self-consistent Born approximation, we show that disorder can drive a topological Lifshitz transition from an insulator to a semi-metal, as it generates a momentum independent off-diagonal contribution to the self-energy. Breaking time-reversal symmetry enriches the topological phase diagram with three distinct regimes– single-node trivial, two-node trivial and two-node Chern. We find that disorder can drive topological transitions from both the single- and two-node trivial to the two-node Chern regime. We further analyze these transitions in an appropriate tight-binding Hamiltonian of an anisotropic hexagonal lattice, by calculating the real-space Chern number. Additionally we compute the disorder-averaged entanglement entropy which signals both the topological Lifshitz and Chern transition as a function of the anisotropy of the hexagonal lattice. Finally, we discuss experimental aspects of our results.

HL 7.4 Mon 10:15 A 151

Optical properties of topological insulator nanoparticles — •Gleb Siroki, Derek Lee, Peter Haynes, and Vincenzo Giannini — Imperial College London, South Kensington, SW7 2AZ, London, UK

Topological insulators are materials that have metallic surface states protected by time-reversal symmetry. Such states are delocalised over the surface and are immune to non-magnetic defects and impurities.

Building on previous work [1] we have studied the interaction of light with topological insulator nanoparticles. Our main finding is that the occupied surface states can lead to charge density oscillations akin to plasmons in metallic nanoparticles. Furthermore, these oscillations can couple to phonons forming a previously unreported excitation [2]. Because the states occur at the surface a small number of them is enough to change the absorption spectrum of a particle containing many thousands of atoms. We are going to show how the effect can be adjusted by varying the particle's size and shape. Furthermore, we will discuss the robustness of the effect in the presence of disorder [3].

In conclusion, topological insulator nanoparticles can be used as a highly-tunable building block to create a metamaterial operating in THz range. This may be interesting for plasmonics and metamaterials communities as well as researchers working on cavity electrodynamics and quantum information.

[1] Imura et al, PRB 86, 235119 (2012)
[2] Siroki et al, Nat. Comm. 7, 12375 (2016)
[3] Siroki et al, PRMaterials, 1, 024201 (2017)

HL 7.5 Mon 10:30 A 151

Multi probe transport measurements on Bi_2Te_3 thin films — •Sebastian Bauer, Stephanie Hoepken, Mandana Soleimani, Christian A. Bobisch, and Rolf Möller — Faculty of Physics, Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, 47048 Duisburg, Germany

We present a detailed study of the electron transport properties of a thin Bi_2Te_3 film on Si(111). Bi_2Te_3 is a prototype system of so called three dimensional topological insulators. Such materials are insulating inside their bulk while they provide a metallic state on their surface

which is protected by the materials topology [1]. The nanoscale transport field of the Bi_2Te_3 surface was studied by scanning tunneling potentiometry (STP), an extension of the scanning tunneling microscope (STM) which allows us to analyze the microscopic topography and the correlated microscopic electrochemical potential of the surface simultaneously [2]. The STP analysis shows that morphological features like step edges and grain boundaries are barriers for conduction electrons. The conductivity of step edges and grain boundaries were determined to 700 S/cm and 350 S/cm in the surface state, confirming former STP studies [3,4].

[1] M. Z. Hasan, C. L. Kane, Rev. Mod. Phys. 82, 3045 (2010). [2] A. Bannani, C. A. Bobisch, R. Möller, Rev. Sci. Instrum. 79, 083704 (2008). [3] S. Bauer und C. A. Bobisch, Nat. Com. 7, 11381 (2016). [4] F. Lüpke et al., Nat. Com. 8, 15704 (2017).

HL 7.6 Mon 10:45 A 151

Mixed topological semimetals in two-dimensional spin-orbit ferromagnets — •Chengwang Niu[1], Jan-Philipp Hanke[1], Patrick M. Buhl[1], Hongbin Zhang[2], Gustav Bihlmayer[1], Daniel Wortmann[1], Stefan Blügel[1], and Yuriy Mokrousov[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Materials Science, Technische Universität Darmstadt, 64287 Darmstadt, Germany

Topological states of matter and ferromagnetism in two dimensions are nowadays two of the most intriguing and intensively researched fields in solid state physics. Here, we predict that diverse topological semimetallic phases can be obtained in 2D ferromagnets as a consequence of the spin-orbit driven changes in the electronic structure as the magnetization direction is varied. We show that the most natural way to classify these phases lies in analyzing either points or lines of degeneracies which occur in an extended phase space of Bloch vector and the magnetization direction. The emergence of the corresponding topological states, which we refer to as mixed Weyl semimetal and mixed nodal line semimetal, respectively, can be thereby confirmed by accessing corresponding topological invariants and edge states. We demonstrate the possible complexity of the topological phase diagram of 2D ferromagnets based on several model systems, and, using density functional theory, we identify two realistic examples exhibiting mixed Weyl semimetal and mixed nodal line semimetal phases.

This work was supported by SPP 1666 of the DFG.

HL 7.7 Mon 11:00 A 151

Microscopic theory of the surface anomalous Hall conductivity — •Tomáš Rauch[1], Thomas Olsen[2], David Vanderbilt[3], and Ivo Souza[1,4] — [1]Centro de Física de Materiales, San Sebastián, Spain — [2]Technical University of Denmark, Kongens Lyngby, Denmark — [3]Rutgers University, Piscataway, New Jersey, USA — [4]Ikerbasque Foundation, Bilbao, Spain

The dimensionless axion coupling θ describes the isotropic part of the linear magnetoelectric tensor. In a bulk crystal θ is only defined modulo 2π, and only its space-time gradients enter Maxwell's equations. At surfaces, the spatial gradient of θ gives rise to a surface anomalous Hall conductivity (AHC). In this work, we derive a microscopic expression for the AHC of an insulating surface. We find that in general it comprises not only a geometric contribution that is a property of the occupied states, but also a non-geometric "cross-gap" term that is absent from the expression for the intrinsic AHC of a free-standing film or slab. By constructing tight-binding models in a slab geometry, we numerically test our analytical results and explore the connection between the surface AHC and the bulk axion coupling. In particular, we illustrate how different insulating surfaces of the same bulk crystal can have AHCs that differ by an integer multiple of e^2/h, and that this difference resides in the geometric term alone.

15 min. break.

HL 7.8 Mon 11:30 A 151

A room-temperature and switchable Kane-Mele quantum spin Hall insulator — •Antimo Marrazzo, Marco Gibertini, Davide Campi, Nicolas Mounet, and Nicola Marzari — Theory and Simulation of Materials (THEOS) and National Centre for Computational Design and Discovery of Novel Materials (MARVEL), Ecole Polytechnique Federale de Lausanne, 1015, Switzerland

Fundamental research and technological applications of topological insulators are hindered by the rarity of materials exhibiting a robust topologically non-trivial phase, especially in two dimensions (2D). Here, by means of extensive first-principles calculations, we propose a novel quantum spin Hall insulator (QSHI) with a sizeable band gap of ∼0.5 eV at the G_0W_0 level, that is a monolayer of a naturally occurring layered mineral. This system realises the paradigmatic Kane-Mele model for QSHIs in a potentially exfoliable 2D monolayer with helical edge states that are robust even beyond room temperature and that can be manipulated exploiting a unique strong interplay between spin-orbit coupling, crystal-symmetry breaking, and dielectric response.

HL 7.9 Mon 11:45 A 151

Testing Topological Protection of Edge States in Bismuthene on SiC — •Fernando Dominguez[1], Benedikt Scharf[1], Gang Li[2], Werner Hanke[3], Ronny Thomale[3], and Ewelina Hankiewicz[1] — [1]Institute for Theoretical Physics and Astrophysics, TP4, University of Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]School of Physical Science and Technology, ShanghaiTech University, Shanghai 201210, China — [3]Institute for Theoretical Physics and Astrophysics, TP1, University of Würzburg, Am Hubland, 97074 Würzburg, Germany

Due to its large bulk band gap, bismuthene on SiC offers intriguing new opportunities for room-temperature quantum spin Hall (QSH) applications. Although edge states have been observed in the local density of states (LDOS), there has been no experimental evidence until now that they are spin polarized and topologically protected. Here, we predict experimentally testable fingerprints of these properties originating from magnetic fields, such as changes in the LDOS and in ballistic magnetotransport due to a gap of a few meV opened at the crossing point between the QSH states. For armchair edges in particular, we find a distinct difference of behavior under out-of-plane (gap opening between the QSH states) and in-plane (no or tiny gap) fields. This unexpected robustness of armchair QSH edge states against in-plane fields can be understood from an effective low-energy model, where a helicity operator provides an additional protection of the QSH states. While we focus here on bismuthene on SiC, our main findings should also be applicable to other honeycomb-lattice-based QSH systems.

HL 7.10 Mon 12:00 A 151

High-temperature quantum oscillations of the Hall resistance in bulk Bi_2Se_3 — •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, 12489 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

Protected topological surface states (TSS) with helically spin-polarized Dirac fermions (HSDF) are of high interest as a new state of quantum matter. Electronic bulk states in three-dimensional (3D) materials with TSS often mask the transport properties of HSDF. In recent work, the high-field Hall resistance and low-field magnetoresistance indicate that the TSS may coexist with a layered two-dimensional electronic system (2DES) [1]. Here, we demonstrate quantum oscillations of the Hall resistance for temperatures up to 50 K, in nominally undoped bulk Bi_2Se_3 with a high electron density n of about $2{\cdot}10^{19}$ cm^{-3}. From the angular and temperature dependence of the Hall resistance and the Shubnikov-de Haas oscillations we identify 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 that the coexistence of TSS and 2D layered transport stabilizes the quantum oscillations of the Hall resistance.

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

HL 7.11 Mon 12:15 A 151

Exploiting Topological Insulators for Majorana Devices — •Peter Schüffelgen[1], Daniel Rosenbach[1], Chuan Li[2], Michael Schleenvoigt[1], Tobias Schmitt[1], Sarah Schmitt[1], Abdur Jalil[1], Jonas Kölzer[1], Lidia Kibkalo[1], Benjamin Bennemann[1], Umut Parlak[1], Martina Luysberg[1], Gregor Mussler[1], Alexander Golubov[2], Alexander Brinkman[2], Thomas Schäpers[1], and Detlev Grützmacher[1] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, D-52425 Jülich, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, 7500AE Enschede, The Netherlands

At the interface of s-wave superconductors (SC) and topological insulators (TI) exotic Majorana modes are predicted to occur. In this work, a

novel fabrication technique is presented, which allows to construct TI-SC hybrid devices of high quality under ultra-high vacuum conditions. A stencil mask is applied to the substrate before growth of Bi-based TI thin films by means of molecular beam epitaxy. The shadow mask is used for stencil lithography of superconductive electrodes on top of the topological thin film in a second growth step. Measurements on such in-situ fabricated Josephson junctions indicate a high interface transparency. Furthermore, a missing first Shapiro step was detected in radio frequency experiments, indicating signatures of gapless Andreev bound states, so-called Majorana bound states. The presented process is applicable to a variety of new geometries, allowing fabrication of elaborated TI-SC hybrid devices, for further research on Majorana signatures.

HL 7.12 Mon 12:30 A 151

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

We report on the realization of one-dimensional topological states of matter within electrical circuits. At the example of the Su-Schrieffer-Heeger circuit, we elaborate how topological edge states and domain walls manifest themselves in the impedance read-out of a periodic electrical circuit. We further outline prospective generalizations and applications.

HL 7.13 Mon 12:45 A 151

Topolectrical Band Structures — •Tobias Hofmann[1], Tobias Helbig[1], Ching Hua Lee[2,3], and Ronny Thomale[1] — [1]Institute for Theoretical Physics and Astrophysics, University of Würzburg, Am Hubland, D-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 constitute a new avenue of topological states realized in a classical environment. With them, it is possible to reproduce band structures seen in models for topological insulators (TI) where the bands correspond to impedance (or admittance) eigenvalues. Because electrical circuits are more easily accessible than TIs, they are particularly suitable for studying topological states, reaching from the simplest models to non-hermitian and other types of rather "exotic" physics. In our talk, we illustrate the explicit measurement of topological band structures in the context of topolectrical circuits.

HL 8: 2D materials (joint session HL/DS)

Time: Monday 15:00–16:30 Location: EW 201

HL 8.1 Mon 15:00 EW 201

Predicting and Understanding Quantum Spin Hall Insulators with the Help of Compressed Sensing/SISSO — Carlos Mera Acosta[1,2], Runhai Ouyang[1], Adalberto Fazzio[2], Matthias Scheffler[1], Luca Ghiringhelli[1], and •Christian Carbogno[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin — [2]University of São Paulo, São Paulo, Brazil

Quantum Spin Hall insulators (QSHIs), i.e., two-dimensional insulators with conducting edge states protected by time-reversal symmetry, have attracted considerable scientific interest in recent years. In this work, we perform first-principles calculations to compute the Z_2-invariant for 220 functionalized honeycomb-lattice materials. Using the recently developed sure independence screening and sparsifying operator (SISSO) method [1], we derive a "map of materials", in which metals, trivial insulators, and QSHIs are spatially separated. The axes of this map are defined by physically meaningful descriptors, i.e., non-linear functions that only depend on the properties of the material's constituent free atoms. First, this yields fundamental insights into the mechanisms driving topological transitions. Second, we are able to predict the topological character of materials that are not part of the originally investigated set just from their position on the map (predictive power greater than 95%). By this means, we are able to predict 89 yet unknown QSHIs.
[1] Runhai Ouyang *et al.*, *arXiv:1710.03319* (2017).

HL 8.2 Mon 15:15 EW 201

Superconductivity and electron-phonon properties of intrinsic and doped antimonene — •Andrei Lugovskoi, Mikhail Katsnelson, and Alexander Rudenko — Institute for Molecules and Materials, Radboud University Nijmegen, Nijmegen, The Netherlands

Antimonene is a recently discovered elemental 2D phase of Sb with buckled honeycomb structures. The material was successfully obtained experimentally, and posses interesting set of properties. It was shown to have high stability on base of both experimental observations and *ab initio* modeling, and is also predicted to have interesting optical properties and strain tunable band gap. At the same time, superconductivity in doped phosphorene and graphene was recently observed experimentally, which opens new opportunities for the application of 2D materials.

We present the *ab initio* calculations of electron-phonon coupling properties and critical superconducting temperature in both n- and p-doped antimonene at experimentally achievable carrier concentrations. The effects of small strains and bias voltage on the critical temperature are also considered. Required quantities are obtained by using density functional theory implementation of electron-phonon Wannier-Fourier interpolation in EPW and QE codes. Critical temperature at various carrier densities is estimated using McMillan-Allen-Dynes equation.

The work is a part of the research program "Two-dimensional semiconductor crystals" (prj. 14TWOD01), which is partly financed by the Netherlands Organization for Scientific Research (NWO).

HL 8.3 Mon 15:30 EW 201

Dielectric Engineering of Intra-excitonic Correlations in a van der Waals Heterostructure — •Philipp Steinleitner[1], Philipp Merkl[1], Alexander Graf[1], Philipp Nagler[1], Christian Schüller[1], Tobias Korn[1], Rupert Huber[1], Samuel Brem[2], Malte Selig[3], Gunnar Berghäuser[2], and Ermin Malic[2] — [1]Department of Physics, University of Regensburg, Regensburg, Germany — [2]Department of Physics, Chalmers University of Technology, Gothenburg, Sweden — [3]Department of Theoretical Physics, Technical University of Berlin, Berlin, Germany

Atomically thin transition metal dichalcogenide monolayers promise novel optoelectronic applications due to their direct bandgap in the optical range. Reduced Coulomb screening, in combination with the two-dimensionality, stabilizes excitons, even at room temperature. Due to the extreme confinement perpendicular to the plane of the material, excitons are particularly sensitive to the local surrounding environment. Thus, capping the monolayer with a dielectric material allows one to non-invasively change their hydrogen-like structure. Here we report how an insulating hexagonal boron nitride cover layer influences the intra-excitonic 1s-2p transition. Using time resolved pump/THz probe techniques, we trace both optically bright and dark exciton states and are able to extract quantitative information about transition energies and linewidths. We find that the cover layer redshifts the 1s-2p transition and leads to a decrease of its linewidth. Using microscopic modelling, we show that our experimental data also support the formation of dark excitons from an initially bright population.

HL 8.4 Mon 15:45 EW 201

high-throughput search of novel 2d materials for electronic and optoelectronic applications — •davide campi, thibault sohier, antimo marrazzo, marco gibertini, nicolas mounet, and nicola marzari — Theory and simulation of materials (THEOS) and national center for computational design and discovery of novel materials (MARVEL), école polytechnique fédéral lausanne, ch-1015, lausanne, switzerland

2D materials provide a novel paradigm and toolbox for materials scientists to discover or engineer new properties and functionalities. However, the handful of 2D materials intensively studied up to now represent only a few of the manifold possibilities. In this work we present the results of an applications-oriented screening that, using state-of-the-art first-principles simulations and automatized high-throughput calculations through the AiiDA platoform[1], identifies new promising candidates for field effect transistors (FET), photocatalytic water splitting and nanoporous crystalline membranes, selected among the hindreds

of 2D materials (1844)[2] discovered by performing a "computational exfoliation" of a dataset of more than 100000 bulk parent structures.

[1] G.Pizzi, A.Cepellotti, R.Sabatini, N.Marzari and B.Kozinsky, Comp. Mat. Sci. 111, 218 (2016). [2] N.Mounet, M.Gibertini, P.Schwaller, D.Campi, A.Merkys, A.Marrazzo, T.Sohier, I.E.Castelli, A.Cepellotti, G.Pizzi and N.Marzari, in press (2018).

HL 8.5 Mon 16:00 EW 201

Spin- and valley-dependent transport through a 2D semiconductor with magnetic substrate — •Gerhard Fechteler, Andor Kormányos, and Guido Burkard — University of Konstanz, Germany

Motivated by recent theoretical [1] and experimental [2,3] works, we study spin- and valley-dependent electron scattering in monolayers of transition metal dichalcogenides through a region with an underlying magnetic substrate. The valley splitting and changes in the parameters such as Fermi velocity and effective electron mass induced by the magnetic substrate lead to novel spin- and valley selection possibilities compared to gated structures [4]. Neglecting Rashba spin-orbit coupling (SOC), we study the Fermi energy and incident angle dependence of spin and valley selective scattering processes. Moreover, we find pronounced and tuneable Goos-Hänchen shifts. In the presence of Rashba SOC, we find that the transmitted and reflected electron beams are split due to spin mixing in the scattering region. Such a spin-dependent scattering can prove useful for the design of novel spintronic devices. [1] J. Qi et al., Phys. Rev. B 92, 121403 (2015). [2] C. Zhao et al., Nat. Nanotechnol. 12, 757-760 (2017). [3] D. Zhong et al., Sci. Adv. 3, e1603113 (2017). [4] H. Ghadiri et al., J. Phys.: Condens. Matter 29, 115303 (2017).

HL 8.6 Mon 16:15 EW 201

Electron quantum optics in anisotropic pseudospin one systems — •Yonatan Betancur Ocampo and Dario Bercioux — Donostia International Physics Center (DIPC), Paseo Manuel de Lardizabal, 4 20018 Donostia-San Sebastián, Spain

We proposed the development of electron quantum optics devices through heterojunctions formed by anisotropic and relativistic pseudospin one materials. Based on our theoretical calculations, we found that the probability transmission, reflection and refraction law present atypical behavior. We have shown that collimation effect, Veselago lenses, and beam splitters are enhanced using pseudospin one particles. Moreover, novel quantum optics devices could be designed such as asymmetric Veselago and diverging lenses. Our findings suggest that these devices can be built from the strain-engineering of Lieb lattices.

HL 9: III-V semiconductors (other than nitrides)

Time: Monday 15:00–17:30 Location: EW 202

HL 9.1 Mon 15:00 EW 202

Resonant inelastic light scattering on indirect excitons and overflow of dipolar traps at high magnetic fields — •Lukas Sponfeldner[1], Sebastian Dietl[1], Lukas Sigl[1], Katarzyna Kowalik-Seidl[2], Dieter Schuh[3], Werner Wegscheider[4], Jörg Kotthaus[2], Aron Pinczuk[5], Ursula Wurstbauer[1], and Alexander W. Holleitner[1] — [1]Walter Schottky Institut und Physics Department, Am Coulombwall 4a, Garching, TU Munich, Germany. — [2]Center for Nanoscience and Fakultät für Physik, LMU, Germany. — [3]Institute of Experimental and Applied Physics, University of Regensburg, Germany. — [4]Solid State Physics Laboratory, ETH Zurich, Switzerland. — [5]Department of Applied Physics and Applied Mathematics, Columbia University, New York, USA.

We present resonant inelastic light scattering (RILS) studies to explore the many-body quantum phase diagram and respective phase transitions of indirect excitons (IXs). The photogenerated IXs are confined in very clean GaAs double quantum well structures and electrostatically trapped by local gate electrodes. The IXs coexist with a photogenerated excess 2D hole system located in one of the quantum wells. The RILS studies of such ensembles reveal a collective excitation mode at the transferred in-plane momentum and an energy of only 0.44 meV at low temperatures. The mode is consistent with a plasma excitation of the 2D excess holes coherently coupled to the IXs.

HL 9.2 Mon 15:15 EW 202

Carbon doping of GaAs grown by molecular beam epitaxy on GaAs(100) and GaAs(111)B — •Alexander Trapp, Tobias Henksmeier, and Dirk Reuter — Optoelektronische Materialien und Bauelemente, Universität Paderborn, 33098 Paderborn, Germany

Bipolar devices, e. g., diodes, require n- as well as p-type doping. In GaAs, a material important for optoelectronic applications, carbon, beryllium, zinc and silicon are possible acceptors. Carbon is especially attractive because of its low diffusivity, very weak amphoteric behavior and high solubility in GaAs. Carbon doping in molecular beam epitaxy (MBE) grown GaAs(100) employing a solid source for carbon is already well studied. However, for GaAs(111)B this has not been studied so far.

In this work we compare the incorporation of carbon into GaAs grown on GaAs(100) and GaAs(111)B with a 1° miscut towards (211). A carbon sublimation source, where a pyrolytic graphite filament is directly heated by an electric current, is used to generate the carbon flux. GaAs layers with carbon concentrations from 10^{16} to 10^{19} per cm^3 have been grown by solid source MBE. The samples are characterized by temperature-dependent Hall measurements using the van-der-Pauw method and photoluminescence spectroscopy. It is shown that the activation energy of the p-dopant found in GaAs(100) and GaAs(111)B are nearly identical. The dependence of free carrier concentration on the surface orientation is weak and will be discussed in detail.

HL 9.3 Mon 15:30 EW 202

Magnetic properties of InP wurtzite nanowires from theory: g-factors and exciton Zeeman splitting — •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

Spin-dependent phenomena in III-V wurtzite (WZ) semiconductor nanowires (NWs) have recently attracted great attention. For instance, recent experiments showed that InP WZ NWs exhibit an unconventional and unexplained nonlinear Zeeman splitting (ZS) under high magnetic fields[1,2]. Starting with a robust k.p Hamiltonian[3], we investigate the magnetic properties of InP in the WZ phase, specifically focusing on g-factors and excitonic ZS. Our calculated values of effective g-factors are in excellent agreement with experimental data[1,2] and also show the independent contributions of electron and hole g-factors, typically entangled in experiments due to excitonic effects. Regarding the nonlinear ZS of excitons in large magnetic fields, we showed that the origin for such nonlinearity is the interaction between heavy and light hole bands with spin up from different Landau level indices[2,4]. [1] De Luca et al., Nano Lett. 14, 4250 (2014). [2] Tedeschi et al., in preparation. [3] Faria Junior et al., PRB 93, 235204 (2016). [4] Faria Junior et al., in preparation. Supported by: Alexander von Humboldt Foundation, Capes, DFG SFB 689, DFG SFB 1170, ENB Topological Insulators, Awards2014 and Avvio alla Ricerca (Sapienza Università di Roma).

HL 9.4 Mon 15:45 EW 202

Mutual Indirect Exciton Interactions in Double Quantum Well Stacks — •Colin Hubert[1], Yifat Baruchi[2], Yotam Harpaz[2], Kobi Cohen[2], Ronen Rapaport[2], and Paulo Santos[1] — [1]Paul Drude Institut, Berlin, Deutschland — [2]Racah Institut, Jerusalem, Israel

Indirect excitons (IXs) in double quantum well (DQW) structures subjected to a transverse electric field Ez form dipoles oriented along the field direction. The interaction between intraplanar IXs, i.e. IXs in the same DQW, is always repulsive. If, however, the IXs are placed in two different DQWs stacked along the z direction, the interaction becomes attractive as the dipoles orient themselves coaxially.

We have investigated the attraction between IXs in stacked DQW in GaAs structures by spatially resolved photoluminescence spectroscopy. The experiments are carried out by selectively exciting IXs in each of the two DQWs using tunable laser beams. Specifically the population in one of the wells is perturbed locally, while surrounded by a reservoir of IXs in the second well, whose population is kept constant. By observing the corresponding changes in density in the second DQW, we

show the existence of the attractive interplanar interaction. The effect increases with increasing IX density. Single indirect exciton pairs in coupled DQWs stacks are predicted to have a very low binding energy of 0.2 meV. The IXs at high density show larger energy shifts and can reach as large as 4 meV. We will present both these results and our current understanding of interactions that cause a larger than predicted binding energy, especially at higher densities.

HL 9.5 Mon 16:00 EW 202

Phase coherent transport and spin-orbit coupling in GaAs/InSb core/shell nanowires — •Anna Linkenheil[1,2], Patrick Zellekens[1,2], Thorsten Rieger[1,2], Nataliya Demarina[1,2], Hans Lüth[1,2], Mihail Ion Lepsa[1,2], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institute, Forschungszentrum Jülich — [2]JARA Fundamentals of Future Information Technology (FIT)

InSb nanowires are very interesting for future spin-based devices because of the large g-factor and the strong spin-orbit coupling. Furthermore, InSb has the highest electron mobility of all III/V semiconductors. However, growing bulk InSb nanowires directly was found to be very difficult. In order to tackle this issue we introduced a new concept, where InSb is grown as a shell around a GaAs nanowire core. At room temperature the GaAs/InSb nanowires were conductive, revealing an ambipolar behavior depending on the shell thickness and gate voltage.

We conducted low temperature transport measurements on GaAs/InSb core/shell nanowires. In a perpendicular magnetic field information on phase coherence length and spin-orbit coupling strength was extracted from weak antilocalization and universal conductance fluctuation measurements. In an axially oriented magnetic field Aharonov-Bohm-type conductance oscillations were observed. They are caused by angular momentum states in the InSb shell, representing the radial component of the electron propagation through the nanowire. They are thus directly related to the dimensions of the InSb shell.

15 min. break.

HL 9.6 Mon 16:30 EW 202

AlAsSb/GaSb Double Barrier Quantum Well Resonant Tunneling Diodes with Ternary Prewell-Emitters — •Andreas Pfenning[1], Georg Knebl[1], Robert Weih[1], Manuel Meyer[1], Andreas Bader[1], Monika Emmerling[1], Lukas Worschech[1], and Sven Höfling[1,2] — [1]Technische Physik, Physikalisches Institut and Röntgen Center for Complex Material Systems (RCCM), Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]SUPA, School of Physics and Astronomy, University of St. Andrews, St. Andrews, KY16 9SS, United Kingdom

Recently, we proposed and demonstrated for the first-time room temperature resonant tunneling in GaSb-based double barrier quantum well resonant tunneling diodes (RTDs) by electron injection from ternary GaInSb and GaAsSb prewells. In the present study, we investigate the impact of an increasing As concentration in the emitter prewell on the electrical transport characteristics of these resonant tunneling diodes over a broad temperature range. We observe that room temperature resonant tunneling can be boosted up to 2.4 by increasing the As mole fraction up to 11 % and attribute this to an enhanced population of the Γ-valley within the emitter prewell. The incorporation of As in the tunneling structure however degrades the crystal quality as observed by the resonant tunneling characteristic obtained at cryogenic temperatures that leads to enhanced defect scattering at the interfaces and hence lowers the PVCR.

HL 9.7 Mon 16:45 EW 202

Increased sensitivity of spin noise spectroscopy using homodyne detection in n-doped GaAs — •Aleksandr Kamenskii[1], Mikhail Petrov[2], Dmitry Smirnov[3], Manfred Bayer[1], and Alex Greilich[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]Spin Optics Laboratory, Saint Petersburg State University, 198504 St. Petersburg, Russia — [3]Ioffe Physical-Technical Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

Optical spin noise spectroscopy is a minimally invasive method of obtaining dynamical information on carrier spins by measuring mesoscopic time-dependent spin fluctuations [1-3]. We implement the homodyne detection scheme to increase the polarimetric sensitivity of the spin noise spectroscopy. Controlling the laser intensity of the local oscillator, which travels around the sample and does not perturb the measured spin system, we are able to amplify the signal. This opportunity of additional amplification allows us to reduce the probe laser intensity incident onto the sample and therefore to approach a non-perturbative regime. The efficiency of this scheme with enhancement of the detected signal by more then a factor 3 at low probe powers is demonstrated on bulk n:GaAs. Additionally, the control of the optical phase provides us a possibility to switch between the measurements of Faraday rotation and Faraday ellipticity without changes in optical elements. [1] Crooker et al., Nature 431, 49 (2004). [2] Li et al., New J. Phys. 15, 113038 (2013). [3] Lucivero et al. Phys. Rev. A 93, 053802 (2016).

HL 9.8 Mon 17:00 EW 202

Infrared nanoscopy on Si-doped GaAs-InGaAs core-shell nanowires — •Denny Lang[1,2], Leila Balaghi[1,3], Emmanouil Dimakis[1], René Hübner[1], Susanne C. Kehr[2], Lukas M. Eng[2,3], Stephan Winnerl[1], Harald Schneider[1], and Manfred Helm[1,2,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Technische Universität Dresden, Germany — [3]cfaed - Center for Advancing Electronics Dresden, Germany

Semiconductor-based nanowires (NWs) are highly promising nm-sized building-blocks for future (opto-)electronic devices (i.e. photovoltaics, LEDs, THz detectors, polarizers, and lasers). Knowledge on the electrical characteristics of individual NWs is mandatory for any such application. Here, we investigate the plasma resonance of the free charge carriers in Si-doped GaAs-InGaAs core-shell NWs by applying scattering-type scanning near-field infrared microscopy (s-SNIM [1]) in the mid- to far-infrared wavelength range [2]. The shell doping may be varied over a broad range, revealing a plasma resonance around 10 μm for the highest doping level [3]. We compare IR-s-SNIM results obtained by both a CO_2 laser and the pulsed free-electron laser light source, and observe a power-dependent red-shift of the plasma resonance, most probably arising through nonlinear effects such as intervalley scattering [4] occurring in strong electric fields.

[1] Stiegler, J. M. et al. Nano Lett. 10, 1387−1392 (2010).
[2] Kuschewski, F. et al., Appl. Phys. Lett. 108, 113102 (2016).
[3] Dimakis, E. et al., Nano Res. 5, 796−804 (2012).
[4] Razzari, L. et al., Phys. Rev. B 79, 193204 (2009).

HL 9.9 Mon 17:15 EW 202

Properties of In-Plane Gate transistors for use in sensing gaseous and liquid dielectric environments. — •Benjamin Feldern, Sascha R. Valentin, Arne Ludwig, and Andreas D. Wieck — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Bochum, Germany

For the purpose of sensing dielectrics, In-Plane-Gate (IPG) transistors are written in Gallium-Arsenide based high-electron-mobility-transistor (HEMT) structures using focused ion beam (FIB) implantation. These FIB-implanted IPGs are to be used to sense dielectrics in different compositions.

Using the Petrosyan-Stikh formula for the depletion length of the implanted region in addition to the representation of the IPG by a parallel-plate geometry by de Vries and Wieck, the dielectric constant of the environment can be calculated and analysed. Additionally, varied mobility of the underlying HEMT is taken into consideration. We demonstrate an influence of the dielectric on the properties, while a quantitative analysis still shows some deviations.

Beyond this, also surface treatments were performed and tested on their influence of the sensing capability. It was found that surface depletion was increased by both exposure of the IPGs to a N_2-Plasma as well as dipping in N_2H_8S.

Simulations of the electric field reveal the influence of the geometry and the charge carrier density in the HEMT.

HL 10: Nitrides: Devices

Time: Monday 15:00–17:30 Location: EW 203

HL 10.1 Mon 15:00 EW 203

Mechanism and Reduction of temperature-dependent RF loss of GaN-HEMTs on Silicon substrate — •Tien Tung Luong, Yi Heng Chen, Chung Han Chiang, Yen Teng Ho, Shane Chang, and Edward Yi Chang — National Chiao Tung University, Hsinchu, Republic of China (R.O.C)

Regarding the unique characteristics (high breakdown field, high power density, high efficiency, and broadband); GaN-based HEMTs are able to operate at high power, high frequencies, and high temperatures; exhibiting various excellent characteristics superior to those of conventional Si-based semiconductors. GaN-HEMTs on Si technology is expected to drastically reduce the fabrication cost. Nevertheless, one of the main issues is the parasitic loss that can adversely impact the RF device performances. In order to reduce the loss of RF operation of devices on Si, a high-resistivity (HR) Si substrate is commonly used; however, the RF loss drastically increases at high-junction temperature. A free-electron inversion channel, which is caused by the positive piezoelectric charge at the AlN/Si interface induced by the piezoelectric field in the tensile AlN grown on Si, plays a critical role in the RF losses. Understanding the loss mechanisms of GaN-HEMT on Si will undoubtedly help to design epitaxial growth structure for further improving the overall device RF performance. An adoption of a low-temperature AlN near Si interface induces an unintentionally carbon-doped layer acting as a negatively fixed charge layer that is able to compensate for positive piezoelectric charge resulting in the improvements of both the RF losses and thermal degradation.

HL 10.2 Mon 15:15 EW 203

Implementation of a GaN:Mg/GaN:Ge tunnel junction in blue vertical-cavity surface-emitting laser structures — •Christoph Berger, Silvio Neugebauer, Gordon Schmidt, Cleophace Seneza, Jürgen Bläsing, Jürgen Christen, Armin Dadgar, and André Strittmatter — Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg

Due to their unique properties GaN-based vertical-cavity surface-emitting lasers (VCSELs) are desirable for various applications. Besides the demanding realization of nitride-based microcavities with highly reflective distributed Bragg-reflectors, major challenges are the homogeneous current injection into the cavity region and the realization of a current aperture to achieve a sufficient current density in the gain region. Most commonly, current apertures are formed by selective passivation of the cavity p-side with SiO2 or SiNx and lateral current injection is accomplished by covering the aperture with an ITO-layer. In our approach the p-doped GaN is overgrown with highly doped GaN:Ge by metalorganic chemical vapor phase epitaxy. This transparent conductive nitride ensures excellent lateral current spreading, while carrier injection is enabled via tunneling at the GaN:Mg/GaN:Ge interface. Such VCSEL structures give reason to expect a significant reduction of internal losses in the cavity that are otherwise induced by the relatively high absorption coefficient of the ITO-layer. For current confinement we will address different approaches, like selective passivation of the p-GaN or selective oxidation of a buried, lattice-matched AlInN layer.

HL 10.3 Mon 15:30 EW 203

$Al_xGa_{1-x}N$:Mg short period superlattice cladding layers with $x \geq 0.6$ for UVC laser diodes — •C. Kuhn[1], M. Guttmann[1], N. Susilo[1], M. Martens[1], F. Mehnke[1], L. Sulmoni[1], T. Wernicke[1], and M. Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

Key challenges for the realization of UVC laser diodes with emission wavelength below 270 nm are carrier injection, light absorption and waveguiding. The waveguiding requires low loss $Al_xGa_{1-x}N$ cladding layers with high aluminum content $x > 0.7$. However, this limits efficient carrier injection due to the typically high resistance of Mg-doped AlGaN layers. To increase the conductivity short period superlattices (SPSL) can be implemented. Nevertheless, a high conductivity and its accurate determination still remains particularly demanding, especially for high Al contents.

This paper investigates the optical and electrical properties of AlGaN:Mg SPSLs up to $x = 0.8$. Such high Al contents shift the absorption edge far away from the lasing wavelength resulting in low absorption $< 50\,cm^{-1}$ in the layers due to Mg-related transitions. AlGaN:Mg SPSLs with average $x = 0.22$ exhibit a relatively low lateral resistivity of 0.6 Ωcm which strongly increases to 70 Ωcm for transparent AlGaN:Mg with $x = 0.6$. Vertical resistivity measurements hint to an additional field-induced ionization of the Mg acceptors leading to an increase of the turn-on voltage, but allowing for relatively low series resistances and high pulsed current densities up to $5\,kA/cm^2$.

HL 10.4 Mon 15:45 EW 203

AlGaN-based deep UV LEDs grown on sputtered and high temperature annealed AlN/sapphire — •Norman Susilo[1], Sylvia Hagedorn[2], Dominik Jaeger[3], Hideto Miyake[4], Ute Zeimer[2], Christoph Reich[1], Bettina Neuschulz[1], Luca Sulmoni[1], Martin Guttmann[1], Frank Mehnke[1], Christian Kuhn[1], Tim Wernicke[1], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Institute of Solid State Physics, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany — [3]Evatec AG, Hauptstraße 1a, 9477 Trübbach, Switzerland — [4]Department of Electrical and Electronic Engineering, Mie University, Mie 514-8507, Japan

The structural and electro-optical properties of AlGaN-based deep ultraviolet light emitting diodes (UV-LEDs) grown by metalorganic vapor phase epitaxy on sputtered and high temperature annealed (HTA) AlN/sapphire templates are investigated and compared to LEDs grown on epitaxially laterally overgrown (ELO) AlN/sapphire. Both templates show similar threading dislocation densities in the range of $1\times10^9\,cm^{-2}$. The output powers are also comparable and in the range of 0.4 mW at 20 mA for the emission wavelength of 268 nm. This opens a new way for the fabrication of efficient UVC-LEDs with reduced complexity and thus reduced costs.

HL 10.5 Mon 16:00 EW 203

Structural and optical properties of $In_xAl_yGa_{1-x-y}N$ layers for UVB-LEDs — •Tolga Teke[1], Johannes Enslin[1], Gunnar Kusch[2], Lucia Spasevski[2], Christoph Reich[1], Bettina Neuschulz[1], Tim Wernicke[1], Robert Martin[2], and Michael Kneissl[1] — [1]Technische Universität Berlin, Institute of Solid State Physics — [2]University of Strathclyde, Department of Physics, SUPA

There are numerous applications for UVB-light emitting diodes (LED) emitting in the range from 280 nm to 315 nm such as UV-curing, phototherapy, and plant growth lighting. However, currently the external quantum efficiency (EQE) of these devices is just in the low percentage range. Several reports have indicated a strong increase of the internal quantum efficiency (IQE) for LEDs with quaternary $In_xAl_yGa_{1-x-y}N$ quantum wells (QWs). However, detailed studies on how the indium-content influences the IQE, polarizaion fields and carrier localization in the QWs are still missing. In this work, we investigate bulk $In_xAl_yGa_{1-x-y}N$ layers in order to realize UVB-LEDs with $In_xAl_yGa_{1-x-y}N$ QWs with different In-content and emission wavelengths near 310 nm. A series of bulk $In_xAl_yGa_{1-x-y}N$ layers with thickness of 150 nm was grown by MOVPE where the In-content was varied by changing the growth temperature and the In precursor supply. We will present the dependence of the quaternary composition of these layers on the growth conditions determined by wavelength dispersive x-ray spectroscopy (WDX) and its influence on the optical properties by photoluminescence, transmission and cathodoluminescence spectroscopy.

15 min. break.

HL 10.6 Mon 16:30 EW 203

Evidence of nanoscale Anderson localization induced by intrinsic compositional disorder in InGaN/GaN quantum wells by scanning tunneling luminescence spectroscopy — •Wiebke Hahn[1], Jean-Marie Lentali[1], Petr Polovodov[1], Nathan Young[2], Shuji Nakamura[2], James S. Speck[2], Claude Weisbuch[1,2], Marcel Filoche[1], Fouad Maroun[1], Lucio Martinelli[1], Yves Lassailly[1], and Jacques Peretti[1] — [1]Laboratoire de Physique de la Matière Condensée, Ecole polytechnique, CNRS, Université Paris Saclay, Palaiseau Cedex, France —

[2]Materials Department, University of California, Santa Barbara, USA

In nitride ternary alloys, intrinsic compositional disorder, resulting from the random distribution of atoms on the crystal lattice, induces strong electronic localization effects. We will present direct experimental evidences of Anderson localization induced at a scale of a few nanometers by the intrinsic alloy compositional disorder in an InGaN/GaN quantum well (QW). The experiment consists in locally injecting electrons from a scanning tunneling microscope (STM) tip into a p-type heterostructure incorporating an InGaN/GaN QW nearby the surface. The luminescence spectrum from the electrons captured in the QW is detected as a function of the injecting tip position. Spatial fluctuations of the luminescence peak energy and linewidth are observed on the scale of a few nanometers, characteristic of disorder-induced carrier localization. A model based on the so-called localization landscape theory accounts well for the observed nanometer scale carrier localization and the fluctuations in the luminescence peak energy.

HL 10.7 Mon 16:45 EW 203

Transport of localized charge carriers in disordered media — Jean-Marie Lentali[1], Marcel Filoche[1], and •Svitlana Mayboroda[2] — [1]Physique de la Matière Condensée, Ecole Polytechnique, CNRS, 91128 Palaiseau, France — [2]School of Mathematics, University of Minnesota, Minneapolis, Minnesota 55455, USA

Our work is based on the theory of the localization landscape, which purpose is to study the effects of disorder on the localization of wave functions without actually solving the Schrödinger equation. Bypassing the Schrödinger equation notably allows 3D computations, self-consistent with the Poisson equation and the drift-diffusion transport equations. This new approach has been successfully applied to nitride based structures such as InGaN quantum wells, where the disorder stems from the random distribution of Indium atoms during growth process [1]. However, the transport between localized states in the plane of the well could only be described by an effective mobility, until recently. We now propose a dynamic transport model which integrates the coupling between neighboring localized states by an external potential such as the electric field and/or the phonon-electron interaction. Evaluating this coupling requires the use of the Agmon distance, which describes the exponential decay of localized wave functions in any dimension, and we report its first utilization in quantum physics.

[1] Localization landscape theory of disorder in semiconductors. III. Application to carrier transport and recombination in light emitting diodes Chi-Kang Li, et al. - Phys. Rev. B 95, 144206 - Published 18 April 2017

HL 10.8 Mon 17:00 EW 203

Electronic processes in nitride compounds and devices — Wiebke Hahn[1], Jean-Marie Lentali[1], James S. Speck[2], Claude Weisbuch[1,2], Marcel Filoche[1], Lucio Martinelli[1], and •Jacques Peretti[1] — [1]Laboratoire de Physique de la Matière Condensée, Ecole polytechnique, CNRS, Université Paris-Saclay, 91128 Palaiseau, France — [2]Materials Department, University of California, Santa Barbara, CA, USA

Despite the fast development of nitride semiconductor technology, a deep understanding of the fundamental properties of nitride compounds and heterostructures is still lacking in order to understand the microscopic mechanisms which govern electronic processes in nitride devices. Here, we present unconventional approaches which allow to address challenging issues like multivalley transport [1,2], non-radiative recombination processes [1], disorder-induced localization effects [3-5]. Direct spectroscopic signatures of critical electronic processes are obtained which provide novel inputs both for the theoretical description of nitride compounds and heterostructures and for the modeling and design of devices [6]. [1] Iveland et al., Phys. Rev. lett. 110, 177406 (2013) [2] Piccardo et al., Phys. Rev. B 89, 235124 (2014) [3] Filoche et al., Phys. Rev. B 95, 144204 (2017) [4] Piccardo et al., Phys. Rev. B 95, 144205 (2017 [5] Li et al., Phys. Rev. B 95, 144206 (2017) [6] Hahn et al., Submitted.

HL 10.9 Mon 17:15 EW 203

Q factor limitation in the UVA in III-nitride-on-silicon photonic crystal cavities — •Farsane Tabataba-Vakili[1,2,3], Iannis Roland[1], Thi-Mo Tran[1], Xavier Checoury[1], Moustafa El Kurdi[1], Sébastien Sauvage[1], Christelle Brimont[4], Thierry Guillet[4], Stéphanie Rennesson[5], Jean-Yves Duboz[5], Fabrice Semond[5], Bruno Gayral[2,3], and Philippe Boucaud[1] — [1]C2N, CNRS, Univ. Paris-Sud, Université Paris-Saclay, F-91405 Orsay, France. — [2]CEA, INAC-PHELIQS, F-38000 Grenoble, France. — [3]Univ. Grenoble Alpes, F-38000 Grenoble, France. — [4]Laboratoire C. Coulomb (L2C), CNRS-Univ. Montpellier, F-34095 Montpellier, France. — [5]Université Côte d'Azur, CRHEA-CNRS, F-06560 Valbonne, France.

In this work, we investigated L3 photonic crystal (PhC) cavities that were fabricated in a 75 nm AlN layer, containing five 1.2 nm GaN QWs. The III-N PhC membranes were released by selective underetching of the Si substrate. The devices were probed by room temperature micro-photoluminescence to measure the Q factor of the cavities. We demonstrate resonances down to 315nm and Q factors up to 1085 at 337nm. Using spectroscopic ellipsometry, we determine residual absorption in thin AlN layers grown on Si by molecular beam epitaxy. This residual absorption is expected to be the main cause of substantially decreased Q factors at shorter wavelengths when no active layers with a large absorption, such as quantum wells or quantum dots are present. Ultimately, the residual absorption should thus limit the Q factor to 2000 at 300 nm when no active layers are present.

HL 11: Topological insulators II (joint session HL/TT)

Time: Monday 15:00–17:30 Location: A 151

HL 11.1 Mon 15:00 A 151

Advanced MBE techniques for improved Bi2Se3 thin film growth — •Sarah Schmitt, Peter Schüffelgen, Abdur Jalil, Michael Schleenvoigt, Tobias Schmitt, Jonas Kölzer, Daniel Rosenbach, Thomas Schäpers, Gregor Mussler, and Detlev Grützmacher — Peter Grünberg Institut, Forschungszentrum Jülich & JARA Jülich-Aachen Research Alliance, D-52425 Jülich, Germany

Topological Insulators (TIs) are semiconductors with an inverted bulk band gap, but topologically protected states at their surface. The surface states exhibit promising features, useful for example for spintronic and quantum computing applications. In this study, we focus on the binary 3D TI Bi2Se3, which is unique due to its large bulk band gap and its freestanding Dirac point that lies in between valence and conduction band. However, binary compounds suffer from high back ground doping due to crystal defects in the bulk. To reduce defects in Bi2Se3, the quality of the thin films grown by molecular beam epitaxy (MBE) on Si(111) has been optimized. By varying the Bi, Se and substrate temperature as well as using InP as alternative substrate. The best conditions for low roughness, homogeneous domains and reduction of defects were investigated.

For transport measurements Hall bar structures were designed. To avoid defect formation during device fabrication, electrodes were deposited in-situ via stencil lithography. Still in-situ, the stencil mask was removed and the thin film capped with a thin dielectric layer to conserve the sample before taking it to ambient conditions. This technique allows the access to clean ultra-thin TI films by means of MBE.

HL 11.2 Mon 15:15 A 151

Interplay of Chiral and Helical states in a Quantum Spin Hall Insulator Lateral Junction — •M. R. Calvo[1,2,5], F. de Juan[2], R. Ilan[2], E. J. Fox[3], A. J. Bestwick[3], P. Leubner[4], J. Wang[3], C. Ames[4], S. C. Zhang[3], H. Buhmann[4], L. W. Molenkamp[3], and D. Goldhaber-Gordon[4] — [1]CIC Nanogune, San Sebastián, Spain — [2]University of California, Berkeley, USA — [3]Stanford University, Stanford, USA — [4]Wuerzburg University, Wuerzburg, Germany — [5]Ikerbasque, Basque Foundation for Science, Bilbao, Spain

We study the electronic transport across an electrostatically gated lateral junction in a HgTe quantum well, a canonical 2D topological insulator, with and without an applied magnetic field. We control the carrier density inside and outside a junction region independently and hence tune the number and nature of 1D edge modes propagating in each of those regions. Outside the bulk gap, the magnetic field drives the system to the quantum Hall regime, and chiral states propagate at the edge. In this regime, we observe fractional plateaus that reflect

the equilibration between 1D chiral modes across the junction. As the carrier density approaches zero in the central region and at moderate fields, we observe oscillations in the resistance that we attribute to Fabry-Perot interference in the helical states, enabled by the broken time reversal symmetry. At higher fields, those oscillations disappear, in agreement with the expected absence of helical states when band inversion is lifted.

HL 11.3 Mon 15:30 A 151

Topological transport in dimer chains — •Sina Böhling[1], Georg Engelhardt[1], Gernot Schaller[1], and Gloria Platero[2] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Berlin, Germany — [2]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain

In many fields, dimer chains have aroused great interest - not least because of the emergence of topologically protected edge states, localized to the two ends of the chain and promising lossless long-range transfer of particles. [1] Our work provides insight into properties of a dimer chain that is subject to dissipation. Applying an exact Green's function formalism applicable for any coupling strength, we investigate transport properties of a finite Su-Schrieffer-Heeger model, a paradigmatic model for a one-dimensional topological insulator, which is coupled to fermionic reservoirs at its ends.

For long chains, we observe that current and noise strongly decrease in the topologically non-trivial phase. This can be understood as a topological fingerprint, namely the occupation of edge states which are stronger coupled to the reservoirs than the conducting modes but do hardly contribute to the transmission. We show how to exploit this behavior to dissipatively prepare an edge state, while all other modes are practically unoccupied. Moreover, we discuss thermodynamic properties of the system by subjecting it to both, a potential and a thermal gradient, and discover regimes where the chain serves either as a heat engine or as a refrigerator.

[1] Bello, Creffield, Platero, Scientific Reports 6, 22562 (2016)

HL 11.4 Mon 15:45 A 151

Direct -1 to $+1$ Hall conductivity transitions in HgTe quantum wells — •Wouter Beugeling[1,2,3], Jan Böttcher[2], Christoph Brüne[1,4], Andreas Budewitz[1], Hartmut Buhmann[1], Ewelina M. Hankiewicz[2], Cristiane Morais Smith[5], and Laurens W. Molenkamp[1] — [1]Physikalisches Institut (EP3), Universität Würzburg, Würzburg, Germany — [2]Institut für Theoretische Physik und Astrophysik (TP4), Universität Würzburg, Würzburg, Germany — [3]Lehrstuhl für Theoretische Physik I/II, Technische Universität Dortmund, Dortmund, Germany — [4]Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway — [5]Institute for Theoretical Physics, Utrecht University, Utrecht, The Netherlands

Mercury telluride (HgTe) quantum wells have been one of the primary platforms for realization of topological states, due to its 'inverted' band structure. Typically, transport measurements of HgTe quantum well samples in a magnetic field show Hall quantization. The quantum spin Hall effect manifests itself as a special type of 'zero conductivity' Landau plateau.

We present remarkable transport measurement results, where the zero-conductivity plateau is absent, and where the Hall conductivity jumps from $-e^2/h$ to e^2/h directly. We provide a theoretical explanation, connecting this exotic transition to the 'second inversion', i.e., between the first electron (E1) and second heavy-hole (H2) subbands. We also discuss the effect of the exchange interaction induced by manganese (Mn) doping.

HL 11.5 Mon 16:00 A 151

Parallel conduction channels in topological insulator thin films: Determination of conductance through bulk, interface and surface states — •Sven Just[1,2], Felix Lüpke[1,2], Peter Schüffelgen[1,2], Tristan Heider[1,2], Vasily Cherepanov[1,2], Gregor Mussler[1,2], Lukasz Plucinski[1,2], Detlev Grützmacher[1,2], Claus M. Schneider[1,2], F. Stefan Tautz[1,2], and Bert Voigtländer[1,2] — [1]JARA-FIT, Forschungszentrum Jülich, Germany — [2]Peter Grünberg Institute (PGI-3, PGI-6, PGI-9), Forschungszentrum Jülich, Germany

Topological insulator (TI) thin films can exhibit multiple parallel conduction channels for current transport. Beside the topological protected surface states (TSS) on top and bottom side of the film there can be more parasitic channels, i.e. the interior (bulk) of the not perfectly insulating TI film, the interface layer and the substrate. It is a crucial task to determine and minimize the influence of these parasitic parallel channels on the total current transport for taking advantage of the special TI properties in electronic devices. By using gate-dependent surface-sensitive four-probe measurements performed with a multi-tip STM and ARPES measurements in combination with theoretical calculations of the near-surface band-bending in the TI thin film, it is possible to disentangle the contributions of the different parallel conduction channels and to determine the conductivities of the interface reconstruction and the film bulk, as well as the charge carrier densities and mobilities of the top and bottom TSS for TI materials grown by van-der-Waals epitaxy, e.g. the ternary system $(Bi_{0.53}Sb_{0.47})_2Te_3$.

15 min. break.

HL 11.6 Mon 16:30 A 151

Quantum interference phenomena in selectively grown topological insulator nanoribbons — •Jonas Kölzer[1], Daniel Rosenbach[1], Tobias Schmitt[1], Christian Weyrich[1], Peter Schüffelgen[1], Michael Schleenvoigt[1], Sarah Schmitt[1], Abdur Rehman Jalil[1], Gregor Mussler[1], Vincent Sacksteder[2], Detlev Grützmacher[1], and Thomas Schäpers[1] — [1]PGI-9, Forschungzentrum Jülich and JARA-FIT, Germany — [2]Royal Holloway University of London, United Kingdom

Quantum topology offers a lot of intriguing physical phenomena and has a huge potential to realize robust quantum computing. Selectively deposited nano devices grown by means of molecular beam epitaxy (MBE) are a first step towards scalable topological insulator (TI) quantum computation.

In order to probe the evidence of topologically protected surface states, magneto conductance measurements are performed. In detail we studied quantum interference effects in the magneto conductance on selectively grown TI nanoribbons at low temperatures. From the conductance modulations we could trace distinct electron paths using FFT analysis in angular dependent measurements. Temperature dependent measurements reveal the quantum nature of the oscillations observed, since they vanish for increasing temperatures.

The next step in characterizing the material system will be to selectively grow Aharonov-Bohm ring structures to characterize quantum oscillations inside the van der Waals layer system.

HL 11.7 Mon 16:45 A 151

THz conductivity of charge puddles in the topological insulator BSTS — •Yu Mukai, Suqin He, Zhiwei Wang, Markus Grüninger, Yoichi Ando, and Paul H. M. van Loosdrecht — II, Physikalisches Institut, Universität zu Köln, Cologne, Germany

Strong Coulomb disorder in the compensation doped topological insulator $BiSbTeSe_2$ (BSTS) leads, at low temperatures, to the formation of charge puddles and consequently a non-monotonic temperature dependence of mid-infrared optical conductivity [1]. In contrast, the DC conductivity shows a monotonous decrease with temperature, as expected for an insulator [1]. To experimentally reconcile these observations we performed time domain THz spectroscopy on BSTS over the wide frequency range of 0.3 - 6 THz, thereby largely filling the gap between the DC and mid-infrared experiments. We present the temperature dependence of the conductivity spectrum in this energy range and discuss contributions from the charge puddles and thermally activated free carriers.

[1] Borgwardt et al., Phys. Rev. B 93, 245149 (2016).

HL 11.8 Mon 17:00 A 151

Topological design applied to the control of acoustic phonons — •Martin Esmann, Omar Ortiz, Fabrice R. Lamberti, Pascale Senellart, Aristide Lemaitre, and Daniel Lanzillotti-Kimura — CNRS Centre de Nanosciences et de Nanotechnologies (C2N), 91460 Marcoussis, France

The control and manipulation of acoustic phonons in the GHz-THz range appears as a new resource in the engineering of nanodevices. Here, we introduce the use of spatial mode symmetries of Bloch modes in a semiconductor superlattice to confine and control the propagation of phonons. We generate confined topological modes that are described by topological invariants and a topological transition upon band gap inversion [1]. This topological interface state between two finite size superlattices of different topology is a concept readily extendable to 3D in micropillars [2,3].

We experimentally evidence such a topologically confined nanophononic interface state in a planar structure both by coherent

phonon generation (pump-probe) measurements and high resolution Raman scattering spectroscopy. Nanophononic topological interface states like the ones presented here could be at the base of developing single phonon sources, phononic sensors and phonon lasers, whose optical counterparts all led to key advances in applied photonics.

[1] M. Xiao et al., Phys. Rev. X 4, 021017 (2014).
[2] F. R. Lamberti et al., Opt. Express 25, 24437-24447 (2017).
[3] M. Esmann et al., submitted (2017).

HL 11.9 Mon 17:15 A 151

Low-dimensional topological Josephson junctions on selectively grown topological insulator nanoribbons — •Tobias W. Schmitt[1], Daniel Rosenbach[1], Peter Schüffelgen[1], Michael Schleenvoigt[1], Abdur R. Jalil[1], Chuan Li[2], Gregor Mussler[1], Stefan Trellenkamp[1], Alexander Brinkman[2], Detlev Grützmacher[1], and Thomas Schäpers[1] — [1]Peter Grünberg Institute 9, Forschungszentrum Jülich & JARA-FIT, 52425 Jülich, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands

At the interface of a topological insulator and a s-wave superconductor, exotic Majorana modes are predicted to arise. In lateral topological Josephson junctions comprised of two superconducting leads on top of a topological insulator thin film, possible Majorana assisted transport is expected to occur in addition to conventional Andreev bound states. The latter superimpose the indications of Majorana excitations in Shapiro response measurements and make their detection more difficult. As the number of conventional Andreev bound states depends on the total number of conducting modes, their impact can be reduced in low-dimensional Josephson junctions. In our recent work, we focus on the realization of low-dimensional topological Josephson junctions by (I) selectively depositing TI nanoribbons of reduced width and (II) increasing of the Fermi wavelength by adjusting the Fermi level to the Dirac point of the linear disperse surface states. Such junctions have been prepared and characterized electrically at low temperatures, including their Fraunhofer diffraction pattern and their Shapiro response.

HL 12: Invited Talk: Mark Holmes

Time: Monday 16:45–17:15 Location: EW 201

Invited Talk HL 12.1 Mon 16:45 EW 201

III-Nitride Quantum Dots as Single Photon Emitters — •Mark Holmes[1,2], Kang Gao[1], Florian Le Roux[1], Kihyun Choi[2], Satoshi Kako[1,2], Munetaka Arita[1,2], and Yasuhiko Arakawa[1,2] — [1]Institute of Industrial Science, The University of Tokyo — [2]Institute for Nano Quantum Information Electronics, The University of Tokyo

III-nitride quantum dots are becoming increasingly interesting and important for the generation of single photons of light. They provide strong quantum confinement to enable operation at elevated temperatures, and also a wide range of band gaps over which the emission energy can be tuned (in theory from the UV all the way to the IR). In this presentation I will discuss our recent work at The University of Tokyo on realizing single photon emission from III-nitride quantum dots. In particular, I will discuss our efforts to realize high temperature operation from GaN/AlGaN nanowire based structures, and also high purity emission from interface fluctuation GaN/AlGaN quantum dots. Recently, with the aim of generating indistinguishable photons, we have been making measurements on the spectral diffusion time scales in such structures, which I will discuss in detail.

HL 13: Poster Session I

Time: Monday 17:30–19:30 Location: Poster B

HL 13.1 Mon 17:30 Poster B

Transmission Electron Diffraction on a really free-standing heterostructure and analysis of the resulting Moiré pattern — •Marlene Adrian, Arne Senftleben, Silvio Morgenstern, and Thomas Baumert — University of Kassel, Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), D - 34132 Kassel

The combination of various 2D layered materials in multilayer heterostructures arises great interest in the current science. Due to the large variety of electronic properties of the group of 2D layered materials the combination opens a new pathway towards ultrasmall electronic devices.

In this contribution we present a full mathematical description of multilayer heterostructure samples and their diffraction images including a proposal of a consistent assignment of the superstructure diffraction spots. A 27 nm thick MoS2-graphite heterostructure was produced and fully analysed with the methods presented. Additionally, the ultrafast lattice dynamics after optical excitation of the sample will be discussed.

HL 13.2 Mon 17:30 Poster B

First Principles Phase Diagram Calculations for the 2D TMD systems MoS_2-MoTe_2 and WS_2-WTe_2. — •Benjamin Burton — Materials Measurement Laboratory, National Institute of Standards and Technology (NIST), Gaithersburg, MD 20899, USA

First Principles Phase Diagram Calculations were performed for the 2D Transition Metal Dichalcogenide Systems MoS_2-MoTe_2 and WS_2-WTe_2. These FPPD calculations were performed with the ATAT system using VASP calculated formation energies for $MS_{2-2x}Te_{2x}$ supercells (M=Mo or W) as input. For both of these systems, very surprising results were obtained: (1) although all calculated formation energies for systems with 16 or fewer anion sites were positive, suggesting a miscibility gap, entropy stabilized intermediate phases were predicted in $Mo(S,Te)_2$; (2) although one expects immiscibility to be greater on the S-rich sides of these diagrams (because S^{2-} is a smaller ion than Te^{2-}) it is much greater on the Te-rich sides.This surprising asymmetry is understood as reflecting a preponderance of lower-energy metastable ordered states on the S-rich sides of the systems.

The calculated phase diagrams are for bulk systems, but results for monolayers of $Mo(S,Te)_2$ on a saphire substrate [Al-terminated, (0001) face] will also be discussed.

HL 13.3 Mon 17:30 Poster B

Anderson localization and magnetization in graphene quantum dots — •Abdulmenaf Altintas and Alev devrim Guclu — Izmir Institute of Technology, Izmir, Turkey

We theoretically try to understand the effects of vacancy related disorders and electron-electron interactions on Anderson type localization and the magnetic properties of hexagonal armchair graphene quantum dots. Our model is based on mean-field Hubbard model. Removing p_z orbital induce local magnetic puddle in vacancy related region. Disorders leads to localization of electronic states when they are introduced randomly. Localization length decreases with breaking of sub lattice symmetry.

HL 13.4 Mon 17:30 Poster B

Strain tuning of CVD grown MoS_2 monolayers — •Anna F. Blob[1], Iris Niehues[1], Valentino Jadriško[2], Borna Radatović[2], Marko Kralj[2], Steffen Michaelis de Vasconcellos[1], and Rudolf Bratschitsch[1] — [1]Physikalisches Insitut, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Institute of Physics, Zagreb, Croatia

Single layers of transition metal dichalcogenides are a new class of 2D materials. Mechanical straining makes it possible to change their fundamental optical transitions [1]. We apply reversible uniaxial tensile strain to CVD grown MoS_2 monolayers by bending a flexible polycarbonate substrate on which the ultrathin semiconductor is placed. To avoid slippage of the MoS_2 monolayer, it is covered with a PDMS layer.

Absorption spectra of the atomically thin semiconductor are measured for increasing and decreasing strain levels. The energetic shifts of the exciton resonances are determined to be $-42\,\mathrm{meV}/\%$ and $-43\,\mathrm{meV}/\%$ for the A and B exciton, respectively. These gauge factors are in ecxellent agreement with those derived from monolayers exfoliated from naturally occuring molybdenite crystals.

[1] R. Schmidt, I. Niehues, R. Schneider, M. Drüppel, T. Deilmann, M. Rohlfing, S. Michaelis de Vasconcellos, A. Castellanos-Gomez, and R. Bratschitsch, Reversible uniaxial strain tuning in atomically thin WSe_2 in: 2D Materials 3, 021011 (2016)

HL 13.5 Mon 17:30 Poster B

Hysteresis in Graphene Nanoribbon Field-Effect Transistors — •Alexander Tries[1,2,3], Nils Richter[1,3], Zongping Chen[2], Akimitsu Narita[2], Klaus Müllen[2,4], Hai I. Wang[2], Mischa Bonn[2], and Mathias Kläui[1,3] — [1]Institut für Physik, Johannes Gutenberg Universität, Mainz, Germany — [2]Max Planck Institute for Polymer Research, Mainz, Germany — [3]Graduate School of Excellence Materials Science in Mainz, Mainz, Germany — [4]Institut für Physikalische Chemie, Johannes Gutenberg-Universität, Mainz, Germany

Hysteresis in carbon based Field-Effect Transistors (FET) such as Graphene FETs or Carbon Nanotube FETs is a known feature that impacts the device performance [1,2]. In this work, we show that also atomically perfect Graphene Nanoribbons (GNR) exhibit a hysteresis behavior while measuring transfer curves. We perform a systematic study on armchair GNRs with a width of 5 and 9 carbon atoms (aGNR5 and aGNR9) using GNR-FET devices. Temperature and gate sweep rate dependent measurements reveal charge carrier trapping as a main cause of the hysteresis. From the measurements, we are able to extract the density and energy of the trap states that result in the hysteresis[3].

[1] Kim et al., Nano Letters 3, 193-198 (2003)
[2] Singh et al., Journal of Applied Physics 122, 195305 (2017)
[3] Tries et al., Manuscript in preparation (2018)

HL 13.6 Mon 17:30 Poster B

The Hofstadter Butterfly under periodic driving — •Martin Wackerl and John Schliemann — Institut für Theoretische Physik, Universität Regensburg

The focus is on externally driven graphene which is additonally in a magnetic field where the external driving is put into practice by polarized light. The Hofstadter buttery problem is treated in a rigerous manner. Then we generalize it to the case with a periodic driving, realized by linear and circular polarized light. We show some representative numerical results for different frequencies, intensities and polarizations. Finally, the topological properties of the Floquet-Hofstadter problem is characterized with Chern numbers. We compare the ground state Chern numbers for different frequencies and intensities. This work gives an analytical as well as a numerical approach to the above formulated system.

HL 13.7 Mon 17:30 Poster B

Valley polarization dynamics of interlayer excitons in dichalcogenide heterostructures in high magnetic fields — •Johannes Holler[1], Jonas Zipfel[1], Mariana Ballotin[2], Anatolie Mitioglu[2], Michael Kempf[1], Philipp Nagler[1], Fabian Mooshammer[1], Alexey Chernikov[1], Peter Christianen[2], Christian Schüller[1], and Tobias Korn[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]High Field Magnet Laboratory (HFML EMFL), Radboud University Nijmegen, Netherlands

In the recent years, research on two-dimensional materials has been a rapidly expanding field. Among these materials, a promising class are the transition-metal dichalcogenides (TMDCs). Besides very interesting physics of monolayers, such as spin-valley locking, these TMDCs can be combined to heterostructures, revealing new excitonic properties.

Here, we study $MoSe_2$-WSe_2 heterostructures, which create a staggered band alignment so that optically excited electron-hole pairs are spatially separated, leading to the formation of interlayer excitons (IEXs). In magnetic fields of up to 30 Tesla, we observe a giant valley-selective splitting in low-temperature photoluminescence measurements and a resulting near-unity valley polarization. Furthermore, we probe the valley dynamics of the IEX in dependence of the magnetic field. 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 13.8 Mon 17:30 Poster B

Influence of oxygen and water on the stability and optical properties of monolayer MoS_2 — •Christian Tessarek, Oleg Gridenco, Kathrin Sebald, Stephan Figge, Jürgen Gutowski, and Martin Eickhoff — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, D-28359 Bremen, Germany

2D materials such as graphene, BN and transition metal dichalcogenides (TMDs) are promising candidates for further miniaturization of (opto-)electronic devices. Monolayer MoS_2, a member of the TMD family, is a semiconductor with a direct band gap of 1.9 eV and thus suitable for transistor, photovoltaic and light emitting applications. Its large surface-to-volume ratio and chemical activity enables strong interaction with the environment essential for highly sensitive optical sensors. In this context it is necessary to understand the influence of the environment on the optical properties of MoS_2.

In this study, thin layers are prepared by exfoliation of bulk MoS_2. Raman spectroscopy is used to identify the number of layers and photoluminescence measurements are performed to investigate the influence of different gases and liquids on the optical properties of mono- and multilayer MoS_2. A strong enhancement of the photoluminescence intensity is achieved by exposing MoS_2 to oxygen and water. It is found that MoS_2 is more stable in oxygen compared to water. Degradation mechanism are analyzed by Raman spectroscopy.

HL 13.9 Mon 17:30 Poster B

Drag Experiments in Double Bilayer Graphene — Matthias Troiber[1], Kenji Watanabe[2], Takashi Taniguchi[2], Dieter Weiss[1], and •Jonathan Eroms[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Regensburg, Germany — [2]National Institute for Materials Science, Tsukuba, Japan

We present experimental results on longitudinal and transverse drag in double bilayer graphene heterostructures. The graphene sheets were separated by a few nm thick hexagonal boron nitride (hBN) layer and were embedded into hBN using the van der Waals stacking technique. The density in both layers was controlled by a back and top gate, respectively. Drag measurements were performed at temperatures up to $T = 100$ K and both at $B = 0$ and in the quantum Hall regime. Similar to [1], at $B = 0$ we observe a sign inversion of the drag voltages close to simultaneous charge neutrality in both layers. In the quantum Hall regime at elevated temperatures, we observe pronounced signatures in the drag signal at integer filling factors in either layer, despite the fact that in transport the QHE features are only barely visible. Also, at constant combined filling factor similar features appear in the drag signal. The results can be mostly interpreted within the Oppen-Simon-Stern theory [2], and we will discuss possible reasons for remaining discrepancies.

[1] J. I. A. Li, *et al.*, Phys. Rev. Lett. **117**, 046802 (2016).
[2] F. von Oppen, S. H. Simon, and A. Stern, Phys. Rev. Lett. **87**, 106803 (2001).

HL 13.10 Mon 17:30 Poster B

Optical properties the Ferromagnetic CrI_3 monolayer — •Claudia Cardoso[1], David Soriano[1], and Joaquín Fernández-Rossier[1,2] — [1]International Iberian Nanotechnology Laboratory (INL), Braga, Portugal — [2]Departamento de Física Aplicada, Universidad de Alicant, Spain

The recent reports of ferromagnetic order in two dimensional crystals sign the beginning of a new chapter in the field of 2D materials. Bulk CrI_3 is a layered van der Waals ferromagnet and, in its monolayer form, a 2D ferromagnet. Distinct from the Wannier-Mott excitons which dominate the optical response in 2D van der Waals semiconductors, the recently reported absorption photoluminescence measurements on CrI_3 were explained in terms of ligand-field, charge-transfer and parity-forbidden $d-d$ transition characteristic of Cr^{3+} complexes.

The aim of the present work is to go beyond phenomenological models, and study the ferromagnetic CrI_3 monolayer optical properties from first principles. On the one hand, it is possible to describe the properties of a magnetic system in terms of effective single spin Hamiltonians, yet the determination of the different parameters requires experimental input. On the other hand, Density Functional Theory (DFT) provides an accurate description of the ground state electronic properties, however it does not describe low energy spin excitations. By combining these two approaches we derive the effective spin Hamiltonian starting from an atomistic DFT description. This method allows us to interpret the experimental findings and identify

the origin of the transitions in the recently reported photoluminescence measurements.

HL 13.11 Mon 17:30 Poster B

Impact of non-resonant terahertz excitation on excitons in $MoSe_2$ 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

We have studied the interaction of excitons in $MoSe_2$ monolayers with high terahertz electric fields by means of THz pump - optical probe spectroscopy. The experiment has been performed with the free electron laser at the Helmholtz-Zentrum Dresden-Rossendorf synchronized to a mode-locked Ti:Sapphire laser. Various frequencies in the range of 3 - 30 THz have been selected for non-resonant pumping of the $MoSe_2$ monolayer, while the probe beam (748 nm) is resonant with the exciton. During the time overlap between the picosecond THz and NIR pulses, we observe a significant reflectivity increase at the exciton resonance. We discuss free carrier absorption, excitonic dynamical Franz-Keldysh effect and AC Stark effect as possible scenarios for this non-resonant interaction.

HL 13.12 Mon 17:30 Poster B

ultrafast Auger-mediated hole trapping and coherent phonon dynamics in CdSe/CdS core/shell colloidal semiconductor nanoplatelets — •shuo dong[1,2], jie lian[3], yinthai chan[3,4], and zhiheng loh[1] — [1]Division of Chemistry and Biological Chemistry, and Division of Physics and Applied Physics, School of Physical and Mathematical Sciences, Nanyang Technological University, 21 Nanyang Link, Singapore 637371, Singapore — [2]Fritz Haber Institut of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany — [3]Institute of Materials Research & Engineering A*STAR, 3 Research Link, Singapore 117602, Singapore — [4]Department of Chemistry, National University of Singapore, 3 Science Drive 3, Singapore 117543, Singapore

The narrow absorption and photoluminescence emission spectra of atomically flat, quasi-two-dimensional, colloidal semiconductor nanoplatelets (NPLs), which originate from the atomically precise thickness, have motivated increasing research interest. Here, we report the use of ultrafast transient absorption spectroscopy to study the early-time carrier dynamics of CdSe/CdS core/shell NPLs. By selective monitoring the excitonic transitions, fluence-dependent measurements reveal a sub-picosecond Auger-mediated hole trapping process. The low-frequency oscillatory features observed in the first-moment time traces can be assigned to the hitherto undetected coherent acoustic phonons (5 and 20 cm-1). The elementary carrier and phonon dynamics of colloidal semiconductor NPLs observed herein could potentially influence their optoelectronic properties.

HL 13.13 Mon 17:30 Poster B

The influence of field effect doping on the optical properties of a MoS_2 monolayer — •Shun Okano[1], Apoorva Sharma[1], Mahfujure Rahaman[1], Akira Nishimura[2], Nicole Köhler[3], Kenji Ikushima[2], and Dietrich R.T. Zahn[1] — [1]Semiconductor Physics, Chemnitz University of Technology, D-09107 Chemnitz — [2]Department of Applied Physics, Tokyo University of Agriculture and Technology, Tokyo 184-8588, Japan — [3]Zentrum für Mikrotechnologien, Chemnitz University of Technology, D-09107 Chemnitz

Since the discovery of graphene, 2D materials are in the centre of attention in the scientific community. Within the 2D material family MoS_2 possesses semiconducting properties with a band gap unlike graphene, which is a conductor. This makes MoS_2 a suitable candidate for various device applications such as transistors etc. Furthermore, K.F. Mak et al. reported a novel property of modulating the light absorption for a monolayer of MoS_2 with field effect doping [1]. However, a detailed optical spectroscopic analysis of this material is still lacking. Here we present the results obtained from microscopic imaging spectroscopic ellipsometry and a thorough analysis of the results. The study was conducted on mechanical exfoliated MoS_2 flakes stamped on highly doped p-type silicon substrate with a thermally grown 375 nm thick silicon dioxide layer. To induce field effect doping in the MoS_2, gold electrodes were patterned with e-beam lithography technique. From the results obtained the modulation of the optical properties can be correlated to the change in carrier concentration. [1] Mak,K. F.,Nature materials 12.3(2013):207-211.

HL 13.14 Mon 17:30 Poster B

Single-photon emitters in hBN — •Johann Preuss, Osvaldo del Pozo-Zamudio, Robert Schmidt, Philipp Tonndorf, Johannes Kern, Steffen Michaelis de Vasconcellos, and Rudolf Bratschitsch — Physikalisches Institut und Center for Nanotechnology, Westfälische Wilhelms-Universität Münster, Deutschland

Single photon emitters (SPEs) have gained increased attention due to their application in quantum technologies, such as quantum computation and communication. Solid-state SPEs are promising due to their high stability and scalability in addition to the excellent optical properties. Recently, the 2D semiconductors WSe2 and WS2 have been shown to host SPEs [1,2,3]. Hexagonal boron nitride (hBN), a van der Waals insulator, exhibits ultrabright and narrowband single photon emission also at room temperature [4]. We investigate the optical properties of single localized emitters in hBN using photoluminescence spectroscopy.

[1] Tonndorf et al., Optica 2, 347-352, 2015 [2] Maragkou, Nature Materials 14, 564, 2015 [3] Palacios-Berraquero et al., Nature Comm 7, 12978, 2016 [4] Tran et al., Nature Nanotech 11, 37-42, 2016

HL 13.15 Mon 17:30 Poster B

Electroluminescence in strain-reduced MoSe2 monolayer p-n-junctions — •Georg Winkens[1], Jhih-Sian Tu[1], Thomas Grap[2], Joachim Knoch[2,3], Detlev Grützmacher[1], and Beata Kardynal[1,3] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany — [2]Institute of Semiconductor Electronics, RWTH Aachen University — [3]JARA - Fundamentals of Future Information Technology, RWTH Aachen University, Germany

P-n junctions are one of the fundamental elements of modern semiconductor devices, such as diodes, LEDs, transistors and photodetectors. Doping needed to form p-n junctions in monolayers of transition metal dichalcogenides (TMD MLs) is proving difficult, while strong interest in this class of material has been fueled by their unique properties which could lead to new applications. The strong spin-orbit interaction combined with favourable optical selection rules makes them extremely interesting for opto-spintronics and valleytronics. A shift of the electrochemical potential in TMD MLs can be achieved by the use of local gating instead of dopants, allowing very flexible manipulation of doping levels and thus fabrication of complex devices. In this presentation we will compare two alternative designs of devices based on local gating, both aiming at eliminating strain from the TMD monolayers in the patterned devices. While one relies on preparing van der Waals heterostructures, the second makes use of substrates with buried tungsten gates. We will compare the two designs by characterizing MoSe2 ML light emitting diodes.

HL 13.16 Mon 17:30 Poster B

Determination of the crystal orientation of monolayer transition metal dichalcogenides and transition metal dichalcogenide heterostructures. — •Michael Kempf, Johannes Holler, Philipp Nagler, Christian Schüller, and Tobias Korn — Universität Regensburg, 93053 Regensburg Germany

We investigate the crystal orientation of monolayer transition metal dichalcogenides (TMDC) and especially the relative crystal orientation of single layer TMDC heterostructures. This difference is of special interest for interlayer effects, for example the formation and recombination of interlayer excitons, and can be determined by using polarized second harmonic generation (SHG) measurements. The heterostructure samples are fashioned through mechanical exfoliation of monolayer $MoSe_2$ and WSe_2 and stepwise transfer onto a SiO_2 substrate. We perform scanning SHG measurements of our structures with sub-μm resolution and defined polarization. For a 0° and 60° orientation difference of the monolayers in a heterostructure we observe a constructive and destructive interference of the SHG intensity, respectively.

HL 13.17 Mon 17:30 Poster B

Resonant Raman scattering on few layer $MoSe_2$ — •Sebastian Meier, Philipp Nagler, Andreas Hecht, Tobias Korn, and Christian Schüller — Universität Regensburg, 93040 Regensburg, Germany

We perform resonant Raman scattering to look for electronic scattering mechanisms in $MoSe_2$. Our samples are prepared by mechanical exfoliation and transferred to a Si/SiO_2 substrate. Using a Ti:Sapphire laser, we can tune the excitation energy across the whole region of excitonic transitions at the K and K' points in $MoSe_2$. This allows us to record the detailed resonance behaviour of known phonon modes as

well as to look for new peaks in the low-energy region. Such measurements were done for room temperature and at $T = 4\,\mathrm{K}$.

For both temperatures, a new peak is observed on few-layer samples, which we can not explain by phonon scattering. It is located at very low wavenumbers and appears only at extremely resonant excitation. We then investigate the properties of this peak by changing the electrostatic environment of our samples.

HL 13.18 Mon 17:30 Poster B

The impact of the substrate material on the optical properties of 2D WSe_2 monolayers — •Jan Kuhnert[1], Lorenz Maximilian Schneider[1], Sina Lippert[1], Simon Schmitt[1], Obafunso Ajayi[2], Dylan Renaud[1], Young Duck Kim[2,3], Wolfram Heimbrodt[1], James C. Hone[2], and Arash Rahimi-Iman[1] — [1]Department of Physics and Material Sciences Center, Philipps-Universit[f]at Marburg, 35032 Marburg , Germany — [2]Department of Mechanical Engineering, Columbia University, 10027 New York, USA — [3]Department of Physics and Center for Humanities and Sciences, Kyung Hee University, 02447 Seoul, Republic of Korea

Layered transition-metal dichalcogenides have attracted great interest in the last few years due to their outstanding optical properties caused by the direct band gap located at the K-point in the brillouin zone. Due to the monolayer thickness, the direct environment plays a crucial role concerning the excitonic and therefor the optical properties of these materials. Our study focuses on optical measurements performed on WSe_2 monolayers on three different substrates. Raman, time-integrated photoluminescence (TIPL) and time-resolved photoluminescence (TRPL) reveal influences of an additionally introduced intermediate hexagonal boron nitride (hBN) layer between substrate and the monolayer on the power-dependent time-evolution of the photoluminescence signal.

HL 13.19 Mon 17:30 Poster B

Synthesis and characterization of graphite oxide based ink for printed transistors — •Tessy Theres Baby[1], Abhinav Chandresh[1,2], Surya Abhishek Singaraju[1], Ben Breitung[1], and Horst Hahn[1,3] — [1]Institute for Nanotechnology, Karlsruhe Institute of Technology (KIT), D-76344 Eggenstein-Leopoldshafen, Germany — [2]Christian-Albrechts-University of Kiel, Kaiserstrasse 2, 24143 Kiel, Germany — [3]KIT-TUD Joint Research Laboratory Nanomaterials, Institute of Materials Science, TU Darmstadt, Petersenstr. 32, 64287 Darmstadt, Germany

Graphene, the one atom thick layer of carbon, is ideally suited for numerous electronic applications on account of its high conductivity, carrier concentration and extraordinary mobility (15,000 cm2 V-1s-1). However, the absence of an electronic band gap has been an impediment in realizing graphene based devices. Therefore, the aim of this work is to synthesize graphite oxide/graphene oxide (GO) with tunable electronic properties at variable temperatures. We have followed the well know Hummer's method to synthesize good quality GO. Acid functionalization has been carried out to obtain stable dispersions with tailored morphology. Finally, in the course of fabricating field-effect devices, a printable (ink-jet) grade of nanoink consisting of GO has been prepared. In order to preserve the electronic properties, no surfactants or additives have been added. Relatively low temperature was used to process the devices. Electrochemically-gated field-effect transistors using composite solid polymer electrolytes have been characterized systematically. Fabricated devices showed p-type behavior.

HL 13.20 Mon 17:30 Poster B

Mechanical exfoliation of MoS2 monolayer flakes — •Yuhao Zhang, Eicke Icking, and Stefan Linden — Physikalisches Institut, Nussallee 12, Universit at Bonn , 53115 Bonn, Germany

Transition metal dichalcogenide (TMDC) monolayers have attracted considerable interest in recent years. Here we report on the mechanical exfoliation and all-dry viscoelastic stamping [1] of MoS2 monolayer and few-layer flakes onto different substrates. The optical properties of these layers are characterized by differential reflectance and transmittance spectroscopy. Additional electron energy loss spectroscopy experiments are currently being carried out.

[1] Castellanos-Gomez A. et al. . Deterministic transfer of twodimensional materials by all-dry viscoelastic stamping. 2D Mater. 1, 011002 (2014).

HL 13.21 Mon 17:30 Poster B

Spatially resolved photoluminescence of mono- and bilayer molybdenum ditelluride — •Matthias Kunz[1], Sophia Helmrich[1], Robert Schneider[2], Alexander W. Achtstein[1], Ashish Arora[2], Bastian Herzog[1], Steffen Michaelis de Vasconcellos[2], Mirco Kolarczik[1], Oliver Schöps[1], Rudolf Bratschitsch[2], Nina Owschimikow[1], and Ulrike Woggon[1] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Germany — [2]Physikalisches Institut, Westfälische Wilhelms-Universität Münster, Germany

We study the photoluminescence of a mechanically exfoliated molybdenum ditelluride ($MoTe_2$) flake in the spatial crossover region from monolayer (ML) to bilayer (BL) at low temperatures. To repeatedly address identical locations on the flake, we develop a camera-piezo feedback loop and confirm the reproducibility of the data obtained in different runs. In contrast to other transition metal dichalcogenides (TMD) materials, the $MoTe_2$ BL shows a strong luminescence comparable in intensity to the ML. The peak energy of the BL exciton is red-shifted by about 35 meV with respect to the ML, but displays a shift to larger energies at close distances to the ML/BL border. With edge effects thus influencing the peak positions, our results underline the importance of correct positioning of the excitation spot on TMD flakes.

HL 13.22 Mon 17:30 Poster B

Manipulation of the Environmental Interaction and Optical and Electrical Properties of Single-Layer MoS_2 Transistors — •Philip Klement[1], Christina Steinke[2], Tim Wehling[2], Sangam Chatterjee[1], and Martin Eickhoff[1,3] — [1]Institute of Experimental Physics I, Justus Liebig University Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany — [2]Institute for Theoretical Physics and Center for Computational Material Sciences, University of Bremen, Otto-Hahn-Allee 1, 28359 Bremen, Germany — [3]Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, 28359 Bremen, Germany

The optical and electrical properties of two-dimensional transition metal dichalcogenides such as MoS_2 exhibit a high sensitivity to their dielectric environment due to their large surface-to-volume ratio and the presence of active surface sites. Further, they offer the possibility of manipulating the Coulomb interaction by electrostatic screening through gaseous species or external electric gating. We studied the underlying interaction mechanism by a variation of the Fermi level and its influence on the adsorption and desorption behavior of oxygen. Photoluminescence and photo-induced channel current measurements show a strong variation of the electrical and optical properties of single-layer MoS_2. A reversible charge carrier transfer between O_2 and MoS_2 is confirmed, and is very sensitive to the density of free carriers. This concept is supported by theoretical calculations.

HL 13.23 Mon 17:30 Poster B

Ultrafast Coulomb-induced intervalley coupling in monolayer WS_2 — Robert Schmidt[1], Gunnar Berghäuser[2], •Robert Schneider[1], Malte Selig[3], Philipp Tonndorf[1], Ermin Malic[2], Andreas Knorr[3], Steffen Michaelis de Vasconcellos[1], and Rudolf Bratschitsch[1] — [1]Institute of Physics and Center for Nanotechnology, University of Münster, 48149 Münster, Germany — [2]Department for Applied Physics, Chalmers University of Technology, SE-41296, Gothenburg, Sweden — [3]Department for Theoretical Physics, Technical University Berlin, 10623 Berlin, Germany

Monolayers of semiconducting transition metal dichalcogenides are promising for information processing due to the presence of two valleys, which are located at the K and K' point of the Brillouin zone and separately addressable by circularly polarized light of different helicity. We perform ultrafast, spectrally and polarization-resolved pump-probe measurements on single mechanically exfoliated WS_2 monolayers to elucidate the underlying coupling between the two valleys. Together with microscopic theory, we demonstrate that the strong signal, which is observed in the unpumped valley, is due to Coulomb-induced intervalley coupling [1]. This interaction explains the different degree of valley polarization obtained with ultrafast pump-probe measurements compared to photoluminescence studies.

[1] R. Schmidt et al.,"Ultrafast Coulomb-induced intervalley coupling in atomically thin WS2", Nano Lett. 16, 2945-2950, (2016)

HL 13.24 Mon 17:30 Poster B

Optimization of charge injection into few layered Indium Selenide for high performance logic devices — •Vivek Koladi Mootheri, Phanish Chava, Himani Arora, and Artur Erbe — Helmholtz Zentrum Dresden Rossendorf, Dresden, Germany.

Two-dimensional materials provide the ideal physical basis for field effect devices based on alternative materials and architectures, owing to the absence of interfacial dangling bonds. Indium Selenide (InSe) falls under the III-VI semiconducting layered chalcogenide group of the two-dimensional materials family. Its properties such as high mobility and direct band gap in few layered exfoliated flakes provide a basis for exploring its potential for future electronic/optoelectronic devices. However, the intrinsic superior electronic properties of InSe have not been completely utilized due to inefficient charge injection into the material from the source and drain electrodes. This project thus focuses on optimizing the charge injection with the help of different contacting techniques on few layered InSe flakes. Here we demonstrate the use of few layered graphene to contact hexagonal Boron Nitride (hBN) encapsulated InSe flake and also realize implanted contacts by a focused ion beam. This work hence provides a comparative study of the various contacting approaches used, identifying the most beneficial approach.

HL 13.25 Mon 17:30 Poster B

Dielectrically Defined Lateral Heterojunctions in Transition Metal Dichalcogenide Monolayers — •Sven Borghardt[1], Leo Yu[2], Archana Raja[3], Jhih-Sian Tu[1], Detlev Grützmacher[1], Tony F. Heinz[2,4], and Beata E. Kardynal[1] — [1]Peter Grünberg Institute 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Department of Applied Physics, Stanford University, Stanford, CA 94305, USA — [3]Kavli Energy Nanoscience Institute, University of California, Berkeley, CA 94720 — [4]SLAC National Accelerator Laboratory, Menlo Park, CA 94025, USA

Heterojunctions (HJs), i.e. the interfaces of two semiconductors with unequal band gaps, are the backbone of established semiconductor technology. Recently, we have demonstrated that both the electronic and optical band gaps of transition metal dichalcogenide monolayers (TMD-MLs) can be manipulated through externally induced dielectric screening. However, to the present date, little is known about exciton dynamics in dielectrically induced lateral HJs.

In order to shed light on exciton dynamics in dielectrically defined lateral HJs, we have prepared TMD-MLs encapsulated with nanopatterned hexagonal boron nitride sheets. Photoluminescence and reflectance measurements with μm-resolution are performed to probe an ensemble of dielectrically defined HJs, with the temperature, charge level and pattern layout as tunable parameters. From these ensemble measurements, we expect to obtain insights into both exciton diffusion and lateral exciton confinement processes in dielectrically induced HJs, paving the way towards well-engineered dielectrically defined devices.

HL 13.26 Mon 17:30 Poster B

Effective passivation of ultra-thin layers of InSe to enhance electrical properties — •Himani Arora[1,2], Younghun Jung[3], Sanghoon Chae[3], Daniel Rhodes[3], Ghidewon Arefe[3], Takashi Taniguchi[4], James Hone[3], and Artur Erbe[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Department of Mechanical Engineering, Columbia University, New York, NY, 10027, USA — [4]Advanced Materials Laboratory, National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

We report electrical properties of ultrathin layers of Indium Selenide (InSe), a member of the III-VI chalcogenides family, which has shown a mobility two orders of magnitude higher than MoS2, alongside better stability than black phosphorus.

InSe has light electron effective mass and high mobility enabling its usage for fast, high performance electronics. State-of-the-art InSe transistors reported so far, consist of 6 nm thick InSe flake contacted using graphene edge contacts and reaching a mobility of 1500 cm2V-1s-1 at RT in top-gate configuration. However, InSe being an air-sensitive material loses its conductance over time, resulting the transistor to become unfunctional.

In this study, we report an InSe-based transistor fully encapsulated in h-BN layers which enhanced its electrical properties compared to an un-encapsulated device. The transistor reached a high Hall mobility at RT, while retaining its performance for a long period of time.

HL 13.27 Mon 17:30 Poster B

Momentum-resolved hole and exciton dynamics in WSe_2 — •Patrick Xian, Michele Puppin, Christopher Nicholson, Martin Wolf, Laurenz Rettig, and Ralph Ernstorfer — Fritz-Haber-Institut der Max-Planck-Gesellschaft

Time-resolved ARPES (trARPES) is a unique tool for direct tracking of electronic dynamics in momentum space. We used a 500 kHz XUV source to photoemit electrons from the valence and conduction bands of WSe_2 following optical excitation of A excitons. We uncover the momentum dependence of various aspects of the excited state dynamics, in particular signatures of a bright to dark exciton transition. We extract bright exciton lifetimes with an optical Bloch equation model. The momentum dependence of the hole dynamics is retrieved by a global fitting algorithm that extracts the time dependence of 2D band structure parameters. Finally, we condensed our analysis pipeline into an open-source software package for trARPES data handling from 2D background removal to band position detection to multidimensional data visualization. Its Python implementation and support for Igor data formats invite public contribution and adoption.

HL 13.28 Mon 17:30 Poster B

Intermediate band solar cells - Characterization of transition metal doped indium sulfide — •Ron Hildebrandt[1], Tanja Jawinski[2], Leonard Wägele[2], Holger von Wenckstern[1], Roland Scheer[2], and Marius Grundmann[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstraße 5, 04103 Leipzig, Germany — [2]Martin-Luther-Universität Halle-Wittenberg, Institut für Physik, 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 present a deep level impurity approach for IB solar cells. The heterostructure is p-$ZnCo_2O_4$/i-In_2S_3/n-ZnO:Al with Au contacts on each side. The transition metal 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 by current voltage, thermal admittance spectroscopy, photocurrent and transmission measurements, as well as atomic force microscopy. The solar cells showed rectification of 3.5 orders of magnitude and a clear photovoltaic response.

[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.

HL 13.29 Mon 17:30 Poster B

Thin films made of Cu_2ZnSnS_4 nanocrystal inks for solar cells — •Karen P. Stroh, Ismael Gerardo Pérez Marín, Yasir A. Altowairqi, Marek Szablewski, and Douglas P. Halliday — Centre for Materials Physics, University of Durham, United Kingdom

Thin film solar cells based on nanocrystal inks, which make use of earth-abundant elements and may be fully printable, are a promising approach to sustainable, low-cost, and high-efficiency photovoltaic devices. The quaternary chalcogenide Cu_2ZnSnS_4 (CZTS) nanoparticles investigated are synthesised by a solution-based hot injection method. Being redispersed they form an ink, which is then used to deposit thin films via spin coating.

The influence of the temperature as well as the duration of the sintering process on the film properties is investigated, alongside with a characterisation of the nanocrystals used. The broader objective of the study is to enhance grain-growth and to achieve better uniformity throughout the films regarding composition, phase, and structure. This is substantial for limiting recombination losses and carrier scattering at grain boundaries and for enlarging the fraction of absorber layer material which effectively contributes to the generation of current. Opto-electronic properties, chemical composition, and structure of the synthesised nanoparticles as well as the resulting films are analysed by use of UV-visible spectroscopy, XRD, Raman, and SEM measurements.

HL 13.30 Mon 17:30 Poster B

polymer solar cells using an AgAl alloy anode — Xiangkun Jia[1,2] and •Xiaohong Chen[1] — [1]Engineering Research Center for Nanophotonics and Advanced Instrument, Ministry of Education, and Department of Physics, East China Normal University, Shanghai 200062, China. — [2]Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and Institute for Applied Physics, Technische Universität Dresden, Nöthnitzer Str. 61, 01187 Dresden, Germany.

In this work, we improve the performance and air stability of inverted polymer solar cells (PSCs) using a combination of a LiF-modified ITO cathode and a MoO3/AgAl alloy anode. The power conversion effi-

ciency (PCE) of PSCs with the AgAl contact reaches 9.4%, which is higher than that of the cells with a Ag (8.8%) or Al electrode (7.6%). This improvement is primarily attributed to the formation of thin AlOx at MoO3/AgAl interface, preventing the Ag diffusion and improving the hole tunneling probability and built-in potential across the active layer in the cells. The PCE of AgAl-based PSCs is further increased to up to 10.3% through the incorporation of an ultrathin LiF-modified ITO, due to an improvement in electron collection. These devices exhibit a superior stability as compared to the cells with Ag and Al contacts. The PCE of the AgAl-based cells without encapsulation remains 78% of its original value after the cells were aged for 380 days in air.

HL 13.31 Mon 17:30 Poster B

High-throughput calculations for the identification of novel materials for tandem cells — •Hossein Mirhosseini, Ramya Kormath Raghupathy, Hendrik Wiebeler, and Thomas D. Kühne — Department of Chemistry, University of Paderborn, Paderborn, Germany

One straightforward way to considerably enhance the efficiency of the solar cells is the realization of multi-junction solar cells such as tandem cells: the efficiency of a two sub-cells tandem can be raised up to 42% [1]. In this work, high-throughput ab-initio calculations were employed to identify the most promising absorber and p-type transparent conducting materials (TCMs) for future tandem cells [2]. Non-toxic semiconductors with hole effective masses smaller than 1 and band gaps larger than 1 eV (for absorber) and 1.7 eV (for TCMs) were considered here. The dopability and extrinsic dopants were investigated to determine the performance of the selected compounds.

[1] A. De Vos, J. Phys. D: Appl. Phys. 13, 839 (1980)

[2] D. Broberg, B. Medasani, N. Zimmermann, A. Canning, M. Haranczyk, M. Asta, G. Hautier, arXiv:1611.07481

HL 13.32 Mon 17:30 Poster B

Ab initio study of binary pnictides and halides for the identification of transparent p-type conducting materials — •Hendrik Wiebeler, Kormath Raghupathy Ramya, Hossein Mirhosseini, and Thomas D. Kühne — Department of Chemistry, University Paderborn, Germany

Transparent conducting materials (TCMs) have received attention owing to their wide range of applications from solar cells to transparent electronics[1]. Transparent conducting oxides (TCOs) have been predominantly commercialized as n-type TCMs. In contrast to this, the performance of p-type TCOs is not satisfactory, due to the nature of their valence bands. Hence, in this work, ab initio calculations were employed to identify high-performance p-type semiconductors[2]. Materials having wide band gaps (E_g) and low hole effective masses (m_h) are promising p-type TCMs. Therefore, non-toxic and non-expensive binary semiconductors with $E_g > 1.7$ eV and $m_h < 1$ were considered. The role of intrinsic and extrinsic point defects was explored to determine the p-type performance.

[1] K. Zhang et al., J. Phys.: Condens. Matter 28 383002 (2016)

[2] D. Broberg et al., arXiv:1611.07481v1 (2016)

HL 13.33 Mon 17:30 Poster B

Suppression of interference effects in electroreflectance spectroscopy on Cu(In,Ga)(S,Se)$_2$ solar cell buffer layers — •J. Seeger[1], U. Piesch[1], O. Kiowski[3], D. Hariskos[3], W. Witte[3], M. Powalla[2,3], P. Eraerds[4], R. Lechner[4], T. Dalibor[4], H. Kalt[1], and M. Hetterich[2] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Light Technology Institute, KIT, 76131 Karlsruhe, Germany — [3]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany — [4]AVANCIS GmbH, 81739 München, Germany

Cu(In,Ga)(S,Se)$_2$ thin-film solar cells are a great alternative to the widely spread silicon technology. One approach to further improve them is to find alternative materials for the commonly used CdS buffer layer. CIGS solar cells with different buffer materials are investigated utilizing electroreflectance spectroscopy (ER). While ER can readily be applied to absorber layers [1], the investigation of buffer layers is often quite challenging. One reason for this is the low thickness of the buffer layer, which leads to a weak signal. Therefore, occurring interference effects in the layer stack can have a strong influence on the ER spectra. Measuring scattered instead of specularly reflected light can reduce such interference effects [2]. Another approach is the reduction of the ZnO window layer thickness by etching it partially away. Results for both techniques will be discussed in this contribution.

[1] C. Huber *et al.*, Phys. Rev. B 92, 075201, 2015.

[2] C. Krämmer *et al.*, Appl. Phys. Lett. 107, 222104, 2015.

HL 13.34 Mon 17:30 Poster B

In Situ TEM Studies of Rear Contact Formation of Aluminium with Multi-Crystalline Silicon — •Christoph Flathmann, Tobias Meyer, and Michael Seibt — IV. Physikalisches Institut der Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

For various reasons, the rear contact of a solar cell is a crucial part concerning energy conversion efficiency. The most important requirements are a low resistance ohmic contact and a smooth as well as highly reflective interface, for both minority carriers and photons. In order to create such contacts for multi-crystalline silicon (mc-Si) solar cells, aluminium (Al) is alloyed to the back of the cells. Hence, a heavily Al doped p^+-region and thus a back-surface field (BSF), which increases cell efficiency, is created. However, rear contacts suffer from flaws due to non-uniform alloying and crystal defects, such as grain boundaries.

To thoroughly investigate the alloying process, cross-section lamellas for transmission electron microscopy (TEM), mimicking the rear of a solar cell, are either prepared employing a focused ion beam or conventionally. Subsequently, the samples are heated and *in situ* studied by TEM. High resolution and analytical TEM are utilized for analysing structure and chemical composition, respectively. Particular attention is paid to the effect of grain boundaries on the alloying characteristics and the evolution of {113} defects in the silicon during BSF formation.

HL 13.35 Mon 17:30 Poster B

Investigation of $Pr_{1-x}Ca_xMnO_3$-$SrTi_{1-y}Nb_yO_3$ Interfaces Using Electron Beam Induced Voltage (EBIV) — •Tobias Westphal[1], Patrick Peretzki[1], Tobias Meyer[1], Birte Kressdorf[2], Christian Jooss[2], and Michael Seibt[1] — [1]4th Physical Institute, Georg-August-Universität Göttingen, 37077 Göttingen, Germany — [2]Institute of Material Physics, Georg-August-Universität Göttingen, 37077 Göttingen, Germany

P-n heterojunctions consisting of the p-doped manganite $Pr_{1-x}Ca_xMnO_3$ (PCMO) and the n-doped titanite $SrTi_{1-y}Nb_yO_3$ (STNO), both perovskite-structured, have been investigated with Electron Beam Induced Current (EBIC). To further study the photovoltaic properties of this system, the Electron Beam Induced Voltage (EBIV) technique is used in this work. The standard form for EBIV models predicts a behaviour logarithmic to the EBIC, which is useful for measuring the nanometer scale diffusion length of minority charge carriers in this system.

To investigate the interface of PCMO-STNO, both a wedge shaped lamella and a cleaved cross section are prepared to perform cross-section measurements. Focused Ion Beam is used for lamella preparation and cleaning the cleaved edge. The temperature dependence of EBIV is measured in the range from 80 K to 300 K especially in the regime of the charge ordering temperature of PCMO ($T_{CO} \approx 230$ K). Beam current dependent measurements at $T \approx 300$ K are performed as well. Results show the important role of measurement time limits due to an emerging capacitance in the measure circuit at low temperature.

HL 13.36 Mon 17:30 Poster B

The environmental stability of PbS quantum dot solar cells — •David Becker-Koch — Universität Heidelberg, Kirchhoff-Institut für Physik, Heidelberg

Colloidal inorganic nanocrystal quantum dots (QDs) are excellent solution-processed candidates for third-generation photovoltaics. Due to the quantum-confinement effect their absorption and emission spectra can be readily tuned over the entire visible-NIR spectrum by controlling their compositions and dimensions from synthesis. The state-of-the-art power conversion efficiency of single-junction solid-state QD solar cells reaches 11.6%, which together with their near-IR absorbing capabilities makes them of great interest for a myriad of applications. While the efficiencies are being improved constantly by intensive research, the Achilles heel of these devices seems to be their environmental instability. So far only limited research has been done to study the fundamental causes and mechanisms leading to the environmental instability in devices based on nanocrystal quantum dots.

We investigate the effects of oxygen, humidity, light and their combinations on the performance of high efficiency lead(II)-sulfide (PbS) solar cells. We find that while individual degradation factors cause device instabilities, the combination of exposure to oxygen, humidity and light may result in a recovery of the performance of the device

after a short initial degradation phase.

HL 13.37 Mon 17:30 Poster B

Computational Screening of Ternary Selenides for Water Splitting — •Estefanía Garijo, Mohnish Pandey, and Karsten Wedel Jacobsen — Computational Atomic-scale Materials Design (CAMD), Department of Physics, Technical University of Denmark, DK-2800 Kogens Lyngby, Denmark

Photoelectrochemical water splitting is one of the possible solutions for efficient production of sustainable fuels. However, a suitable large band-gap photoabsorber that matches silicon in the so-called tandem cell has not been identified yet. Here, we present a large survey of ternary selenides in the stoichiometry $ABSe_3$, with A and B metal atoms. In our screening study, key properties, such as stability, photoabsorption, carrier mobility and defects are evaluated step-wise, so that the resulting computationally expensive descriptors are only evaluated for those candidates that have been identified as promising in previous, less expensive steps.

HL 13.38 Mon 17:30 Poster B

Theoretical analysis of optical properties of Cu2ZnSn(S,Se)4 solar absorbers. — •Sergii Zamulko[1], Kristian Berland[1], and Clas Persson[1,2] — [1]Centre for Materials Science and Nanotechnology, University of Oslo, P. O. Box 1048 Blindern, NO-0316 Oslo, Norway — [2]Department of Materials Science and Engineering, Royal Institute of Technology, Brinellvägen 23, SE-100 44 Stockholm, Sweden

Kesterite Cu2ZnSn(SxSe1-x)4 are attracting much attention for application in thin film solar cells, as they consist of earth-abundant elements and operate in a favorable size of band-gap. In this work, we study the dielectric functions of this compound for different alloy composition $0 < x < 1$. Results of ellipsometry measurements are compared with density functional theory (DFT) calculations. The calculations were performed at three levels of theory, using a generalized gradient approximation (GGA), meta-GGA - both relying on on-site +Ud Coloumb correction - and a hybrid functional approach. Furthermore, using a recently developed k.p interpolation scheme, we show that a dense Brillouin zone sampling is needed to accurately account for the shape of the dielectric function. Comparing experimental and theoretical data with enhanced numerical accuracy sheds light on how the critical points in the real part of dielectric function shifts as a function of sulfur content.

HL 13.39 Mon 17:30 Poster B

Charge Carriers Dynamics in Kesterite: From Ultra-fast Trapping via Localized Transport to Surface Recombination — •Hannes Hempel, Rainer Eichberger, and Thomas Unold — Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Hahn-Meitner Platz 1, 14109 Berlin

Kesterite solar cells materials are known to exhibit band tails originating from potential fluctuations and defect bands. We investigate how these tails affect the dynamics of photo-excited charge carrier by applying transient absorption and time resolved THz spectroscopy to coevaporated Cu2ZnSnSe4 thin films. We find that 100 fs after excitation with 1.5 eV photons the carriers form a hot Boltzmann distribution in the band states. Within 2 ps they thermalize to lattice temperature and reach simultaneously band edge and tail states. Afterwards the carriers are distributed in bands, tails and defects and exhibit in average a localized mobility with a DC-value of 100 cm2/Vs. Their transport can be described by a sequence of trapping and detrapping between extended band and localized tail states.

HL 13.40 Mon 17:30 Poster B

In-Silico Homovalent Screening of Hybrid Halide Perovskite Materials for Tandem Solar Cells — •Manaswita Kar and Thomas Körzdörfer — AG Computational Chemistry, University of Potsdam, Institute of Chemistry, Karl-Liebknecht Straße 24-25, D-14476 Potsdam-Golm

Solar cells based on hybrid organic-inorganic lead-halide perovskites are among the most promising emerging photovoltaic materials of the past decade. Within only a very short research time span, record efficiencies were achieved with solar cells based on methylammonium lead iodide ($CH_3NH_3PbI_3$). The presence of Pb in the currently most efficient perovskite solar cells has raised questions over the possible toxicity of these devices and the extent of their environmental impact. Therefore, a lot of research has been devoted to finding alternative perovskite materials with similar or even better optoelectronic properties. A flipside strategy to improve the efficiency of thin-film solar cells is to build efficient tandem cells by combining materials with specifically tailored band-gaps.

As a first step, geometrical and electronic structure of 48 candidate structures (combination of 12 metals, and 4 halogens) are calculated in 3 different phases, namely, orthorhombic, tetragonal, and cubic using semilocal (PBE) with relativistic corrections. The band gap of these materials are then screened using hybrid functional (HSE), to get candidates in the band-gap range of 1 eV and 1.9 eV. In the next step, the stability of these materials are tested using Quasi-harmonic approximation, in order to find their room-temperature stable phase.

HL 13.41 Mon 17:30 Poster B

Morphology control of methylammonium bismuth iodide films for photovoltaics — •Christian Fettkenhauer, Martina Pantaler, Irina Anusca, and Doru C. Lupascu — Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Universitätsstraße 15, 45141 Essen, Germany

Recently, perovskite solar cells have attracted much attention due to the high achievable efficiencies using abundant hybrid organic-inorganic perovskite absorber materials. The benchmark perovskite absorber is methylammonium lead iodide (MAPI). In this material lead causes serious discussion about potential environmental hazards. Bismuth derived materials like $MA_3Bi_2I_9$ (MBI) might be a less poisenous alternative to MAPI. Although MBI has already been known since the 1960ies its suitability as absorber material has just recently been evaluated. The current power conversion efficiency (PCE) record is 1.64 %. One of the reasons for the lower performance compared to MAPI based solar cells are the anisotropic charge carrier transport properties. Thus, one of the approaches to further increase the PCE is the controlled growth of MBI thin films with a-b planes perpendicular to the substrate. In this work we compare different vapor- and solution processed MBI films with respect to their crystal growth direction, optical absorption, and morphology of the resulting films aiming for further efficiency improvement of MBI based solar cells.

HL 13.42 Mon 17:30 Poster B

Insights into lead-free double perovskite Cs2AgBiBr6 thin films for photovoltaic application — •Martina Pantaler[1], Svetlana Syrotinskaya[2], Selina Olthof[3], Alexsander Schmitz[4], Christian Fettkenhauer[1], Irina Anusca[1], Niels Benson[2], Gard Bacher[4], Roland Schmechel[2], and Doru C. Lupascu[1] — [1]Institute for Materials Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen Universitätsstraße 15, 45141 Essen — [2]Institute of Technology for Nanostructures and Technology (NST), University of Duisburg-Essen, Bismarckstraße 81, 47057 Duisburg — [3]Department of Chemistry, University of Cologne, Luxemburger Straße 116, 50939 Köln — [4]Department of Electrical Engineering and Information Technology, University of Duisburg-Essen, Bismarckstrasse 81 BA, 47057 Duisburg

The double perovskites are a promising lead free alternative to MAPbI3 based perovskite solar cell. Promising photovoltaic properties are long carrier recombination lifetime, good stability against air and moisture, low effective carrier masses, and band gap around 2 eV. We investigate double perovskite thin films and the possibility of solar cell fabrication. We prepared thin films on different substrates using spin-coating. Their crystalline structure, chemical composition, and morphology can be investigated using XPS, XRD, and SEM. Measuring time-resolved photoluminescence we got better insights into the charge carrier lifetime of double perovskite thin film. Finally we determined the valance band energy using ultraviolet photoelectron spectroscopy. Inverted (p-i-n) planar solar cell achieves PCE of 0,42%.

HL 13.43 Mon 17:30 Poster B

A2BX4 Absorber as thin films for photovoltaic application — •Irina Anusca, Christian Fettkenhauer, Martina Pantaler, and Doru C. Lupascu — Institute for Material Science and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Universitätsstraße 15, 45141 Essen

Two-dimensional (2D) organic inorganic perovskites A2BX4 (A= CnH2n+1NH3, B = Cu, Mn, X = Cl, Br, I) can serve as photoabsorber for lead free perovskite solar cells [1-3]. The perovskite layer is the most crucial factor for the high performance of solar cells. The controlled synthesis of materials as thin films (the process deposition) is a fundamental step for good crystallization. We prepare different series of Cu and Mn based 2D-perovskites by mixing different CnH2n+1

organic ammonium cation (alkyl and aromatic) and X halide ions. Film processing steps are discussed. The quality of the obtained films is examined combining the effect of solvents (nature and concentration) with the nature of the deposition process. Both X-ray diffraction (XRD) spectroscopy and scanning electron microscopy (SEM) were used to study film crystallinity and surface morphology.

Keywords: layered 2D perovskite, solvent engineering, photoabsorber

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HL 13.44 Mon 17:30 Poster B

Photoluminescence of Methylammonium Lead Iodide Perovskites in Terms of Stoichiometric Ratios — •Fabian Meier, Sebastian Reichert, Alexander Wagenpfahl, and Carsten Deibel — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Understanding recombination mechanisms of electrical charge carriers is of tremendous importance for understanding the extraordinary power conversion efficiencies, which increased from 4 % up to almost 23 %. We investigate thin films of methylammionium lead iodide perovskite in terms of their stoichiometric ratio of methylammonium iodide and lead iodide. The perovskites are deposited on top of PTAA transport layers on ITO coated glass. By confocal photoluminescence measurements we determine radiative recombination of electric charges as function of time and spatial location. We discuss our results in terms of illumination intensity as well as temperature dependence and compare it to the energetically resolved emission spectra. We furthermore interpret our results in terms of tail states and their impact on the performance of solar cells.

HL 13.45 Mon 17:30 Poster B

Electromodulation Spectroscopy on Organic-Inorganic Perovskite Solar Cells — •Alice Magin[1], Fabian Ruf[1], Moritz Schultes[2], Erik Ahlswede[2], Jonas Schwenzer[3], Heinz Kalt[1], and Michael Hetterich[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, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany

Organic-inorganic perovskites are promising candidates for low-cost solar cells, showing power-conversion efficiencies above 20% [1] and band-gap tunability. Many fundamental material properties of both methylammonium lead iodide and mixed-cation lead mixed-halide compounds have already been studied, e.g. phase transitions [2] and charge-carrier transport [3]. We investigate the electronic structure of solution-processed perovskite solar cells using temperature-dependent electromodulation spectroscopy in order to determine the energetic position of optical transitions. The temperature dependence reflects the phase transition from the orthorhombic to the tetragonal phase. Comparison with absorption measurements allows estimating the nature of the observed resonances. [1] M. A. Green et al., Prog. Photovolt: Res. Appl. 2017, 25:3-13. [2] A. Poglitsch et al., J. Chem. Phys. 87, 6373 (1987). [3] I. Grill et al., ACS Appl. Mater. Interfaces, 2017, 9 (43), pp 37655-37661.

HL 13.46 Mon 17:30 Poster B

Spectroscopic Characterisation of Trap States in Perovskite Solar Cells — •Sebastian Reichert, Fabian Meier, Alexander Wagenpfahl, and Carsten Deibel — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Perovskite solar cells constitute an intensely studied topic in photovoltaics caused by their fast improvement in power conversion efficiency. Investigation of perovskite solar cells has been challenging due to the richness of physical processes occuring on similar time scales. Recently, significant attention has been paid to the capacitance properties in dependence of frequency and applied voltage. Capacitance spectroscopy can be used to infer underlying physical mechanisms such as the charge carrier loss mediated by trap states within the active layer. We present the analysis of methyl ammonium lead iodide solar cells by impedance spectroscopy, capacitance–voltage measurements and deep level transient spectroscopy. These techniques offer access to many electronic processes and allow to understand the influence of trap states on the device performance.

HL 13.47 Mon 17:30 Poster B

Optimization and Characterization of Perovskite Thin-Films — •Sandhya Tammireddy, Fabian Meier, Alexander Wagenpfahl, and Carsten Deibel — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

In the past few years, organo-metal trihalide perovskite solar cells have been attracting tremendous interest because of their unique properties in photovoltaic applications such as high mobilities and long lifetimes of charge carriers. In order to obtain high power conversion efficiencies in perovskite solar cells it is essential to fabricate high quality thin-films with controlled morphology and crystallinity. We produce methyl ammonium lead iodide solar cells by optimizing the absorber layer using solvent engineering techniques. Subsequently, we characterize our thin-films by measuring the time dependent photoluminescence. The decay of the photoluminescence signal allows us to determine the dominant charge carrier loss mechanisms in order to understand recombination in hybrid perovskites.

HL 13.48 Mon 17:30 Poster B

Analyzing optical properties of methylammonium lead bromide using photoluminescence spectroscopy — •Lukas Falk, Paul Fassl, and Yana Vaynzof — Kirchhoff-Institute for Physics / Centre for Advanced Materials, Heidelberg University, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Organometal halide perovskites drew a lot of research attention over the last years due to their intriguing material properties which make them suitable active layers in both photovoltaic (PVs) and light-emitting diodes (LEDs).

We employ photoluminescence spectroscopy to investigate the optical properties of methylammonium lead bromide ($MAPbBr_3$) layers that are commonly used either as emissive layers in perovskite LEDs or as the active layer of a front cell in tandem perovskite PVs. We find that subtle variations in layer processing result in variations of the optical properties and subsequently variations in the performance of the devices. We also investigate the effect of exposure to oxygen on the photoluminescence quantum efficiency of the layers and compare the results to those obtained for methylammonium lead iodide ($MAPbI_3$).

HL 13.49 Mon 17:30 Poster B

High Performance Planar Perovskite Solar Cells by ZnO Electron Transport Layer Engineering — •qingzhi an[1,2], paul fassl[1,2], yvonne jasmin hofstetter[1,2], david becker koch[1,2], alexandra bausch[1,2], paul hopkinson[1,2], and yana vaynzof[1,2] — [1]kirchhoff institute for pyhsics,heidelberg,germany — [2]centre for advanced materials,heidelberg,germany

Due to the many advantageous properties of ZnO, such as high electron mobility and low processing temperatures, it is commonly used as an electron extraction layer in organic photovoltaic devices. However, it has been reported that ZnO cannot be successfully utilized in perovskite photovoltaics due to surface hydroxide groups induced instabilities in the perovskite layers. In this work, we modify the bulk ZnO layer by incorporating Cs or Li dopants and the surface of ZnO layer by depositing a self-assembled monolayer and demonstrate that this combined approach leads to significant improvements in the performance of planar MAPBI3 perovskite solar cells. A maximum power conversion efficiency of 18% is achieved accompanied by a reduction in hysteresis and a significant enhancement of the device stability.[1] Our work shows that ZnO can serve as a practical alternative to TiO2 in standard perovskite solar cells with low fabrication temperatures.

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HL 13.50 Mon 17:30 Poster B

A chain is as strong as its weakest link – Stability study of $MAPbI_3$ under light and temperature — •Philippe Holzhey[1,2] and Michael Saliba[2] — [1]Fachbereich Physik, Freie Universität Berlin, D-14195 Berlin, Germany — [2]Laboratory of Photonics and Interfaces, Institute of Chemical Sciences and Engineering, École Polytechnique Fédérale de Lausanne, Lausanne CH-1015, Switzerland

The stability of perovskite solar cells has been considered poor compared to other solar cells. One reason for this is thought to be the volatile organic methylammonium (MA) cation. At the same time,

small amounts of MA are used for practically all highest performing solar cells with efficiencies beyond 21%. These compositions have also shown some of the best reported stabilities indicating that MA might not be as unstable as previously assumed. This raises the question whether excluding MA for the sake of stability has been concluded prematurely. Here, we use weakest link devices, i.e. $MAPbI_3$, to study the stability under light and different temperatures.

HL 13.51 Mon 17:30 Poster B

Cause Study of the Low Fill Factor of Squaraine Based Solar Cells by Steady-State Methods — •Oliver Kolloge[1], Dorothea Scheunemann[1], Matthias Schulz[2], Arne Lützen[2], and Manuela Schiek[1] — [1]Energy and Semiconductor Research Laboratory, Institute of Physics, University of Oldenburg, D-26111 Oldenburg, Germany — [2]Kekulé Institute for Organic Chemistry and Biochemistry, University of Bonn, Gerhard-Domagk-Str.1, D-53121 Bonn, Germany

Organic solar cells whose active layer consists of a model squaraine donor blended with a fullerene acceptor are particularly interesting because they show absorption within the deep-red combined with a high open circuit voltage. Unfortunately, these devices suffer from a low fill factor [1]. To gain deeper understanding of the limiting factors we utilize steady-state current-voltage measurements to assess the electronic quality factor of devices with varying layer thickness by a recently described method [2]. In addition, we investigate the wavelength dependence of the loss mechanisms by voltage- and white-light-biased external quantum efficiency measurements.

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HL 13.52 Mon 17:30 Poster B

Applicability and limitations of hopping-based transport theories — •Sebastian Hutsch and Frank Ortmann — Center for Advancing Electronics Dresden, Technische Universität Dresden, 01062 Dresden, Germany

Many theories have been developed to describe charge transport in organic semiconductors, which is a complex task due to the strong electron-phonon coupling. Two of the most commonly used approaches use hopping-rates based on the classical Marcus theory and on the more advanced Levich-Jortner theory, which distinguishes classical and quantum mechanical contributions of the phonons. In this work, based on ab-initio material parameters, we test the applicability of both theories for a broad range of established organic crystals. The variety of materials allows us to assess the accuracy of both methods and to introduce a classification. The physical reasons for the different behaviour is analyzed and suggestions for an improved method are given.

HL 13.53 Mon 17:30 Poster B

In situ transport measurements in organic field effect transistors with F_{16}CuPc — •Mareike Dunz, Karsten Rott, Jan Schmalhorst, and Günter Reiss — Center for Spinelectronic Materials and Devices, Physics Department, Bielefeld University, Germany

Organic semiconductors are widely used in OLED and organic photovoltaic systems. However, organic field effect transistors cannot yet compete with silicon based technology due to their low charge carrier mobility. Fluorinated copper phtalocyanine (F_{16}CuPc) is reported to be one of the rare air-stable n-channel organic semiconductors that can be considered for transistor applications [1].

We prepared organic field effect transistors with thermally evaporated F_{16}CuPc on oxidized silicon substrates in a bottom contact configuration. Electrical in situ measurements allow for the detection of a thickness dependent source-drain current during the evaporation of the organic molecules. We found a maximum of the source-drain current around a thickness of 20 nm. Subsequent temperature dependent measurements of the electron mobility in the range from $-150\,^{\circ}C$ to $150\,^{\circ}C$ reveal charge transport via the hopping mechanism. At room temperature, the electron mobility is determined to lie around $2 - 8 \cdot 10^{-3}\,cm^2/Vs$, depending on the applied gate voltage. Furthermore, we show how those transistors react when exposing them to gases like oxygen.

[1] Z. Bao et al., J. Am. Chem. Soc. 7863(23), 207 (1998)

HL 13.54 Mon 17:30 Poster B

Charge Transfer at the Interface of Indoline Dye/ZnO Solar Cells — •Nico Hofeditz[1], Ingo Meyenburg[1], Raffael Ruess[2], Derck Schlettwein[2], and Wolfram Heimbrodt[1] — [1]Department of Physics and Material Sciences Center, Philipps-University Marburg, Renthof 5, 35032 Marburg, Germany — [2]Institute of Applied Physics, Justus-Liebig-University Gießen, Heinrich-Buff-Ring 16, 35392 Gießen, Germany

Dye-sensitized solar cells containing mesoporous ZnO and the indoline dyes D131 and DN216 have been prepared either with an iodide/triiodide or with a cobalt-based redox electrolyte with different concentrations of 4-tert-butylpyridine (TBP). The TBP additive reduces the acidity of the cobalt redox electrolyte. An important process in high efficient dye-sensitized solar cells is an optimized electron transfer, i.e., the electron injection yield from the dye into the conduction band of the ZnO at the organic-inorganic interface. We studied the photoluminescence intensity as well as the decay time of the dyes by varying the applied voltage. We were able to reveal the electron transfer times from the excited dye by analyzing the photoluminescence transients of the excitons after femtosecond excitation and applying kinetic model calculations. We will compare both dyes and show that the level alignment and the number of anchoring groups have a strong influence on the charge transfer. Furthermore, we discuss in our contribution the influence of cell aging as well as the influence of dye aggregation on the charge transfer times, i.e., electron injection efficiency.

HL 13.55 Mon 17:30 Poster B

Graphite Oxide Obtained From Bamboo as Possible Selective Contact For Solar Cells — Jhon Jairo Prias-Barragan[1], •Katherine Gross[1], Jose D Perea[3], Nial Kilallea[3], Wolfgang Heiss[3], Christoph Brabec[3], Hernando Ariza-Calderon[1], and Pedro Prieto[2] — [1]IIs, Universidad del Quindío, Colombia — [2]cenm, Department of Physics, Universidad del Valle, Colombia — [3]i-MEET, FAU, Germany

The effect of the carbonization temperature (TCA) on the optoelectronic response of Graphene Oxide (GO) multilayers obtained from bamboo tar (BPA) was investigated. RAMAN, XRD and FTIR spectra indicate that increased TCA increases graphite conversion and reduces oxygen coverage. Decreased oxygen content from 17% to 4% tunes the Bandgap energy from 0.30 to 0.11 eV. Implicit solvation model COSMO was used to visualize the surface charge density; here we could observe that by increasing the oxygen content the electron acceptor and donor abilities increase in the material, showing the electron-hole pair density distributions by multifunctional oxide presence. The optoelectronic response investigated via UV-VIS, PL-Vis-NIR and PL-MIR measurements have shed light on the mechanism involved in light absorption processes. UV-VIS spectra show a broadband light absorption from 200 nm until 1100 nm. Interestingly, increasing TCA results in a blue-shift of the absorption. Broadening and blue-shift in the absorbance spectrum could be correlated with the large size distribution of the graphitic nano-crystals. This study suggests that GO-BPA can be appropriate as selective contact in OPV.

HL 13.56 Mon 17:30 Poster B

Optimization of the Base Electrode in Organic Permeable Base Transistors — •Yang Li, Felix Dollinger, Markus P. Klinger, Axel Fischer, Hans Kleemann, and Karl Leo — Dresden Integrated Center for Applied Physics and Photonic Materials(IAPP), Dresden, Germany

Flexible electronics are a hot topic in the field of electronics. Organic semiconductors represent one way to realize flexible transistors. Organic permeable base transistors (OPBT) are a special thin-film transistor architecture having an extremely short channel length, down to 100 nanometers, achieved by a vertical geometry. OPBT devices consist of a base electrode permeable for electrons. With an applied voltage, the base can either block or transmit the electrons traveling from the emitting electrode. The short channel length allows for a current density above 10 A/cm^2 at a relatively low voltage (1 V). This device can also achieve an on/off ratio as high as 10^6. These devices are suited for applications in the high-frequency regime above 10 MHz.

The state-of-the-art fabrication process of these devices had been published previously, but still, the reproducibility needs to be improved. The crucial part is the thin oxide layer around the base electrode. The oxide layer is fabricated by directly oxidizing the base aluminum electrode. We studied the performance of the devices under different oxidants. The result shows that the performance of the transistor is highly related to the quality of the oxide layer around the base. The detailed influence of different oxidants and annealing temperatures will be shown on the poster.

HL 13.57 Mon 17:30 Poster B

EPR spectroscopic signatures of C_{60} and C_{70} fullerene cations — •René Wieczorek, Svetlana Kucher, Sven Berlekamp, and Wolfgang Harneit — Fachbereich Physik, Universität Osnabrück, Deutschland

Due to their relatively high reactivity, spectroscopic data are scarce for fullerene cations in condensed matter. Especially EPR parameters seem to depend greatly on the choosen method of cation preparation.

Nevertheless, there is a growing interest in charged fullerene species within several research fields. For organic solar cells, the role of oxidized fullerene derivatives as possible intermediates in charge carrier transport has been discussed. Correspondingly, magnetic resonance methods (EPR, EDMR) rely on precise spectroscopic signatures to identify the different species taking part in such processes. Similarly, the potential application of endohedral group-V fullerenes, either as qubits or as molecular probes for magnetic fields, requires identification of competing spin carrying derivatives, namely C_{60} and C_{70} cations or anions.

We therefore use a reported protocol, oxidation of fullerenes by means of iron(III)-exchanged zeolite NaY, to conduct a systematic study of fullerene cations using EPR spectroscopy. We report on pulsed and cw measurements at different frequency bands (X-, Q-, and W-band). Consequences of our findings for the different research fields are discussed.

HL 13.58 Mon 17:30 Poster B

Electric-field-induced Molecular Modifications in Organic Semiconductors: Studies in Frequency and Time Domain — •Debkumar Rana, Patrice Donfack, Javid Shirdel, Vladislav Jovanov, Veit Wagner, and Arnulf Materny — Physics and Life Sciences, Jacobs University Bremen, Campus Ring 1, 28759 Bremen

Recently, the field of organic electronics has seen an impressive progress, which was pushed forward due to the attractive application potential of the organic semiconductors. Thin film transistors, diodes, solar cells etc. based on polymers like Poly(3-hexylthiophene) (P3HT) show advantages due to their wide range of variability, mechanical properties, ease of fabrication, and, related to this, low costs.

The performance of organic electronics has been improved greatly, but still a more detailed understanding of the elementary processes is required. For this, we have studied the influence of external electric fields on the vibrational/vibronic and excitonic properties of Poly(3-hexylthiophene) (P3HT)-based semiconductor systems using Raman spectroscopy as well as femtosecond time-resolved spectroscopy. Changes in the Raman spectra (line broadenings and shifts) yield information about the coupling of vibrations to the electric fields. The influence on the life time of excitons after excitation with a femtosecond laser pulse gives insights into the field-dependence of relaxation and decay channels. First experimental results will be presented and discussed.

HL 13.59 Mon 17:30 Poster B

Formation Dynamics of Charge-Transfer States at the Pentacene/Perfluoropentacene Interface — •Melanie Fey[1], Robin Carl Döring[1], Andre Rinn[2], Tobias Breuer[2], Gregor Witte[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 Science Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany

Model crystalline molecular donor-acceptor heterostructures allow systematic investigations of the charge-carrier dynamics at the internal interfaces. Here, we investigate the charge-transfer (CT) exciton dynamics in different intermixed and layered heterostructures of pentacene (PEN) and perfluoropentacene (PFP). We study the formation of interfacial CT states by comparing low-temperature photoluminescence excitation spectroscopy and linear absorption spectroscopy measurements. We find that an excitation at the lowest-energy bright exciton resonance of PEN directly leads to emission at the CT exciton energies while no such contribution is observed for the lowest bright exciton energy of PFP. The corresponding linear absorption spectra, however, reveal significant oscillator strength for both resonances. Our results thus indicate firstly, that PEN is the main contributor to the formation of CT excitons in PEN-PFP heterosystems and, secondly reveals limitations of a description of CT exciton states relying on the robustness of the frontier molecular orbitals at the hetero interface.

HL 13.60 Mon 17:30 Poster B

Determination of Trap Distribution in Polymer-based Diodes with Complementary Techniques — •Michael Bretschneider, Christopher Wöpke, Clemens Göhler, Alexander Wagenpfahl, and Carsten Deibel — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

The understanding of transport phenomena inside polymer-based diodes is one key point of improving organic optoelectronic devices. The interplay between traps and charge carriers inside these diodes has a strong impact on the charge carrier mobility and thus determines the device performance. We investigate three different polymer-based (P3HT, PCDTBT, MDMO-PPV) diodes with the Thermally Stimulated Current (TSC) method. We present the density of occupied traps distribution with fractional TSC and compare the results with temperature dependent J_{SC}–V_{OC} measurements for complementary investigation. We discuss the interplay of traps with mobile charge carriers in order to gain deeper insight into charge transport in disordered organic diodes.

HL 13.61 Mon 17:30 Poster B

Degradation mechanism in high performance PffBT4T-2OD:PC71BM organic devices — •Joshua Kress and Andreas Weu — Centre for Advanced Materials, Heidelberg, Deutschland

Although in recent years significant progress has been made in improving the performance of organic photovoltaic devices, their environmental stability remains a limiting factor preventing their integration in industrial applications. We investigate the degradation mechanisms of high performance photovoltaic devices based on PffBT4T-2OD:PC71BM which result in record power conversion efficiencies of 11%. To identify the contribution of the deterioration of charge transport during degradation to the photovoltaic performance loss, the active layers of the photovoltaic devices have been investigated in bottom-gate/top-contact field effect transistors (OFETs) which have been degraded under identical conditions to complete photovoltaic devices. The studies are combined with x-ray photoemission spectroscopy (XPS), photothermal deflection spectroscopy (PDS) and transient absorption spectroscopy (TA). We compare the effects of exposure to nitrogen or oxygen with and without light and find that exposure to oxygen alone (in dark) results in a similar degradation of the photovoltaic performance as that caused by exposure to light (in inert atmosphere). Despite this, the effect on charge transport is very different and is a consequence of oxygen induced p-doping of the active layer. This highlights the importance of identifying the individual causes of degradation introduced by the various environmental factors in order to be able to develop relevant mitigation strategies.

HL 13.62 Mon 17:30 Poster B

Charge storage in β-$FeSi_2$ nanoparticle — •fangfei li[1], martin geller[1], hans orthner[2], hartmut wiggers[2], and axel lorke[1] — [1]Experimental Physics and CENIDE, University of Duisburg-Essen, Germany — [2]Institute for Combustion and Gas Dynamics and CENIDE, University of Duisburg-Essen, Germany

The development of portable electronic devices drives the increasing demand for electrochemical energy storage with high energy density. Among various energy storage devices, supercapacitors provide a promising solution to fast charging and discharging.

Normally, supercapacitors work with liquid or solid electrolytes. Here, we present a non-toxic, environmentally friendly and cost-effective capacitor that works in gaseous atmosphere, such as water vapor. Unlike traditional parallel double plate capacitors, an interdigitated capacitor structure is employed. The active material, i.e., β-$FeSi_2$ nanoparticles are spin-coated onto the gold interdigitated structure, which is lithographically defined on SiO_2 substrate.

Compared to the bare electrodes without β-$FeSi_2$ nanoparticles, the β-$FeSi_2$ nanoparticles-coated capacitor exhibits an up to 3−4 orders of magnitude increased capacitance. Also, the capacitance of β-$FeSi_2$ capacitor that runs under dry air is negligible, compared with a capacitor that is operated in humid atmosphere. In this work, the charging and discharging mechanism is studied with cyclic voltammetry, X-ray photoelectron spectroscopy and capacitance-voltage measurement. Also, the possibility of working under other gaseous atmosphere, such as acetone, is explored.

HL 13.63 Mon 17:30 Poster B

Functional nanostructuring with nanoporous alumina membranes as templates for advanced energy conversion and storage — •Huaping Zhao, Yang Xu, Yan Mi, Rui Xu, Long Liu, Yaoguo Fang, Min Zhou, and Yong Lei — Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilme-

nau, Germany

Nanostructures have drawn great attentions for functional device applications. Among the various techniques developed for fabricating arrayed nanostructures of functional materials, nanostructuring technique with nanoporous alumina membranes as templates becomes more attractive owing to the superior geometrical characteristics and low-cost. Herein, we summarize our recent progress about functional nanostructuring based on perfectly-ordered nanoporous alumina membranes to prepare perfectly-ordered nanostructure arrays of functional materials toward constructing high-performance energy conversion and storage devices. By employing the perfectly-ordered nanoporous alumina membranes as templates, arrayed nanostructures in the form of nanoparticle, nanorod, nanotube and nanopore have been synthesized over large area. These as-obtained nanostructure arrays have large specific surface area, high regularity, large-scale implementation, and tunable nanoscale features. All these advanced features enable them to be of great advantage for the performance improvement of energy conversion and storage devices, including photoelectrochemical water splitting cells, supercapacitors, and sodium-ion batteries, etc.

HL 13.64 Mon 17:30 Poster B

Solution-Based Layers of Nickel Oxide for Applications in Electrochromic Windows — •Florian Eberheim, Christian Lupó, and Derck Schlettwein — IAP, JLU Giessen, Germany

Electrochromic windows are of interest in light-managing devices like smart windows or smart mirrors. The aim of this work consist in the preparation of an electrochromic ion storage anode which is compatible to other device constituents. Nickel oxide can serve for this purpose with properties complementary to tungsten oxide as cathode. Because of the thermal sensitivity of intercalated tungsten oxide layers the production temperature of the nickel oxide layers should be sufficiently low. In this project nickel oxide is produced at $230°C$ by an internal combustion reaction with urea as fuel. For this synthesis nickel nitrate hexahydrate, urea and a solvent were mixed. Ethanol, acetone, H_2O, methanol, 1-Propanol or DMSO where used as solvents. The nickel oxide layer is made by spin-coating this solution onto the substrate (FTO on glass) and heating on a hot-plate. Non-stoichiometric NiO is formed with a considerable concentration of Ni^{3+} centers, leading to a dark-brown color. These layers were characterized by SEM and studied by cyclic voltammetry in contact to a Li^+-containing organic electrolyte. Upon reduction and Li^+-intercalation the layers became widely transparent as desired for compatibility with tungsten oxide. The ion-capacity and the reversibility of this reaction was determined dependent on preparation conditions and film thickness. It was shown that ethanol as solvent led to layers with the highest ion capacity and the largest change in coloration.

HL 13.65 Mon 17:30 Poster B

Orbital Angular Momentum sorting of light emitted by exciton polariton vortices — •Marius Kahlert[1], Bernd Berger[1], Daniel Schmidt[1], Marc Assmann[1], Martin Kamp[2], Christian Schneider[2], Sven Höfling[2], and Manfred Bayer[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, D-44221 Dortmund, Germany — [2]Technische Physik, Physikalisches Institut, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, D-97074 Würzburg, Germany

The nonlinear interaction of exciton polariton vortices is a subject of remarkable interest among the rich phenomenology of microcavity exciton polaritons. We generate exciton polariton vortices using light beams carrying orbital angular momentum (OAM) and demonstrate a method for monitoring the time dynamics of the exciton polariton vortex decay. Here the sample emission runs through a custom optical transformation, which translates the helical phase of OAM modes into a linear gradient and in principle enables a simultaneuos detection of all OAM modes. Finally the OAM sorted signal is resolved in time using a streak camera, granting insight into the decay dynamics of exciton polariton vortices.

HL 13.66 Mon 17:30 Poster B

Time-resolved dielectric function tensor of *m*-plane ZnO studied by femtosecond spectroscopic ellipsometry — •Oliver Herrfurth[1], Steffen Richter[1], Mateusz Rębarz[2], Miroslav Kloz[2], Shirly Espinoza[2], Jakob Andreasson[2,3], Marius Grundmann[1], and Rüdiger Schmidt-Grund[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstraße 5, 04103 Leipzig — [2]ELI Beamlines, Institute of Physics, Czech Academy of Science, Na Slovance 2, 182 21 Prague, Czech Republic — [3]Condensed Matter Physics, Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

We report on femtosecond time-resolved spectroscopic ellipsometry measurements on a *m*-plane oriented ZnO single crystal. Our recently developed technique relies on a pump-probe scheme employing an amplified Ti:Sa laser (6 mJ,35 fs). Its third harmonic is used as pump pulse and its fundamental wavelength is used to create a supercontinuum white light probe by focussing onto CaF_2. This method allows to probe a spectral range from 340 nm to 1000 nm with a single shot. The time resolution is estimated as 170 fs. We determine the complex dielectric function tensor from measurements parallel and perpendicular to the crystal's optic axis using a transfer matrix algorithm. A crucial point is the depth-dependence of the model parameters imposed by the finite, temporally varying penetration depth of the pump and probe beam. The relaxation dynamics of the excited charge carriers are observed. In particular, the resonances of excitons and exciton-phonon complexes are suppressed and spectrally shifted.

HL 13.67 Mon 17:30 Poster B

3D stabilization of an optical μ-absorption spectrometer — •Jurek Lange and Sangam Chatterjee — Institute of Experimental Physics I, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany

Spectroscopy of microscopic or even nanoscopic particles requires extreme mechanical stability to enable significantly long exposure times; e.g., even small changes in the ambient temperature can result in sample drifts, which blur or even distort the measurements.

Here, we actively stabilize a home-built optical microscope equipped with a 3D nanopositioner to measure optical transmission in sample areas of less than $1\,\mu m^2$ (0.65 NA). A permanent feedback loop is implemented to rectify the thermal drift in the measuring algorithm. It is based on a live image analysis on multi-dimensional Fourier transform analysis and corrects both the focus and shifts with in the focal plane. The reliability of the approach is verified by stabilizing the optical system using a 1951 USAF target in for 35-hour measurement. The sample drift was reduced from $12\,\mu m$ to $0.4\,\mu m$ for while the ambient temperature randomly changed between 19 and 21 °C.

HL 13.68 Mon 17:30 Poster B

White-light and second-harmonic generation in various SnS-based cluster molecules — •Nils Mengel[1,3], Eike Dornsiepen[2], Florian Dobener[3], Nils Rosemann[4], Stefanie Dehnen[2], and Sangam Chatterjee[3] — [1]Faculty of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany — [2]Department of Chemistry and Material Sciences Center, Philipps-Universität Marburg, Hans-Meerweinstraße, D-35043 Marburg, Germany — [3]Institute of Experimental Physics I, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Gießen, Germany — [4]Department of Chemistry, Lund University, Naturvetarvägen 14, SE-22362, Lund, Sweden

Light sources providing a broad spectral range and well defined beam parameters are needed for numerous scientific experiments and technical applications. Lasers usually offer the advantageous beam properties but have a very small spectral width. To enhance the spectral bandwidth, high-harmonic or supercontinuum generations are commonly used. These require high-power lasers or highly nonlinear optical materials.

Powders containing SnS-based cluster molecules offer very strong nonlinear properties. They enable low-etendue, directional broadband supercontinua even when irradiated with a continuous-wave laser diode. Here, we present the nonlinear optical response of various powder compositions aiming to achieve a better understanding of the underlying processes responsible for the white light generation.

HL 13.69 Mon 17:30 Poster B

Phonon-assisted luminescence in hexagonal boron nitride — •Claudio Attaccalite[1,2] and Elena Cannuccia[2] — [1]CINaM UMR 7325, Aix-Marseille University - CNRS, Marseille, France — [2]Universita Tor Vergata, Roma, Italy

We study luminescence in hexagonal-boron nitride by combining Green's function theory with Williams-Lax theory to simulate phonon replica in the optical spectra. Our results explain recent experiments on h-BN, and point out the role of phonons in the optical response of this material.

HL 13.70 Mon 17:30 Poster B

Exciton-assisted transversal magneto-optical Kerr effect in CdMnTe/CdMgTe quantum well structures — •Lars Klompmaker[1], Felix Spitzer[1], Olga Borovkova[2], Vladimir I. Belotelov[2,4], Ilya A. Akimov[1,3], Alexander N. Poddubny[3,6], Victor F. Sapega[3], Maciej Wiater[5], Tomasz Wojtowicz[5], Grzegorz Karczewski[5], Dmitri Yakovlev[1,3], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, TU Dortmund University, D-44221 Dortmund, Germany — [2]Russian Quantum Center, Skolkovo, Russia — [3]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [4]M.V. Lomonosov Moscow State University, Moscow, Russia — [5]Institute of Physics, Polish Academy of Sciences, PL-02668 Warsaw, Poland — [6]ITMO University, 197101 St. Petersburg, Russia

We studied the influence of excitons in a CdMnTe/CdMgTe quantum well (QW) structure on the transverse magneto-optic Kerr effect (TMOKE) using a Fourier imaging setup, which allows the measurement of the reflected light's intensity as a function of its energy and angular distribution at the same time. Induced by the giant Zeeman splitting of excitons in diluted magnetic semiconductors, we see a two-order enhancement of the TMOKE in the spectral region of the excitonic resonances. We are able to separate between contributions from heavy and light hole exciton states in the TMOKE's spectral dependence with up to 2% effect at an incidence angle of about 20°.

HL 13.71 Mon 17:30 Poster B

Telecom wavelengths photonic crystal cavities: Simulation and Fabrication — •Lucas Rickert, Andrei Kors, Kerstin Fuchs, Johann Peter Reithmaier, and Mohamed Benyoucef — Institute of Nanostructure Technologies and Analytics (INA), CINSaT, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Telecom wavelengths InP-based photonic crystal (PhCs) cavities with embedded quantum dots (QDs) show interesting properties caused by the interaction between the atom-like behaviour of the QD and the degree of confinement of a spectrally and spatially suited cavity mode, leading to possible applications for long-distance quantum communication and quantum information processing.

This work focuses on the study of the influence of geometrical parameters on the quality factor enhancement, light out-coupling and the mode profiles of PhC cavities. Suitable PhC are designed using finite difference time domain (FDTD) simulations. The InP-based L3 PhC cavities are fabricated using electron beam lithography followed by reactive ion etching and wet etching of an underlying sacrificial layer resulting in free standing InP membranes containing QDs. The optical properties of the PhC cavities are examined via low temperature micro-photoluminescence spectroscopy (μ-PL) and exhibit sharp mode profiles at the telecom C-Band and enhanced exciton-biexciton single dot emission confirmed by excitation power dependent PL measurements. Temperature detuning experiments show a weak coupling behaviour.

HL 13.72 Mon 17:30 Poster B

Calculation of zero-field splitting for defects in semiconductors: reaching all-electron accuracy with pseudopotentials — •Timur Biktagirov, Wolf Gero Schmidt, and Uwe Gerstmann — Universität Paderborn, 33098 Paderborn, Germany

Spin centres in semiconducting materials are promising candidates for quantum information processing, photonics and sensing at ambient conditions. For successful quantum applications, a spin centre has to be addressed on a single-defect level. For high-spin ($S > 1/2$) centres, one of the key spectroscopic fingerprints is the zero-field splitting (ZFS) parameter addressable by electron paramagnetic resonance (EPR), which describes the interactions between the unpaired electrons. Here, we report on DFT based calculations of the spin-spin contribution to ZFS tensor being implemented in the GIPAW module of Quantum ESPRESSO package [1]. We use a single-determinant approach proposed by Rayson and Briddon [2,3], and extend it by adding a projector augmented wave (PAW) [4] reconstruction which has not been implemented before. We benchmark our approach against well-established all-electron method for a series of diatomic radicals, and defects in diamond and silicon carbide.

1. P. Giannozzi et al., J. Phys.: Cond. Matter 21, 395502 (2009).
2. M. J. Rayson, P. R. Briddon, Phys. Rev. B 77, 035119 (2008).
3. Z. Bodrog, A. Gali, J. Phys.: Cond. Matter 26, 015305 (2013).
4. P. E. Blöchl, Phys. Rev. B 50, 17953 (1994).

HL 13.73 Mon 17:30 Poster B

Active frequency stabilization of frequency doubled AlGaInP-VECSELs — •Hoy-My Phung[1], Roman Bek[1], Hermann Kahle[1], Michael Böhm[2], Kevin Schmidt[2], Oliver Sawodny[2], Michael Jetter[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, research centers IQST and SCoPE, Universität Stuttgart, Allmandring 3 — [2]Institut für Systemdynamik, Universität Stuttgart, Waldburgstr. 17/19

In recent years, vertical external-cavity surface-emitting lasers (VECSELs) based on the material system AlGaInP have shown outstanding performance for high continuous-wave output power and excellent beam quality in the red spectral range. Furthermore, second harmonic generation to the ultraviolet spectral range enables new applications for AlGaInP-VECSELs such as UV spectroscopy or interference lithography. To achieve laser emission in the ultraviolet spectral range we insert a beta barium borate (BBO) crystal in a v-shaped cavity. A birefringent filter and an etalon are used for tunable single-frequency operation. However, the linewidth of non-stabilized lasers or short-term stability is often not sufficient for the above-mentioned applications and many precision measurements. Based on the side-of-fringe locking technique, we develop a control system to actively stabilize the frequency of the laser. The fundamental frequency is locked to a reference Fabry-Pérot cavity. The position of the flat end mirror is controlled by a piezo actuator in order to compensate for disturbances due to mechanical vibrations. These are measured by acceleration sensors and characterized by amplitude and frequency.

HL 13.74 Mon 17:30 Poster B

Spacer thickness effects on the optical properties of double vertically stacked InP/AlGaInP quantum dots laser structures — •Hatam Mahmudlu, Zhihua Huang, Michael Zimmer, Stefan Hepp, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen and Research Center ScoPE and IQST, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Quantum dots (QDs) as gain medium for semiconductor lasers are attractive for many applications. This is due to the promising lower threshold, higher material gain and the enhanced opportunity for tuning the gain spectral width and the emission wavelength. In the present work, we investigate the effects of the spacer thickness between the double vertically stacked QD layers on the optical properties and lasing performance of the self-assembled InP/AlGaInP QD edge emitting lasers. A numerical model is developed to determine the electron and hole coupling between the QD layers. The QD lasers with varying spacer layer thicknesses were grown by metal-organic vapor-phase epitaxy (MOVPE). The optical properties are carried out by photoluminescence (PL), electroluminescence (EL), and time-resolved measurements. Meanwhile, the laser performance is compared by characterizing the optical gain, internal optical losses, threshold current, and output power, respectively. Our work provides a guideline to determine the optimized spacer layer thickness for the vertically stacked QD lasers.

HL 13.75 Mon 17:30 Poster B

Design and fabrication towards red-emitting AlGaInP based electrically pumped VECSELs — •Michael Zimmer, Zhihua Huang, 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

Electrically pumped external cavity surface emitting lasers (EP-VECSELs) are a new generation of light sources for a wide field of applications, benefiting by the advantage of combining the excellent beam quality of optically pumped VECSELs and the compact size of VCSELs. However, a major challenge in the realization of EP-VECSELs, especially for the short wavelength regime, is to achieve a homogeneous charge carrier distribution within the active region to support the fundamental mode and high power laser output.

In this work, a red-emitting AlGaInP based EP-VECSEL structure is investigated with an electro-thermal numerical model based on the finite element method (FEM). These simulations gave us design proposal where we can achieve a uniform current density distribution. This proposed structure of an EP-VECSEL is grown by metal-organic-vapor-phase-epitaxy (MOVPE) on a GaAs substrate. In this contribution, the fabrication of a flip-chip process is presented and experimentally studied. We are successful to remove the GaAs substrate by wet chemical etching while keeping the heavy doped GaAs contact layer faultless. A fast, smooth and deep mesa etching for GaAs/AlGaAs/AlGaInP materials is also achieved by inductively coupled plasma (ICP) etching.

HL 13.76 Mon 17:30 Poster B

Optical properties of highly excited CuI based microwire cavities — •Evgeny Krüger[1], Marcel Wille[1], Steffen Blaurock[1], Vitaly Zviagin[1], Rafael Deichsel[1], Gabriele Benndorf[1], Volker Gottschalch[2], Harald Krautscheid[2], Rüdiger Schmidt-Grund[1], and Marius Grundmann[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstr. 5, Leipzig — [2]Universität Leipzig, Institut für Anorganische Chemie, Johannisallee 29, Leipzig

We present the first experimental results for lasing in cuprous iodide (CuI) microwire cavities. The microwires with diameter of (2 – 20) μm were grown by vapor-phase transport method in a three-zone furnace with a linear temperature profile between (250 – 450)°C. The microwire crystal structure, chemical composition as well as morphology were evaluated using X-ray diffraction, energy dispersive X-ray spectroscopy and scanning electron microscopy, respectively. The observed excitonic photoluminescence emission lines as well as formation of gain under high optical excitation indicate high optical quality of the investigated microwires. The analysis of the spectral mode positions suggests that the microwires with a triangular cross-section act as whispering-gallery type resonators. Time-resolved micro-photoluminescence studies reveal the dynamics of the laser process on the picosecond time scale.

[1] M. Wille et al., Appl. Phys. Lett. 111, 031105 (2017)

HL 13.77 Mon 17:30 Poster B

Radio-frequency studies of self-mode-locking in a single-section quantum dot laser: experiment and simulation — •Christoph Weber[1], Paolo Bardella[2], Lorenzo Luigi Columbo[2], Mariangela Gioannini[2], and Stefan Breuer[1] — [1]Institut für angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

Self-mode-locked single-section semiconductor lasers (SCLs) with active gain materials based on quantum wells [1], quantum dashes [2] or quantum dots [3], are compact photonic sources that generate optical frequency combs. We experimentally find and numerically study a transition from unlocked multi-modal emission to self-mode-locked emission of a single-section quantum dot based SCL depending on the injected gain current. This transition is characterized by a significantly reduced beat note line-width in the radio-frequency spectrum and a reduction of the integrated relative intensity noise. Experiments and simulations are in good qualitative and quantitative agreement. [1] Sato et al., Electron. Lett. 37 (2001),763. [2] Panapakkam et al., IEEE J. Quantum Electron. 52 (2016),1. [3] Liu et al., Opt. Letts. 33 (2008), 1702. [4] Bardella et al., Opt. Express 25 (2017), 26234.

HL 13.78 Mon 17:30 Poster B

Experimental investigations on the gain and dispersion properties of mode-locked semiconductor lasers — •Stefan Heppe[1], Christoph Weber[1], Paolo Bardella[2], Lorenzo Luigi Columbo[2], Mariangela Gioannini[2], and Stefan Breuer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

Optical frequency combs generated by monolithic mode-locked (ML) semiconductor lasers (SCLs) in the near-infrared wavelength region are ideal sources in time critical applications such as optical communication. Since the phase difference between adjacent modes is fixed over time, ultra-short optical pulses can be emitted but due to group delay dispersion (GDD) inside the laser cavity the pulses are in most cases not Fourier-limited and it is even possible to have ML operation without any pulses in the laser output [Bardella et al, Opt. Expr. 25 (2017), 26234]. To obtain ultra-short pulses, a precise knowledge of the GDD and the gain properties of the laser material is necessary. In this work, we use a method employing a Fourier-transform spectrometer [Hofstetter, Faist, IEEE Phot. Techn. Letts. 11 (1999), 1372; Villares et al, Optica 3 (2016), 152] to measure the wavelength dependent gain and GDD in ML SCLs with different active materials and emission wavelengths.

HL 13.79 Mon 17:30 Poster B

Experimental studies of gain and absorption properties of passively mode-locked semiconductor lasers — •Stefan Heppe[1], Christoph Weber[1], Julien Javaloyes[2], Andreas Klehr[3], Andrea Knigge[3], and Stefan Breuer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Departamendto de Fisica, Universitat de les Illes Balears, 07122 Palma de Mallorca, Spain — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

Passively mode-locked multi-section semiconductor lasers are attractive photonic sources for optical telecommunications, as they can generate ultrashort pulses at high repetition rates. In order to derive new laser geometries, gain and absorption properties need to be accessed. In this work, the gain and absorption spectra of a 1 mm long monolithic multi-section QW laser with a 0.1 mm long absorber section and an emission wavelength of 1070 nm are investigated in dependence on injected gain current and applied absorber reverse bias voltage, by using a Czerny-Turner spectrometer and a photon counting technique. By analyzing the modulation depth of the Fabry-Perot modes in the subthreshold amplified spontaneous emission spectrum, the wavelength dependent gain and absorption of the laser can be determined by the differential Hakki-Paoli method proposed in [Stolarz et al., IEEE Photon. J. 3 (2011), 1067]. This method allows to measure gain and absorption properties in the processed two- or multi-section laser devices.

HL 13.80 Mon 17:30 Poster B

Repetition rate tuning range analysis of passively mode-locked quantum-well semiconductor lasers subject to optical self-feedback: simulation and experiment — •Dominik Auth[1], Christoph Weber[1], Andreas Klehr[2], Andrea Knigge[2], and Stefan Breuer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

Compact monolithic passively mode-locked (PML) semiconductor lasers (SCLs) with multi-GHz repetition rates (RR) emitting at wavelengths of around 1070 nm are attractive ultrafast sources for seeding ytterbium doped fiber amplifiers and for photonic communication at high data rates. In this work, the pulse RR tuning range of PML multi quantum-well (QW) SCLs subject to single cavity optical feedback (OFB) is investigated. A stochastic time-domain model [Drzewietzki et al., Opt. Expr. 21 (2013), 16142] is applied to predict the RR tuning range and timing jitter (TJ) reduction in QW SCLs subject to very long OFB lengths up to 73 m. Furthermore, the obtained RR tuning range predictions for different OFB lengths and the TJ reduction are proven experimentally by studying 3 mm long PML QW SCLs with different absorber lengths and subject to long OFB. The limits of the RR tuning range are also confirmed experimentally.

HL 13.81 Mon 17:30 Poster B

Optical frequency comb stabilization of a self-mode-locked quantum dot laser by optical time-delayed self-feedback — •Sebastian Stutz[1], Dominik Auth[1], Christoph Weber[1], Oleg Nikiforov[1], Luke F. Lester[2], Thomas Walther[1], and Stefan Breuer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Bradley Department of Electrical and Computer Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA

Optical frequency combs generated by self-mode-locked semiconductor lasers based on quantum dot (QD) gain material are ideal sources for application in high data rate optical communication, demanding tunable and stable comb-line spacing in the range of 40 GHz. In this work, the impact of fine-delay tunable dual-cavity optical feedback (DC-OFB) on the mode spacing and the optical frequency comb stability generated by a 1 mm long self-mode-locked single-section QD laser emitting at 1255 nm is studied experimentally and by simulation. The linewidth of the laser mode-beating frequency of 40.67 GHz amounts to 1.4 MHz in the of free running case. By fine-delay tuning of both optical feedback lengths, we find a comb-line spacing tuning range of 70 MHz. The beat note linewidth decreases to 2 kHz for well-adjusted optical feedback cavities. Simulation results based on a stochastic time-domain model [Drzewietzki et al., Opt. Expr. 21 (2013), 16142] reproduce the experimentally observed trends with good qualitative and quantitative agreement.

HL 13.82 Mon 17:30 Poster B

Temperature-control based fiber optical self-feedback config-

uration for passively mode-locked semiconductor lasers — •Sebastian Stutz[1], Dominik Auth[1], Christoph Weber[1], Oleg Nikiforov[1], Luke F. Lester[2], Thomas Walther[1], and Stefan Breuer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Bradley Department of Electrical and Computer Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061, USA

Passively mode-locked (PML) semiconductor lasers (SCLs) generating short optical pulse widths and high pulse repetition rates (RR) are promising compact sources for future time-critical applications. Since the pulse train of PML SCLs can exhibit considerable timing jitter (TJ), experimental concepts to improve the TJ are demanded. A dual-cavity optical self-feedback concept to improve the pulse train stability and control the RR has recently been reported [Nikiforov et al., Opt. Expr. 24, 14301 (2016)]. In this contribution, we present experimental results obtained by an all optical time-delayed feedback configuration where a highly-precise temperature controlled optical fiber delay is employed for the first time. By substantially reducing environmental influences including acoustic noise, temperature instabilities and vibrations, we are able to achieve a substantially improved pulse train stability.

HL 13.83 Mon 17:30 Poster B

Timing stability and repetition rate tuning analysis of a passively mode-locked quantum-well semiconductor laser subject to dual-cavity optical self-feedback — •Dominik Auth[1], Christoph Weber[1], Andreas Klehr[2], Andrea Knigge[2], and Stefan Breuer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

Monolithic passively mode-locked (PML) semiconductor lasers (SCLs) offer pulse repetition rates (RR) in the Multi-GHz range and picosecond-short optical pulses. Their pulse train timing stability, however, is considerable lower as compared to fiber-based pulsed lasers. All-optical self-feedback (OFB) configurations are elegant concepts without using any additional sources for external time reference and they allow to improve the timing stability and control the RR frequency, both of which are important in photonic communication applications. In this work, we study the influence of OFB by fine-delay controlled dual optical cavities on the pulse RR and the timing jitter (TJ) of a multi quantum-well (QW) SCL emitting at 1070 nm. A 3 mm long PML QW SCL with a saturable absorber length of 10% of the total cavity length is studied. We quantify the timing stability improvement by radio-frequency, temporal and optical domain analysis and in dependence on the OFB strengths as well as the feedback delays. We report on single digit Gigahertz RR control while simultaneously ensuring a substantial TJ reduction.

HL 13.84 Mon 17:30 Poster B

Intensity noise of a two-state quantum dot laser — •Robert Pawlus[1], Lorenzo L. Columbo[2], Paolo Bardella[2], Stefan Breuer[1], and Mariangela Gioannini[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Dipartimento di Elettronica, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy

We study experimentally and by numerical simulations the intensity noise behavior of an InAs/InGaAs quantum dot (QD) laser emitting simultaneously at the ground-state (GS) and the excited-state (ES) wavelengths. Experimentally, a reduction in power fluctuations up to 4 dB is found when GS and ES emit simultaneously as compared to the case of single GS or ES emission. This stability is also studied by spectrally resolved GS and ES time-signal analysis. By means of numerical simulations we explain this phenomenon and qualitatively reproduce its trend with the laser biasing conditions. The coupling of GS and ES emissions trough the common carrier reservoir is identified as the underlying physical mechanism leading to a quasi anti-phase dynamics.

HL 13.85 Mon 17:30 Poster B

Performance and Dynamics of Three-Section Tapered Mode-Locked Lasers — •Stefan Meinecke[1], Lukas Drzewietzki[2], Christoph Weber[2], Benjamin Lingnau[1], Stefan Breuer[2], and Kathy Lüdge[1] — [1]Institut für Theoretische Physik, Technische Universtität Berlin, Berlin, Germany — [2]Institut für Angewandte Physik, Technische Universtität Darmstadt, Darmstadt, Germany

Passively mode-locked semiconductor lasers are inexpensive sources of short optical pulses with high repetition rates. They find applications in high-capacity optical interconnects and high-precision metrology, where stable pulse trains with small amplitude and timing jitter are required. Optimizing the design of monolithic mode-locked semiconductor lasers for such demands has therefore become of major interest.

Combining a traveling-wave model for the electric field propagation with microscopically based quantum-dot (QD) charge-carrier rate equations, we investigate the performance and dynamics of monolithically integrated multi-section QD mode-locked lasers. In this work, we focus on a three section device with two short straight sections at one end, which can be individually biased, and a long tapered gain section at the pulse emission facet.

Our simulations nicely reproduce experimental results and furthermore enable us to predict device geometry for stable operating regimes that exhibit short and high power pulses with low timing jitter. We especially study the influence of the position and length of saturable absorber and the taper angle of the long gain section.

HL 13.86 Mon 17:30 Poster B

Characterization of high-efficiency AlGaInP VECSELs in a gain chip holder with optimized heat flow — •Alexander Peschken[1], Hermann Kahle[2], Roman Bek[1], Cherry May Mateo[3], Uwe Brauch[3], Marwan Abdou Ahmed[3], Michael Jetter[1], Thomas Graf[3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, SCoPE, IQST, Univ. Stuttgart, Germany — [2]Tampere Univ. of Technology, Finland — [3]Institut für Strahlwerkzeuge, SCoPE, Univ. Stuttgart, Germany

Vertical external-cavity surface-emitting lasers (VECSELs) provide in principle power scalability at constant beam quality and vast wavelength flexibility. However, due to the limited charge-carrier confinement in AlGaInP-based VECSELs, an optimized heat extraction is essential in order to enable power scalability. Unfortunately, the substrate and the distributed Bragg reflector in such VECSELs show a low thermal conductivity. Hence, an additional intra-cavity heat spreader is inevitable to overcome occurring temperature problems. A modified chip holder with mechanically improved thermal contact between gain element and heat spreader showed already a doubling of the maximum output power compared to the standard one. However, recent thermal and laser measurements have shown that the heat transfer out of the heat spreader is still hampered by bottlenecks at the transitions between different parts of the gain chip holder, limiting the power scaling ability. A new chip-holder was designed to overcome these thermal problems. Its design as well as results of AlGaInP VECSELs emitting at 665 nm will be presented.

HL 13.87 Mon 17:30 Poster B

Probing the (opto)electronic properties of functional materials by scanning near-field optical microscopy — •Jinhui Zhong[1,2], Bin Ren[2], and Christoph Lienau[1] — [1]Institute of Physics and Center of Interface Science, Carl von Ossietzky University, 26111 Oldenburg, Germany — [2]College of Chemistry and Chemical Engineering, Xiamen University, Xiamen 361005, China

Scanning near-field optical microscopy (SNOM) is a powerful tool that allows for nanoscale physical and chemical analysis. In this contribution, we first demonstrated the use of tip-enhanced Raman spectroscopy (TERS) for atomic- and molecular-level characterization of heterogeneous catalyst. With plasmon-enhanced Raman scattering effect, TERS provides simultaneous topographical and chemical information at the nano/atomic scale. We show that TERS can chemically and spatially probe the site-specific chemical (electronic and catalytic) and physical (plasmonic) properties of an atomically well-defined Pd(submonolayer)/Au(111) bimetallic model catalyst at 3 nm resolution in real space using phenyl isocyanide as a probe molecule. We observe a weakened NC bond and enhanced reactivity of phenyl isocyanide adsorbed at the Pd step edge compared with that at the Pd terrace. Density functional theory corroborates these observations by revealing a higher d-band electronic profile for the low-coordinated Pd step edge atoms.

We further discuss the combination of SNOM with ultrafast spectroscopy to study the nanoscale exciton properties of 2D heterostructures.

HL 14: 2D Materials: Session II (joint session DS/CPP/HL)

Time: Tuesday 9:30–13:15 Location: H 2032

HL 14.1 Tue 9:30 H 2032

Structural and electronic interactions in vdW heterostructure MoSe2/few-layer-graphene — •Minh Tuan Dau[1], Maxime Gay[1], Daniela Di Felice[2], Céline Vergnaud[1], Alain Marty[1], Cyrille Beigné[1], Gilles Renaud[1], Olivier Renault[1], Pierre Mallet[3], Toai Le-Quang[3], Jean-Yves Veuillen[3], Loïc Huder[1], Vincent Renard[1], Claude Chapelier[1], Giovanni Zamborlini[4], Matteo Jugovac[4], Vitaliy Feyer[4], Yannick Dappe[2], Pascal Pochet[1], and Matthieu Jamet[1] — [1]INAC-SPINTEC-PHELIQS-MEM, LETI, CEA/CNRS, Univ. Grenoble Alpes, F-38000 Grenoble, France — [2]SPEC, CEA, CNRS, Univ. Paris Saclay, CEA Saclay, 91191 Gif-sur-Yvette cedex, France — [3]Institut Néel, CNRS, Univ. Grenoble Alpes, F-38000 Grenoble, France — [4]Peter Grünberg Institute (PGI-6), Forschungszentrum Jülich GmbH, D-52425, Jülich, Germany

We have employed surface-sensitive techniques ranging from atomic resolution (STM-STS) to microscopic scale (synchrotron diffraction, photoemission electron microscopy k-PEEM) in order to probe structural and electronic properties of the van der Waals (vdW) heterojuction: MoSe2/few-layer-graphene grown by molecular beam epitaxy. We find that the crystallographic directions of the MoSe2 lattice align perfectly along the ones of graphene, resulting in only one commensurate configuration. Furthermore, we observe a clear evolution of the band structure of the heterojunction compared to the one of bare few-layer-graphene. Indeed, we evidence a large bandgap opening in few-layer-graphene resulting from significant charge transfer between vdW layers.

HL 14.2 Tue 9:45 H 2032

Interplay of magnetization between graphene and magnetoelectric multiferroics — •Zeila Zanolli — RWTH Aachen Uiniversity, Aachen, Germany

Graphene and magnetoelectric multiferroics are promising materials for spintronic devices with high performance and low energy consumption. We combine the features of both materials by investigating from first principles the interface between graphene and $BaMnO_3$, a magnetoelectric multiferroic. We show [1] that the hybrid systems behaves as a spin filter. Electron charge is transferred across the interface and magnetization is induced in the graphene sheet due to the strong interaction between C and Mn. A remarkably large proximity induced spin splitting of the Dirac cones (300 meV) is achieved and doping can make the high-mobility region of the electronic bands experimentally accessible.

Going further, we investigate spin dynamics at finite temperature using a Monte Carlo approach with exchange coupling parameters fitted from first principles. We find that graphene strongly affects the magnetic properties of the substrate, beyond the interface layer, and induces a softening of the Mn magnetization.

Spin Orbit Coupling calculations reveal that the influence of graphene on the substrate is even more radical and is able to change the direction of the easy axis with respect to the bare $BaMnO_3$ surface. We predict a Rashba splitting of the electronic bands near the K point, and the presence of a Quantum Anomalous Hall effect.

[1] Z. Zanolli, Sci. Rep., 6 (2016) 31346

HL 14.3 Tue 10:00 H 2032

Gate-Dependent Vacancy Migration in Graphene — •Rohit Babar[1] and Mukul Kabir[1,2] — [1]Department of Physics, Indian Institute of Science Education and Research, Pune, India — [2]Center for Energy Science, Indian Institute of Science Education and Research, Pune, India

Graphene based ultrathin devices offer significant advantage due to their high carrier mobility and a gate-tunable carrier density. However, the experimental observations of vacancy diffusion near room-temperature can potentially lead to undesirable void formation and/or edge modification of such devices. Combining transition state theory with first-principles method, we investigate the microscopic vacancy migration mechanism in graphene and its dependence on gate voltage. The intrinsic vacancy diffusion involves a concerted motion of atoms along with an out-of-plane displacement, which is unique to graphene compared with other 2D materials. We further investigate the migration mechanism under gate voltage and find that the activation barrier non-monotonically increases for both electron and hole doping. The trend in activation barrier is explained via collective-phonon stiffening. We estimate a 10^7-fold decrease in vacancy diffusivity at room temperature. Thus, our findings reveal that the graphene-based devices will not degrade further under device operating condition through vacancy migration.

HL 14.4 Tue 10:15 H 2032

Transition between rhombohedral and Bernal stacking in multilayer graphene flakes — •Fabian Rudolf Geisenhof[1], Felix Winterer[1], and Ralf Thomas Weitz[1,2] — [1]Physics of Nanosystems, Physics Department, Ludwig Maximilians Universität München — [2]NanoSystems Initiative Munich (NIM) and Center for NanoScience (CeNS)

Quantum transport in multilayer graphene is interesting in many aspects. For example, it was shown that in ultraclean samples of graphene bilayers [1] and recently also multilayers [2], the exchange interaction leads to a novel phase, who's nature is currently still under debate. At the heart of answering this question is knowledge of the local stacking order during charge transport experiments. Here, we show that the fabrication process has an impact on the structural properties of the flakes. It can lead to the formation of ripples and even to a non-local transition from ABC to ABA stacking. This transformation has been identified by spatially resolved Raman and scattering SNOM measurements, and we discuss possible reasons.

[1] R.T. Weitz, M.T. Allen, B.E. Feldman, J. Martin, and A. Yacoby, "Broken-symmetry states in doubly gated suspended bilayer graphene", Science 330, 812 (2010)

[2] Y. Nam, D.-K. Ki, M. Koshino, E. McCann and A.F Morpurgo, "Interaction-induced insulating state in thick multilayer graphene", 2D Mater. 3 045014 (2016)

HL 14.5 Tue 10:30 H 2032

Chemical vapour growth and delamination of α-MCl3 nanosheets (M = Ru, Mo, Ti) — •Martin Grönke[1,2], Silke Hampel[1], Peer Schmidt[2], Danny Pohflepp[1], Nadine Bronkalla[1], and Bernd Büchner[1] — [1]Leibniz Institute for Solid State and Materials Research, Dresden, Germany — [2]Brandenburg University of Technology Cottbus-Senftenberg, Germany

The two dimensional honeycomb structure of graphene with one monoatomic layer gave an idea to the introduction of other materials with congeneric pattern. Next to carbon based graphene, black phosphorus and binary transition metal chalkogenides, transition metal halides were highly profiled in theory. Among the interest for different materials with strong anisotropic bonding-dependent interactions, resulting frustration effects in honeycomb structures could stabilize new pattern of cooperative magnetic interactions. One candidate to realize a Kitaev Heisenberg (KH) model is the 2D layered honeycomb magnet α-Rutheniumtrichloride (α-RuCl3). Physical properties in nanoscale systems may differ from the respective bulk phase and could even lead to novel physical properties. We herein present to our knowledge the first approach to synthesize phase pure α-RuCl3 crystals on the nanoscale on a substrate via chemical vapour transport (CVT). Beyond that we reveal capabilities to generate thin 2D structures of isostructural compounds like α-MoCl3 and α-TiCl3 on a suitable substrate by means of CVT. Furthermore we show how to increase the number of nanosheets on as grown substrates by different delamination techniques.

HL 14.6 Tue 10:45 H 2032

Suppression of excitonic absorption in few-layer GaSe — •Arne Budweg[1], Dinesh Yadav[1,2], Alexander Grupp[1], Alfred Leitenstorfer[1], Maxim Trushin[1,3], Fabian Pauly[1,2], and Daniele Brida[1] — [1]Department of Physics and Center for Applied Photonics, University of Konstanz, D-78457 Konstanz, Germany — [2]Okinawa Institute of Science and Technology Graduate University, Onna-son, Okinawa 904-0395, Japan — [3]Centre for Advanced 2D Materials, National University of Singapore, 6 Science Drive 2, Singapore 117546

We study the thickness dependent optical absorption of GaSe via highly sensitive differential transmission measurements. Controlling the number of individual layers in a GaSe nanosheet, we observe a suppression of the excitonic transition below a critical value of 8. Ab-

initio modelling enables us to attribute this behavior to a fundamental change in the band structure which, in thin GaSe, leads to a valence band shaped as an inverted Mexican hat. The observed modulation of the optical properties is intrinsic and does not require control via external parameters like substrate material or an applied electric field. Therefore GaSe provides attractive resources for the development of functional optoelectronic devices based on a single material.

HL 14.7 Tue 11:00 H 2032

Lateral heterostructures for sensing small molecules: electronic current features — Ganesh Sivaraman[1], Frank C. Maier[1], Fabio A.L. de Souza[2], Rodrigo G. Amorim[3], Wanderla L. Scopel[2], Ralph H. Scheicher[4], and •Maria Fyta[1] — [1]Institute for Computational Physics, University of Stuttgart, Germany — [2]Departamento de Fisica, Univer- sidade Federal do Espirito Santo, Brazil — [3]Universidade Federal Fluminense, Departamento de Física, Volta Redonda/RJ, Brazil — [4]Department of Physics and Astronomy, Materials Theory, Uppsala University, SwedenDe

Using density functional theory based calculations with the non-equilibrium Greens functions approach, we study in detail the structural, transport, and electronic properties of two types of lateral 2D heterostructures. The first is a combination of graphene with hexagonal boron-nitride (G/hBN). The second is a (1T) metallic MoS_2 phase embedded in a (2H) semiconducting MoS_2 phase (1T/2HMoS_2). Our results identify the importance of the interface within these materials and provide the relation to the electronic current flowing across these. Having understood the basic properties of these structures, we further reveal their high potential and relevance in detecting small molecules. On one hand, we show that the G/hBN heterostructure can detect small gas molecules. On the other hand, by opening a small pore in the 1T/2HMoS_2 heterostructure, we can distinguish between DNA nucleotides. Proof of both detection schemes is provided through the distinct electronic properties and the clear electronic current signals for the various molecules and each heterostructure.

15 min. break

HL 14.8 Tue 11:30 H 2032

Thickness dependent electronic and optical properties of TMDCs within many-body perturbation theory — •Philipp Marauhn, Peter Krüger, and Michael Rohlfing — Institut für Festkörpertheorie, Westfälische Wilhelms-Universität, 48149 Münster, Germany

Experimental studies have shown that the spectrum of MoS_2 and other TMDC materials strongly depends on the number of layers of the system. With increasing thickness of a system, the optical absorption spectrum is generally shifted to lower energies.

In this talk we address this behaviour from a theoretical point of view. To investigate the excited electronic states of the TMDCs, we perform three consecutive steps: (i) DFT (ii) *GW* (iii) BSE (Bethe-Salpeter equation). Our results show that both the fundamental quasiparticle gap and the exciton binding energy are significantly reduced when the number of layers is increased. These two effects do not perfectly compensate each other, but lead to an effective shift of the excitation energies towards lower energy. This redshift with increasing number of layers is in agreement with experimental differential reflectance measurements [1]. We also find significant changes in the wave function of some exciton resonances with increasing sample thickness. In multilayer systems, excitons may be composed from electrons and holes situated on different layers, which can be considered as interlayer excitons [2].

[1] Y. Niu et. al., submitted
[2] A. Arora et. al., Nat. Commun., 8(1), 639 (2017)

HL 14.9 Tue 11:45 H 2032

Elasticity theory for two dimensional systems at finite temperatures — •Johannes Häring and Matthias Fuchs — FB Physik, Universität Konstanz, 78457 Konstanz, Germany

According to the Mermin-Wagner theorem many two dimensional systems only exhibit quasi-long-range order. Recently, we developed an elasticity theory for crystals with point defects and applied it to the defect rich cluster crystal [1]. The theory is able to handle long-range translational order. Now we present a method which includes quasi-long-range order.

Furthermore, orientational degrees of freedom are considered as well. As an example results of the helicity modulus and dynamical matrix of the two dimensional XY model are presented. Temperatures range between zero and the Kosterlitz-Thouless transition.

Finally, the influence of topological defects like vortices is discussed.

[1] J.M. Häring, C. Walz, G. Szamel, and M. Fuchs, Phys. Rev. B **92**, 184103 (2015)

HL 14.10 Tue 12:00 H 2032

Ab Initio Study of the Electronic and Optical Properties of Organic-Inorganic two-dimensional Perovskites: The Role of Many-Body Effects — •Maurizia Palummo[1] and Giacomo Giorgi[2] — [1]INFN and Dip. Fisica University of Roma "Tor Vergata" Via della ricerca scientifica 1 Rome Italy — [2]Dip. Ing. Civile e ambientale Univ. Perugia Italy

Organic-Inorganic Halide Perovskites (OIHPs) represent the most relevant breakthrough in the last decade in photovoltaics (PV) Despite the many attractive features, some serious issues remain that prevent their usage in device mass production, such as the fast air/moisture induced degradatio. For this reason, in the last years two-dimensional Ruddlesden-Popper perovskites (2D-RPOIHPs) have emerged as an alternative to 3D bulk for their superior photo- and chemical-stability coupled with high-performance opto-electronic properties and an enhanced hydrophobic nature of the organic part. While the experimental interest towards this 2D class of materials is nowadays well assessed, ab-initio studies focusing on the role of many-body effects are very limited. By means of a coupled GW plus BSE approach on top of DFT-KS simulations, we here study the electronic and optical properties of a 2D-RPOIHP, as a single sheet and also as a periodic QW. A giant band-gap renormalization of the electronic band-gap and the formation of a strongly bound almost 2D excitons are observed. The relationship between the number of layers is discussed.

HL 14.11 Tue 12:15 H 2032

Layered van der Waals crystals with hyperbolic light dispersion — •Morten Gjerding — DTU Physics, Fysikvej building 311, 2800 Kgs. Lyngby

Compared to artificially structured hyperbolic metamaterials, whose performance is limited by the finite size of the metallic components, the sparse number of naturally hyperbolic materials recently discovered are promising candidates for the next generation of hyperbolic materials. Using first-principles calculations, we extend the number of known naturally hyperbolic materials to the broad class of layered transition metal dichalcogenides (TMDs). The diverse electronic properties of the transition metal dichalcogenides result in a large variation of the hyperbolic frequency regimes ranging from the near-infrared to the ultraviolet. Combined with the emerging field of van der Waals heterostructuring, we demonstrate how the hyperbolic properties can be further controlled by stacking different two-dimensional crystals opening new perspectives for atomic-scale design of photonic metamaterials. As an application, we identify candidates for Purcell factor control of emission from diamond nitrogen-vacancy centers.

HL 14.12 Tue 12:30 H 2032

Influence of Hansen solubility parameters on a shear exfoliation process of organophilic layered silica in chloroform — •Michael Huth, Jonas Köhling, and Veit Wagner — Jacobs University Bremen, Campus Ring 1, 28759 Bremen, Germany

Nanocomposites based on layered silica can be used for several applications, like reinforcement, flame retardant agent, or barrier applications. The understanding of delamination processes of layered silica in organic solvents/polymers is a critical step towards preparing such nanocomposites. In this work, layered silicas with different intercalated molecules are used. Those molecules change the silica surface interaction energies described by Hansen solubility parameters (HSP). HSP of four different synthetic organophilic layered silicas are determined. This allows calculating the dispersibility in chloroform via the Flory-Huggins (F-H) parameter. The F-H parameter can predict the delamination state of organophilic layered silicas in solvents. The delamination state is evaluated quantitatively using atomic force microscopy (AFM). In the case of a high F-H parameter ($\chi > 0.15$), aggregated and unstable layered silica dispersions are found. Whereas in the case of F-H parameters near zero, exfoliated and stable layered silica dispersions are obtained. Additionally, the presence of the surfactant on the surface of fluoromica flakes after exfoliation is proven by Fourier-transform infrared spectroscopy (FT-IR), and density functional theory (DFT) calculations.

HL 14.13 Tue 12:45 H 2032

Theoretical description of photoemission spectroscopy of van der Waals structures — •Bruno Amorim — CeFEMA, Instituto Superior Técnico, University of Lisbon, Av. Rovisco Pais, PT-1049-001 Lisboa, Portugal

I present a general theory to model the angle resolved photoemission spectroscopy (ARPES) of van der Waals (vdW) structures. VdW structures are formed by lattice mismatched and/or misaligned stacked layers of two-dimensional materials and can be commensurate or incommensurate.

The present theory is based on a tight-binding description of the bound electrons and the concept of generalized umklapp processes, being capable of describing both commensurate and incommensurate structures for arbitrary lattice mismatch/misalignment. In this way, the present theory goes beyond previous descriptions of ARPES in incommensurate vdW structures, which are based on continuous, low energy models, which limits their applicability to structures with small lattice mismatch/misalignment.

As an example, I apply the general method to the case of twisted bilayer graphene, obtaining the ARPES bands and ARPES constant energy maps.

The present theory should be useful in correctly interpreting experimental results of ARPES of vdW structures and other system displaying competition between different periodicities, such as density wave phases.

HL 14.14 Tue 13:00 H 2032

Manipulating the Mechanical Properties of Ti2C MXene: Effect of Substitutional Doping — •Poulami Chakraborty[1], Tilak Das[2], Dhani Nafday[1], Lilia Boeri[3], and Tanusri Saha-Dasgupta[1] — [1]Department of Condensed Matter Physics and Materials Science, S.N.Bose National Centre for Basic Sciences, JD Block, Sector-3, Salt Lake , Kolkata 700106, India — [2]Department of Physical Sciences, Indian Institute of Science Education and Research-Kolkata, Mohanpur Campus, PO BCKV Campus Main Office, Nadia * 741252, West Bengal, India — [3]Institute for Theoretical and Computational Physics, TU Graz, Petersgasse 16, 8010 Graz, Austria

Two-dimensional transition metal carbides/nitrides $M_{n+1}X_n$ termed as MXenes have attracted immense interest as potential candidates for Li-ion battery anodes and as a hydrogen storage medium. Our work focuses on the specific case of Ti_2C and Ti_2CO_2 under various tensile strain using density functional theory (DFT). We consider substitutional doping of B and V at Ti and C sites of Ti_2C. We have studied substitutional doping with no surface termination as well as oxygen terminated Ti_2C, i.e., Ti_2CO_2. In-plane stiffness, Young's modulus, and critical strain calculations conclude that B doping is highly effective in improving the elastic properties. This trend is found to hold good even for B-doped and V-doped O terminated systems. However the O passivated compounds are found to have relatively higher critical strain values compared to their pristine counterparts. Thus B doped Ti_2CO_2 , $Ti_2(C_{0.5}, B_{0.5})O_2$, appears to be the best candidate among the studied systems, as compared to pure Ti_2C.

HL 15: Focussed Session: Geometry- and Topology-Controlled Nanoarchitectures I

Study of topological matter is one of the fascinating main roads of modern physics. The realm of topological matter can be conventionally subdivided in two categories. First, non-trivial topology occurs due to a special geometry of structures or fields in real space, e.g., quantum rings, Möbius rings, multi-terminal Josephson junctions, Skyrmions. Second, topologically protected surface/edge states governed by Dirac physics and/or topologically nontrivial electronic structure in the momentum space underlie Quantum Hall effect, topological insulators, superconductors, semimetals. An interplay between those two realms is the subject of the proposed Focus Session.

Organizers: Paul M. Koenraad (TU Eindhoven) and Vladimir M. Fomin (IFW Dresden)

Time: Tuesday 9:30–13:15 Location: EW 015

HL 15.1 Tue 9:30 EW 015

Field-induced quantum rings in cone-shell GaAs quantum dots — •Christian Heyn, Achim Küster, Michael Zocher, and Wolfgang Hansen — Center for Hybrid Nanostructures, University of Hamburg, D-22761 Hamburg, Germany

We study self-assembled GaAs quantum dots (QDs) and rings (QRs) in refilled AlGaAs nanoholes. The holes are fabricated using local droplet etching during molecular beam epitaxy. Controlled by the process conditions, QDs of varied shape can be generated in which the probability distributions of the carriers are concentrated, e.g., in the volume of a cone or on the cone shell. The optical emission of cone-shell QDs (CSQDs) is studied with single-dot photoluminescence (PL). Numerical simulations reproduce the experimental ground and excited-state emission energy of the CSQDs. Further simulations of the influence of a vertical electric field establish a field-dependent displacement of either the electron or the hole away from the tip of the cone. This displacement has several consequences. First, the Coulomb interaction is strongly reduced which compensates the single-particle Stark-shift. Accordingly, simulations as well as PL measurements indicate a non-parabolic Stark-shift with a regime of approximately constant emission energy. Second, the calculated exciton-recombination lifetime establishes a variability up to seven orders of magnitude. Third, regarding the shape of the wave-functions in CSQDs, we predict the controlled transformation of either the electron or the hole from a quasi zero-dimensional dot into a one-dimensional quantum ring by a gate-voltage. The respective other charge carrier remains as a dot.

HL 15.2 Tue 9:45 EW 015

Magnetism in curved geometries — •Denys Makarov — Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, Dresden, Germany

While conventionally magnetic films and structures are fabricated on flat surfaces, the topology of curved surfaces has only recently started to be explored and leads to new fundamental physics as well as applied device ideas. In particular, novel effects occur when the magnetization is modulated by curvature that has major implications on the spin statics and dynamics due to topological constraints. Advances in this novel field solely rely on the understanding of the fundamentals behind the modifications of magnetic responses of 3D-curved magnetic thin films. The lack of an inversion symmetry and the emergence of a curvature induced effective anisotropy and Dzyaloshinskii-Moriya interaction are characteristic of curved surfaces, leading to curvature-driven magnetochiral effects and topologically induced magnetization patterning [1]. In addition to these rich physics, the application potential of 3D-shaped objects is currently being explored as spin filters, magnetic field sensorics and memory devices. To this end, the initially fundamental topic of magnetism in curved geometries strongly benefited from the input of the application-oriented community, which among others explores the mechanical shapeability of curved magnetic thin films. These activities resulted in the development of shapeable magnetoelectronics [2] - spintronics on flexible, bendable and stretchable surfaces. [1] Streubel et al., J. Phys. D: Appl. Phys. (Topical Review) 49, 363001 (2016). [2] Makarov et al., Appl. Phys. Rev. (Focused Review) 3, 011101 (2016).

HL 15.3 Tue 10:00 EW 015

Observation of Aharonov-Bohm oscillations in core-shell nanowire crystal-phase quantum rings — Pierre Corfdir[1], •Oliver Marquardt[1,2], Ryan B. Lewis[1], Chiara Sinito[1], Manfred Ramsteiner[1], Achim Trampert[1], Uwe Jahn[1], Lutz Geelhaar[1], Oliver Brandt[1], and Vladimir M. Fomin[3] — [1]Paul-Drude-Institut für Festkörperelektronik — [2]Weierstraß-Institut für angewandte Analysis und Stochastik — [3]Leibniz-Institut für Festkörper- und Werkstoffforschung

Coherence in nanostructures is at the heart of a wide range of

quantum effects such as Josephson oscillations between exciton-polariton condensates in microcavities, conductance quantization in one-dimensional ballistic transport, or the excitonic Aharanov-Bohm (AB) effect in quantum ring (QR) devices. However, inevitable interface roughness in self-assembled low-dimensional semiconductor heterostructures usually leads to loss of coherency and charge carrier localization. The study of AB oscillations in semiconductor QRs has thus required the fabrication of heterostructures with high interface quality, and has so far been limited to self-assembled ring structures with very limited control of shape and dimension or to nanorings that were fabricated by nanolithography. We demonstrate that core-shell GaAs/AlAs nanowires containing atomically flat polytype segments can be systematically tailored for studies of the excitonic AB effect of neutral and charged excitons. Thanks to their atomically flat interfaces and the absence of alloy disorder, phase coherence is preserved even in QRs with diameters on the order of 90 nm.

HL 15.4 Tue 10:15 EW 015

Microwave-stimulated superconductivity in Nb thin films — •Oleksandr V. Dobrovolskiy[1,2], Roland Sachser[1], Michael Huth[1], Antonio Lara[3], Farkhad G. Aliev[3], Valerij A. Shklovskij[2], Alexei I. Bezuglyj[2,4], and Ruslan V. Vovk[2] — [1]Goethe University, Frankfurt am Main, Germany — [2]V. Karazin National University, Kharkiv, Ukraine — [3]Universidad Autonoma de Madrid, Spain — [4]National Science Center – KIPT, Kharkiv, Ukraine

Stimulation of superconductivity due to the presence of vortices by a microwave (mw) excitation has been recently seen in increase of T_c and H_{c2} in type II superconducting thin films. Here we report on a mw-induced enhancement of the maximal *mixed-state* dc critical current of epitaxial Nb films. The mw-stimulated flux flow is expanded up to 10% larger dc current densities and vortex velocities v^* than in the absence of mw stimulus. Here j^* and v^* correspond to an abrupt transition of the sample into the normal state because of the Larkin-Ovchinnikov (LO) instability. We have performed simulations of the time-dependent Ginzburg Landau (TDGL) equation, which reveal similar results to the ones observed in the experiments. These can be interpreted as a result of massless response of vortices to an external excitation, or as mw-stimulated superconductivity as vortices approach the critical velocity. We furthermore argue that the observed mw-induced enhancement of j^* and v^* can result in a competition between the mw-induced cooling and the dc-induced heating of quasiparticles in the vortex cores.

HL 15.5 Tue 10:30 EW 015

Andreev levels as a quantum dissipative environment — Artem Galaktionov[1], •Dmitry Golubev[2], and Andrei Zaikin[3] — [1]Lebedev Physical Institute, Moscow, Russia — [2]Aalto University, Espoo, Finald — [3]Karlsruhe Institute of Technology, Karlsruhe, Germany

We argue that at subgap energies quantum behavior of superconducting weak links can be exactly accounted for by an effective Hamiltonian for a Josephson particle in a quantum dissipative environment formed by Andreev levels. This environment can constitute an important source for intrinsic inelastic relaxation and dephasing in highly transparent weak links. We investigate the problem of macroscopic quantum tunneling in such weak links demonstrating that - depending on the barrier transmission - the supercurrent decay can be described by three different regimes: (i) weak intrinsic dissipation, (ii) strong intrinsic dissipation, and (iii) strong capacitance renormalization. Crossover between quantum and thermally assisted supercurrent decay regimes can also be strongly affected by the Andreev level environment.

HL 15.6 Tue 10:45 EW 015

Non-equilibrium ϕ_0-junction-like behavior of multi-terminal Andreev interferometers — Pavel Dolgirev[1,2], Mikhail Kalenkov[2], and •Andrei Zaikin[3,2] — [1]Skolkovo Institute of Science and Technology, Skolkovo Innovation Center, 3 Nobel St., 143026 Moscow, Russia — [2]I.E. Tamm Department of Theoretical Physics, P.N. Lebedev Physical Institute, 119991 Moscow, Russia — [3]Institut fuer Nanotechnologie, Karlsruher Institut fuer Technologie (KIT), 76021 Karlsruhe, Germany

We predict a novel (I_0, ϕ_0)-junction state of multi-terminal hybrid superconducting-normal nanostructures with non-trivial topology. This state emerges from an interplay between long-range quantum coherence and non-equilibrium effects. Under non-zero bias V the current-phase relation $I_S(\phi)$ resembles that of a ϕ_0-junction differing from the latter due to a non-zero average $I_0(V) = \langle I_S(\phi)\rangle_\phi$. The flux-dependent thermopower $\mathcal{S}(\Phi)$ of the system exhibits features similar to those of a (I_0, ϕ_0)-junction and in certain limits it can reduce to either odd or even function of Φ in the agreement with a number of experimental observations.

15 min. break.

HL 15.7 Tue 11:30 EW 015

Voltage tuning of exciton topology and g-factor in type-II InAs/GaAsSb quantum dots — •Benito Alén[1], José M. Llorens[1], Edson R. Cardozo de Oliveira[2], Lukasz Wevior[1], Vivaldo Lopes-Oliveira[3], Victor López-Richard[2], José M. Ulloa[4], Marcio D. Teodoro[2], Gilmar E. Marques[2], Alberto García-Cristóbal[5], and Guo-Quiang Hai[3] — [1]IMN-Instituto de Micro y Nanotecnología (CNM-CSIC), Spain. — [2]Dept. de Física, Universidade Federal de Sao Carlos, Brazil. — [3]Instituto de Física, Universidade de Sao Paulo, Brazil. — [4]ISOM, Universidad Politécnica de Madrid, Spain. — [5]ICMUV, Universidad de Valencia, Spain.

We will report experimental and theoretical work done in the InAs/GaAsSb QD system. For Sb molar fractions beyond 16 %, the band alignment becomes type II, with the electron confined inside the InAs and the hole delocalized in the GaAsSb overlayer. Voltage control of the exciton dipole moment in the vertical direction thus allows large tuning of the radiative lifetime. [1] It also brings a topological change in the hole ground state wavefunction from singly to doubly connected. [1,2] The latter causes Aharonov-Bohm oscillations and a change of the exciton g-factor, as observed in the QD ensemble magneto-photoluminescence. Both effects are modulated by external bias in a device and can be explained in the frame of k.p and effective Hamiltonian models. This result could open a venue for new quantum memories beyond the InAs/GaAs realm.

[1] J. M. Llorens et al. Appl. Phys. Lett., 107, 183101 (2015) [2] J. M. Llorens et al. arXiv:1710.08828 [cond-mat.mes-hall]

HL 15.8 Tue 11:45 EW 015

Cleavage Energies of Layered Materials: $Bi_{14}Rh_3I_9$, Bi_2TeI, β-Bi_4I_4 and 2H-MX_2 — •Madhav Prasad Ghimire[1,2], Jeroen van den Brink[1], and Manuel Richter[1,3] — [1]IFW Dresden e. V., Helmholtzstr. 20, D-01069 Dresden, Germany — [2]CMPRC, Butwal-11, Rupandehi, Lumbini, Nepal — [3]DCMS, TU Dresden, D-01062 Dresden, Germany

In recent years weakly bonded layered systems have become important for the manufacturing of two-dimensional materials. Precise knowledge of the interlayer bonding allows to understand in detail the exfoliation process in these compounds. Cleavage energies are crucial in this respect. Here we report the cleavage energies and electronic properties of the weak topological insulators (TIs) $Bi_{14}Rh_3I_9$, Bi_2TeI and β-Bi_4I_4, as well as of 2H-transition metal dichalcogenides (MX_2 where M=Mo, W and X=S, Se, Te) determined by means of density functional theory calculations. Our calculations reproduce the experimentally measured value of cleavage energy of graphite, E_c (graphite) = 0.37 Jm^{-2}, which we use as a benchmark. Based on this, we calculate the cleavage energies of the three weak TIs and 2H-MX_2 systems. We find that all energies are smaller than $2\times E_c$ of graphite. The obtained values suggest the possibility of exfoliation of individual layers in these materials.

HL 15.9 Tue 12:00 EW 015

Topologically Distinct Semiconductor Nanostructures by Droplet Epitaxy — •Stefano Sanguinetti[1,2], Francesco Biccari[3], Sergio Bietti[1], Anna Vinattieri[3], Alexey Fedorov[2], and Massimo Gurioli[3] — [1]L-NESS and University of Milano Bicocca, Via Cozzi 55, 20126 Milano, Italy — [2]IFN-CNR, Via Anzani 42, 22100 Como, Italy — [3]University of Florence and LENS, Via Sansone 1, 50019 Sesto Fiorentino (FI), Italy

Extremely complex semiconductor quantum nanostructures, constituted by multiple concentric rings, disks and dots can be designed and realized by Droplet Epitaxy. Topology induced effects determines the electronic and optical properties of these nanostructures. In particular, carrier dynamics appears to be related to topology induced selection rules. We present in detail the droplet epitaxy growth procedure and the analysis of the emission of individual GaAs/AlGaAs complex nanosystems composed by concentric and topologically distinct quantum nanostructures. Time resolved, temperature and excitation power density dependence of the photoluminescence from single and ensemble nanostructures have been used in order to determine the carrier dynamics. Despite the small spatial separation between the dot

and the ring, the exciton dynamics in the nanostructures is completely decoupled at low temperatures. At higher temperatures it is possible observe a clear change in the carrier dynamics, which shows the onset of the coupling between the nanostructures. Electronic structure calculations show that the interaction takes place via a delocalized common excited energy state.

HL 15.10 Tue 12:15 EW 015

Optical geometric phase in Möbius ring and asymmetric microtube cavities — •Libo Ma — Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany

Optical whispering gallery modes (WGMs) in micro-ring cavities are formed by self-interferences of optical waves with integer numbers of 2π phase differences along a ring trajectory. This kind of phase is usually called as dynamical phase since an extra phase, Berry phase (also known as geometrical phase), was discovered for general physical wave systems in nontrivial evolutions. Optical Berry phase was excluded from conventional WGM cavities because of trivial topology therein. Here, we talk about the generations of Berry phase in optical ring microcavities formed by twisted nano-strip (i.e. Möbius ring) and cone-shaped microtube structures. A Berry phase π is generated in Möbius ring, which leads to the formation of half-integer number of resonant modes and anomalous plasmon modes. More interestingly, the generations of Berry phase together with basis conversion was observed in the cone-shaped microtube cavities due to optical spin-orbit coupling in an anisotropic medium. Berry phase theory and quantum mechanical diagonalization procedure were applied to explain our observations. Our work paves a way for generating and manipulating optical Berry phase for both fundamental and applied studies in the platform of on-chip quantum devices.

HL 15.11 Tue 12:30 EW 015

Artificial magnetoelectric materials with curvilinear helimagnets — •Oleksii Volkov, Jürgen Fassbender, and Denys Makarov — Helmholtz-Zentrum Dresden - Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, Dresden, Germany.

Magnetoelectric (ME) materials are technologically relevant, e.g. as prospective non-volatile memory devices [1]. The ME effect in single-phase bulk materials is weak and observed in rather special crystals. Therefore, artificial ME materials have been proposed and are typically realized as heterostructures of magnetostrictive and piezoelectric layers. Thus, magnetic and electrical subsystems are coupled via strain. However, substrate clamping effect do not allow to achieve full change in the magnetization from zero to remanent value.

Here we propose a novel approach towards artificial ME materials with helimagnetic nanohelices embedded in a piezoelectric matrix. By applying an electric field, geometrical properties of a helical wire (i.e. pitch and radius) could be changed deterministically. In this system not relying on magnetostriction in a magnetic subsystem, pure geometrical change results in a strong modification of a magnetic state of a curvilinear helimagnet [2]. We analyse phase diagrams of magnetic and geometrical parameters, which allow us to realize switching of a magnetic state from a homogeneous (full average magnetic moment) into a periodical one (zero average magnetic moment).

[1] M. Fiebig et. al., Nature Reviews 1, 1-14 (2016).
[2] R. Streubel et. al., J. Phys. D: Appl. Phys. 49, 363001 (2016).

HL 15.12 Tue 12:45 EW 015

Nano-SQUIDs with controllable weak links via electromigration — Wout Keijers[1], Xavier D.A. Baumans[2], Ritika Panghotra[1], Jospeh Lombardo[2], Vyacheslav S. Zharinov[1], Alejandro V. Silhanek[2], and •Joris Van de Vondel[1] — [1]INPAC-Institute for Nanoscale Physics and Chemistry, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium — [2]Experimental Physics of Nanostructured Materials, Q-MAT, CESAM, Université de Liège, B-4000 Sart Tilman, Belgium

This work deals with modifying the weak links of a thin film aluminum nano-SQUID beyond the limit of current lithography techniques using controlled electromigration (EM). In order to achieve this goal, a nano-SQUID is designed and fabricated using e-beam lithography (EBL) and molecular beam epitaxy (MBE) techniques. Since the design of the SQUID consists of two weak links in parallel, the next step was to experimentally verify that this design is indeed compatible with parallel EM. This is achieved by the, direct and in-situ, observation of the parallel EM process using scanning electron microscopy. Hereafter, we investigated the evolution of the superconducting properties of the SQUID using low temperature measurements as function of the cross section of the weak links. The behavior of the SQUID's critical current perfectly matches the numerical calculations based on a SQUID model which takes into account the kinetic inductance and asymmetry of the device. Moreover, it is observed that when EM has sufficiently reduced the junction cross section, the SQUID can be operated in the dissipative state, where magnetic flux readout from voltage is possible.

HL 16: Focussed Session: Quantum Nanophotonics in Solid State Systems: Status, Challenges and Perspectives I (joint session HL/TT)

Photonic quantum technologies provide revolutionary concepts and innovative solutions in the fields of sensing, communication and computing in the so called "second quantum revolution". Activities in this area involve light-matter interaction, light propagation, light manipulation and light detection, mainly at the single photon level. The Focus Session aims at presenting and discussing the current status of quantum nanophotonics, open challenges as well as future directions and perspectives in this very active field of solid state research.

Organizers: Alexander Szameit(U Rostock), Ruth Oulton (U Bristol), and Stephan Reitzenstein (TU Berlin)

Time: Tuesday 9:30–15:45 Location: EW 201

Invited Talk HL 16.1 Tue 9:30 EW 201

Exploring the limits of position measurement with optomechanics — Sergey A. Fedorov, Vivishek Sudhir, Nils J. Engelsen, Ryan Schilling, Hendrik Schütz, Amir H. Ghadimi, Mohammad J. Bereyhi, Dalziel J. Wilson, and •Tobias J. Kippenberg — Institute of Physics (IPHYS), École polytechnique fédérale de Lausanne, 1015 Lausanne, Switzerland

Optomechanics provides a platform to investigate the quantum limits on position measurements and extend quantum control to macroscopic objects. We utilized a microdisk optical cavity with a nanobeam mechanical oscillator in the near-field to perform sensitive measurements of the oscillator position. At cryogenic temperatures, we attained a measurement rate approaching the thermal decoherence rate. Using the measurement record as an error signal, we feedback-cooled the oscillator to a mean phonon number of 5.3 (16% ground state probability). In the same system, we observed ponderomotive squeezing of light and distilled quantum sideband asymmetry from the thermal noise using measurement-based feedback. At room temperature, we demonstrated quantum correlations of light and used these quantum correlations to enhance force sensitivity. However, thermal decoherence remains a major obstacle in our experiments—any potential quantum state preparation must be performed within the decoherence time. Therefore, we have developed ultra-high quality factor mechanical resonators, capable of hundreds of coherent oscillations at room temperature. We are now working to integrate these oscillators with an optical cavity to enable operation in the measurement-backaction dominated regime.

Invited Talk HL 16.2 Tue 10:00 EW 201

On-chip integration of superconducting single photon detec-

tors — •Wolfram Pernice — Universität Münster, Physikalisches Institut, Heisenbergstr. 11, 48149 Münster

Nanophotonic circuits employ waveguiding devices to route light across quasi-planar integrated optical chips in analogy to electrical wires in integrated electrical circuits. Using materials with high refractive index allows for confining light into sub-wavelength dimensions as efficient optical wires. Interaction with the environment is possible through near-field coupling to the evanescent tail of propagating optical modes, given that the measurable system is close to the waveguide surface. The interaction length can then be conveniently tailored by simply choosing a sufficiently long waveguide. This approach is particularly interesting for designing highly sensitive detectors which are able to register individual photons. Because nanophotonic circuits are well-suited for the study of single photon effects on chip, such detectors constitute a fundamental building block for emerging quantum photonic technologies. I will present recent progress on waveguide integrated single photon detectors, with a focus on superconducting nanowire single photon counters. Besides covering the basics of single photon threshold detection, advanced designs for multi-photon and coherent detection will be discussed. In combination with waveguide coupled single photon sources, such detectors are promising ingredients for fully integrated quantum circuits. The heterogeneous integration with nanophotonic circuits allows for implementing compact hybrid systems for non-classical optics in a chipscale framework.

HL 16.3 Tue 10:30 EW 201

Indistinguishable single photons from a quantum dot coupled to a ridge waveguide — •Lukasz Dusanowski[1], Soon-Hong Kwon[1,2], Christian Schneider[1], and Sven Höfling[1] — [1]Technische Physik, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Department of Physics, Korea University, Seoul 136-701, Korea

Here we report on resonance fluorescence of an InAs/GaAs quantum dot coupled to a distributed Bragg-reflection ridge waveguide. The pulsed, resonant excitation was carried out from the top of the waveguide and emitted photons collected from the side facet of the ridge after 2 mm travel distance. Based on the calculations and time-resolved-measurements coupling efficiency into waveguide was estimated to be around 20%. In this case highly linearly polarized photons have been observed with a single-photon purity of >99% and indistinguishability >95% demonstrating a realistic pathway for on-chip quantum photonics.

HL 16.4 Tue 10:45 EW 201

Deterministic integration of QDs into on-chip multimode interference couplers via in-situ electron beam lithography — •Peter Schnauber[1], Johannes Schall[1], Samir Bounouar[1], Jin-Dong Song[2], Theresa Hoehne[3], Sven Burger[3], Tobias Heindel[1], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut fuer Festkoerperphysik, Technische Universitaet Berlin, Berlin, Germany — [2]Korea Institute of Science and Technology, Seoul, Korea — [3]Zuse Institut Berlin, Freie Universitaet Berlin, Berlin, Germany

The deterministic integration of quantum emitters into on-chip photonic elements is crucial for the implementation of scalable on-chip quantum circuits. Recent activities include multistep-lithography[1] as well as AFM tip transfer[2]. Here we report on the deterministic integration of single QDs into on-chip beam splitters using single step in-situ electron beam lithography[3]. In order to realize 50/50 coupling elements acting as central building blocks of on-chip quantum circuits we chose tapered multimode interference (MMI) splitters which feature relaxed fabrication tolerances and robust 50/50 splitting ratio. We demonstrate the functionality of the deterministic QD-waveguide structures by μPL spectroscopy and photon cross-correlation between the two MMI output ports. The latter confirms single-photon emission and on-chip splitting associated with $g^{(2)}(0) < 0.5$.

[1] Coles et al., Nature Communications 7, 11183 (2016)
[2] Zadeh et al., Nano Letters 16, 2289 (2016)
[3] Gschrey et al., Nature Communications 6, 7662 (2015)

15 min. break.

Invited Talk HL 16.5 Tue 11:15 EW 201

Integrated III-V nonlinear quantum optical devices — •Gregor Weihs — Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria

For fundamental tests of quantum physics as well as for quantum communications, non-classical states of light are an important tool. In this talk, we will present our work on nonlinear AlGaAs waveguides. Most III-V semiconductors exhibit a large second-order optical nonlinearity, but phase-matching the nonlinear interaction is notoriously difficult. As a solution Bragg-reflection waveguides (BRW) allow efficient creation of photon pairs through spontaneous parametric down-conversion. They have the potential to be integrated with a pump laser on the chip for a miniaturized room-temperature entangled photon pair source.

In our BRWs we can create high-fidelity polarization and time-bin entangled photon pairs, which cover a large frequency band in the low-loss telecommunication window, suitable for serving multiple users through wavelength division multiplexing. For all our applications it is important that we can design the desired linear and nonlinear properties, which in turn makes precise characterization necessary. For this purpose we have developed a Fourier-transform Fabry-Perot spectroscopy technique, which yields the relevant device parameters with superior accuracy. Finally, we will present our latest results on devices that integrate electrically injected lasers and the nonlinear conversion and give an outlook on the possible integration of other optical elements on-chip.

HL 16.6 Tue 11:45 EW 201

Temporally adjustable photon pairs from semiconductor waveguides — •K. Laiho[1,2], B. Pressl[2], A. Schlager[2], S. Auchter[2], H. Chen[2], T. Günthner[2], H. Suchomel[3], J. Gessler[3], M. Kamp[3], S. Höfling[3,4], C. Schneider[3], and G. Weihs[2] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [3]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [4]School of Physics & Astronomy, University of St Andrews, St Andrews KY16 9SS, UK

Semiconductor Bragg-reflection waveguides (BRWs) are efficient photon-pair sources and well suited for integrated optics. These monolithic structures are made of AlGaAs and profit from its strong second order optical non-linearity. Our BRWs rely on type-II parametric down-conversion (PDC) achieved via spatial mode matching.

In order to become truly practical, BRWs need to be reliably fabricated and applicable in various quantum optics tasks. Our simulations show that too coarse tolerances in fabrication easily distort the design properties. Further, we experimentally investigate the characteristics of PDC emission, verify the indistinguishability of photon pairs and prepare polarization entangled states with a temporally adjustable degree of entanglement [1]. To conclude, a careful study of the PDC process parameters is necessary for controlling and manipulating the BRW's performance in the investigated tasks.

[1] A. Schlager et al., Opt Lett. 42, 2102 (2017) and references therein.

HL 16.7 Tue 12:00 EW 201

On-chip hybrid quantum photonic circuits — Ali W. Elshaari[1], Iman Esmaeil Zadeh[2], Andreas Fognini[2], Dan Dalacu[3], Philip J. Poole[3], Michael E. Reimer[4], Val Zwiller[1,2], and •Klaus D. Jöns[1] — [1]Applied Physics Department, KTH Stockholm, Sweden — [2]Kavli Institute of Nanoscience, TU Delft, The Netherlands — [3]National Research Council of Canada, Ottawa, Canada — [4]Institute for Quantum Computing, University of Waterloo, Canada

Quantum communication applications require a scalable approach to integrate bright on-demand sources of entangled photon-pairs in complex on-chip quantum circuits. Currently, the most promising sources are based on III/V semiconductor quantum dots. However, complex photonic circuitry is mainly achieved in silicon photonics due to the tremendous technological challenges in circuit fabrication. We take the best of both worlds by developing a new hybrid on-chip nanofabrication approach [1], allowing to integrate III/V semiconductor nanowire quantum emitters into silicon-based photonics. We demonstrate for the first time on-chip generation, spectral filtering, and routing of single-photons from selected single and multiple nanowire quantum emitters all deterministically integrated in a CMOS compatible silicon nitride photonic circuit [2]. Our new approach eliminates the need for off-chip components, opening up new possibilities for large-scale quantum photonic systems with on-chip single- and entangled-photon sources.

[1] I. Esmaeil Zadeh et al., Nano Lett. 16(4), 2289-2294 (2016).
[2] A. W. Elshaari et al., Nat. Commun. 8, 379 (2017).

HL 16.8 Tue 12:15 EW 201

Reconfigurable integrated optical circuits on an stretchy polymer chip — •James A. Grieve[1], Kian Fong Ng[1], Filip Auksztol[1], Manuel J.L.F. Rodrigues[2], Neo Ho[2], José Viana-Gomes[2,3], and Alexander Ling[1,3] — [1]Centre for Quantum Technologies, National University of Singapore, Singapore — [2]Centre for Advanced 2D Materials and Graphene Research Centre, National University of Singapore, Singapore — [3]Department of Physics, National University of Singapore, Singapore

We describe the development of a waveguide platform in the flexible, stretchy polymer polydimethylsiloxane (PDMS). The pliable substrate enables tuning of integrated optical components by mechanical deformation of the host chip, overcoming a key limitation in many bespoke waveguide platforms. We illustrate this capability via the continuous on-chip tuning of a beamsplitter. We also apply these techniques to continuously coupled photonic random walks. Here, appropriate deformation of the chip allows reconstruction the spatial evolution of light in a coupled 1D array by observation of the end face alone. The PDMS platform is compatible with visible wavelengths and is insensitive to polarization, making it a compelling candidate for the integration of quantum optics experiments.

HL 16.9 Tue 12:30 EW 201

Confined microcavity polaritons: effect of trap geometry on potential shape — •Alexander Kuznetsov, Paul Helgers, Klaus Biermann, and Paulo Santos — Hausvogteiplatz 5-7, 10117 Berlin, Germany

Micorcavity (MC) exciton-polaritons (MPs) result from the strong light-matter coupling. MPs may be quantum-confined using micrometer-sized static potentials (traps). Arrays of such traps have been suggested for quantum-simulators. The latter require energy- and spatial overlap of wave functions of trapped single polaritons and thus precise control of the trap shape and size. In this work, we investigate the two-dimensional and three-dimensional confinement of MPs in traps produced by shallow etching and overgrowth of (Al,Ga)As MC. Using low-temperature photoluminescence, atomic-force microscopy and numerical modeling we correlate trap shape and size with the energy spectrum and spatial profile of MPs wave functions. We find that the um-sized potential is of neither purely square nor parabolic type. We show that the trap potential is anisotropic due to the different overgrowth kinetics along [-110] and [-1-10] directions. We present a model to explain non-degenerate energy levels in the emission spectra of confined MPs, which also predicts the minimum size and confinement strength of MPs traps.

HL 16.10 Tue 12:45 EW 201

Photo-luminescence of defects in GaAs double quantum wells in the trion blockade regime — •Mingyun Yuan, Alberto Hernández-Mínguez, Colin Hubert, Klaus Biermann, and Paulo Santos — Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany

Electrostatic traps are commonly used to control excitons in double quantum well (DQW) structures, in our case a GaAs/AlGaAs DQW. When the traps are biased to the flat-band regime, only direct (i.e. in the same QW) excitons and trions can be formed. Away from the flat-band, indirect (in different QWs) excitons appear due to their favorable binding energies. At the edge of the flat-band, we observe a narrow regime in which the photo-luminescence (PL) of direct excitons, trions and indirect excitons is supressed, while unexpected narrow spectral lines from individual emission centers become visible.

We conclude that such PL spectra arise from trion blockade. The excess charge of a trion cannot break away and tunnel to the second QW, since the resulted direct exciton would have a higher energy. However, if defect states with sufficiently lower energies exist in the second QW, the excess charge can tunnel and recombine with such a defect, emitting photons during the process. By moving the sub-micron excitation spot we can map out the precise location and the density of these emission centers. Their intensity saturates with increasing excitation power, indicating their single-photon nature. This phenomenon in the trion blockade regime can assist engineering of defects in a DQW. The potential of using them as single photon sources can also be explored.

HL 16.11 Tue 13:00 EW 201

Enhanced single-photon emission from a CdSe quantum dot in a ZnSe nanowire featuring a bottom-up photonic shell — Mathieu Jeannin[1], Thibault Cremel[2], Teppo Häyrynen[3], •Niels Gregersen[3], Edith Bellet-Amalric[2], Gilles Nogues[1], and Kuntheak Kheng[2] — [1]Université Grenoble Alpes, CNRS, Institut Néel, Grenoble, France — [2]Université Grenoble Alpes, CEA, Grenoble, France — [3]DTU Fotonik, Technical University of Denmark, Kongens Lyngby, Denmark

A quantum dot in a semiconductor nanowire represents an attractive platform for an efficient single-photon source. While demonstrations so far have mainly been for III-V materials, the II-VI platform offers the possibility of room-temperature operation, where CdSe quantum dots inserted in ZnSe nanowires have demonstrated the ability to emit single photons at 300 K.

In this work, we present a bottom-up approach to fabricate a photonic nanowire-like structure around such CdSe quantum dots by depositing an oxide shell using atomic-layer deposition. Simulations suggest that the intensity collected in a 0.6 NA microscope objective can be increased by a factor 7 with respect to the bare nanowire case. Combining micro-photoluminescence, decay time measurements, and numerical simulations, we obtain a fourfold increase in the collected photoluminescence from the quantum dot. We show that this improvement is due to an increase of the quantum-dot emission rate and a redirection of the emitted light.

45 min. break.

Invited Talk HL 16.12 Tue 14:00 EW 201

Hybrid waveguide platforms for quantum optics — •Michal Bajcsy — IQC, University of Waterloo, Waterloo, ON, Canada

While often challenging to implement, combining systems and building blocks from different areas of quantum optics and nanophotonics can open avenues for realizing novel devices and for studies of previously unexplored phenomena. I will describe three hybrid nanophotonic platforms my group has been exploring in the past few years.

In the first platform, we attempt to integrate superconducting-nanowire single-photon detectors with waveguide arrays laser-written in glass. In the second platform, we propose to couple individual quantum emitters, such as trapped atoms, colour centres, or quantum dots, with dispersion engineered chiral waveguides to implement deterministic single-photon subtraction. Our third platform combines hollow-core waveguides with dielectric metasurfaces acting as mirrors to realize integrated Fabry-Perot cavities that can be designed to be polarization selective.

HL 16.13 Tue 14:30 EW 201

Heterogeneous quantum networks: Combine QDs with long lived atomic quantum memories — •Janik Wolters[1], Lucas Béguin[1], Roberto Mottola[1], Jan-Philipp Jahn[1], Andrew Horsley[1], Fei Ding[2], Armando Rastelli[3], Oliver G. Schmidt[2], Richard J. Warburton[1], and Philipp Treutlein[1] — [1]Universität Basel, Department Physik, Switzerland — [2]IFW Dresden, Germany — [3]Johannes-Kepler Universität Linz, Austria

Semiconductor quantum dots (QDs) are excellent single-photon sources, providing triggered single-photon emission at a high rate and with high spectral purity. Independently, atomic ensembles have emerged as one of the best quantum memories for single photons, providing high efficiency storage and long memory lifetimes. We aim at combining these two disparate physical systems to exploit the best of both worlds. For this, the bandwidth mismatch between QDs typically emitting GHz-broad photons and atomic lines of 10 MHz width must be solved. We demonstrate a scheme to generate temporally shaped narrow-bandwidth single photons with QDs [1], and we push forward an EIT-based quantum memory to store broadband photons in a dense ensemble of 87Rb atoms [2].

[1] L. Béguin et al., On-demand semiconductor source of 780 nm single photons with controlled temporal wave packets, arXiv:1710.02490 (2017).

[2] J. Wolters et al., Simple atomic quantum memory suitable for semiconductor quantum dot single photons, Phys. Rev. Lett. 119 060502 (2017).

HL 16.14 Tue 14:45 EW 201

Rare-earth doped nanoparticles with millisecond-long spin coherence lifetime — •Diana Serrano[1], Jenny Karlsson[1], Alexandre Fossati[1], Alban Ferrier[1,2], Alexandre Tallaire[1], and Philippe Goldner[1] — [1]Institut de Recherche de Chimie Paris (IRCP), UMR 8247 CNRS Chimie-Paristech, 11 rue Pierre et Marie Curie, 75005 Paris — [2]Sorbonne Universités, UPMC Université Paris 06, 75005, Paris, France

Nanoscale systems possessing long-lived spins and the ability to coherently couple to light are highly demanded for quantum devices implementations. Several approaches, like NV centers in diamond, semiconductor quantum dots are intensively investigated in the field, where an outstanding challenge is to preserve properties, and especially optical and spin coherence lifetimes, at the nanoscale. Here, we investigate for the first time the spin coherence properties of rare-earth doped nanoparticles. Using all-optical techniques, we observed spins echoes and measured spin coherence lifetimes up to T2=2.9 ms at 5 K. Moreover, we achieve spin T2 extension using all-optical spin dynamical decoupling and observe high fidelity between excitation and echo phases. Rare-earth doped nanoparticles are thus the only reported nano-material in which optically controlled spins with millisecond coherence lifetimes have been observed.

Acknowledgement:

This research work has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 712721 (NanQTech).

HL 16.15 Tue 15:00 EW 201

Cavity Optomagnonics — •Silvia Viola Kusminskiy[1], Florian Marquardt[1,2], Hong Tang[3], and Jasmin Graf[1,2] — [1]Max Planck for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [3]Yale University, New Haven, USA

In optomagnonics, light couples coherently to collective magnetic excitations in solid state systems. This topic is of high interest for quantum information processing platforms at the nanoscale, and recent experiments have demonstrated the optomagnonic coupling for the first time. In this talk, I show how to obtain the microscopic optomagnonic Hamiltonian starting from the Faraday effect and discuss the optically-induced classical nonlinear dynamics for a homogeneous magnetic mode. A unique feature of optomagnonic systems is moreover the possibility of coupling light to spin excitations on top of magnetic textures. For the case of a microdisk geometry, I discuss the coupling between magnon modes in the presence of a magnetic vortex, and light confined to whispering gallery modes.

HL 16.16 Tue 15:15 EW 201

Quantization of three-dimensional leaky and lossy cavities using quasinormal modes — •Sebastian Franke[1], Stephen Hughes[2], Andreas Knorr[1], and Marten Richter[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, EW 7-1, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [2]Department of Physics,Engineering Physics and Astronomy,Queen's University, Kingston, Ontario, Canada K7L 3N6

Open cavity systems, e.g. plasmonic metal nanoparticles or micropillar cavities, are of high interest in modern research on quantum optics and quantum plasmonics. However, the dissipative character of these systems prevents the use of a canonical quantization scheme with the open cavity photon modes.

We develop a rigorous quantization scheme using a Green's function approach[1] of an inhomogeneous and dispersive medium, and quasinormal modes[2] (QNMs) with complex eigenfrequencies $\tilde{\omega}_\mu$ and complex eigenfunctions $\tilde{\mathbf{f}}_\mu$ as a basis for the mode expansion of the quantization. In this way we obtain suitable annihilation and creation operators for modified QNMs to create QNM multi-photon Fock states. Applications to density matrix equations and comparison to the Jaynes-Cummings model will be shown, including extensions to the multimode case.

[1]T. Gruner, and D.-G. Welsch, *Phys. Rev. A* **53**, 1818, 1996

[2]P. T. Leung, S. Y. Liu, and K. Young, *Phys. Rev. A* **49**, 3057, 1994

HL 16.17 Tue 15:30 EW 201

Quantum correlations of strongly-coupled emitters inside a nanoantenna-enhanced plasmonic cavity — •Matthias Hensen[1], Tristan Kenneweg[2], Tal Heilpern[3], Stephen K. Gray[3], and Walter Pfeiffer[2] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Center for Nanoscale Materials, Argonne National Laboratory, 9700 Cass Avenue, Lemont, Illinois 60439, USA — [3]Fakultät für Physik, Universität Bielefeld, Universitätsstraße 25, 33615 Bielefeld, Germany

Plasmon-mediated strong coupling between spatially separated and thus selectively addressable quantum emitters is a worthwhile goal for conveying quantum optical many-body interactions to ultrafast timescales. For this purpose we employ a recently demonstrated hybridization scheme [1] that combines the longevity and waveguide character of an elliptical plasmon cavity with the strong field enhancement of nanoantennas positioned in the associated focal spots. Quantum dynamical simulations reveal an oscillatory exchange of excited state population and a notable degree of entanglement between the attached quantum emitters over a distance of 1.8 μm [2].

Presently, we study coherent control and time-resolved spectroscopy of quantum emitter-related nonclassical photon correlations in this device and show first results.

[1] Aeschlimann et al., *Light: Science & Applications* 6, e17111 (2017)

[2] Hensen et al., *ACS Photonics*, doi:10.1021/acsphotonics.7b00717

HL 17: Focussed Session: Atomic Scale Characterization

For a detailed understanding of complex semiconductor nano- and heterostructures as well as the physics of devices based on them, a systematic determination and correlation of the structural, chemical, electronic, and optical properties on a nanometer or atomic scale is essential. This session brings the atomic structural and chemical imaging using scanning tunneling microscopy, atomic probe tomography, and ultra-high resolution transmission electron microscopy together with the nanoscopic mapping of the optical and electronic properties using scanning transmission microscopy cathodoluminescence spectral imaging.

Organizers: Holger Eisele(TU Berlin), Frank Bertram and Jürgen Christen (OvGU Magdeburg)

Time: Tuesday 9:30–13:00 Location: EW 202

Invited Talk HL 17.1 Tue 9:30 EW 202

Quantitative Electron Microscopy for III/V on Silicon integration — •Kerstin Volz — Philipps-Universität Marburg, Department of Physics and Materials Science Center, Marburg, Germany

Integration of active III/V devices on Silicon substrates tremendously increases the functionality of this semiconductor material. In order to realize true monolithic integration, a defect-free nucleation layer is of outmost importance. Moreover, the exact atomic structure of the interface as well as of possible defects, like antiphase domains, is important as they have a decisive impact on charge carrier characteristics and band alignment at the interface. In this presentation several electron microscopic techniques will be explained, which are used to derive not only the quantitative atomic arrangement across a heterointerface, but also the local as well long-range electric field at and across interfaces. These techniques include high angle annular dark field STEM (Scanning Transmission Electron Microscopy), which allows - after appropriate simulation of the scattering process - to gain the three-dimensional quantitative composition. Complementary to this, in 4D STEM a fast pixelated detector is used to obtain information on electric fields. Both techniques, which are operated in an aberration-corrected microscope, will be applied to GaP/Si specimens, grown by metal organic vapour phase epitaxy under highly different conditions, to derive information on the exact structure of interfaces and defects.

Invited Talk HL 17.2 Tue 10:00 EW 202

Total Tomography of Nonplanar Heterostructures: Doping and Confinement Pontentials — •Lincoln Lauhon — Northwestern University, USA

The direct visualization of nanoscale structure enables the development of predictive models of novel physical behaviors. The talk will discuss recent advances in the nanoscale tomography of non-planar III-As semiconductor heterostructures including narrow gap III-As nanowire and related heterostructures for next generation compact light sources and novel computing schemes. Atom probe tomography is used to visualize the distribution of atoms in three dimensions with nanoscale resolution, providing new insights into growth mechanisms and the resulting the distribution of dopant atoms. Of particular interest is the evolution of composition of AlGaAs barrier layers and InGaAs quantum wells and nanowires when multiple growth facets are present. Generically, we find that alloy composition and doping rates vary considerably with surface faceting and polarity. Three-dimensional maps of the composition, when combined with appropriate models, reveals how the confinement of electrons and photons is influenced by size, shape, and interfaces, providing a foundation for device engineering. The tomography effort has recently been expanded to include 3-D mapping of strain using x-ray Bragg projection ptychography. The novel combination of atom probe tomography and x-ray ptychography illuminates a route to the total tomography of nanostructures.

HL 17.3 Tue 10:30 EW 202

Atomic Scale Investigation of Near Interface Defects at the SiC/SiO_2-Interface: Microscopy, Atom Probe Tomography and Theory — •Dipanwita Dutta[1,2], Deb De[2], Elisabeth Müller[1], Stephan Gerstl[3], Stefan Goedecker[2], Holger Bartolf[5], Jörg Lehmann[5], Giovanni Alfieri[5], Massimo Camarda[1], Adolf Schöner[4], and Thomas Jung[1,2] — [1]Paul Scherrer Institute, Switzerland — [2]University of Basel, Switzerland — [3]ETH Zürich, Switzerland — [4]Ascatron, Kista, Sweden — [5]ABB Switzerland Ltd, Corporate Research Baden Dättwil, Switzerland

SiC is in many aspects superior to Si. SiC MOSFETs, however, are compromised by low channel mobilities due to the poor quality of the SiC/SiO_2 interface after thermal oxidation, the method of choice for fabrication. Defects occur near the SiC/SiO_2 interface due to the complex thermal oxidation process for SiC in comparison to Si which requires removal of carbon in the form of CO and CO_2. We identify the most relevant defects for degrading the MOS performance. We analyzed near-oxide defects at different stages of fabrication and passivation by DFT-based theory and by experimental means. Atomic Force Microscopy (AFM), performed after oxide removal, reveals smoother interfaces near N_2O passivated oxides as compared to the O_2 processed oxides. Raman spectroscopy of the buried interface shows clear evidence for unwanted carbon for the first time. Electron Microscopy and Local Electrode Atom Probe (LEAP) data, will be shown at the conference along with theoretical approaches to explain the carbon-cluster formation.

HL 17.4 Tue 10:45 EW 202

A three dimensional structural model of antiphase domains in GaP on Si(001) — •Pascal Farin[1], Malte Marquardt[1], Celina S. Schulze[1], Wjatscheslav Martyanov[1], Andreas Beyer[1], Kerstin Volz[2], and Andrea Lenz[1] — [1]Technische Universität Berlin, Institute of Solid State Physics, 10623 Berlin, Germany — [2]Philipps-Universität Marburg, Materials Science Center, 35032 Marburg, Germany

The integration of III/V-semiconductors on Si(001) has been a long standing research aim to lower the cost of optoelectronic devices and simultaneously improve their performance. Because there is only a small lattice mismatch between Si and GaP, this particular III/V semiconductor is used preferentially. However, due to charged defects called antiphase domains (APDs) in GaP forming at the interface, this has proven to be quite challenging. While the search for growth conditions to avoid their formation has been successful, their exact shape remains unclear. In this work APDs in GaP on Si(001) are investigated by means of cross-sectional scanning tunneling microscopy (XSTM). This method offers unique insight into the appearance of APDs due to its high surface sensitivity. Two perpendicular cross sections of a GaP/Si sample are investigated to develop a three dimensional model for the APDs.
This work is supported by the DFG, project LE 3317/1-2.

HL 17.5 Tue 11:00 EW 202

Structural and electronic properties of AlkInSe2/CuInSe2 (Alk = K, Rb, Cs) interfaces from density functional theory calculations — •Maria Malitckaya, Hannu-Pekka Komsa, Ville Havu, and Martti Puska — Department of Applied Physics, Aalto University, P.O. Box 11000, Espoo, Finland

The efficiency of Cu(In, Ga)Se_2 (CIGS) - based solar cells has increased very fast, thanks to the alkali post deposition treatment (PDT). The latest record efficiency of CIGS solar cells has been achieved by using heavy alkali (K, Rb, and Cs) PDT. After K, Rb, and Cs PDT, chalcopyrite solar cells exhibit improved junction quality, open-circuit voltages and fill factors. However, the physical reasons behind these effects are still under discussion. At the microscopic level CIGS absorbers demonstrate changes in surface composition and morphology after Alk PDT. This effect has been associated with formation of Alk-In-Se secondary phases. Using first-principles calculations within the density functional theory, we have considered the role of alkali metal atoms in the efficiency enhancement. We have investigated the most important parameters of $AlkInSe_2$ phases, secondary phase formation during the PDT process and $AlkInSe_2$/$CuInSe_2$ interfaces.We have found that conduction band offsets are small for all orientations of the interfaces. The increase of the surface band gap seen in XPS measurements can be explained by the formation of $AlkInSe_2$ phases. In the case of K-PDT the measured band gap of 2.5 eV is consistent with the calculated value for monoclinic $KInSe_2$.

15 min. break.

Invited Talk HL 17.6 Tue 11:30 EW 202

Modulating electron beams in space and time to probe for genuine structures and function at the atomic scale — •Christian Kisielowski — Lawrence Berkeley National Laboratory

n high resolution electron microscopy objects are actively altered by the intense electron irradiation that is necessary to reach single atom sensitivity. In these circumstances a control of beam-sample interactions is no longer a commodity but a necessity. Therefore, it is of outstanding interest to develop new tools and concepts that strive for a stricter control of the probing electron beam in space and time in order to optimize the detection of every scattering event.

This contribution describes research that aims at exploiting the emerging ability to better understand layered semiconductors and other nano-materials containing soft and hard matter components by directly determining their atom arrangement in three-dimensions using low-dose rate electron microscopy. The approach mimics best practices in biological research by capturing series of entirely noise dominated images with dose rates that can be smaller than 20 e/Å2s, which are successively reconstructed to obtain in-line holograms with unprecedented contrast and resolution.

In such images we observe a variety of previously unknown atom configurations that are otherwise hidden behind a barrier of beam-induced object alterations and capture radiation sensitive structures at atomic resolution even if they are greatly affected by an exposure of the material to water vapor or other gases. Recent progress with time resolved electron microscopy further accelerates the progress.

Invited Talk HL 17.7 Tue 12:00 EW 202

Advanced Nano-scale Characterization of Nitrides using Helium Temperature Scanning Transmission Electron Microscopy Cathodoluminescence — •Gordon Schmidt — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany

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 microscopy (STEM) ($<$ 1 nm at RT, $<$ 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. Typical results which will be presented include nm-scale correlation of the optical and structural properties as well as appearance of structural defects in nitride based nanostructures.

Invited Talk HL 17.8 Tue 12:30 EW 202

Tip-enhanced Raman spectroscopy in semiconductor nanostructures and graphene — Emanuele Poliani[1] and •Janina

Maultzsch[1,2] — [1]Technische Universität Berlin, Germany — [2]Friedrich-Alexander-Universität Erlangen

Tip-enhanced Raman spectroscopy provides spatial resolution beyond the diffraction limit and is therefore useful for application in the characterization of semiconductor nanostructures. We will present experimental results on group-III nitride nanostructures and on graphene-based materials. In a doped GaN DBR structure, we investigate the carrier dependence of the Raman signal and the periodicity of the structure. In isotopically modified graphene with 12C and 13C regions, we discuss our investigations of the interface between the two regions and of superlattice structures. Finally, we show in carbon nanotubes that the strong polarization dependence present in conventional Raman scattering is almost absent in TERS.

HL 18: Perovskite and Hybrid Photovolatics

Time: Tuesday 9:30–12:45 Location: EW 203

HL 18.1 Tue 9:30 EW 203

Temperature-Dependent Electroabsorption Spectroscopy on Organic-Inorganic Perovskite Solar Cells — •Fabian Ruf[1], Alice Magin[1], Moritz Schultes[2], Erik Ahlswede[2], Heinz Kalt[1], and Michael Hetterich[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, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany

Organic-inorganic halide perovskites have demonstrated their potential as promising candidates for efficient, low-cost solar cells with power-conversion efficiencies surpassing established technologies such as amorphous silicon. However, despite the strong progress made, many fundamental material properties are not yet well understood. We investigate the nature of the optical transition in solution-processed perovskite solar cells utilizing temperature-dependent electroabsorption (EA) spectroscopy. The resulting EA spectra are suitable for a precise determination of the energetic position of optical transitions in the band structure. These results can be correlated with generalized Elliott fits of standard absorption spectra to investigate the nature of the observed resonances. Additional lineshape analysis of the spectra supports the conclusion of an excitonic nature of the resonances. Nevertheless, efficient charge-separation is possible in these devices which is reflected by power-conversion efficiencies up to 11.5 % (stabilized).

HL 18.2 Tue 9:45 EW 203

Active Materials and interfaces for stable perovskite solar cells — •Antonio Abate — Helmholtz-Zentrum Berlin für Materialien und Energie GmbH

Halide perovskites are quickly overrunning research activities in new materials for cost-effective and high-efficiency photovoltaic technologies. Since the first demonstration from Kojima and co-workers in 2009, several perovskite-based solar cells have been reported and certified with rapidly improving power conversion efficiency. Recent reports demonstrate that perovskites can compete with the most efficient inorganic materials, while they still allow processing from solution as a potential advantage to deliver a cost-effective solar technology. Compare to the impressive progress in power conversion efficiency, stability studies are rather weak and often controversial. An intrinsic complication comes from the fact that the stability of perovskite solar cells is strongly affected by any small difference in the device architecture, preparation procedure, materials composition and testing procedure. In the present talk, we will focus on the stability of perovskite solar cells in working condition. We will discuss a measuring protocol to extract reliable and reproducible ageing data. We will present new materials and preparation procedures, which improve the device lifetime without giving up on high power conversion efficiency.

HL 18.3 Tue 10:00 EW 203

Ultrafast dynamics in quadrupole cationmixed halide perovskites — •Kestutis Budzinauskas[1], Elina Patsikatheodorou[1], Senol Oez[2], Sanjay Mathur[2], and Paul H.M. van Loosdrecht[1] — [1]II physikalisches Institut, Zuelpicher 77, Köln — [2]Institut für Anorganische Chemie, Greinstr. 6, Köln

Hybrid perovskites are currently one of the most promising classes of materials for alternative solar cell technologies. Apart from the high power conversion efficiency which can be reached with these materials, one can also easily tune their optoelectronic properties by chemical substitutions. The quadrupole cation mixed halide perovskite $Gu_{1.4}Cs_{4.3}MA_{13.2}FA_{72.9}Pb(I_{1-x}Br_x)_3$ is stable at room temperature and allows tuning of the optical absorption spectrum via the Br:I ratio. Nevertheless little is known about the initial steps of the charge generation process. To obtain a better insight in the charge generation and exciton dynamics in this material we performed transient absorption spectroscopy experiments. Our pump-probe experiments show a pronounced pump energy dependence of the response near the optical band-gap. These results are discussed in terms of exciton diffusion and local structural variations

HL 18.4 Tue 10:15 EW 203

Scalable, uniform coevaporated formamidinium lead triiodide thin-films for photovoltaics — •Juliane Borchert, Rebecca L. Milot, Jay B. Patel, Christopher L. Davies, Adam D. Wright, Laura Martínez Maestro, Henry J. Snaith, Laura M. Herz, and Michael B. Johnston — Clarendon Laboratory, Department of Physics, University of Oxford, Parks Road, OX1 3PU, United Kingdom

A rapid rise in solar cell efficiencies and bandgap tunablity over much of the visible spectrum have made perovskite materials the focus of intense research. Initially, $MAPbI_3$ was the most commonly investigated material, however recently, a variety of other materials have been developed by substituting the organic cation in the perovskite structure. In particular, perovskites containing formamidinium (FA) and cesium as well as mixed cations have shown promise. With mixed cation perovskites high efficiencies and also stability improvements have been achieved [1]. Coevaporation is an advantageous deposition technique for perovskite thin-films allowing for the deposition of smooth, pinhole free, uniform films over a large area [2]. Currently, only a small number of perovskite materials have been realized using this technique. We present a study showing that coevaporation can be used to deposit $FAPbI_3$. We fabricated solar cells with efficiencies of up to 15% . The material exhibited high charge carrier mobilities and excellent optical properties [3]. This is an important step towards the fabrication of evaporated, stable, mixed cation perovskite thin-films.

[1] S.N. Habisreutinger et al., APL Mater. 2016, 4 [2] M. Liu et al., Nature 2013, 501 [3] J. Borchert et al., ACS Energy Lett 2017, 2

HL 18.5 Tue 10:30 EW 203

Cation substitution reduces non-radiative bimolecular losses in hybrid lead-halide perovskites — •Sascha Feldmann, Jasmine P. H. Rivett, Tudor H. Thomas, Michael Saliba, and Felix Deschler — University of Cambridge, JJ Thomson Avenue, CB3 0HE Cambridge, UK

Tailored monovalent cation substitution in mixed-cation hybrid perovskites enables solar cell efficiencies beyond 20% and enhanced stability. Here, we use transient absorption and photoluminescence spectroscopy to study the effect of cation substitution on the carrier recombination dynamics in Rbx(Csy(MAzFA1-z)1-y)1-xPb(I0.83Br0.17)3 (MA=methylammonium, FA=formamidinium) hybrid perovskite thin-films. We perform a detailed analysis of the recombination dynamics, from which we separate radiative and non-radiative recombination pathways. We find that careful tuning of the cation composition leads to a reduction in trap-assisted non-radiative recombination channels, which supports enhanced lifetimes and high luminescence yields. Unexpectedly, we further observe the reduction of a non-radiative bimolecular recombination channel, particularly upon inclusion of formamidinium. Using Raman and X-ray diffraction techniques, we study the effect of cation substitution on lattice order. We find that formamidinium inclusion, aided through the presence of Rb and Cs during fabrication, leads to a reduction of the tetragonal distortion, and an increased rigidity of the lattice. We attribute the enhanced luminescence yields to reduced defect formation through carrier trapping due to the reduced lattice disorder.

HL 18.6 Tue 10:45 EW 203

Circular structured Distributed Feedback Laser in Br based organic-anorganic perovskite — •Matthäus Jäckle[1], Heiko Linnenbank[1], Michael Saliba[2], Mario Hentschel[1], Michael Grätzel[2], and Harald Giessen[1] — [1]4th Physics Institute, University of Stuttgart — [2]Laboratory of Photonics and Interfaces, École polytechnique fédérale de Lausanne

Organic-anorganic perovskites are direct semiconductors which are emerging as a new type of solution-processable semiconductors for optoelectronical applications. One particular interesting characteristic is that the bandgap can be tuned over the whole visible spectrum by using different halides. Most of the present research on perovskites is aimed at their usage as solar cells because of their high absorption rate and favorable material properties. However, recent scientific publications also employ these materials for light-emitting applications such as LEDs or Lasers. Based on the intense research in the solar cell community, lasing from Iodide containing perovskites has been recently presented. As this material is designed to absorb at visible wavelengths it will emit light at red or infrared wavelengths. In this work we will in contrast present stimulated emission of radiation from Bromide based structures, which radiate in the green part of the visible spectrum. We will demonstrate a circular distributed feedback (2D-DFB) laser, based on a lithographic structuring of the supporting substrate. This allows us to make use of the solution-processability of the perovskite as active material, as well as achieving a higher cofinment compared to previously presented 1D-DFB structures.

HL 18.7 Tue 11:00 EW 203

First-principles-based modeling of atomic processes in hybrid perovskites — •Jingrui Li[1], Jari Järvi[1,2], Mariana Rossi[3], and Patrick Rinke[1] — [1]Department of Applied Physics, Aalto University, Finland — [2]Department of Physics, University of Helsinki, Finland — [3]Fritz Haber Institute of the Max Planck Society, Theory Department, Berlin, Germany

To further advance hybrid-perovskite-based photovoltaic technology, we need to understand these materials on the atomic scale, on which the light-to-energy conversion and transport processes occur. Currently, this atomic scale is riddled with controversies. For the detachment of methylammonium (MA) cations from the PbI_3 cage in $MAPbI_3$, very low ($\sim$10 meV) as well as high ($\sim$100 meV) activation energies E_a have been reported. Quasi-elastic neutron scattering measurements (QENS) for the orthorhombic phase found $E_a = 48$ meV, which was attributed to the axial rotation of the whole MA cation [1]. To shed light on this controversy, we performed density-functional theory calculations (PBE0 functional + van der Waals corrections + inclusion of nuclear quantum effects) for several rotational MA processes. For the rotation of CH_3 against the NH_3 unit which remains bound to the PBI_3 cage, we obtain $E_a = 42$ meV in good agreement with the QENS result. We therefore ascribe this barrier to this torsional motion. For the full axial rotation, which breaks three hydrogen bonds, we obtain a barrier of $\sim$ 130 meV which is much higher than the QENS results.

[1] Chen *et al.*, *Phys. Chem. Chem. Phys.* **17** 31278 (2015).

15 min. break.

HL 18.8 Tue 11:30 EW 203

Light and Temperature Modulated Magneto-Transport in hybrid Lead Halide Perovskites — •Masoumeh Keshavarz[1], Steffen Wiedmann[2], Haifeng Yuan[1], Elke Debroye[1], Maarten Roeffaers[3], and Johan Hofkens[1] — [1]Molecular Imaging and Photonics, Department of Chemistry, KU Leuven, 3001 Leuven, Be — [2]High Field Magnet Laboratory, Radboud University, 6525 ED Nijmegen, Nl — [3]Department of Molecular and Microbial Systems, KU Leuven, 3001 Heverlee, Be

Hybrid lead-halide perovskites exhibit exceptional properties such as high carrier mobility and long diffusion lengths providing a variety of applications as the absorbing layer in solar cells, LEDs and photodetectors. In spite of their rapid evolution in devices, knowledge of the nature and microscopic origin of the intrinsic optical, electrical and structural properties is only just emerging. Using temperature-dependent magneto-transport and Hall measurements on single crystals of MAPbI3 and MAPbBr3 in magnetic fields up to 30 T, we have identified different transport regimes [1]. For temperatures up to 25 K, transport is determined by thermally-activated hopping of charge carriers reflected in a diverging zero-field resistance. Above 25 K, acoustic phonon scattering is the dominant charge transport evident in the temperature dependence of both zero and high-field resistance. Our findings shed new light on the fundamental charge carrier dynamics under steady-state illumination and emphasize the need for a comprehensive theoretical model for perovskite based devices. [1] M Keshavarz, et al., ACS Energy Lett. 2018, 3, 39-45.

HL 18.9 Tue 11:45 EW 203

From the Very Beginning: Linking Photovoltaic Evolution and Crystal Formation by the Example of Perovskite Solar Cells — •Vita Mergner[1,2], Lukas Wagner[1], Simone Mastroianni[1], Uli Würfel[1], Carmen Sanchez-Valle[2], and Andreas Hinsch[1] — [1]Fraunhofer Institute for Solar Energy Systems ISE, Heidenhofstraße 2, D-79110, Freiburg, Germany — [2]Institute for Mineralogy, Universität Münster, Corrensstraße 24, D-48149, Münster, Germany

We present an experimental approach, which, for the first time, allows an observation of the photovoltaic effect in semiconductor devices during crystallization. The examination is facilitated by a nano-porous contact scaffold for the extraction of the charge carriers within which a precursor solution is infiltrated as the final processing step to form a methylammonium lead iodide absorber layer in the perovskite solar cell. With this approach, we were able to simultaneously relate radiative recombination and transport of the photo-excited charges to the perovskite formation process. [1] Thereby, the former perovskite crystallization model could be refined by providing the crystallization stages associated with the photovoltaic performance in real-time as well as microscopically resolved real-time imaging of the photoluminescence. The results provide deeper understanding in the evolvement of crystal growth of the perovskites and electrical coupling to the contact material which are key parameters for an optimization of perovskite solar cells. [1] Wagner, Mundt et al. Scientific Reports (2017). DOI: 10.1038/s41598-017-13855-6

HL 18.10 Tue 12:00 EW 203

Large scale compositional and electronic inhomogeneities in MAPbI3 perovskite films — •Qing Sun[1,2] and Yana Vaynzof[1,2] — [1]Kirchhoff Institute für Physik, Universität Heidelberg — [2]Center for Advanced Material, Universität Heidelberg

Recently, hybrid organic-inorganic halide perovskites have gained significant attention in the field of thin film photovoltaics due to its rapid increase in power conversion efficiencies from 3.8% to around 22%. This tremendous progress is a result of the advantageous optoelectronic properties of perovskite materials and extensive research efforts dedicated to improving the layer microstructure and charge extraction layers. While significant amount of work had been performed to further improve the efficiency of the devices, much less attention has been focused on the large variations observed in the performance of identically prepared perovskite solar cells within single studies. Here, we preform macroscopic characterisation of the CH3NH3PbI3 films prepared by different methods and identify large scale inhomogeneities in the layer properties across each sample. After deposition of ETL and electrode and analyzing their current density-voltage curves, we are able to correlate the variation in PSCs performance to the inhomogeneities observed in the perovskite films.

HL 18.11 Tue 12:15 EW 203

Exciton dynamics in quantum confined $CsPbBr_3$ nanoplatelets — •Moritz Gramlich, Bernhard J. Bohn, Yu Tong, Lakshminarayana Polavarapu, Alexander S. Urban, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Department of Physics, Ludwig-Maximilians-Universität, Munich, Germany

In contrast to bulk perovskite films, new reports have shown that in perovskite nanocrystals the excitonic absorption onset and photoluminescence (PL) peak exhibit a blue shift due to quantum confinement when their size in at least one dimension approaches the exciton Bohr radius of that material [1]. For decreasing thickness of organic-inorganic perovskite nanoplatelets – separated by centrifugation – increasing exciton binding energies and decreasing PL decay times have been observed [2]. Now a new method has been developed which enables the direct synthesis of quantum-confined inorganic $CsPbBr_3$ nanoplatelets of uniform thickness. Here, transient absorption spectroscopy is applied to such nanoplatelets of different thickness varying from two to seven crystal layers to gain additional insight into confinement effects on fast charge carrier dynamics in these systems. A comparison to the results of organic-inorganic perovskite nanoplatelets

is givens to investigate the role of the A-site cation.

[1] J. A. Sichert, et al. Nano letters 2015, 15(10), 6521-6527. [2] V. A. Hintermayr, et al. Advanced Materials 2016, 28(43), 9478-9485.

HL 18.12 Tue 12:30 EW 203

Effect of Varying the Density of Defects on the Properties of Organometal Halide Perovskites — •Paul Fassl[1], Vincent Lami[1], Alexandra Bausch[1], Zhiping Wang[2], Henry Snaith[2], and Yana Vaynzof[1] — [1]Kirchhoff-Institute for Physics, Heidelberg University — [2]Department of Physics, University of Oxford, UK

Organometallic halide perovskite solar cells have become a promising class of material with certified efficiencies up to 22.7 % to date. [1] However, reports investigating the fundamental mechanisms limiting the material and device stability remain scarce.

In our recent work we investigated the role of microstructure on the degradation rate of methylammonium lead triiodide (MAPbI3) perovskite films upon exposure to light and oxygen, however the role of the density of defects remains unknown. [2] In this work we therefore vary the density of defects in the films while keeping the microstructure unchanged. We characterize the perovskite films using photoemission spectroscopy, x-ray diffraction, photoluminescence and photothermal deflection spectroscopy and correlate the findings to the photovoltaic parameters and stability of complete devices.

[1] Research Cell Efficiency Records: https://www.nrel.gov/pv/assets/images chart.png (accessed: December 2017)

[2] Q. Sun, P. Fassl, D. Becker-Koch, A. Bausch, B. Rivkin, S. Bai, P. E. Hopkinson, H. J. Snaith, Y. Vaynzof, Adv. Energy Mater. 2017, 7, 1700977.

HL 19: Quantum dots and wires: Transport properties

Time: Tuesday 9:30–13:15 Location: A 151

HL 19.1 Tue 9:30 A 151

Tunnelling dynamics and hole storage of quantum dots measured by conductance spectroscopy — •Carsten Ebler, Arne Ludwig, and Andreas D. Wieck — Ruhr-Universität Bochum, Bochum, Deutschland

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.

We establish the SAQDs in tunnel contact with an inverted $GaAs/Al_{0.3}Ga_{0.7}As$ HEMT structure containing 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.

The structure is appropriately biased, that the Fermi level is in electronical resonance with the X^0state in the QD to store one single hole. This metastable hole state is read out over conductivity changes in the channel of the HEMT. Thereby it is possible to resolve electron tunnelling dynamics in and out of the quantum dots and furthermore the interaction with the holes trapped inside the QDs. It was possible to store the metastable hole for at least 4 s and to read it out during this time laps. Further experimentation with different voltage pulses provide information about tunnelling processes of the electron states and dynamics of non-equilibrium states.

HL 19.2 Tue 9:45 A 151

Illumination-induced non-equilibrium charge states in self-assembled quantum dots — Sascha R. Valentin[1], Jonathan Schwinger[1], Pia Eickelmann[1,2], Patrick A. Labud[1], Andreas D. Wieck[1], Björn Sothmann[2], and •Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]Fakultät für Physik und CENIDE, Universität Duisburg-Essen, Lotharstraße 1, 47048 Duisburg, Germany

We report on capacitance-voltage spectroscopy of self-assembled InAs quantum dots under constant illumination [1]. Besides the electronic and excitonic charging peaks in the spectrum reported earlier [2], we find additional resonances associated with non-equilibrium state tunneling unseen in C(V) measurements before. We derive a master-equation based model to assign the corresponding quantum state tunneling to the observed peaks. C(V) spectroscopy in a magnetic field is used to verify the model-assigned non-equilibrium peaks. The model is able to quantitatively address various experimental findings in C(V) spectroscopy of quantum dots such as the frequency and illumination dependent peak height, a thermal shift of the tunneling resonances [3] and the occurrence of the additional non-equilibrium peaks.

[1] S. R. Valentin, et al., arXiv:1710.07545.

[2] P. Labud, A. Ludwig, A. Wieck, G. Bester, and D. Reuter, Phys. Rev. Lett. 112, 046803 (2014).

[3] F. Brinks, A. D. Wieck, and A. Ludwig, New J. Phys. 18, 123019 (2016).

HL 19.3 Tue 10:00 A 151

Magnetotransport measurements of single MnAs/InAs hybrid nanowires — •Patrick Uredat[1], Ryutaro Kodaira[2], Ryoma Horiguchi[2], Shinjiro Hara[2], Peter J. Klar[3], and Matthias T. Elm[1] — [1]Center for Materials Research, Justus Liebig University, 35392 Giessen, Germany — [2]Research Center for Integrated Quantum Electronics, Hokkaido University, Sapporo 060-8628, Japan — [3]Institute for Experimental Physics I, Justus Liebig University, 35392 Giessen, Germany

III-V semiconducting nanowires are seen as building blocks for future nano-scaled optical or electrical devices. To be suitable for spintronic applications nanowires have to exhibit adjustable ferromagnetic properties. As the growth of diluted magnetic semiconductors is still challenging, MnAs/InAs hybrid nanowires may represent an alternative. MnAs/InAs hybrid nanowires are grown using selective-area MOVPE followed by endotaxial growth of MnAs nanoclusters. By varying temperature and time of this endotaxial growth process one can tune the shape as well as the number of nanoclusters. Structural analysis confirms high crystal quality of the hybrid nanowires, while magnetic force microscopy reveals the ferromagnetic properties of the MnAs nanoclusters. Magnetotransport measurements of pure InAs nanowires show quantum interference effects and a large positive magntoresistance effect. In contrast, MnAs/InAs hybrid nanowires exhibit a linear negative magnetoresistance effect. Furthermore, angle-dependent transport measurements indicate additional boundary scattering at intermediate temperatures due to the confined transport pathway.

HL 19.4 Tue 10:15 A 151

Random-walk topological transition revealed via electron counting — Georg Engelhardt[1], •Mónica Benito[2,3], Gloria Platero[3], Gernot Schaller[1], and Tobias Brandes[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [3]nstituto de Ciencia de Material de Madrid, CSIC, 28049 Madrid, Spain

The appearance of topological effects in systems exhibiting non-trivial topological band structures strongly relies on the coherent wave nature of the equations of motion. Here, we reveal topological dynamics in a classical stochastic random walk version of the Su-Schrieffer-Heeger model with no relation to coherent wave dynamics. We explain that the commonly used topological invariant in the momentum space translates into an invariant in a counting field space. This quantization gives rise to clear signatures of the topological phase in an associated waiting time distribution.

HL 19.5 Tue 10:30 A 151

Laplace DLTS on InAs-SAQDs — •Laurin Schnorr[1], Thomas Heinzel[1], Arne Ludwig[2], and Andreas Wieck[2] — [1]Solid State Physics Laboratory, Heinrich-Heine-Universität, Düsseldorf, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Self-assembled InAs quantum dots in a GaAs matrix are studied by Laplace deep level transient spectroscopy (LDLTS). It is shown that in the tunneling regime, the superior resolution in comparison to conventional DLTS weighting functions allows for the separation of the two s-states and a meaningful analysis of the electric field dependence of their life times. It can also be used to check the validity of the widely used tunneling corrections of conventional DLTS results in the

thermal emission regime. Furthermore, we use Laplace DLTS to determine the effective height of the self-assembled quantum dots via the Poole-Frenkel effect.

HL 19.6 Tue 10:45 A 151

Nanoscale Tipping Bucket Effect In A Quantum Dot Transistor-Based Counter — •Fabian Hartmann[1], Patrick Maier[1], Mariama Rebello Sousa Dias[2], Sebastian Göpfert[2], Leonardo Castelano[2], Monika Emmerling[1], Christian Schneider[1], Martin Kamp[1], Yuriy Pershin[3], Gilmar Marques[2], Victor Lopez-Richard[2], Sven Höfling[1,4], and Lukas Worschech[1] — [1]Technische Physik, Universität Würzburg — [2]Departamento de Fisica, Universidade Federal de Sao Carlos — [3]Department of Physics and Astronomy, University of South Carolina — [4]SUPA, University of St Andrews

Electronic circuits composed of one or more elements with inherent memory, memristors, memcapacitors, and meminductors, offer lower circuit complexity and enhanced functionality for certain computational tasks. Networks of these elements are proposed for novel computational paradigms that rely on information processing and storage on the same physical platform. We show a nanoscaled memdevice able to act as an electronic analogue of tipping buckets that allows reducing the dimensionality and complexity of a sensing problem by transforming it into a counting problem. The device offers a well adjustable, tunable and reliable periodic reset that is controlled by the amounts of transferred quantum dot charges per gate voltage sweep. When subjected to periodic voltage sweeps the quantum dot (bucket) may require up to several sweeps before a rapid full discharge occurs thus displaying period doubling, period tripling and so on between self-governing reset operations.

HL 19.7 Tue 11:00 A 151

Scaling of the Fermi-Edge-Singularity in Asymmetric Quantum Dots — •Jan K. Kühne and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany

We study the transport properties of a self-assembled InAs quantum dot at low temperatures. Transport properties depend on a variety of parameters, such as temperature, size of the dots, magnetic field and thickness of the two tunneling barriers. We focus on the influence of the dimensionality of the connected leads on the tunneling in and out of the quantum dot.

In dependence on the direction of current we encounter different transport behavior, especially under the influence of a magnetic field. This can be explained by a different density of states in the two leads. Further information is gained via shot noise measurements, which are known to reveal more about the correlation between electrons than current measurements alone; e.g. interaction effects have been shown to suppress or enhance shot noise [1]. The Fermi-edge-singularity (FES) is one example, where interaction between the dot and the emitter electrons can lead to a Fano-factor larger than one [2]. To study the FES in more detail we use a scaling function approach introduced by H. Frahm [3] to analyze the temperature-dependent current resonance.

[1] H. C. Liu, et al., Phys. Rev. B 51, 5116 (1995).
[2] N. Ubbelohde, et al., Scientific Reports 2, 374 (2012).
[3] H. Frahm, et al., Phys. Rev. B 74, 35329 (2006).

15 min. break.

HL 19.8 Tue 11:30 A 151

Charge Reconfiguration in Quantum Dot Arrays — •Johannes C. Bayer, Timo Wagner, Eddy P. Rugeramigabo, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany

The quantum dot device is based on a two-dimensional electron gas formed in a GaAs/AlGaAs heterostructure. Metallic Schottky gates are used to laterally define arrays of up to four quantum dots in series. Two quantum point contacts (QPCs) in the vicinity act as sensitive charge detectors, allowing the real-time detection of electrons tunneling through the system [1].

Isolating a double quantum dot from the electron reservoirs has been shown to significantly simplify the stability diagram and at the same time increase the tunability of the system [2]. While transport vanishes for isolated quantum dots, charge reconfigurations inside the array are still observable in the detector signal. Our experimental studies on isolated double, triple and quadruple quantum dot arrays are complemented by model simulations which enable us to identify the different transitions occurring in our systems, including higher order tunneling in triple and quadruple quantum dots.

References

[1] T. Wagner, P. Strasberg, J. C. Bayer, et. al., Nat. Nanotech. **12**, 218-222 (2017).
[2] B. Bertrand, H. Flentje, S. Takada, et. al., Phys. Rev. Lett. **115**, 096801 (2015).

HL 19.9 Tue 11:45 A 151

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 excess noise was already found to be related to an electron's transmission probability [1]. In this work, cross-correlated noise measurements are performed in etched $Al_xGa_{1-x}As$/GaAs based ballistic quasi 1D quantum rings 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] Y. M. Blanter *et al.*, Phys. Rep. **336**, 1 (2000).

HL 19.10 Tue 12:00 A 151

Quantum stochastic resonance in driven single-electron tunneling — •Timo Wagner[1], Johannes C. Bayer[1], Eddy P. Rugeramigiabo[1], Peter Hänggi[2], and Rolf. J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Institut für Physik, Universität Augsburg, Germany

Ambient noise is generically considered to be harmful for an error-free signal detection. However, a certain level of noise can actually have a constructive influence and boost an otherwise subthreshold signal, known as stochastic resonance (SR) [1]. All reported SR systems thus far exhibit either thermal noise or need an additional external noise generator. For quantum systems, theory predicted that intrinsic quantum randomness may give rise to stochastic resonance as well [2,3]. Here, we experimentally evidence quantum stochatic resonance (QSR) in the periodically driven charging of single-electrons in a quantum dot. By extracting the counting statistics [4,5], we demonstrate that the synchronization of the tunneling events with the periodic driving runs across an optimum, no matter whether the external frequency or the internal shot-noise level are tuned. The tunneling events were temporally resolved, using single-electron charge detection [5,6].

[1] L. Gammaitoni, et al. Rev. of Mod. Phys. 7, 223-288 (1998)
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[3] M. Grifoni & P. Hänggi, Phys. Rev. Lett. 76, 1611-1614 (1996).
[4] P. Talkner, et al. New J. Phys. 7, 14 (2005).
[5] S. Gustavsson, et al. Phys. Rev. Lett. 96, 076605 (2006).
[6] T. Wagner, et al. Nature Nanotech. 12, 218-222 (2017).

HL 19.11 Tue 12:15 A 151

High-speed error counting in silicon quantum dot charge pumps — •Máté Jenei[1], Ruichen Zhao[2], Alessandro Rossi[3], Kaun Yen Tan[1], Yuxin Sun[2], Andrew Dzurak[2], and Mikko Möttönen[1] — [1]QCD Labs, Department of Applied Physics, Aalto University, Espoo, Finland — [2]School of Electrical Engineering and Telecommunications, University of New South Wales, Sidney, Australia — [3]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom

Single-charge pumps have demonstrated to produce a highly accurate quantized current of 160 pA with a relative uncertainty below 0.27 ppm, specifically for applications in quantum metrology[1]. The reported uncertainty mostly dominated by the experimental apparatus, resulting inconveniently long averaging times. To overcome this and systematic errors, in-situ charge sensing is a promising solution. We present our most recent progress on a novel twin aluminium single-

electron-transistor charge sensor capacitively coupled to a silicon quantum dot pump. The sensor constitutes an improvement in the detection sensitivity that was the limiting factor of our first generation of designs [2]. The new hybrid device potentially allows us to carry out error counting by combining bidirectional pumping and charge sensing.

[1] R. Zhao et al., Phys. Rev. Applied 8, 044021 (2017)
[2] T. Tanttu et al., New J. Phys 17, 10, 103030 (2015)

HL 19.12 Tue 12:30 A 151

Coulomb staircase in CMOS-compatible large-area junctions of self-assembled quantum dots using graphene — Hippolyte P.A.G. Astier[1], Joel M. Fruhman[1], Lissa Eyre[1], Bruno Ehrler[4], Marcus Boehm[1], Piran R. Kidambi[2], Ugo Sassi[2], Domenico De Fazio[2], Jonathan P. Griffiths[1], Alexander Robson[3], Benjamin J. Robinson[3], Stephan Hofmann[2], Andrea C. Ferrari[2], and •Christopher J.B. Ford[1] — [1]Cavendish Laboratory, JJ Thomson Av. CB3 0HE, Cambridge, UK — [2]Cambridge Graphene Centre, 9 JJ Thomson Av. CB3 0FA, Cambridge, UK — [3]Department of Physics, University of Lancaster, Lancaster LA1 4YB, UK — [4]Center for Nanophotonics, AMOLF, Science Park 104, 1098 XG, Amsterdam, The Netherlands

Nanomaterial and molecular electronics suffers from unscalable and complex fabrication. Here, we use graphene to make arrays of $\sim 1\mu m^2$ junctions contacting self-assembled monolayers of PbS quantum dots (QDs) to obtain films with zero-dimensional transport characteristics. Our junctions exhibit Coulomb blockade and staircases with a yield above 40% before optimisation, thus demonstrating single-electron effects in a robust and scalable architecture. Electron-beam lithography can reduce contact areas to nanometre sizes, enabling a statistical comparison between junctions with a range of QD numbers. Topographical imaging combining atomic force microscopy (AFM) and ultrasonic force microscopy (UFM) allows us to investigate the conduction parameters in these complex films in relation to their mechanical aspect.

HL 19.13 Tue 12:45 A 151

Electrical characterization of semiconductor nanowires with axial pn-junction — •Cornelia Timm[1], Andreas Nägelein[1], Matthias Steidl[1], Klaus Schwarzburg[2], Peter Kleinschmidt[1], and Thomas Hannappel[1] — [1]Institute of Physics, TU Ilmenau, Germany — [2]Helmholtz Zentrum Berlin, Germany

Semiconductor nanowires are of great interest for applications in future nanoscale optoelectronic devices. For optimal performance it is crucial to understand the precise electrical characteristics of the nanowires, in particular their electrical transport properties.

Here we present resistance profiling along the axial pn-junction of GaAs nanowires. This was probed directly using a 4-tip STM, an advanced technique resulting in a high spatial resolution of the nanowire resistance. Applying a transport model allows for the determination of the doping profiles. As expected we detected a voltage drop at the pn-junction, correlated to the forward bias of the diode. The nonlinear I-V characteristic revealed a reduced differential conductivity at the pn-junction.

Additionally, spatially resolved photoluminescence and cathodoluminescence measurements were conducted to further examine the pn-junction of the GaAs nanowire. The p and n-segment of the nanowire exhibited a different photoluminescence spectrum. Due to the electric field gradient, the photoluminescence intensity at the pn-junction was strongly quenched. Cathodoluminescence measurements confirmed the findings of the photoluminescence measurements.

HL 19.14 Tue 13:00 A 151

Orbital contributions to the electron g-factor in semiconductor nanowires — Georg Winkler[2], Daniel Varjas[1], •Rafal Skolasinski[1], Alexey Soluyanov[2], Matthias Troyer[2,3], and Michael Wimmer[1] — [1]QuTech, Delft University of Technology, Delft, Netherlands — [2]Theoretical Physics and Station Q, ETH Zurich, Zurich, Switzerland — [3]Quantum Architectures and Computation Group, Microsoft Research, Redmond, WA, United States

Recent experiments on Majorana fermions in semiconductor nanowires [Albrecht et al., Nat. 531, 206 (2016)] revealed a surprisingly large electronic Landé g-factor, several times larger than the bulk value - contrary to the expectation that confinement reduces the g-factor. Here we assess the role of orbital contributions to the electron g-factor in nanowires and quantum dots. We show that an LS coupling in higher subbands leads to an enhancement of the g-factor of an order of magnitude or more for small effective mass semiconductors. We validate our theoretical finding with simulations of InAs and InSb, showing that the effect persists even if cylindrical symmetry is broken. A huge anisotropy of the enhanced g-factors under magnetic field rotation allows for a straightforward experimental test of this theory.

HL 20: Focussed Session: Geometry- and Topology-Controlled Nanoarchitectures II

Organizers: Paul M. Koenraad (TU Eindhoven) and Vladimir M. Fomin (IFW Dresden)

Time: Tuesday 14:00–15:45 Location: EW 015

HL 20.1 Tue 14:00 EW 015

Optical Aharonov-Bohm oscillations with disorder effects and Wigner molecule in a single quantum ring — •Kwangseuk Kyhm — Pusan National University, Busan, South Korea

The Aharonov-Bohm (AB) effect is observed mostly by electrical measurements at extremely low temperatures (<100 mK) through oscillations of the conductance and persistent current with external magnetic field. Very recently, the AB effect became accessible to optical experiments at tens of Kelvin by using type-II quantum dots (QDs) and quantum rings (QRs) in ensembles. However, the exciton Aharonov-Bohm oscillations in a single QR are rarely observed. This difficulty is associated with disorder effects. In the presence of structure anisotropy, localisation, in- ternal electric field, and impurity scattering, we found that optical Aharonov-Bohm oscillations of an electron-hole pair become modulated. Additionally, provided that a strongly correlated exciton pair is formed in a single quantum ring similar to the Wigner molecule, novel oscillations can be observed for increasing magnetic field. In this case, the biexciton emission energy changes abruptly at transition magnetic fields with a fractional oscillation period compared to that of the exciton, the so-called fractional optical Aharonov-Bohm oscillations.

HL 20.2 Tue 14:30 EW 015

Gold-dye plexcitonic Fano systems — •Carola Kryschi and Johannes Kupka — Friedrich-Alexander University of Erlangen, 91058 Erlangen, Germany

Coherent coupling between surface plasmons of noble-metal nanostructures and molecular excitons may create particular polaritonic modes, the so-called plexcitons. In this contribution we report surface-structure mediated stationary optical properties and ultrafast excitation relaxation dynamics of plexcitonic gold-nanostructure dye nanohybrid systems. Optical excitation of self-organized assemblies of spherical gold nanoparticles and laser dye molecules resulted into the generation of plexcitonic Fano resonances in absorption which manifest the interference between the plasmonic and molecular resonances. Moreover, we could show that spaser emission can be generated by amplifying longitudinal surface plasmon modes in gold nanorods by optically pumping surface-attached resonantly-coupled laser dyes.

HL 20.3 Tue 14:45 EW 015

Engineering topological states, spin textures and spin interferometers by shape deformations — •Carmine Ortix — Institute for Theoretical Physics, Utrecht University, Princetonplein 5, 3584 CC Utrecht, Netherlands

I will discuss the possible interplay between curvature effects on the electronic properties and the topological properties of the quantum states in low-dimensional nanomaterials. In particular, I will present the intricate twist between spin textures and spin transport in shape deformed nanostructures. Non-uniform Rashba spin-orbit coupling in shape deformed quantum rings leads to spin textures with a tunable topological character. These topologically non trivial spin patterns affect the electron spin interference, thereby resulting in different geometry-driven electronic transport behavior

HL 20.4 Tue 15:00 EW 015

Stretchable and Imperceptible Magnetoelectronics — •Michael Melzer[1], Martin Kaltenbrunner[2], Denys Makarov[3], Daniil Karnaushenko[1], Dmitriy Karnaushenko[1], and Oliver G. Schmidt[1,4] — [1]IFW Dresden, Institute for Integrative Nanosciences, 01069 Dresden, Germany — [2]JKU Linz, Soft Matter Physics, 4040 Linz, Austria — [3]HZDR, Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [4]TU Chemnitz, Material Systems for Nanoelectronics, 90107 Chemnitz, Germany

Future electronic skin aims to mimic nature's original in functionality and appearance. While several of its features have recently been demonstrated in artificial counterparts, magnetoception allows going even beyond imitation and equip us with unfamiliar cognition.

Here we introduce e-skins with a magneto-sensory system[1] able to perceive the presence of static or dynamic magnetic fields. The demonstrated ultra-thin giant magnetoresistive (GMR) sensor foils are less than 2 um thick, extremely lightweight and feature unmatched flexibility and mechanical endurance, while maintaining the sensor characteristics of their rigid chip-based counterparts. A geometric transition from flat to a highly wrinkled surface on top of an elastic support, generates an outstanding stretchability of up to 270% with high long term stability.

Our ready-to-use sensing elements offer magnetic functionalities as well as motion and displacement sensorics for e-skins, soft robotics and medical implants.

[1] M. Melzer et al. Nature Communications 6, 6080 (2015).

HL 20.5 Tue 15:15 EW 015

Intrinsic spin-orbit coupling and spin-Hall effect in graphene — •Marta Prada[1], Jonas Sichau[2], and Robert H Blick[2] — [1]I. Institute for Theoretical Physics, Jungiusstr. 9, Hamburg (Germany) — [2]Center for Hybrid Nanostructures (ChyN), Luruper Chaussee 149, Hamburg (Germany)

The fundamental assumption of graphene is the celebrated linear energy dispersion relation for charge carriers, as it occurs in the Dirac equation. However, zooming in the low energy scales, a finite gap, and hence, a finite mass is expected. The magnitude of this gap in graphene is of great interest, determining the possibility to observe a topological (spin Hall) insulator. However, controversy exists around the value of this gap, with theoretical predictions varying within two orders of magnitude, while an experimental value has not been determined to this date.

Here, we present evidence that intrinsic spin-orbit interaction in monolayer graphene leads to a measurable bulk gap of 42 μeV [J. Sichau, M. Prada, T. J. Lyon, B. Bosnjak, L. Tiemann, and R. H. Blick arXiv:1709.05705 (2017).]. We experimentally resolve the spin and pseudo-spin states using microwave excitation in a resistively detected electron spin resonance experiment. We develop a theoretical model that includes the effects of the d-orbitals in a rectangular sample of graphene, and find perfect agreement with the experimental data. Our results are consistent with a spin Hall insulator to a Dirac semimetal phase transition.

HL 20.6 Tue 15:30 EW 015

Manipulating quantum Hall edge channels through Scanning Gate Microscopy — Lennart Bours[1], Stefano Guiducci[1], Alina Mrenca–Kolasinska[2], Bartłomiej Szafran[2], Jan C. Maan[3], and •Stefan Heun[1] — [1]NEST, Istituto Nanoscienze–CNR and Scuola Normale Superiore, Piazza San Silvestro 12, 56127 Pisa, Italy — [2]AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, al. Mickiewicza 30, 30–059 Kraków, Poland — [3]Radboud University Nijmegen, High Field Magnet Laboratory, Toernooiveld 7, 6525 ED Nijmegen, The Netherlands

We show evidence of the backscattering of quantum Hall edge channels in a narrow graphene Hall bar, induced by the gating effect of the conducting tip of a Scanning Gate Microscope, which we can position with nanometer precision. We show full control over the edge channels and are able, due to the spatial variation of the tip potential, to separate co-propagating edge channels in the Hall bar, creating junctions between regions of different charge carrier density, that have not been observed in devices based on top– or split–gates. The solution of the corresponding quantum scattering problem is presented to substantiate these results, and possible follow–up experiments are discussed.

HL 21: Photo-voltaics II

Time: Tuesday 14:00–15:15 Location: EW 202

HL 21.1 Tue 14:00 EW 202

First principles carrier lifetimes, effective masses, and mobilities in $MAPbI_3$ — •Martin Schlipf, Samuel Ponce, and Feliciano Giustino — Department of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, United Kingdom

Electron-phonon coupling (EPC) fundamentally limits the mobility of charge carriers in halide perovskites. A comprehensive study of all EPC effects has not been conducted fully from *ab initio*, because the organic molecule leads to a large number of atoms in the primitive unit cell. We performed a detailed analysis of the prototypical methylammonium (MA) lead iodide ($MAPbI_3$) in its orthorhombic ground state structure. This contribution assesses the relative impact various scattering channels on the lifetime, mass renormalization, and carrier mobility. A breathing mode of the octahedra emerges as the dominant scattering channel, but two further polar phonon modes exhibit a significant contribution to lifetime and mass renormalization. The coupling to acoustical and transversal phonon modes is weak. The relaxation time of carriers due to this scattering mechanism is below 10 fs at room temperature. The calculated mobilities of the electron and the hole are very similar due to their comparable effective masses and agrees with experimental observations over a wide temperature range. We expect the possibility of higher mobility devices by selective engineering of the identified relevant scattering processes.

HL 21.2 Tue 14:15 EW 202

The application of Direct Laser Interference Pattern (DLIP) on antimony sulfide hybrid solar cell — •wei wang, shaista andleeb, eugen zimmermann, thomas möller, johannes boneberg, and lukas schmidt mende — Department of Physics ,University of Konstanz

Antimony sulfide (Sb2S3) is a promising candidate for hybrid thin film solar cells due to its various favorable properties, such as suitable optical band gap (1.75 eV), high dielectric constant and good band alignment in combination with many organic hole transport materials. In our study, thin layer amorphous Sb2S3 were first spin-coated on the substrates. Then the Sb2S3 film were patterned by direct laser interference. Thin film hybrid solar cells were made by using annealed Sb2S3 film as absorber and P3HT as hole transporter. The photovoltaics performances of the solar cells fabricated from laser patterned Sb2S3 film were superior to the unpatterned ones. Light intensity-dependent current-voltage measurements, transient photocurrent and photovoltage decay measurements, external quantum efficiency measurement as well as total absorption measurement were utilized to characterize the underlying physical mechanisms and measure the photovoltaic device performance.

HL 21.3 Tue 14:30 EW 202

Effect of transition metals on the optoelectronic properties of Nb3O7(OH) — •Wilayat Khan[1], Christina Scheu[2], Lotsch Bettina[3], Ondrej Sipr[1], and Jan Minar[1] — [1]Technologies-Research Center, University of West Bohemia, Univerzitn 8, 306 14 Plzen, Czech Republic — [2]Max-Planck-Institut fr Eisenforschung GmbH, Max-Planck-Strae 1, Dusseldorf, Germany — [3]Department of chemistry and Center for NanoScience, Butenandtstrae 11, 81377 Munchen, Germany

Nb3O7(OH) has a vital role in the water splitting research due to its remarkable efficiency. However, despite this progress, the performance of the Nb3O7(OH) photoelectrode could be substantially increased through doping. Density functional theory, full-potential linearized augmented plane wave method based WIEN2k code was employed to study the effect of doped transition metals in Nb3O7(OH) for the first time. The analysis of the formation energies of doping atoms confirmed that they substitute the Nb atoms within the crystal structure. The electronic structure of the doped- Nb3O7(OH) has also been derived and explained on the basis of relative concentrations of the dopants. The electron energy loss spectra and energy loss near the edge of the

structure were calculated and compared with the experimental data, which confirmed the presence of impurity.

HL 21.4 Tue 14:45 EW 202

Thermal Conductivity in Kesterite Crystals — •Martin Handwerg[1,2], Rüdiger Mitdank[1], Laura-Elisa Valle-Rios[2,3], Sergej Levcenco[2], Thomas Unold[2], Susan Schorr[2,3], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, 14109 Berlin, Germany — [3]Free University Berlin, Institute of Geological Sciences, 14195 Berlin, Germany

The kesterite materials Copper-Zinc-Tin-Sulfide (CZTS) and -Selenide (CZTSe) are of huge interest for future solar cell applications, due to the ideal band gap and high absorption rate. Insight in the thermal conductivity of a solar absorption material is important for the thermal management of the cell and therefore for the temperature-dependent efficiency. However, thermal conductivity investigations are rare.
Here we used the 3ω-method to investigate the thermal conductivity of CZTS and CZTSe macro-crystals. The crystal thicknesses were in the range of several hundred micrometers. The metal heater lines with a width of 10 μm were deposited on the polished crystal surface. The measured thermal conductivity is about $3-5$ $\mathrm{Wm^{-1}K^{-1}}$. The measured temperature dependence of the thermal conductivity allows conclusions concerning the transport process. Phonon-phonon-Umklapp-scattering dominates the thermal conductivity for $T > 180$ K and point-defect-scattering occurs for $T < 180$ K. With these two scattering processes there is a maximum of the thermal conductivity at $T = 100$ K with increased conductivity values up to 8 $\mathrm{Wm^{-1}K^{-1}}$.

HL 21.5 Tue 15:00 EW 202

Exceeding the Shockley-Queisser limit within the detailed balance framework — •Marnik Bercx, Rolando Saniz, Bart Partoens, and Dirk Lamoen — EMAT & CMT groups, Department of Physics, University of Antwerp

The Shockley-Queisser limit is one of the most fundamental theoretical results in the field of photovoltaics. Based on the principle of detailed balance, it defines an upper limit for a single junction solar cell that uses an absorber material with a specific band gap. More recently, Yu and Zunger introduced a more refined selection metric, the Spectroscopic Limited Maximum Efficiency (SLME), which includes the absorptivity of the material in the calculation of the efficiency. We use first-principles DFT calculations based on the HSE06 functional to determine the SLME of the CuAu-like phase of a selected list of I-III-VI_2 compounds, and find several materials with a calculated efficiency above the corresponding chalcopyrite material. Moreover, we find materials for which the calculated efficiency is above the Shockley-Queisser limit. Although it is possible to surpass the Shockley-Queisser limit using several mechanisms, none of these are implemented in the SLME. We show that it is possible to exceed the Shockley-Queisser limit within the detailed balance approach, related to the fact that Shockley and Queisser's assumption of optimal absorption properties also maximizes the recombination current. We conclude that considering a finite thickness for the absorber layer allows the efficiency to exceed the Shockley-Queisser limit, and that this is more likely to occur for materials with small band gaps.

HL 22: Nitrides: Preparation and characterization I

Time: Tuesday 14:00–15:30 Location: EW 203

HL 22.1 Tue 14:00 EW 203

GaN as a photo-catalyst for carbon dioxide reduction — •Andreas Zeidler, Viktoria Kunzelmann, and Martin Stutzmann — Walter Schottky Institut, Technische Univeristät München, Deutschland

Carbon dioxide (CO_2) has reached a critical level in the atmosphere and counts as one of the main reasons for global warming. Reducing this greenhouse gas to hydrocarbon fuels would help solving environmental issues and simultaneously address challenges such as energy storage and energy resource shortage. Converting CO_2 into usable fuels via photo-catalytic reactions is one way to address this issue. Using gallium nitride (GaN) as a photo-electrode is promising, since GaN is relatively stable under operating conditions and provides electrons with sufficient energy for CO_2 reduction. A critical aspect for the use of GaN as a cathode material is the electronic band level profile at the surface of the material. Different doping of GaN will influence this level profile. Therefore, p-type doped and p/n-structured GaN, grown by molecular beam epitaxy, is studied via open-circuit voltage measurements, surface photovoltage and Kelvin probe force microscopy. In addition, X-ray diffraction, Raman spectroscopy, temperature-dependent photoluminescence and atomic force microscopy measurements give insights into the role of defects in the grown material and the topography of the sample surfaces.

HL 22.2 Tue 14:15 EW 203

Microscopic interface and composition analysis of one-directionally lattice-matched AlInN — •Philipp Horenburg, Heiko Bremers, Ronald Korn, Uwe Rossow, and Andreas Hangleiter — Institute of Applied Physics, TU Braunschweig, Germany

We present microscopic evidence of interfacial indium depletion in c-lattice-matched AlInN grown by metalorganic vapor phase epitaxy on m-plane GaN. Further, in contrast to reports from the literature, we see no hints at parasitic gallium incorporation into the AlInN.

It is well known that lattice matching to GaN can be achieved in various crystal orientations. However, as the ideal growth conditions of its binary constituents AlN and InN are fairly different, epitaxy of AlInN remains a complex endeavour with a small window of suitable growth parameters. We performed a series of high-angle annular dark field (HAADF) and energy-dispersive X-ray spectroscopy (EDS) measurements at the AlInN/GaN interface. In a quantitative analysis, it becomes evident that the nominal In composition of 28% is reached at later instant of the AlInN growth process as compared to Al. This leads to a 0.4 nm thick In-depleted phase at the initial stage of growth accompanied by a slight spreading of Ga beyond the interface with no auto-incorporation into the bulk AlInN. These observations are consistent with X-ray diffraction studies on c-plane AlInN/GaN super lattice structures. We conclude the intrinsic tendency of AlInN to form an Al-rich phase in the early stage of growth independent of the crystal orientation. We thank FEI for providing HAADF and EDS data.

HL 22.3 Tue 14:30 EW 203

Correlation of structural and optical properties of GaN/AlN quantum disks embedded in nanowires by highly spatially cathodoluminescence microscopy — •Bowen Sheng[1,2], Frank Bertram[2], Ping Wang[1], Xiaoxiao Sun[1], Gordon Schmidt[2], Marcus Müller[2], Peter Veit[2], Thomas Hempel[2], Jürgen Christen[2], and Xinqiang Wang[1] — [1]PKU, Beijing, China — [2]IEP, OvGU, Magdeburg, Germany

Single photon emitters are the fundmental device applications in quantum optics and quantum information processing. Due to their large band offset and high binding energy of the excitons, III-nitrides quantum structures are most promising candidates for such devices. Despite the success in growing quantum dots, operating up to 300 K in 2014, the inherent piezoelectric fields, alloy fluctuations, shape and size control of the active region pose severe challenges with respect to fast and efficient generation of a single photon flux at a well-defined wavelength.

In this work, self-assembled hexagonally shaped GaN nanowires (NWs) with AlN/GaN/AlN quantum disk on top have been grown on Si (111) substrate in a dense array by plasma-assistant molecular beam epitaxy. To correlate the structural and optical properties of individual nanowires, highly resolved cathodoluminescence spectroscopy (CL) inside a scanning transmission electron microscope has been performed at 18 K along single NWs. CL linescans along the NWs clearly identify the emission coming from GaN bottom part around 359 nm and the GaN Q-disks around 347 nm with smallest FWHM of 60 meV, respectively. Other detailed analysis will be reported as well.

HL 22.4 Tue 14:45 EW 203

Investigation of AlN layer growth evolution under a Ga surfactant effect — •Christopher Hein, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institute of Applied Physics, Braunschweig, Germany

A key problem for high quality growth of AlN in MBE are low growth temperatures as well as the tendency to droplet formation in a metal rich regime. The latter can be overcome by codeposition of gallium as a surfactant during growth. We will investigate the evolution of thin AlN epilayers (10nm to 40nm thickness) under gallium surfactant. The samples were grown on MOVPE 2.5μm thick GaN layers on c-oriented sapphire substrates. The MBE growth starts with a 20nm GaN buffer layer grown at 745°C followed by an AlN epilayer in a double-pulsed growth scheme. Metal pulses were 22s long, followed by 25s nitrogen. In case of surfactant samples, gallium was supplied in parallel to aluminum. The total ratio of gallium contributing to the group III flux was fixed at 26% in the gas phase. Symmetric 2θ-ω-scans around the (0002) and (10$\bar{1}$0) reflex for samples grown with gallium surfactant show a residual GaN surface layer, formed after growth from accumulated gallium. As a consequence a sample series was grown which implemented a desorption step for the surface gallium. AFM of samples shows the tendency to crack formation for all samples, indicative for an onset of relaxation as confirmed by XRD. The surfactant and desorption treated samples show an additional reduction in surface RMS roughness value. This is attributed to a benefiting effect of the gallium surfactant on lateral growth of the AlN layer.

HL 22.5 Tue 15:00 EW 203

Analysis of the low temperature internal quantum efficiency of GaInN/GaN quantum wells — •Fedor Alexej Ketzer[1], Torsten Langer[1], Philipp Henning[1], Heiko Bremers[1], Uwe Rossow[1], Dirk Menzel[2], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, TU Braunschweig — [2]Institut für Physik der Kondensierten Materie, TU Braunschweig

The internal quantum efficiency (IQE), one of the key parameters for light emitting devices, is often measured by temperature dependent photoluminescence spectroscopy. By normalizing the integrated intensities at different temperatures and excitation powers to the excitation power and dividing by the maximum value one can estimate the IQE. For this estimation it is assumed that nonradiative recombination gets suppressed at low temperatures, which may be indicated by a saturation of the measured IQE. But tunneling processes with no, or a weak dependence on temperature may reduce the IQE even at low temperatures, which results in an overestimation of the IQE. Therefore we studied the absolute intensities at low temperatures as well as the IQEs for samples with changed nonradiative recombination. For this purpose we introduced intentional defects inside the quantum well region by ion implantation with different doses and compared the data with an unimplanted sample. Furthermore we investigated a set of samples with various radiative recombination rates and similar nonradiative recombination rates. From both series we estimate the IQE at low temperatures to clarify if a low temperature saturation of the temperature behavior is sufficient to neglect nonradiative recombination.

HL 22.6 Tue 15:15 EW 203

Photoelectrochemical characterization of p-type GaN for application as a photocatalyst for CO_2 reduction — •Viktoria Kunzelmann, Andreas Zeidler, Ian Sharp, and Martin Stutzmann — Walter Schottky Institute and Physics Department, Technische Universität München, Garching, Germany

The photocatalytic conversion of CO_2 into useful hydrocarbons can provide an excellent sustainable way to store energy. Finding a suitable semiconductor for efficient CO_2 reduction is challenging as it must fulfill several requirements: it must provide high energy electrons to split the inert CO_2 molecule, the band edges must straddle the desired redox levels and it needs to be stable under operating conditions. Gallium nitride (GaN) is promising as a photocatalyst as it fulfills most of these requirements. GaN is also known for its superior chemical stability, however, surface oxidation during photoelectrochemistry is still a major issue, especially for n-type GaN. To diminish oxidation effects, p-doped GaN could be used as it exhibits surface electrons during photoexcitation due to the downward surface band bending. Understanding the charge transfer processes across the p-GaN/electrolyte interface is essential to optimize the material properties. Hence, in this work we focus on the photoelectrochemical investigation of p-GaN electrodes and the effect of different surface treatments on the (photo)current-voltage characteristics as well as on the stability during operation. Changes in the chemical composition caused by photoelectrochemistry are studied by XPS, and changes in the surface photovoltage are monitored by contact potential difference measurements.

HL 23: 2D materials: Graphene and BN (joint session HL/DS)

Time: Tuesday 14:00–15:45 Location: A 151

HL 23.1 Tue 14:00 A 151

Field-effect proximity exchange coupling in bilayer graphene on ferromagnetic insulator — •Klaus Zollner, Martin Gmitra, and Jaroslav Fabian — Institute for Theoretical Physics, Regensburg, Germany

Graphene can be made magnetic by proximity effect through ferromagnetic substrates. We show, by realistic first-principles calculations, that bilayer graphene on $Cr_2X_2Te_6$, a family of ferromagnetic insulators that can be exfoliated in single layers (X = Si and Ge), experiences a layer dependent proximity exchange effect [1]. Due to short range of this proximity effect and the intrinsic layer dependent formation of low energy bands in bilayer graphene, only the valence band gets spin split. In addition, we apply realistic electric fields across the heterostructure, to tune the potential energy of the bilayers and find that we can switch electron and hole bands, along with the exchange splitting. With that we predict fully electrically tunable magnetism for transport carriers, which opens a vast field of proximity spintronics.

This work was supported by DFG SPP 1666, SFB 689, SFB 1277, and by the European Unions Horizon 2020 research and innovation programme under Grant agreement No. 696656.

[1] K. Zollner, M. Gmitra, and J. Fabian, arXiv:1710.08117 (2017).

HL 23.2 Tue 14:15 A 151

Spin-relaxation and Yu-Shiba-Rusinov states in Superconducting Graphene — •Denis Kochan — University of Regensburg, Regensburg, Germany

2D materials in a proximity of superconductor are expected to host a wide spectrum of different phenomena. In my talk I will focus on spin-relaxation in graphene proximitized by an s-wave superconductor. Adatom impurities can affect spin-relaxation via locally enhanced spin-orbit coupling (SOC) and local magnetic moments. I will discuss their impact on quasiparticle spin-relaxation with an attempt to disentangle contributions from the local SOC and local magnetic moments. Moreover, I will analyze a stability of the induced local magnetic moments and the emergence of Yu-Shiba-Rusinov (YSR) bound states in such proximity induced superconducting systems.

This research was supported by DFG SFB 1277 and GRK 1570 and by the European Union's Horizon 2020 research and innovation programme under Grant agreement No. 696656.

HL 23.3 Tue 14:30 A 151

Magnetic field-induced metal-insulator transition of graphene at filling factor ν=0 — •Sung Ju Hong, Christopher Belke, Johannes C. Rode, Benedikt Brechtken, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany

We have observed magnetic field-induced metal-insulator transition (MIT) at filling factor ν=0 of hexagonal boron nitride (h-BN) encapsulated single-layer graphene. The temperature dependent longitudinal resistance (R_{xx}) with ν=0 shows MIT at critical magnetic field, $B_c \approx 8$T below (above) which metallic (insulating) behavior occurs. In the metallic regime, the negative magnetoresistance appears, which can be explained by counter-propagating opposite-spin polarized edge state [1,2]. In the insulating regime, the divergence of the R_{xx} was obtained and the resistance showed thermal activation gap behavior. We attribute the MIT with ν=0 to the magnetic field-induced transition from spin polarized state to valley polarized state at B_c.

[1] Peng Wei *et al.*, Nature Mater. **15**, 711 (2016).
[2] Javier D. Sanchez-Yamagishi *et al.*, Nature Nanotech. **12**, 118 (2017).

HL 23.4 Tue 14:45 A 151

Graphene Nanoribbons on Hexagonal Boron Nitride: De-

position and Transport Characterization — Christian Kick[1], Andreas Lex[1], •Tobias Preis[1], Akimitsu Narita[2], Kenji Watanabe[3], Takashi Taniguchi[3], Klaus Müllen[2], Dieter Weiss[1], and Jonathan Eroms[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Regensburg, Germany — [2]Max Planck Institute of Polymer Research, Mainz, Germany — [3]National Institute for Materials Science, Tsukuba, Japan

We contacted cove-type graphene nanoribbons (cGNRs) of different widths (4 and 6 carbon dimers) with different metals (NiCr-Au and Pd) and measured their I-V-characteristics. The cGNRs were chemically synthesized and are solution processable in THF or chlorobenzene after sonification (see [1] for the synthesis). This solution was subsequently drop-cast onto exfoliated hexagonal boron nitride (hBN) on an SiO_2 wafer. With AFM we observe the formation of ordered cGNR domains that are aligned along the crystallographic axes of the hBN. With electron beam lithography and metalization, we successfully contacted the cGNRs with NiCr-Au and Pd contacts and measured their I-V-characteristics. The transport through the ribbons was dominated by the Schottky behavior of the contacts between the metal and the ribbon. We could not observe any gate dependence so far which could be due to screening effects of the metal contacts.

[1] A. Narita, *et al.*, Nature Chemistry **6**, 126 (2014).

HL 23.5 Tue 15:00 A 151

Plasmons and excitons in few layer graphenes — •Jorge Enrique Olivares Peña and Sam Shallcross — FAU Erlangen-Nürnberg

We present a general method for studying plasmons and excitons in low dimensional systems, based on (i) an operator equivalence method to establish a continuum $H(\mathbf{r}, \mathbf{p})$ Hamiltonian from a general underlying tight-binding method, and (ii) application of the bootstrap functional within the framework of time dependent density functional theory to study excitonic effects. We apply this method to the graphene twist bilayer, finding that the excitonic correction to the optical absorption spectrum is important in the small angle limit.

[1] S. Shallcros et al., arXiv 1607.00920 (2016)
[2] S. Shallcross et al. , Phys. Rev. B 93,035452 (2016)

HL 23.6 Tue 15:15 A 151

Towards gate-controlled photoluminescence of hexagonal boron nitride quantum emitters — •Alessio Scavuzzo[1], Christian Strelow[2], Marko Burghard[1], Alf Mews[2], and Klaus Kern[1,3] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Institute of Physical Chemistry, University of Hamburg, Germany — [3]École Polytechnique Fédérale de Lausanne, Switzerland

In the past few years, quantum emission from defect states embedded in crystalline structures has attracted increasing interest due to its promising applications in future quantum information technologies. While the properties of color centers in large band-gap 3D semiconductors like diamond or 4H-SiC are well-established, more recently attention is directed toward quantum emission from 2D systems. Along these lines, hexagonal boron nitride (hBN) has recently emerged as a very attractive 2D platform to host robust, visible light single photon emitters. Here, we report our experiments that address the possibility to control the quantum emission from hBN monolayers through electrostatic gating. To this end, we use confocal microscopy to probe the lifetime and intensity of the light emission from hBN quantum emitters within hBN/graphene vertical heterostructures as a function of temperature and back gate voltage. Moreover, through complementary Raman mapping, we demonstrate the importance of the hBN and graphene layer thickness, as well as the quality of the interface between the layers.

HL 23.7 Tue 15:30 A 151

Quantum Light in 1D and 2D Curved Hexagonal Boron Nitride Systems — •Nathan Chejanovsky[1,2], Youngwook Kim[2], Andrea Zappe[1], Benjamin Stuhlhofer[2], Takashi Taniguchi[3], Kenji Watanabe[3], Durga Dasari[1,2], Amit Finkler[1], Jurgen H. Smet[2], and Jörg Wrachtrup[1,2] — [1]3rd Physics Institute, Universität Stuttgart, Pfafenwaldring 57, 70569, Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstr. 1, 70569, Stuttgart, Germany — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

Low-dimensional wide bandgap semiconductors open a new playing field in quantum optics using sub-bandgap excitation. 2D hexagonal boron nitride (h-BN) has been reported to host single quantum emitters (QEs), linking QE density to perimeters. [1] We investigate a curvature and perimeter-abundant BN system - one-dimensional BN nanotubes (BNNTs).

I discuss our recent publication [2] demonstrating similarities between QEs in BNNT and h-BN for: Emission spectra, anti-bunching, SEM imagery, curvature effects, boron-oxide emission and sensitivity to commercial solvents.

These findings open possibilities for precision engineering of QEs, puts h-BN under a similar umbrella of transition metal dichalcogenides QEs and provides a model explaining QEs spatial localization and formation using electron and ion irradiation and chemical etching.

[1] Chejanovsky, N. et al. Nano letters 2016, 16, 7037-7045. [2] Chejanovsky, N. et al. Scientific reports 2017, 7, 14758 (1-14)

HL 24: Poster Session II

Time: Tuesday 18:30–20:30 Location: Poster F

HL 24.1 Tue 18:30 Poster F

Applying Photon-Number Resolving Detectors for the Metrology of Quantum Light Sources — •Jonas Böhm[1], Martin von Helversen[1], Marco Schmidt[1,2], Jan-Hindrik Schulze[1], André Strittmatter[1], Sven Rodt[1], Tobias Heindel[1], Jörn Beyer[2], 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

Single-photon sources are key building blocks for future applications in quantum information, communication, cryptography and computation. The most important characteristics for single-photon sources are the brightness, the purity of single-photon emission and the indistinguishability of the emitted photons. Directly accessing the number of detected photons via transition-edge sensors, it is theoretically possible to reduce the number of required measurements to obtain these properties and to improve their statistical certainty.

In this work, we analyze deterministically fabricated single-photon sources by means of HBT and HOM experiments exploiting PNR detectors and compare the results with those obtained with Silicon-based click-detectors. Furthermore, we demonstrate statistical methods to evaluate the data obtained from experiments using PNR detectors and to extract key parameters, such as the $g^{(2)}(0)$ value and the two-photon interference visibility. Our analysis demonstrates, that PNR detectors can be used for the metrology of solid-state based quantum-light sources.

HL 24.2 Tue 18:30 Poster F

Deterministic integration of QDs into advanced on-chip photonic elements with in-situ electron beam lithography — •Johannes Schall[1], Peter Schnauber[1], Samir Bounouar[1], Jin-Dong Song[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Korea Institute of Science and Technology, Seoul, Korea

Deterministic integration of quantum emitters into on-chip photonic circuits is a crucial step towards scalable quantum optics. Using in-situ electron beam lithography [1], we present a one-step process for the spectrally and spatially controlled integration of quantum dots (QD) into on-chip photonic elements. We prove the basic functionality of our approach by integrating preselected QDs into waveguides and 50/50 multimode interference (MMI) splitters, measuring single photon emission on-chip. We further discuss a variety of advanced photonic structures that can be realized having full spectral and spatial control during integration. This includes resonators and mode converter approaches to increase the coupling of QD emission to the guided mode[2]. Furthermore, it allows the realization of chiral waveguides, where a controlled displacement of the QD inside the WG is necessary, and enables interfacing two QDs with identical exciton energy inside a single waveguide[3].

[1] Gschrey et al., Nature Communications 6, 7662 (2015)
[2] Davanco et al., Nature Communications 8, 889 (2017)
[3] Coles et al., Nature Communications 7, 11183 (2016)

HL 24.3 Tue 18:30 Poster F

Optical enhancement of quantum dot emission by nanowires — •Sven Scholz, Rüdiger Schott, Marcel Schmidt, Arne Ludwig, and Andreas D. Wieck — Ruhr-Universität Bochum, Universitätsstr. 150, D-44801 Bochum

Molecular beam epitaxy (MBE) quantum dot (QD) structures are used as fundamental research structures. To further enhance their optical properties we use nanowires as a subwavelength waveguide. While common photonic crystal structures work with holes or micro pillars, we use focused ion beam (FIB) to catalyze nanowire growth on QD structures. An LED-NW-QD structure is optimized regarding the optical emission. Therefore we use an AlAs layer to remove the wetting layers (WL) PL signal. To access a wide emission spectrum we use rapid-thermal annealing (RTA) and a flushing technique coupled with the WL suppression. This results in tunable and good separated QD emission peaks. The NW growth is characterized and optimized with regards to crystalline quality and morphology. The samples are characterized by photoluminescence/electroluminescence and scanning electron microscope imaging.

HL 24.4 Tue 18:30 Poster F

Self-assembled InAs and GaN quantum dots upon ion impact — •Charlotte Rothfuchs, Andreas D. Wieck, and Arne Ludwig — Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum

In the flourishing field of quantum communication, there is a great demand for single photon sources. Single electrically and optically active quantum dots (QDs) are promising candidates due to the appealing properties of QDs generally and of self-assembled QDs particularly. These features range from high stability and wide spectral tunability to narrow linewidths and strong quantum confinement. Focused ion beam implantation into QD structures provides a possible pathway towards their fabrication based on QD disabling around an intentional self-assembled one.

Here, we present a study on the ion impact on QD structures. For this purpose, fluence-dependent models for QD morphology and luminescence are developed based on ion-induced intermixing processes and an altered quantum efficiency. The luminescence of both InAs and GaN QDs and the size and density of the latter are described by the models. A high radiation hardness is hereby observed for GaN QDs. These are influenced by a change of the quantum confined Stark effect.

HL 24.5 Tue 18:30 Poster F

Speeding up a single quantum dot pump-probe experiment — •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

We recently showed [1] that it is possible to measure transient reflection on single semiconductor quantum dots in the far field. Here we discuss how to improve these measurements. Due to the short lifetime of an excited quantum dot of around 300 ps we plan to increase the measurement speed. We increase the repetition rate of our laser system by a factor of 13 now the time delay between two laser pulses in the new setup is only 1 ns.

We are interested in the characterization of a single quantum dot two-level system and its interaction with the environment through transient absorption spectroscopy. We plan to add plasmonic structures for antenna-enhanced single quantum dot spectroscopy.

[1] C. Wolpert, C. Dicken, P. Atkinson, L. Wang, A. Rastelli, O. G. Schmidt, H. Giessen, and M. Lippitz, Nano Lett. 12, 453 (2012).

HL 24.6 Tue 18:30 Poster F

Tunneling rates of quantum dots for single electron pumps — •Tobias Wenz[1], Friederike Stein[1], Frank Hohls[1], Hans Werner Schumacher[1], Jevgeny Klochan[2], and Vyacheslavs Kashcheyevs[2] — [1]Physikalisch-Technische Bundesanstalt (PTB), 38116 Braunschweig, Germany — [2]Faculty of Physics and Mathematics, University of Latvia, LV 1002 Riga, Latvia

Quantum dots with tunable barriers can be used as single electron pumps. By capturing a well-defined number of electrons n from source and emitting them to drain with a high frequency f a quantized current $I = nef$ is produced, where e is the electron charge [1]. This concept is useful for on-demand electron sources for electron quantum optics and for the redefinition of the ampere by fixing the value of e.

So far, mainly the back-tunneling process has been studied, as it is the limiting factor to the accuracy of a single-electron pump. In this work, we study the loading of electrons into the dynamic quantum dot using custom-tailored waveforms. This allows us to investigate in-tunneling rates to the dot and extract information on ground- and excited states. Their dependencies are studied as a function of temperature and magnetic field. Our goal is to extract an absolute energy scale that may be used for the description of the back-tunneling process, for example in the decay-cascade model [2].

[1] Kaestner and Kashcheyevs, Rep. Prog. Phys. 78, 103901 (2015)
[2] Kashcheyevs and Kaestner, Phys. Rev. Lett. 104, 186805 (2010)

HL 24.7 Tue 18:30 Poster F

Spectroscopy of Single Silicon quantum dots in the vicinity of metal films — •Aswin Asaithambi, Guenther Prinz, and Axel Lorke — Lotharstrasse 1, Faculty of Physics, CENIDE, University of Duisburg-Essen, Duisburg 47057

Silicon is the most important and extensively used semiconductor concerning industrial production of electronic devices. However, the indirect band nature of Silicon makes it a poor light emitter. Light emitting efficiency can be increased by different methods such as use of III/V integration or using Si quantum dots (SiQDs).

In this contribution, we focus on photo-luminescence (PL) spectroscopy of single SiQDs. For this purpose, we use fluoride passivated SiQDs with a good ensemble PL quantum yield. We choose flourinated SiQDs because of their stable luminescence from 100K to RT. This makes them promising for building devices. These SiQDs are immobilized in a PMMA matrix on top of different metal films namely Au, Ag and Al. The optically excited SiQDs can couple to the metal film which can alter their luminescence behavior. We find that suitable metal films can couple effectively with SiQDs located at an optimal distance and can enhance the luminescence of the SiQDs. This makes it possible to measure time traces of PL spectra of single SiQDs to obtain data showing single dot optical phenomena such as PL intermittency and spectral jitter of the emission line. The measured data is discussed within the framework of the Efros-Rosen model and compared to the results available for CdSe QDs.

HL 24.8 Tue 18:30 Poster F

InP-based quantum dots for telecom wavelength: Growth and characterisations — •Birk Fritsch, Andrei Kors, Johann-Peter Reithmaier, and Mohamed Benyoucef — Institute of Nanostructure Technologies and Analystics (INA), CINSaT, Kassel University, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Semiconductor quantum dots (QDs) enable intriguing optoelectronic devices due to their discrete density of states and morphology-dependent band gap. Self-assembled InP-based QDs have proven to emit single photon emission at the telecom C band [1]. Utilising them for long-distance quantum communication requires precise growth control to obtain high quality QDs [2].

Here, we investigate the effects of different growth parameters to optimise Stranski-Krastov telecom wavelengths InP-based QD structures grown by molecular beam epitaxy with controlled dot density. High-resolution micro-photoluminescence measurements performed on the QD structures show single dot emission with narrow spectral linewidths and small fine structure splittings. Temperature dependent measurements exhibit a characteristic band gap shift, activation energy and charge carrier diffusion. Morphological analyses of the QDs using atomic force microscopy are compared with photoluminescence measurements. Moreover, studies related to doped QD structures and fabrication of pin-diode structures with embedded QDs emitting at telecom wavelength are presented.

[1] Benyoucef et al., Appl. Phys. Lett. 103 162101 (2013)
[2] Yacob et al., Appl. Phys. Lett. 104 022113 (2014)

HL 24.9 Tue 18:30 Poster F

Long-lasting fluorescence enhancement of CdSe-nanowires — •Jonas Albert, Subhasis Adhikari, and Markus Lippitz — Experimentalphysik III, Universität Bayreuth

One dimensional structures like semiconductor or molecular nanowires are interesting systems for optoelectronic devices, because generated charges can be directed along the wire axis.We combine optical microscopy with atomic force microscopy (AFM) to study these struc-

tures and how they can be manipulated. By introducing a metallic AFM tip to CdSe nanowires these can show different behavior from photoluminescence quenching to very strong fluorescence enhancement. We want to emphasise on the enhancement effect by the presence of the AFM tip. This enhancement effect can even occur when the tip is micrometers away from the diffraction limited excitation spot. Also a memory effect is present, since the enhanced luminescence decays only on a second timescale when the tip is removed.

HL 24.10 Tue 18:30 Poster F

Spin relaxation in self-assembled quantum dots — •Isabel Oppenberg[1], Kevin Eltrudis[1], Annika Kurzmann[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg — [2]Chair for Applied Solid State Physics, Ruhr-Universität Bochum, Universitätsstr. 150, 44780 Bochum, Germany

Self-assembled quantum dots (QDs) are promising candidates for quantum information devices that require a two level system. One possible realization is the excited two-electron spin triplet state and its singlet ground state. We use self-assembled InAs QDs that are embedded in a GaAs/AlGaAs heterostructure (FET). An electron reservoir (2DEG) is coupled to the QDs for controlled charging and sensitive detection of the charge state of the dots. The method we use is time-resolved transconductance spectroscopy with spin-to-charge conversion [1]. By preparation of the excited two-electron triplet states, we can subsequently observe the spin relaxation in electron emission during the discharging process. At zero magnetic field, we observe spin relaxation times of about 25 μs [2].Optical experiments have already shown a very strong magnetic field dependence of the spin relaxation, even for low fields of a few ten mT [3]. Here, we investigate the magnetic field dependence with our all-electrical measurement technique with fields up of 2 T. [1] B. Marquardt. et al., Nature Commun. 2, 209 (2011) [2] K. Eltrudis. et al., Appl. Phys. Lett. 111, 092103 (2017) [3] R. Dahbashi. PRL 112, 156601 (2014)

HL 24.11 Tue 18:30 Poster F

Designing a charge counter for a single electron counting scanning tunneling microscope — •Felix Jekat[1], Benjamin Pestka[1], Sebastian Heedt[2], Patrick Zellekens[3], Stefan Trellenkamp[4], Werner Prost[5], Marcus Liebmann[1], and Markus Morgenstern[1] — [1]II. Institute of Physics, RWTH Aachen University — [2]QUtech, Kouwenhoven Lab, TU Delft — [3]PGI-9, Forschungszentrum Jülich — [4]PGI-8, Forschungszentrum Jülich — [5]Center for Semiconductor Technology and Optoelectronics, University of Duisburg-Essen

Single electron counting provides access to the statistical distribution of tunneling events eventually leading to information of electronic correlations. While this approach is established in quantum devices, it has not been employed to a spatially resolving technique. We aim to implement single electron counting within a STM using indium arsenide nanowires as tips. Such nanowires have been shown to be as suitable as tungsten tips for STM [1]. Here, we show the design of a device, which should enable time-resolved detection of single electrons directly at the STM tip. To this end, we place a second nanowire in close proximity and couple the two wires via a floating gate [2]. Hexagonal boron nitride as a dielectric separates the nanowire from a set of fingergates, which enable the formation of quantum dots.
[1] K. Flöhr et al. "Scanning tunneling microscopy with InAs nanowire tips", Appl. Phys. Lett. 101, 243101 (2012) [2] Y. Hu et al. "A Ge/Si heterostructure nanowire-based double quantum dot with integrated charge sensor", Nature Nanotechnol. 2, 622 (2007)

HL 24.12 Tue 18:30 Poster F

Quantum Dots grown by Local Droplet Etching on GaAs (111)A Substrates — •Julian Ritzmann[1], Nandlal Sharma[2], Dirk Reuter[1,2], Henning Moldenhauer[3], Jörg Debus[3], 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

The generation of entangled photon pairs is a key to practical quantum communications. In the case of biexcitons in SK-grown quantum dots (QD), the fine structure splitting (FSS) of the energy levels causes the transition paths of biexciton and exciton to be distinguishable. Therefore, we need quantum dots with strongly reduced FSS. This was theoretically proposed and experimentally shown for GaAs quantum dots on (111)A-oriented AlGaAs by droplet epitaxy (DE). However, these QDs exhibit a strong distribution in size resulting in rather broad photoluminescence (PL) spectra. Nearly uniform quantum dots were achieved by filling up nanoholes on (001)-oriented Al(Ga)As with GaAs achieving a PL linewidth of less than 10 meV. These nanoholes were generated via local droplet etching (LDE) of gallium droplets on an Al(Ga)As surface. Our approach is to use LDE for the growth of uniform, triangular QDs on (111)A-oriented substrates with low density and reduced FSS. Here, we present a study on different parameters for the LDE and LDE QD process on GaAs (111)A surfaces using atomic force microscopy, PL and micro-PL.

HL 24.13 Tue 18:30 Poster F

Far-Field imaging of Solid-State Quantum-Light Sources using Fourier-Optics — •Christoph Vincent Heine, Peter Schnauber, Sarah Fischbach, Sven Rodt, Jan-Hindrik Schulze, André Strittmatter, Manuel Gschrey, Tobias Heindel, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623, Berlin, Germany

Quantum-light sources based on semiconductor quantum dots (QDs) play an important role in future development of quantum information science. For practical applications it is crucial, to efficiently couple the emission of the respective quantum emitters to a single-mode optical fiber. This coupling efficiency is largly determined by the far-field emission of the emitter.

In this work, we investigate the far-field emission characteristics of QD-based quantum light sources using Fourier imaging. The experimntal setup is introduced and exploited to measure the far-field of deterministically fabricated single-QD microlenses. These measurements and their comparison to simulations enables us to optimize the lens designs and verify theoretical simulations.

HL 24.14 Tue 18:30 Poster F

Optical detection of Coulomb interaction in self-assembled quantum dots — •Jens Kerski[1], Pia Eickelmann[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 quantum dots (QDs) can be used in an optical detection scheme to probe their electrical and spin environment on the nanoscale [1, 2]. In resonance fluorescence, such a nano-electrometer could be also used to investigate transport phenomena, like single electron tunneling into a single quantum dot [3].

In this work, we combine the optical detection with transport measurements by using two quantum dots that are coupled by Coulomb interaction. We perform resonant time-resolved optical measurements on a single InAs QD, which acts as a nanoscale electrometer for detection of tunneling events into a second, nearby dot. The latter is charged by applying a gate voltage. Once an electron is captured in the second QD, its electric field changes the exciton transition energy by the quantum-confined Stark effect of the first dot, which can be observed in a time-resolved measurement.
[1] A. V. Kuhlmann et al., Nature Physics **9**, 570-575 (2013).
[2] J. Houel et al., Phys. Rev. Lett. **108**, 107401 (2012).
[3] A. Kurzmann et al., Phys. Rev. Lett. **117**, 017401 (2016).

HL 24.15 Tue 18:30 Poster F

Low-Temperature Transport Measurements of Selectively-Grown Te-doped InAs Nanowires — •Patrick Liebisch, Patrick Zellekens, Pujitha Perla, Dinesh Kumar Arumugam Gurunathan, Nicholas Güsken, Mihail Ion Lepsa, Detlev Grützmacher, and Thomas Schäpers — Peter Grünberg Institute 9, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

We investigated the transport properties of n-type InAs nanowires grown by selective-area molecular beam epitaxy. Instead of Si doping, which is known for strongly disturbing the lattice structure, we employed Te as n-type dopant. In a series of growth runs the doping concentration was varied systematically up to a value corresponding to $1 \cdot 10^{19}$ cm^{-3} in (100) GaAs. For doping a stoichiometric GaTe source was used. In order to gain information on the doping efficiency, transport experiments were performed on Nb contacted nanowires. From field effect transistor measurements using either a back gate or a top gate the carrier concentration as well as the mobility were extracted. We found that the electron concentration systematically increases with supply of Te dopants. The results of the field-effect transistors are compared to photoluminescence as well as thermoelectric measurements performed on nanowires from the same growth runs.

HL 24.16 Tue 18:30 Poster F

Energy Tuning of Self-Organised Quantum Dot Ensembles via Piezomechanical Strain — •Nikolai Bart[1], Sascha Valentin[1], Arne Ludwig[1], Andreas Wieck[1], Yan Chen[2], Fei Ding[2], and Oliver Schmidt[2] — [1]Lehrstuhl für Angewandte Festkörperpyhsik, Ruhr-Universität Bochum — [2]Institute for Integrative Nanosciences, IFW Dresden

Beside temperature, magnetic and electric fields tuning of the energetic states in quantum dots (QDs) for opto-electronic applications, piezomechanical strain offers an additional tuning knob. We present photoluminescence (PL) and capacitance-voltage (CV) spectroscopy measurements of bi-axially strained self-organised InAs QD ensembles on a piezoelectric actuator. While for PL at room temperature a redshift of 5 meV and inhomogeneous ensemble linewidth broadening of 20 % can be observed when the piezo actuator is biased with 550 V (tensile strain), this effect is diminished at 77 K. CV spectroscopy at 4.2 K on the other hand exhibits a shift in the opposite direction, towards higher gate voltages. While the PL redshift is well documented by others and can be attributed to an altered QD confinement potential due to piezo strain induced morphological changes, the CV results require additional research, which may be provided by introducing a magnetic field to the CV measurements and by wave function mapping.

HL 24.17 Tue 18:30 Poster F

Simulating Optical Signals of the Spatiotemporal Dynamics of Carrier Capture Processes — •Frank Lengers, Roberto Rosati, Tilmann Kuhn, and Doris E. Reiter — Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

Carrier capture processes are frequently encountered in semiconductor structures as, e.g., scattering from the wetting layer to an embedded quantum dot or as trapping of carriers in defects or strain-induced potentials. Those processes happen on an ultrafast timescale and on nanometric length scales such that a quantum description is necessary. These scales require an ultrafast and localized measurement as found in spatially resolved pump-probe measurements.
In this contribution we study the optical signals resulting from the phonon-mediated carrier-capture from a GaAs quantum wire into an embedded quantum dot. To this end we consider a two-band model coupled to a light field and under the influence of carrier-carrier and carrier-phonon interaction. The microscopic description of the carrier-phonon scattering is treated within a Markovian Lindblad single-particle (LSP) approach, which is able to account for the local nature of carrier-phonon scattering [1]. We propose a two-pulse measurement: The first pulse excites a wave packet far from the quantum dot which travels onto the quantum dot where the local capture occurs. The dynamics of the capture process is probed by a second pulse. We find that the capture dynamics is clearly reflected in the probe spectra.
[1] Rosati et al, Phys. Rev. B **95**, 165302 (2017)

HL 24.18 Tue 18:30 Poster F

Room-temperature photoluminescence mapping of GaAs quantum dots — •Roman Korneev, Michael Zocher, Christian Heyn, and Wolfgang Hansen — Center for Hybrid Nanostructures, University of Hamburg, D-22761 Hamburg, Germany

We study the photoluminescence (PL) emission from spatially well separated GaAs quantum dots (QDs) in refilled AlGaAs nanoholes at room temperature (RT). The self-assembled nanoholes are produced by local droplet etching during molecular beam epitaxy. Afterwards, the holes are filled with GaAs and capped with AlGaAs for QD generation. At T = 4 K, the QDs show clear excitonic peaks and nearly perfect single-photon emission. On the other hand, at RT the intensity of emitted light is strongly reduced. Although the emission of an ensemble of QDs is easily detected, the study of single QD emission at RT remains difficult. We demonstrate the detection of single-dot emission at RT by using a modified Raman microscope. Furthermore, a xy-stage allows us to produce PL maps of the samples. PL maps recorded at different wavelengths will be discussed in view of the QD ensemble properties like the density and the average luminescence energy.

HL 24.19 Tue 18:30 Poster F

Deterministic fabrication of circular Bragg gratings around pre-selected quantum dots for high performance light sources — •Sascha Kolatschek, Stefan Hepp, Marc Sartison, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart.

Highly efficient single photon sources are a crucial component for quantum information processes. Semiconductor quantum dots (QDs) have been proven to be excellent candidates due to their outstanding optical properties. Among different stratergies to increase light extraction, the use of photonic nanostructures enables, together with increased brightness, also an improved indistinguishability and reduced lifetime using linear optics and cavity quantum electrodynamic effects. Here we show Purcell enhancement for non-deterministically positioned circular Bragg grating cavities and, together with a novel deterministic fabrication method for the integration of preselected QDs into the respective cavities, count rate increases up to a factor of 60 with respect to measurements before cavity fabrication.

HL 24.20 Tue 18:30 Poster F

Development of GaAs based QD structures for VECSEL and MIXSEL applications — •Tanja Finke[1], Vitalii Sichkovskyi[1], Cesare Alfieri[2], Matthias Golling[2], Ursula 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 vertical external cavity surface emitting lasers (VECSEL) with a semiconductor saturable absorbing mirror (SESAM), one can form a so-called mode-locked integrated external-cavity surface emitting laser (MIXSEL). With MIXSEL structures it is possible to realize very compact ultra-short high power femtosecond laser source for the frequency comb generation. By using quantum dots (QDs) for the gain and absorber material, the material properties can be tailored by additional geometry based degrees of freedom.

For the VECSEL and MIXSEL structures gain section series of test samples optimized for high dot density have been grown by MBE. The influence of the growth parameters on the optical and morphological properties of InGaAs QDs was studied by PL and AFM respectively. An overall reduction of PL FWHM down to 26 meV at 10 K was achieved. The optimum QDs were included into VECSEL gain section. For SESAM structures InGaAs QDs test samples with different designs were grown on DBR mirrors and characterized by pump-probe experiment. Fast recovery time of only 10 ps and good saturation parameters very close to QW based SESAMs were shown.

HL 24.21 Tue 18:30 Poster F

Identification of individual transitions in InGaAsSb/GaP quantum dot by power and temperature dependent photoluminescence — •Petr Steindl[1,2], Petr Petr Klenovský[1,2], Elisa Maddalena Sala[3], Benito Alén[4], and Dieter Bimberg[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institut für Festkörperphysik Technische Universität Berlin, Hardenbergstraße 36 10623 Berlin, Germany — [4]Instituto de Micro y Nanotecnología, IMN-CNM, CSIC Isaac Newton, 8 PTM Tres Cantos 28760 Madrid, Spain

We investigated a set of InGaAsSb/GaP quantum dot samples by photoluminescence spectroscopy. These structures are interesting because they combine direct and indirect optical transitions. We reveal those transitions by performing power, temperature and polarization depended measurements and find the dominant emission band from these dots to occur around 700 nm (1.77 eV). A considerable blueshift of the emission of 27 meV typical for type-II transitions is found by increasing the laser power by 3 orders of magnitude. Temperature resolved data facilitate deconvolution of the broad emission band to contributions of individual transitions.

HL 24.22 Tue 18:30 Poster F

Recombination dynamics of InGaAsSb/GaP quantum dots — •Petr Steindl[1,2], Petr Petr Klenovský[1,2], Elisa Maddalena Sala[3], Benito Alén[4], and Dieter Bimberg[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institut für Festkörperphysik Technische Universität Berlin, Hardenbergstraße 36 10623 Berlin, Germany — [4]Instituto de Micro y Nanotecnología, IMN-CNM, CSIC Isaac Newton, 8 PTM Tres Cantos 28760 Madrid, Spain

We examined the dynamics of optical transitions in ensemble In-

GaAsSb/GaP quantum dot samples by time-resolved photoluminescence spectroscopy. The studied dots provide a simultaneous occurrence of direct and indirect optical transitions. We focused on discerning those for the dominant dot emission band around 700 nm (1.77 eV) by performing time-resolved measurements for different wavelengths, sample temperatures and excitation intensities. We fit the time-resolved data by a double exponential model characterizing two separate recombination processes with average lifetimes of 60 ns and 10 ns. For the former we observe a considerable decrease of lifetime with temperature and we attribute that to spatially indirect transitions in quantum dots. On the other hand, lifetime of the latter transition does not appreciably depend on temperature and is probably connected with bulk recombinations.

HL 24.23 Tue 18:30 Poster F

Focussed ion beam induced site selective growth of single gallium arsenide and indium arsenide nanowires — •Schott Rüdiger, Scholz Sven, Schmidt Marcel, Ludwig Arne, and Wieck Andreas D. — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Semiconductor nanowires (NWs) are used as building blocks for a new generation of advanced devices intended for different applications in the field of nanoelectronics, nanophotonics and nanomechanics. NWs are near one-dimensional structures that typically have a high length-to-width ratio. This is the fundament of fascinating structural properties. Heterostructures of highly lattice mismatched materials can be combined without dislocations and metastable phases are feasible, unattainable in bulk materials like wurtzite GaAs. We present the possibility to modify the surface of a semiconductor substrate by focussed ion beam (FIB) lithography for site selective catalyst-assisted and catalyst-free growth of NWs. In implanting distinct spots of Au ions and clusters in arbitrary distributions on GaAs(111)B, we initiate GaAs and InAs NW growth in molecular beam epitaxy (MBE) via the vapor-liquid-solid mechanism [1,2]. By heating up the GaAs(111)B substrate before growth, the implanted Au ions form small droplets on predefined sites as NW seeds. Ordered catalyst-free NW growth is possible on Si(111) substrates covered with a thin silicon oxide layer by implanting Si or Ga ions.

[1] G. Bussone et al., J. Appl Crystallogr., 46, 887-892 (2013).
[2] S. Scholz et Al., J. of Crystal Growth, 470, 45-50 (2017).

HL 24.24 Tue 18:30 Poster F

Soft- and Hardware Development of a Compact Ultra High Vacuum Pressure Monitoring for Process Control of the Molecular Beam Epitaxy — •Christoph Ringkamp[1,2], Arne Ludwig[1,2], and Andreas Wieck[1,2] — [1]Ruhr-Universität Bochum — [2]Lehrstuhl für Angewandte Festkörperphysik

Monitoring the pressure is an important part to ensure quality while growing semiconductor structures with a molecular beam epitaxy system. For this matter, we have built a compact real-time monitoring system for an ultra-high vacuum out of a Raspberry Pi. The use of a 12-bit A/D in combination with using Python for the software allowed us to have a good resolution at a high sample rate. Continuous reading and averaging increase the 12-bit depth to an effectively higher value. Furthermore one has to deal with an enclosed measurement system of which one cannot test if it is fully calibrated. By comparing the analog signal to the electrometer display in addition with the instructions we tried to compensate for the lack of comparability as we adjusted the linear factor of the voltage-pressure relation.

HL 24.25 Tue 18:30 Poster F

Resistance profiling along tapered nanowires: Multi-tip-technique vs. transmission line method — •Andreas Nägelein[1], Lisa Liborius[2], Matthias Steidl[1], Christian Blumberg[2], Peter Kleinschmidt[1], Artur Poloczek[2], and Thomas Hannappel[1] — [1]TU Ilmenau, Ilmenau, Germany — [2]University Duisburg-Essen, Duisburg, Germany

The advantageous properties of nanowire (NW) structures for electronic or optoelectronic devices are well-established. However, precise control of the dopant distribution within the NWs is difficult to obtain and its determination is challenging. Here, the transmission line measurement (TLM) method provides an access via the electrical transport properties, but its spatial resolution is limited and it cannot be applied to as-grown NWs. In contrast, a multi-tip scanning tunneling microscope (MT-STM), with its independently moveable tips, enables the in-system measurement of continuous axial resistance profiles and avoids the necessity of ex-situ deposition of ohmic contacts. In this paper, a comparative analysis of NW resistance profiling is presented. NWs from the very same sample were first measured and evaluated by MT-STM and then detached and transferred to a non-conducting substrate where TLM measurements were performed. Here, tapering of the measured NWs complicates the evaluation of the TLM data. A new model and correction factors were introduced to determine specific resistances and transfer length. We found an agreement of the measured data of both methods and demonstrate the accuracy and the superior resolution of the MT-STM method.

HL 24.26 Tue 18:30 Poster F

Covalent coupling of plasmonic metal and semiconductor nanoparticles — •Jannik Rebmann, Phillip Witthöft, Simon Schneider, Christian Strelow, Tobias Kipp, and Alf Mews — Institute of Physical Chemistry, University Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Hybrid structures consisting of plasmonic metals and semiconductor nanoparticles are of great importance since the plasmonic properties of the metal can strongly influence the fluorescent behavior of the semiconductor. For instance, if the plasmon of the metal is in resonance with the excitonic recombination energy of the semiconductor this would influence the recombination rate and can be observed by a change of the decay of fluorescence lifetime, provided that the semiconductor and metal are not in direct contact, which would lead to fluorescence quenching due to charge transfer processes. Hence, the distance between the metal and the semiconductor has a huge influence on these effects. Therefore, we present a new method for building hybrid structures consisting of gold-nanorods covalently bonded to CdSe/CdS-dot-in-rod (DR) structure, which are covered with a thin silica shell with variable thickness. Using the EDC-NHS-coupling mechanism a covalent amide bond is formed between the carboxyl groups on the plasmonic metal particle and the terminal amine groups on the DRs. The anisotropic geometry of gold nanorods gives great opportunities to tune the plasmon resonance in order to enhance plasmon-exciton-coupling.

HL 24.27 Tue 18:30 Poster F

Optimization of cavity-enhanced single-photon generation from optical two-photon Raman processes in quantum dot systems — •Tom Praschan[1], Dominik Breddermann[1], Dirk Heinze[1], Rolf Binder[2], and Stefan Schumacher[1,2] — [1]Department of Physics and CeOPP, Paderborn University, Paderborn, Germany — [2]College of Optical Sciences, University of Arizona, Tucson, Arizona, USA

We investigate cavity-enhanced single-photon emission from optical two-photon Raman transitions in quantum dot systems. For this emission process, it has been shown that basic properties such as frequency, linewidth and emission time of the emitted Raman photon are determined by the external control laser [1,2]. In this context, especially Λ-shaped systems, e.g. in quantum dots or atomic systems, have already been studied in great detail [3]. However, higher Raman photon output towards on-demand generation – which is crucial for quantum communication networks – has not been realized yet. We use numerical algorithms to design an optimized chirped laser pulse in order to achieve on-demand single photon emission. As an optimization criterion, here we use the Raman emission probability that can be defined based on the cluster-expansion approach [4].

[1] D. Heinze, D. Breddermann, et al., Nat. Commun. 6, 8473 (2015).
[2] D. Breddermann, D. Heinze, et al., Phys. Rev. B 94, 165310 (2016).
[3] T. M. Sweeney, S. G. Carter, et al., Nat. Photonics 8, 442 (2014).
[4] D. Breddermann, T. Praschan, et al., arXiv:1711.11490 (2017).

HL 24.28 Tue 18:30 Poster F

MBE growth and characterization of InAs/GaSb core-shell nanowire arrays — •Gunjan Nagda[1,3], Dinesh Arumugam[1,3], Pujitha Perla[1,3], Torsten Rieger[1,3], Thomas Schäpers[1,3], Detlev Grützmacher[1,2,3], and Mihail Lepsa[2,3] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich GmbH, 52425 Jülich — [2]Peter Grünberg Institute (PGI-10), Forschungszentrum Jülich GmbH, 52425 Jülich — [3]JARA - Fundamentals of Future Information Technology

InAs and GaSb are almost lattice matched and when in contact, the structure has a broken gap heterointerface. In a core-shell NW geometry, these particularities make the combination interesting for low power electronic devices (TFETs) and the study of new physical properties, e.g. two-dimensional topological insulator behavior, Majorana fermions, etc. We report on the MBE growth and characterization of InAs/GaSb nanowire arrays.

For the growth, Si (111) substrates were covered with a thin thermal SiO2 film in which two-dimensional, periodic arrays of nano-sized holes were patterned. The InAs NW growth was optimized regarding the yield and morphology. The substrate preparation is crucial for achieving a high NW yield. The growth of GaSb shell was investigated similarly obtaining optimum growth conditions. NW morphological and structural characteristics have been obtained using different microscopy methods. The small lattice mismatch between InAs and GaSb combined with the one-dimensional geometry results in misfit dislocation free core-shell NW heterointerface.

HL 24.29 Tue 18:30 Poster F

Quenching of the photoluminescence of CdTe QDs by PEDOT:PSS conductive polymer in water solutions and thin films — •Oleksandr Selyshchev[1], Volodymyr Dzhagan[2], Nikolai Gaponik[3], and Dietrich R.T. Zahn[1] — [1]Semiconductor Physics, Chemnitz University of Technology, Chemnitz D-09107, Germany — [2]V. Lashkaryov Institute of Semiconductor Physics, Nat. Acad. Sci. of Ukraine, 03028 Kyiv, Ukraine — [3]Physical Chemistry and Center for Advancing Electronics Dresden, TU Dresden, 01062 Dresden, Germany

Quantum dots attract significant interest first of all due to their optical properties and they are considered for applications in light harvesting and emitting devices, photocatalysts, luminescent biomarkers etc. In all of these applications QDs are not "particles-in-a-box" but interact with other objects such as ligands, substrates, other QDs, which have influence on the properties of the QDs. Here we report about quenching of the PL of CdTe QDs of different sizes by the conductive polymer PEDOT:PSS in aqueous solutions and thin films. PEDOT:PSS resulted in a significant red shift (upto 0.3 eV) of the PL band of CdTe QDs. The magnitude of the shift decreased with increasing QD size. The value of the shift was proportional to the amount of PEDOT:PSS and increased with storage time of the samples. The results obtained reveal a strong and controllable interaction between the QDs and the PEDOT:PSS. The possible mechanisms underlying the observed effects are discussed based on additional information obtained by XPS, UPS, Raman and IR spectroscopies, time-resolved PL, and TEM.

HL 24.30 Tue 18:30 Poster F

Optoelectronic Coupling Between Colloidal Quantum Dots and Burrowed Quantum Wells — •Mikko Wilhelm[1], Atif Masood[1], Wolfgang Parak[2], and Wolfram Heimbrodt[1] — [1]Philipps-Universität Marburg — [2]Universität Hamburg

The optoelectronic coupling between colloidal CdS quantums and a buried quantum well is studied. CdS quantum dots of different sizes have been deposited via drop casting on a MBE grown quantum well structure, which consists of a 5nm thick ZnSe quantum well and a (Zn, Mn)Se barrier of different thickness and Mn concentration. The energy transfer between the quantum dots on top of the substrate and the burrowed quantum well is investigated with cw- and time resolved luminescence measurements in the nano- and picosecond range. Measurements were performed at different temperatures and the results are discussed in detail.

HL 24.31 Tue 18:30 Poster F

Steady state optical spectroscopy and time- and spatially-resolved pump-probe measurements on a plasmonic CdZnTe/CdMgTe waveguiding structure — •Alexander Trautmann[1], Jonas Vondran[2], Felix Spitzer[2], Ilya Akimov[2], Manfred Bayer[2], Nils Weber[1], Cedric Meier[1], Régis Andre[3], Henri Mariette[3], Matthias Reichelt[1], and Torsten Meier[1] — [1]Department of Physics and CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany — [2]Experimentelle Physik 2, TU Dortmund, Otto-Hahn-Str. 4, D-44221 Dortmund, Germany — [3]CEA-CNRS Group Nanophysique et Semiconducteurs, Institut Néel, Université Grenoble-Alpes, 38042 Grenoble, France

A plasmonic gold grating on a CdZnTe/CdMgTe waveguide structure leads to different signatures in the reflectivity spectra for s- and p-polarized light. Experiments and simulations show a significant decrease of the reflectivity for p-polarization due to the excitation of surface plasmon polaritons. Furthermore, nonlinear optical pump-probe experiments with femtosecond laser pulses using spatially-localized excitation pulses are investigated. Both, the experiment and the simulations, using a model based on the Maxwell-Bloch equations, show several interesting effects in the differential reflectivity transients including contributions from the optical Stark effect. The obtained transients are discussed as function of the spatial separation and other relevant parameters.

HL 24.32 Tue 18:30 Poster F

Coherence and Population Dynamics of Excitons in Single Quantum Dots Revealed by Four-Wave Mixing Micro-Spectroscopy — •Daniel Wigger[1], Tilmann Kuhn[1], and Jacek Kasprzak[2,3] — [1]Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Univ. Grenoble Alpes, F-38000 Grenoble, France — [3]CNRS, Institut Néel, "Nanophysique et Semiconducteurs" Group, F-38000 Grenoble, France

Four-Wave Mixing (FWM) micro-spectroscopy is a powerful tool to investigate the level structure and coupling mechanisms of single few-level systems. This knowledge is essential for the use of single emitters in quantum technology. We investigate single self-assembled quantum dots (QDs), which stand out as scalable solid state single emitters. By using two and three exciting pulses, we have access to the dynamics of the microscopic exciton coherences and populations, respectively [1]. We present combined theoretical and experimental studies on the dynamics of FWM signals and discuss the influence of laser intensities [2] and the coupling to phonons [3].

[1] Q. Mermillod et al., Optica **3**, 377 (2016)
[2] D. Wigger et al., Phys. Rev. B **96**, 165311 (2017)
[3] T. Jakubczyk et al., ACS Photonics **3**, 2461 (2016)

HL 24.33 Tue 18:30 Poster F

Ultrafast spin-dependent dynamics and high harmonic generation in semiconductor nanostructures — •Dominik Schulze and Jamal Berakdar — Institute of Physics, Martin-Luther-University Halle-Wittenberg, 06099 Halle/Saale, Germany

Using a direct time propagation technique, we investigate the time-resolved charge and spin quantum dynamics of semiconductor based heterostructures subjected to ultrashort laser pulses. Special attention is devoted to effects related to spin-orbital coupling. It is shown how the time and polarization-resolved emission spectrum can be controlled via the parameters of the driving field as well as by nanostructuring. It is pointed out how the footprints of the spin dynamics can be traced via monitoring in the emission spectrum.

HL 24.34 Tue 18:30 Poster F

Photo-induced magnetic moments in nanostructered quantum rings — •Michael Kraus, Jonas Wätzel, and Jamal Berakdar — Institute for Physics, Martin-Luther-University Halle-Wittenberg, 06099 Halle (Saale), Germany

The generation of strongly focused light beams carrying orbital angular momentum (OAM) for a wide range of pulse parameters opens the door to fascinating new applications in optoelectronics and optical communications. These spatially inhomogeneous light fields allow to change the angular momentum of the sample by an amount set by the topological charge of the OAM beam which can be varied in a large range. Here we focus on nanostructured quantum rings irradiated by OAM beams inducing a substantial magnetic moment which is totally controllable by the laser parameters. Based on a full-fledged quantum simulation we investigate different laser setups to achieve the maximal magnetic moment during and after the application of the pulse. For instance, by increasing the winding number of the optical vortex the magnetic moment can be enlarged as long as the frequencies of the photo-induced electric transitions are within the bandwidth of the pulse. The irreversible relaxation processes induced by the interaction between the photoexcited electrons and acoustic phonons is included by a density matrix approach and indicates how long the generated magnetic moments are detectable.

HL 24.35 Tue 18:30 Poster F

Spatio-temporal resolution studies on a highly compact femtosecond electron diffraction and understanding the phenomena of phonon decay in single crystalline graphite — Christian Gerbig[1], Silvio Morgenstern[1], Marlene Adrian[1], Cristian Sarpe[1], •Muhammad Abdullah Umer[1], Arne Senftleben[1], Matthias Wollenhaupt[2], and Thomas Baumert[1] — [1]University of Kassel, Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany — [2]University of Oldenburg, Institute of Physics, D-26111 Oldenburg, Germany

Ultrafast time resolved electron diffraction has become a promising technique because of its higher temporal and atomic scale spatial resolution and allow to study the ultrafast phenomena occurring in the

atomic structure of matter with ultrafast precision.

We report here the application of ultrafast electron diffraction to study the dynamical processes in single crystalline graphite in order to understand the effect of phonon generation and decay mechanism which is being essential for future carbon based electron devices.

With our highly compact setup we are able to achieve excellent spatial- temporal resolution with coherence length >8nm and electron pulse duration <200 fs. We further present generation and decay processes of incoherent as well as coherent phonons in graphite as a function of film thickness down to few-layer graphene.

HL 24.36 Tue 18:30 Poster F

Directional optical switching and transistor functionality using optical parametric oscillation in a spinor polariton fluid — •Matthias Pukrop[1], Przemyslaw Lewandowski[1], Samuel M. H. Luk[2], Chris K. P. Chan[3], P.T. Leung[3], N.H. Kwong[4], Rolf Binder[2,4], and Stefan Schumacher[1,4] — [1]Physics Department and CeOPP, Universität Paderborn, 33098 Paderborn, Germany — [2]Department of Physics, University of Arizona, Tucson, AZ 85721, USA — [3]Department of Physics, The Chinese University of Hongkong, Hongkong SAR, China — [4]College of Optical Sciences, University of Arizona, Tucson, AZ 85721, USA

Over the past decade, spontaneously emerging patterns in the density of polaritons in semiconductor microcavities [1] were found to be a promising candidate for all-optical switching. But recent approaches were mostly restricted to scalar fields, did not benefit from the polariton's unique spin-dependent properties, and utilized switching based on hexagon far-field patterns with 60° beam switching (i.e. in the far field the beam propagation direction is switched by 60°). Since hexagon far-field patterns are challenging, we present here an approach for a linearly polarized spinor field, that allows for a transistor-like (e.g., crucial for cascadability) orthogonal beam switching, i.e. in the far field the beam is switched by 90°. We show that switching specifications such as amplification and speed can be adjusted using only optical means [2].

[1] V. Ardizzone et al., Scientific Reports 3, 3016 (2013)

[2] P. Lewandowski et al., Opt. Express 25, 31056-31063 (2017)

HL 24.37 Tue 18:30 Poster F

Lift-off of GaN LEDs with ultrashort laser pulses — •Steffen Bornemann[1,2], Nursidik Yulianto[1,2], Andreas Waag[1,2], and Hutomo Suryo Wasisto[1,2] — [1]Institut für Halbleitertechnik (IHT), Technische Universität Braunschweig, Hans-Sommer-Str. 66, 38106 Braunschweig — [2]Laboratory for Emerging Nanometrology (LENA), Technische Universität Braunschweig, Langer Kamp 6a, 38106 Braunschweig

Due to their high efficiency and compact design, GaN-based LEDs are nowadays the light source of choice for many applications. Sapphire is usually taken as a low-cost substrate for epitaxial growth of the InGaN/GaN heterostructure. However, it provides poor electrical and thermal conductivity, limiting its practicability for commercial high-power LEDs as well as for structured light sources. Therefore, a transfer of thin LED structures to more suitable substrates, e.g. rigid silicon or flexible polyimide, is applied. The detachment from sapphire is normally realized with a UV excimer laser, leading to linear absorption in the first layers of GaN.

In this project, we present the successful implementation of a lift-off process based on a versatile femtosecond laser system operating at a wavelength of 520 nm. The corresponding photon energy is too low for direct absorption, but non-linear processes during the high-energy pulses enable separation of the LED from the original substrate. Luminescence experiments prove the functionality of the lifted chip, whereas SEM measurements reveal local laser induced damage on the surface. Possible mechanisms for these phenomena are discussed.

HL 24.38 Tue 18:30 Poster F

Universal short-time response and formation of correlations after quantum quenches — •Klaus Morawetz — Münster University of Applied Sciences, Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — Max-Planck- Institute for the Physics of Complex Systems, 01187 Dresden, Germany

The short-time evolutions of two distinct systems, the pump and probe experiments with a semiconductor and the sudden quench of cold atoms in an optical lattice, are found to be described by the same universal response function. This analytic formula at short time scales is derived from the quantum kinetic-theory approach observing that correlations need time to form. The demand of density conservation leads to a reduction of the relaxation time by a factor of 4 in quench setups. The influence of the finite-trapping potential is derived and discussed along with Singwi-Sjølander local-field corrections including the proof of sum rules. The quantum kinetic equation allows to understand how two-particle correlations are formed and how the screening and collective modes are build up.

Phys. Rev. B 90 (2014) 075303, Phys. Rev. E 66 (2002) 022103, Phys. Rev. E 63 (2001) 20102, Phys. Lett. A 246 (1998) 311

HL 25: Focussed Session: Quantum Nanophotonics in Solid State Systems: Status, Challenges and Perspectives II (joint session HL/TT)

Organizers: Alexander Szameit(U Rostock), Ruth Oulton (U Bristol), and Stephan Reitzenstein (TU Berlin)

Time: Wednesday 9:30–13:15 Location: EW 201

Invited Talk HL 25.1 Wed 9:30 EW 201

The quantum knitting machine: a quantum dot as device for deterministic production of cluster states of many entangled photons — •David Gershoni — The Physics Department and The Solid State Institute, Technion, Haifa, 32000, Israel

Photonic cluster states are a resource for quantum computation based solely on single-photon measurements [1]. We use semiconductor quantum dots to deterministically generate long strings of polarization-entangled photons in a cluster state by periodic timed excitation of a precessing matter qubit [1-2]. In each period, an entangled photon is added to the cluster state formed by the matter qubit and the previously emitted photons. In our prototype device, the qubit is the confined dark exciton [3,4], and it produces strings of hundreds of photons in which the entanglement persists over five sequential photons [5]

[1] H. J. Briegel, "Versatile cluster entangled light", Science 354, 416 (2016)

[2] N. H. Lindner and T. Rudolph, "Proposal for pulsed on-demand sources of photonic cluster state strings", Phys. Rev. Lett. 103, 113602 (2009)

[3] E.Poem, et al, "Accessing the dark exciton with light", Nature Physics 6, 993, (2010)

[4] I. Schwartz, et al, "Deterministic writing and control of the dark exciton spin using short single optical pulses", Phys. Rev. X 5, 011009 (2015)

[5] I. Schwartz, et al, "Deterministic generation of a cluster state of entangled photons", Science 354, 434, (2016)

HL 25.2 Wed 10:00 EW 201

Time reordering of paired photons through two-photon strong coupling and generation of maximally entangled states in quantum dots — •Samir Bounouar[1], Christoph De La Haye[1], Max Strauss[1], Peter Schnauber[1], Alexander Thoma[1], Manuel Gschrey[1], Jan-Hindrik Schulze[1], Andre Strittmatter[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Abteilung für Halbleiterepitaxie, Otto-von-Guericke, Universität, 39106 Magdeburg, Germany

We show that strong coupling of a continuous laser field to the exciton-biexciton radiative cascade of a semiconductor quantum dot (QD) allows for the observation of the dressed states and the manipulation of the paired photons time ordering [1]. Moreover, two-photon Rabi oscillations of the dressed states population, due to the non-linear coherent driving of the radiative cascade, confirm the coherent nature

of the two-photon driving. We also show that maximally entangled states can be efficiently generated from microlens-QD with non-zero fine structure splitting and that their fidelity to the Bell states remains unaffected by the decoherence over the full wave-packet [2].

[1] S. Bounouar et al., Phys. Rev. Lett. 118, 233601 (2017). [2] S. Bounouar et al., (in preparation).

HL 25.3 Wed 10:15 EW 201

Quantum-optical spectroscopy of a two-level system using an electrically driven micropillar laser as resonant excitation source — •Sören Kreinberg[1], Tomislav Grbešic[1], Max Strauss[1], Alexander Carmele[2], Monika Emmerling[3], Christian Schneider[3], Sven Höfling[3], Xavier Porte[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Germany — [3]Technische Physik, Julius-Maximilians-Universität Würzburg, Germany

Two-level emitters constitute the core elements of photonic quantum systems and exploring their physics is at the heart of quantum optics. Of special interest is the strict-resonant optical excitation of such emitters to generate quantum light with close to ideal properties. Up till now related experiments have been performed exclusively using bulky lasers. This hinders the application of resonantly driven two-level emitters in quantum technology, which relies on the availability of compact sources of indistinguishable photons. Here we propose and demonstrate quantum-optical spectroscopy of a single QD embedded in a planar microcavity resonantly excited by an electrically driven high-β quantum dot micropillar laser. We obtain single photons with strong multi-photon suppression $g^{(2)}(0)$=0.02 and high photon indistinguishably V=0.57(9) under pulsed excitation with a repetition rate of 156 MHz. Our results demonstrate the exquisite potential of high-β microlasers as coherent excitation sources in quantum nanophotonics and pave the way to compact, resonantly driven quantum light sources.

HL 25.4 Wed 10:30 EW 201

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

The coherent control of QD excitons can be performed in Ramsey type experiments, where the QD is excited with two phase locked optical $\frac{\pi}{2}$ pulses seperated by a time delay. Here we present an experiment, where the first pulse defines the phase of the exciton, which is subsequently manipulated by ultrafast Stark tuning of the exciton energy. The resulting phase shift is measured by quantum interference using the second $\frac{\pi}{2}$ pulse. 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 SiGe:C BiCMOS chips for the generation of ultrafast electric pulses (rise times <20 ps @ cryogenic operationality) and ultrafast 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 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.

Ref: [1] S. de Vasconcellos et al., Nature Photonics 4, 545 (2010).

HL 25.5 Wed 10:45 EW 201

Telecom-wavelength GaAs-based quantum dots for practical single-photon sources — •A Musiał[1], Ł Dusanowski[1,2], P Holewa[1], P Mrowiński[1], A Maryński[1], K Gawarecki[1], N Srocka[3], T Heuser[3], D Quandt[3], A Strittmatter[3,4], S Rodt[3], S Reitzenstein[3], and G Sek[1] — [1]Faculty of Fundamental Problems of Technology, Wrocław Uni of Science and Technology, Wrocław, Poland — [2]Technical Physics, Uni of Würzburg, Würzburg, Germany — [3]Institute of Solid State Physics, Technical Uni of Berlin, Berlin, Germany — [4]Institute of Experimental Physics, Otto von Guericke Uni Magdeburg, Magdeburg, Germany

Quantum communication applications require stand-alone, high-purity on-demand single-photon sources (SPS) operating at telecom wavelengths, preferably fiber-coupled for easy integration with existing optical networks. In this regard, we evaluated the potential of GaAs-based quantum dots (QDs) grown by high-throughput and mature MOCVD technology. The emission wavelength was shifted to telecom wavelengths utilizing an InGaAs strain reducing layer. The electronic structure of the QDs was optimized for well-separated ground state exciton emission to allow for high single-photon purity and good thermal stability. Single QDs have been placed deterministically in nanophotonic structures for increased light extraction. The influence of temperature and excitation energy on single-photon generation was studied resulting in triggered high-purity single-photon emission under p-shell resonant excitation at 30K suitable for commercializing fiber-coupled single-photon sources based on cryogenic-free Stirling cryocoolers.

HL 25.6 Wed 11:00 EW 201

Quantum emitter coupled to photonic modes: superradiant to subradiant phasetransition generates a dark state cascade — Michael Gegg, Alexander Carmele, Andreas Knorr, and •Marten Richter — Institut für Theoretische Physik, Technische Universität Berlin, Germany

If an ensemble of quantum emitter like quantum dots, NV centers or atom are coupled to photonic or plasmonic modes, collective effects can lead to collective super- or subradiance. Here, we discuss a type of phase transition, that describes the transition from predominantly superradiant states to subradiant states with applications to quantum information storage. The simulation for a large number of two level systems is made possible by a method exploiting the permutation symmetry for identical system [1,2] available through the library PsiQuaSP [3]. In the described situation the important quantity for the generation of the subradiant states is the cavity decay and not the individual quantum emitter decay. Experimental signatures as well as entanglement properties are discussed.

[1] Phys. Rev. B 91, 035306 (2015)
[2] New J. Phys. 18, 043037 (2016)
[3] Sci. Rep. 7, 16304 (2017)
[4] New J. Phys. (in press), (2017), https://doi.org/10.1088/1367-2630/aa9cdd, arXiv:1705.02889

15 min. break.

Invited Talk HL 25.7 Wed 11:30 EW 201

Exploiting the Bright and the Dark Side of Deterministic Solid-State Quantum-Light Sources — •Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany

Quantum-light sources are key building blocks for future photonic technologies with applications in the fields of quantum communication, quantum computation and quantum metrology.

Here, we will review recent experiments exploiting quantum-light sources based on photonic microlenses deterministically fabricated above pre-selected semiconductor quantum dots (QDs). The first part of the talk will focus on experiments demonstrating the efficient, triggered generation of photon twins - a light state comprised of two temporally correlated photons degenerate in energy and polarization [1]. For this purpose, we select QDs whose exciton finestructure splitting equals the biexciton binding energy $\Delta E_{\mathrm{FSS}}=|E^{\mathrm{XX}}_{\mathrm{bin}}|$. In the second part, we demonstrate that we can exploit photonic QD microlenses to all-optically access the dark exciton (DE) state [2]. By clearly observing the quantum beats of the DE spin-eigenstates $|\uparrow\Uparrow \pm \downarrow\Downarrow\rangle$, we provide evidence for the robustness of the DE as a long-lived coherent spin-qubit and pave the way towards its wider application. Finally, we briefly discuss prospects of QD-based quantum-light sources for the realization of quantum-secured communication networks.

[1] T. Heindel et al., Nature Communications 8, 14870 (2017)
[2] T. Heindel et al., APL Photonics 2, 121303 (2017)

HL 25.8 Wed 12:00 EW 201

Two-photon interference with remote quantum dots at 1550 nm after quantum frequency conversion — •J. H. Weber[1], B. Kambs[2], J. Kettler[1], S. Kern[1], H. Vural[1], J. Maisch[1], S. L. Portalupi[1], M. Jetter[1], C. Becher[2], and P. Michler[1] — [1]IHFG, IQ$^{\mathrm{ST}}$ Center and SCoPE, Universität Stuttgart — [2]Fachrichtung Physik, Universität des Saarlandes

Two-photon interference (TPI) with telecom photons from remote quantum emitters is of key importance for future long-distance quantum networking. Here, quantum frequency conversion (QFC) is exploited to transfer single near-infrared photons from semiconductor quantum dots to the telecom C-band. We demonstrate that the presented technology opens the path for on-demand generation of highly

bright single-photon emission at 1550 nm without the need for special sample design or intrinsic tuning mechanisms. Standing prove for the feasibility of this hybrid technology, we report on TPI with remote quantum dots, being only limited to spectral wandering due to the charge environment of the bulk material. The feasibility of this technology is further strengthened by unprecedented overlap of measured TPI contrast and theoretical prediction which is only possible due to the convenient and highly stable tuning mechanism delivered by QFC. With this respect, the theoretical derivations consider both off-resonant TPI as well as inhomogeneous broadening and blinking of the emitters. Finally, we simulate wave propagation in optical fibers to study the effect of dispersion and experimentally demonstrate that 2 km of fiber delay does not affect the remote TPI visibility.

HL 25.9 Wed 12:15 EW 201

Photon-Number-Resolving Transition Edge Sensors for the Metrology of Quantum-Light Sources — •Marco Schmidt[1,2], Martin von Helversen[1], Fabian Gericke[1], Elisabeth Schlottmann[1], Manuel Gschrey[1], Peter Schnauber[1], Jan-Hindrik Schulze[1], André Strittmatter[1], Jörn Beyer[2], 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

Photon-number-resolving detectors (PNR) allow for direct access to the photon number distribution of nanophotonic light sources and can thus be exploited to explore the photon statistics of semiconductor-based non-classical light sources. In this work, we report on the realization of a stand-alone measurement system with two fiber-coupled transiton edge sensors (TESs) integrated within a compact adiabatic demagnetization refrigerator. The performance of the detector system is analyzed in terms of its detection efficiency, which is determined to be larger than 87 % (850 - 950 nm). As an exemplary application in QD-metrology, we employ this detector to evaluate the photon number distribution of QD-based single- and twin- photon sources [1] based on deterministically fabricated QD microlenses.

[1] T. Heindel et al., Nat. Commun. 8, 14870, (2017)

HL 25.10 Wed 12:30 EW 201

Hong-Ou-Mandel Experiment using Single-Photon Fock-States and Photon-Number Resolving Detectors — •Martin von Helversen[1], Jonas Böhm[1], Marco Schmidt[1,2], Jan-Hindrik Schulze[1], André Strittmatter[1], 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

Quantum light sources based on semiconductor quantum dots (QDs) are promising candidates for many applications in the research fields of quantum metrology and quantum communication. Important characteristics of such emitters, e.g. the degree of single-photon purity and photon indistinguishability, are typically assessed via time-correlated measurements using silicon-based click detectors in Hanbury-Brown and Twiss (HBT-) and Hong-Ou-Mandel (HOM-) type configuration. Here, we employ a state of the art photon-number-resolving detection system based on two transition edge sensors (TES) to analyze the emission of a deterministically fabricated QD-based single-photon source and quantitatively compare our results with experimental data obtained for standard click detectors. Our results demonstrate that photon-number resolving detectors are very attractive tools for the metrology of quantum light sources.

HL 25.11 Wed 12:45 EW 201

Effect of second order piezoelectricity on exciton dipole, fine-structure and binding energies of multi-excitons in strain-tuned InGaAs/GaAs quantum dots — •Petr Klenovský[1,2], Petr Steindl[1,2], Johannes Aberl[3], Eugenio Zallo[4,5], Thomas Fromherz[3], Armando Rastelli[3], and Rinaldo Trotta[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Altenbergerstraße 69, A-4040 Linz, Austria — [4]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstraße 20, D-01069 Dresden, Germany — [5]Paul-Drude-Institut für Festkörperelektronik, Hausvogteilplatz 5-7, 10117 Berlin, Germany

We study the effects of nonlinear piezoelectricity on the exciton electric dipole moment, fine-structure, and binding energies of multi-exciton complexes in strain-tuned InGaAs/GaAs quantum dots and investigate the influence of various elements of the expansion of electrical polarization in terms of applied elastic stress. We find that a presence of a large built-in stressor (like quantum dot) is necessary for the dipole inversion to occur. Furthermore, the analysis provides a simple relation to estimate the influence of applied stress on the electrical polarization in zincblende nanostructures.

HL 25.12 Wed 13:00 EW 201

Strain tuning of deterministically fabricated quantum dot microlenses for advanced quantum communication — •Sarah Fischbach, Marco Schmidt, Ronny Schmidt, Arsenty Kaganskiy, André Strittmatter, Tobias Heindel, Sven Rodt, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, Germany

Long distance quantum communication requires networks of quantum repeaters, which are based on the generation of indistinguishable pairs of entangled photons. Quantum dots (QDs) can generate entangled photons from their exciton-biexciton cascade and methods of semiconductor nanofabrication allow one to realize efficienct sources emitting highly indistinguishable photons.
Due to the random nature of the self-assembled growth process, QDs vary over a wide range in their emission wavelength. Deterministic nanoprocessing needs to be applied to integrate QDs matching a target wavelength. Additionally, to enable entaglement distribution, two QD-based sources need to be tuned into resonance by spectral fine-tuning. Strain tuning is a very accurate tuning method which maintains the high optical quality of the QD emission.
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. QD microlenses can act as efficient single-photon sources with low $g^{(2)}(0)$-values and a high photon indistinguishability, which are now equipped with the feature of strain tunability.

HL 26: Ultra-fast phenomena

Time: Wednesday 9:30–13:00 Location: EW 202

HL 26.1 Wed 9:30 EW 202

Towards femtosecond on-chip electronics based on plasmonic hot electron nano-emitters — Christoph Karnetzky[1,2], Philipp Zimmermann[1,2], Noelia Fernandez[1,3], •Christopher Trummer[1,2], Carolina Duque-Sierra[1,2], Martin Wörle[4], Reinhard Kienberger[4], and Alexander W. Holleitner[1,2] — [1]Walter Schottky Institute and Physics Department, Technical University of Munich, Am Coulombwall 4a, 85748 Garching, Germany — [2]Nanosystems Initiative Munich (NIM), Schellingstr. 4, 80799 Munich, Germany — [3]Max Planck Institut für Quantenoptik, Hans Kopfermann Str. 1, 85748 Garching, Germany — [4]Physik-Department E11, Technical University of Munich, James-Franck-Str. 1, 85748 Garching, Germany

To combine the advantages of ultrafast nano-optics with an on-chip communication scheme, optical signals with a frequency of several hundreds of THz need to be down-converted to coherent electronic signals of GHz or less.Here, we demonstrate that 14 fs optical pulses in the near-infrared can drive electronic on-chip circuits with a bandwidth up to 10 THz. The electronic pulses propagate in macroscopic striplines on a millimeter scale. We exploit femtosecond photoswitches based on tunneling barriers in nanoscale metal junctions to drive the pulses. The non-linear ultrafast response is based on a combination of plasmonically enhanced, multi-photon absorption and quantum tunneling, and gives rise to a field emission of ballistic electrons propagating across the nanoscale junctions. Our results pave way towards femtosecond electronics integrated in wafer-scale quantum circuits.

HL 26.2 Wed 9:45 EW 202

Tunable high harmonics from nanorings swirled by optical vortices — •Jonas Wätzel and Jamal Berakdar — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Karl-Freiherr-Von-Fritsch-Str. 3, 06112 Halle (Saale)

The interaction of light carrying orbital angular momentum, also called optical vortices, with matter opens the door to exciting effects and mechanisms beyond the optical dipole selection rules. We demonstrated in the past that the transfer of OAM to charge density can be used to manipulate and steer the carrier dynamics. A direct consequence is the possibility to generate a sizable, directed photocurrent.

Here we report on the irradiation of intercalated nanorings by optical vortices which ignites a charge flow that emits coherent trains of high harmonic bursts. The frequencies and time structures are highly controllable by the topological charge of the driving vortex beam. As a demonstration of the fundamental quantum mechanical tunneling process, the non-equilibrium orbital magnetic moment triggered in a ring is translated to the smaller and larger attached rings leading, respectively, to high and low-frequency harmonic generation.

Our findings show that the frequencies of the emitted harmonics are tunable by changing the waist and/or the winding number of the optical vortex, without the need to increase the pulse intensity which, in return, could lead to material damage. The proposed setup is non-destructive as short vortex pulses of moderate intensities are needed, and it offers a versatile tool for nanoscale optical and spectroscopic applications such as local, single beam pump-probe experiments.

HL 26.3 Wed 10:00 EW 202

Ultrafast quasi-particle dynamics in graphene nanoribbons. — •Raphael German, Jingyi Zhu, Boris Senkovskiy, Alexander Grüneis, and Paul H.M. van Loosdrecht — II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

The opening of a bandgap in one-dimensional graphene nanoribbons paves the road toward carbon based optical applications. Here, we report on a study of the optical dynamics in N=7 armchair graphene nanoribbons (7-AGNR) using steady state and time-resolved spontaneous Raman spectroscopy. The Raman spectra show a strong resonance behavior for excitation energies around 2.2 eV, which is interpreted as an excitonic Raman resonance. We use the resonant enhancement to study both the phonon as well as the exciton population dynamics in 7-AGNRs. The observed lifetime of the D and G phonons is found to be limited to about 2 ps due to optical-acoustical phonon scattering. The exciton population dynamics shows a multi-exponential decay which is interpreted in terms of the presence of an inhomogeneous distribution of defect bound excitons and dark states.

HL 26.4 Wed 10:15 EW 202

High-harmonic generation from tailored solid targets — •Murat Sivis[1,2], Marco Taucer[2], Kyle Johnston[2], Giulio Vampa[2], André Staudte[2], Andrei. Yu. Naumov[2], David. M. Villeneuve[2], Paul B. Corkum[2], and Claus Ropers[1] — [1]4th Physical Institute - Solids and Nanostructures, Georg-August University, Göttingen, Germany — [2]National Research Council of Canada and University of Ottawa, Ottawa, Canada.

In recent years, high-harmonic generation (HHG) in semiconductor and dielectric crystals has enabled new all-optical means to investigate solid-state matter [1,2]. On the other hand, solid targets offer unique opportunities to develop novel types of sources for coherent extreme-ultraviolet radiation with tailored wave fields. Here, we present a study on high-harmonic generation in locally modified zinc oxide and silicon targets driven by femtosecond laser pulses at 2 μm central wavelength [3]. We demonstrate how the local intensity, polarization and phase of the generated radiation (up to the ninth harmonic order of the fundamental) can be controlled by changing the structural and chemical composition of the target. Our results indicate unprecedented means to link high-harmonic generation with optoelectronics, suggesting solid-target HHG as an all-optical probe for ultrafast dynamics on the nanoscale.

[1] S. Ghimire, *et al. Nat. Phys.* **7**, 138-141 (2011).
[2] G. Vampa,*et al. Nature* **522**, 462-464 (2015).
[3] M. Sivis *et al. Science* **357**, 303-306 (2017).

HL 26.5 Wed 10:30 EW 202

Electron mobility and lifetime in $GaAs/In_xGa_{1-x}As$ core/shell nanowires studied by optical pump – THz probe spectroscopy — •Ivan Fotev[1,2], Leila Balaghi[1,2], René Hübner[1], Johannes Schmidt[1], Markus Hähnel[1], Harald Schneider[1], Manfred Helm[1,2], Emmanouil Dimakis[1], and Alexej Pashkin[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]TU Dresden, Germany

We utilize ultrafast optical pump – terahertz probe spectroscopy in order to investigate charge carrier response of $GaAs/In_xGa_{1-x}As$ core/shell nanowires (NWs) produced by molecular beam epitaxy. The NWs were $\approx 2\,\mu$m long. The GaAs core diameter was 25 nm and the InGaAs shell thickness was 80 nm. We studied the shells with different compositions, from $x = 0.20$ to $x = 0.44$.

From the pump-probe measurements we extracted terahertz photoconductivity of NWs and used the localized surface plasmon model to fit the results. The charge carrier lifetimes were estimated to be around 80–100 ps while the extracted electron mobilities reach $3700\,\mathrm{cm^2V^{-1}s^{-1}}$ at room temperature. Even without a surface passivation shell, these values are higher than those in previously studied GaAs/AlGaAs core/shell nanowires, but still lower than the ones for bulk InGaAs. Possible reasons (sources of electron scattering) which affect the mobility will be discussed.

HL 26.6 Wed 10:45 EW 202

The role of the Σ-point in the ultrafast dynamics of intervalley hole scattering in PbTe — •Prashant Padmanabhan, Manpreet Kaur, Kestutis Budzinauskas, and Paul H. M. van Loosdrecht — II. Physics Institute, University of Cologne, Germany

PbTe is a leading thermoelectric material, notable for its low thermal conductivity and large carrier mobility at low doping levels. Using time-resolved differential reflectivity measurements, we investigate the ultrafast relaxation of highly excited carriers, probing the dynamics of electron-phonon interactions on the femtosecond and picosecond timescales. Our experimental and theoretical results show that phonon-mediated intervalley scattering involving the Σ-point plays a significant role in the hole cooling process due to the unique topology of its valence band. In addition, anomalous temperature dependencies in the carrier relaxation rates show the dramatic influence of the softening of phonons characteristic of incipient ferroelectrics.

HL 26.7 Wed 11:00 EW 202

Finite system effects on high harmonic generation: from atoms to solids — •Kenneth Hansen[1], Dieter Bauer[2], and Lars Bojer Madsen[1] — [1]Department of Physics and Astronomy, Aarhus University, DK-8000, Denmark — [2]Institute of Physics, University of Rostock, 18051 Rostock, Germany

Using time-dependent density field theory (TDDFT)[1] high harmonic generation (HHG) has been studied in one-dimensional structures of intermediate sizes from a single nucleus upto hundreds of nuclei. The well known HHG cutoff for atomic systems is observed to extent linearly with system size and is found to converge into previously observed cutoffs for bulk solids only for large systems. The change from atomic HHG to solid state HHG is observed from system sizes of 6-8 nuclei and is first fully converged at system sizes of 60 nuclei. The systems size dependence of the observed HHG cutoffs is found to follow the limitations of movement of classical electron-hole pairs in the band structure. Because of the correlation between recombination energy and electron-hole propagation length high energy recombination events are not possible in small systems, but become available for larger systems resulting in the change of the cutoff energies with system size. When varying the field intensity we observe that the cutoffs move linearly with the intensity even for small systems that are far from a true bulk solid.

Kenneth K. Hansen, Tobias Deffge, Dieter Bauer, *High-order harmonic generation in solid slabs beyond the single-active-electron approximation*, Phys. Rev. A 96, 053418 (2017).

15 min. break.

HL 26.8 Wed 11:30 EW 202

Lightwave-driven electron-hole recollisions in layered materials — •Christoph P. Schmid[1], Fabian Langer[1], Stefan Schlauder[1], Philipp Nagler[1], Tobias Korn[1], Christian Schüller[1], Peter G. Hawkins[2], Johannes T. Steiner[2], Ulrich Huttner[2], Stefan W. Koch[2], Mackillo Kira[3], and Rupert Huber[1] — [1]University of Regensburg, 93040 Regensburg, Germany — [2]University of Marburg, 35032 Marburg, Germany — [3]University of Michigan, Ann Arbor, Michigan 48109, USA

Utilizing intense light pulses to realize collisions of valence electrons

with their parent ion lies at the heart of high-harmonic generation and attosecond science. In solids, a similarly powerful collider scheme for quasiparticles would be highly desirable. Here, we demonstrate a sub-cycle quasiparticle collider. Electron-hole pairs are resonantly prepared in tungsten diselenide, while phase-controlled multi-THz waveforms accelerate and recollide them. This ballistic dynamics manifests itself in the emission of high-order sidebands, the spectra and sub-cycle time structure of which carry key information about the colliding quasiparticles, such as the excitonic binding energy. We also show that lightwave acceleration can not only change the translational motion of quasiparticles, but even control internal quantum attributes such as the spin and the valley pseudospin. We introduce this new paradigm by demonstrating lightwave-driven intervalley transport of valley-polarized electron-hole pairs in monolayer tungsten diselenide, opening a new pathway towards ultimately fast valleytronics at optical cycle scales.

HL 26.9 Wed 11:45 EW 202

Decay channels of the coherently excited A_{1g} phonon in antimony — •Sergej Krylow[1], Eeuwe S. Zijlstra[1], Fairoja Cheenicode Kabeer[2], Tobias Zier[1], Bernd Bauerhenne[1], and Martin E. Garcia[1] — [1]Universität Kassel, Theoretische Physik II — [2]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin

The analysis of phonon decay channels is of great importance in order to understand the dynamics of a system excited by an ultrafast laser pulse. Femtosecond laser excitation of Antimony generates a coherent A_{1g} phonon and, at the same time, softens the covalent bonds between the atoms. Both effects crucially affect the dynamics of antimony after laser excitation. It is in general difficult to disentangle the influence of both effects and to extract information about the decay channels of the coherent A_{1g} phonon. In this work we develop a method to analyze the phonon decay channels in ultrafast excited antimony using ab initio molecular dynamic simulations. Our simulations allow us to account for all phonon degrees of freedom, which was previously not possible. In particular we find, that at low excitation densities the dominating decay channel is a third order scattering process for which one A_{1g} phonon decays into two other phonons. At high excitation densities a fourth order scattering process becomes dominant for that two A_{1g} phonons decay into two phonons.

HL 26.10 Wed 12:00 EW 202

Laser-induced vacancy diffusion in silicon — •Tobias Zier and Martin E. Garcia — Theoretische Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Defects, like, vacancies and/or impurities in a crystal are an ambivalent topic in the scientific dialogue. On the one hand, it is tried to decrease the number of impurities due to the high efficiency of pure materials. On the other side well defined defects are the basis of promising new effects, like, NV centers in diamond as a possible one-photon emitter. Nevertheless, in both cases a controlled mobility of crystal defects is of high interest. In order to study the possibility to guide vacancies by femtosecond-laser pulses we performed ab initio molecular dynamics simulations of laser-excited silicon with a defect density of 3.5 %. Besides the changed mobility of the vacancies by the femtosecond-laser excitation we additionally analyzed their impact on ultrafast phenomena, like, nonthermal melting and thermal phonon squeezing.

HL 26.11 Wed 12:15 EW 202

Where are the "relaxors" and what are they doing? — •Wolfgang Donner[1], Florian Pforr[1], Kai-Christian Meyer[1], Marton Major[1], Karsten Albe[1], and Uwe Stuhr[2] — [1]Technische Universität Darmstadt, Germany — [2]Paul Scherrer Institut, Switzerland

We report on the nano-scale structure and picosecond dynamics of Ba-doped sodium bismuth titanate piezoelectrics. We used diffuse neutron scattering and a combination of Molecular Dynamics Simulation (MD) and Quasi-Elastic Neutron Scattering (QENS) to identify the origin of the frequency-dependence of the dielectric permittivity ("relaxor-behavior") in these materials. Despite the ps-range of the MD and QENS investigations, we assume that also lower frequency ranges of the permittivity are affected by the dynamics of the 20 nm sized tetragonal platelets which we identify as the "relaxors".

References: PRB 94, 014105 (2016), PRB 96, 184107 (2017)

HL 26.12 Wed 12:30 EW 202

Ultrafast electron dynamics in the nodal-line semimetal ZrSiSe — •Gianmarco Gatti, Alberto Crepaldi, Silvan Roth, and Marco Grioni — EPFL, Lausanne, Switzerland (CH)

ZrSiSe is a semimetal where metallic and linearly dispersing bulk conduction and valence bands cross each other along a closed nodal-line in the momentum space. The nonsymmorphic symmetry of the crystal protects the degeneracy of these bands along the whole Brilouin zone edge. Surface states, predicted by calculations and detected by angle-resolved photoemission spectroscopy (ARPES) also contribute to the electrical conduction of this material. A very fast relaxation dynamics of the order of 400 fs of both the bulk and the surface states is revealed by the means of time-resolved ARPES.

HL 26.13 Wed 12:45 EW 202

Phase-Filling Singularities in Femtosecond Transient Dielectric Spectra of Germanium — •Shirly Espinoza[1], Mateusz Rebarz[1], Steffen Richter[1], Oliver Herrfurth[2], Miroslav Kloz[1], Rudiger Schmidt-Grund[2], Jakob Andreasson[1], and Stefan Zollner[3] — [1]ELI Beamlines, Institute of Physics, Czech Academy of Science, Na Slovance 2, 18221 Prague, Czech Republic — [2]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstr. 5, 04103 Leipzig, Germany — [3]Department of Physics, New Mexico State University, Las Cruces, New Mexico 88003-8001, USA

By exciting semiconductors with ultra-short laser pulses and studying the non-equilibrium material, information about the band structure and the dynamics of the generation and relaxation of carriers can be obtained. Time-resolved ellipsometry allows the measurements of changes in the dielectric function of solid state materials in the femtosecond time-scale. In semiconductors, these changes can be assigned to several ultrafast processes such as carrier generation, band gap renormalization, Burstein-Moss shift, carrier-phonon scattering, carrier-carrier scattering, and phase filing singularities. This work presents recent results on femtosecond transient dielectric spectra of undoped Germanium at room temperature. The carriers were generated by the excitation with a 1.55 eV laser beam. The predicted Fermi singularity (Xu et al., Phys.Rev.Lett.118, 2017, 267402) was observed lasting a few picosenconds.

HL 27: Nitrides: Preparation and characterization II

Time: Wednesday 9:30–13:00 Location: EW 203

HL 27.1 Wed 9:30 EW 203

Structural and optical characterisation of germanium doped cubic AlxGa1-xN grown by molecular beam epitaxy — •Michael Deppe[1], Fabian Tacken[1], Jürgen W. Gerlach[2], Dirk Reuter[1], and Donat J. As[1] — [1]Universität Paderborn, Department Physik, Warburger Straße 100, 33098 Paderborn — [2]Leibniz-Institut für Oberflächenmodifizierung e.V., Permoserstraße 15, 04318 Leipzig

In the recent past, much work has been done in investigating germanium as an alternative n-type dopant in both wurtzite and zinc blende GaN. To extend the emission of nitride-based structures further into the ultraviolet spectral region, the ternary alloy $Al_xGa_{1-x}N$ can be employed. The mostly used donor for wurtzite and zinc blende $Al_xGa_{1-x}N$ is silicon and only little work on germanium-doping of $Al_xGa_{1-x}N$ has been published. In this contribution we report on the growth and characterisation of germanium-doped cubic $Al_xGa_{1-x}N$ layers with aluminium mole fractions $0 \leq x \leq 0.6$. The aluminium mole fraction x is determined both by high resolution X-ray diffraction and energy dispersive X-ray spectroscopy. Time-of-flight secondary ion mass spectrometry (TOF-SIMS) is used to verify and quantify the incorporation of germanium into the layers. Furthermore with increasing x an increasing amount of oxygen is observed by TOF-SIMS which causes additional n-type doping. Photoluminescence (PL) spectroscopy is performed at 13 K. Up to $x = 0.25$ the Ge-related emission exactly follows the direct band gap of cubic $Al_xGa_{1-x}N$. For higher x the PL emission sticks to a deep defect level 0.9 eV below the indirect band gap, which seems not to be related to the germanium doping.

HL 27.2 Wed 9:45 EW 203

Photoelectrochemical response of GaN, InGaN and GaNP nanowire ensembles — •Jan M. Philipps[1], Rene Couturier[1], Sara Hölzel[2], Pascal Hille[2], Jörg Schörmann[1], Irina A. Buyanova[3], Sangam Chatterjee[1], Martin Eickhoff[2], and Detlev M. Hofmann[1] — [1]Institute of Experimental Physics I, Justus Liebig University Giessen, 35392 Giessen, Germany — [2]Institute of Solid State Physics, University of Bremen, 28359 Bremen, Germany — [3]Department of Physics, Chemistry and Biology, Linköping University, S-581 83 Linköping, Sweden

The photoelectrochemical responses of GaN, GaNP and InGaN nanowire ensembles are investigated by electrical bias dependent photoluminescence, photocurrent and spin trapping experiments. The results are explained in the frame of the surface band bending model. The model is sufficient for InGaN nanowires, but for GaN nanowires electrochemical etching processes in the anodic regime have to be considered additionally. These processes affect the nanowire shape and lead to oxygen rich surface (Ga_xO_y) conditions as evident from transmission electron microscopy and the analysis of energy dispersive X-ray fluorescence. For the GaNP nanowires a bias dependence of the carrier transfer to the electrolyte is not reflected in the photoluminescence response, which is tentatively ascribed to a different origin of radiative recombination in this material as compared with (In)GaN. The corresponding consequences for the applications of the materials for water splitting or pH-sensing will be discussed.

HL 27.3 Wed 10:00 EW 203

Impact of Growth Interruption on the Structure and Luminescence of two- and zero-dimensional GaN/AlN Heterostructures — •Hannes Schürmann, Gordon Schmidt, Sebastian Metzner, Peter Veit, Frank Bertram, Christoph Berger, Jürgen Bläsing, Armin Dadgar, André Strittmatter, and Jürgen Christen — Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, 39106 Magdeburg, Germany

A systematic series of GaN/AlN quantum dot samples of different growth interruption (GRI) times after GaN deposition has been comprehensively investigated using scanning transmission electron microscopy (STEM) as well as cathodoluminescence (CL) spectroscopy directly performed in a STEM at LHe-temperatures. The sample set was grown by metal organic vapor phase epitaxy on an AlN/sapphire template. Few monolayers (ML) of GaN were grown on top of the smooth AlN surface with a dislocation density of $\sim 3\text{x}10^{10}$ cm^{-2}. Before capping with 100 nm AlN the GaN surface was exposed only to hydrogen carrier gas for different durations (0 s to 60 s). STEM-CL images of the sample without GRI exhibit hexagonally-shaped GaN islands of 20 nm height and ∼100 nm width located at dislocation bundles, which show no luminescence, and a continuous ∼1.8 nm thin GaN film with an intense emission band between 250 nm and 360 nm wavelength. With increasing growth interruption time, split up, smaller islands indicate desorption processes during the GRI. This GaN island emission now dominates, emitting in the range of 260 to 330 nm and the CL of the 1-2 ML thin GaN film is blue shifted (210 nm).

HL 27.4 Wed 10:15 EW 203

Charging of self-assembled GaN quantum dot ensembles by Capacitance-Voltage spectroscopy at room temperature — •Carlo A. Sgroi[1], Julien Brault[2], Jean Y. 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 a capacitance voltage (CV) measurement of charge-tunable self-assembled wurtzite GaN quantum dots (QDs) in an $Al_xGa_{1-x}N$ matrix at room temperature grown by MBE.

GaN and its alloys have excellent properties which makes them an ideal candidate for high power and high temperature microelectronic and QD storage devices, such as their thermal stability, high thermal conductivity and wide bandgap energies.

Due to polarization effects in wurtzite $GaN/Al_xGa_{1-x}N$ heterostructure layers the band structure is deformed. Band structure simulations were run to calculate a proper tunneling barrier and to estimate the quantum dot minimum to be close to the Fermi energy level with a sufficient lever arm to bring the QD energy levels in resonance with the Fermi energy.

Performing CV spectroscopy at room temperature we were able to evaluate a Coulomb blockade energy for electrons in the ground state of approximately 63 meV.

HL 27.5 Wed 10:30 EW 203

Pulsed reactive magnetron sputter deposition of AlN and GaN — •Florian Hörich, Christopher Kahrmann, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Otto-von-Guericke University Magdeburg

Crystalline AlN and GaN buffer layers are essential to grow complex nitride semiconductor heterostructures by epitaxial methods. Using the most common growth technique, metalorganic vapor phase epitaxy, pure AlN buffers are difficult to grow due to GaN deposits in the reactor. We report on the growth of AlN and GaN layers on sapphire (0001) and silicon (111) by pulsed reactive magnetron sputtering. The crystalline quality of the layers is investigated in dependance of the nucleation layer thickness and plasma composition during growth. Atomic force microscopy and X-ray diffraction methods were used for structural analysis. Sputtered GaN layers were first grown on MOVPE-GaN templates to acquire best sputtering parameters. Sputtering of GaN is more difficult than AlN because metallic Ga melts at 29 °C and then tends to splash Ga clusters into the chamber and onto the sample.

HL 27.6 Wed 10:45 EW 203

Direct comparison of structural and optical properties of GaN fin LED microstructure with nonpolar sidewalls — •G. Schmidt[1], P. Veit[1], S. Petzold[1], A. Dempewolf[1], T. Hempel[1], F. Bertram[1], J. Hartmann[2], H. Zhou[2], F. Steib[2], J. Ledig[2], S. Fündling[2], H.-H. Wehmann[2], A. Waag[2], and J. Christen[1] — [1]Institute of Experimental Physics, Otto-von-Guericke-University Magdeburg, Germany — [2]Institute of Semiconductor Technology and Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Germany

We present structural and optical properties of an InGaN/GaN core-shell fin grown by metal organic vapor phase epitaxy (MOVPE) on GaN/sapphire template covered with a patterned SiO_x-mask. The MOVPE process results in selective area growth of Si-doped GaN walls out of the mask openings oriented in m-direction. Enveloping the n-GaN core, an InGaN layer as active region was grown with stepwise decreasing temperature. The fin was completed by a GaN:Mg cover.

Using highly spatially resolved cathodoluminescence (CL) microscopy, we give a direct insight into the optical properties of the individual core-shell layers. The GaN:Si core exhibits drastically low CL intensity above the mask opening. The epitaxially lateral overgrown region over the mask shows high intensity of the GaN near band edge emission. The InGaN region exhibits the highest CL intensity between 370 nm and 450 nm wavelengths. As expected, a redshift of the InGaN emission towards the fin side wall surface was resolved indicating the continuous increase of In-incorporation.

15 min. break.

HL 27.7 Wed 11:15 EW 203

MOVPE growth of large area InGaN LEDs with GaN-based tunnel junctions — •Silvio Neugebauer, Christoph Berger, Florian Hörich, Christopher Kahrmann, Jürgen Bläsing, Armin Dadgar, and André Strittmatter — Institut für Experimentelle Physik, Otto-von-Guericke-University Magdeburg, Germany

Improving current injection in nitride-based devices is an important task to further enhance the efficiencies of light emitting devices. One limiting factor is the low hole mobility in Mg-doped GaN which hampers lateral current spreading in conventional p/n-junction devices. In order to maintain high optical output power, non-epitaxial transparent and semi-transparent contact schemes are widely employed to inject holes into the p-side region. Still, the use of such current spreading layers is limited in terms of lateral conductivity and optical transparency. Epitaxial growth of GaN-based p/n tunnel junctions (TJs) structures is an attractive alternative to improve lateral current spreading in LEDs and VCSELs. However, the effectiveness of the MOVPE grown TJ is limited by the achievable donor and acceptor concentrations as well as the activation of the buried Mg-doped layer. In this study we have grown tunnel junction structures on top of conventional LEDs in a single growth process. The influence of thermal activation and individual parameter variations for the n- and p-type doping within the tunnel junction were analyzed in terms of current-voltage characteristics and light output of processed 1 mm^2 LED devices and compared to the performance of a reference LED with Ni/Au contacts.

HL 27.8 Wed 11:30 EW 203

X-ray diffraction studies of zincblende GaN — •Martin Frentrup[1], Lok Yi Lee[1], Suman-Lata Sahonta[1], Menno J. Kappers[1], Rachel A. Oliver[1], Colin J. Humphreys[1], and David J. Wallis[1,2] — [1]Department of Materials Science and Metallurgy, University of Cambridge, UK — [2]Centre for High Frequency Engineering, University of Cardiff, UK

A possible approach in solving the green gap problem is the growth of III-nitrides in the cubic zincblende phase (zb) with its non-polar nature and reduced bandgap compared to the common wurtzite (wz) GaN phase. However, the relative metastability of the zb phase and low stacking-fault energy, lead to phase mixing and incorporation of planar defects. XRD texture maps of our GaN thin films on 3C-SiC/Si reveal that under optimised MOVPE growth conditions the zb phase can be stabilized as the dominant phase. In non-optimised thin films distorted hexagonal-like reflection patterns were observed originating from a low concentration of wz phase inclusions. Our results also indicate that depending on the template miscut, the growth of wz-like inclusions may occur preferentially along certain directions. Following growth optimisation the hexagonal patterns were very weak with intensities only slightly above the noise level. Reciprocal space maps revealed that these signals are caused by diffuse scattering from stacking faults, while reflections from the wz phase could not be observed.

The presence of dominant cubic phase was also confirmed by TEM measurements, showing a periodic ... AaBbCc ... stacking of the atomic layers typical for the cubic zb structure.

HL 27.9 Wed 11:45 EW 203

Selective area growth of GaN-ZnO core-shell nanowires for photocatalytic CO2 reduction — •Florian Pantle, Max Kraut, Julia Winnerl, Marvin Koch, and Martin Stutzmann — Walter Schottky Institut and Physics Department, Technische Universität München, Garching, Germany

GaN nanowires (NWs) have gained increasing interest as a promising system for photocatalytic water splitting and CO2 reduction due to their large surface-to-volume ratio and the favorable energy position of their bands with respect to many reduction or oxidation reactions. Compared to self-assembled growth, selective area epitaxy of NWs provides a better control over the electronic properties and the active surface area of such NWs due to the well-defined NW diameter and inter NW distance. We present the selective area growth of p-GaN core/n-ZnO shell NWs by plasma assisted molecular beam epitaxy with a shell thickness in the 10 nm range. We have performed photoluminescence and Raman spectroscopy measurements to investigate the optical and structural properties of the as-grown NW heterostructures and numerical simulations of their band structure. The internal field provided by the p-GaN/n-ZnO heterojunction improves the funneling of photo-excited conduction band electrons towards the surface, while the ZnO shell may act as a co-catalyst for CO2 reduction.

HL 27.10 Wed 12:00 EW 203

Parametric model for the anisotropic dielectric function of m-plane AlGaN up to 20eV — •Michael Winkler[1], Martin Feneberg[1], Shigefusa F. Chichibu[2], Ramón Collazo[3], Zlatko Sitar[3], Maciej D. Neumann[4], Norbert Esser[4], and Rüdiger Goldhahn[1] — [1]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Japan — [3]Department of Materials Science and Engineering, North Carolina State University, USA — [4]Leibniz-Institut für Analytische Wissenschaften - ISAS, Berlin, Germany

The linear optical response of nonpolar $(10\bar{1}0)$ (m-plane) $Al_xGa_{1-x}N$ epitaxial films was analyzed quantitatively for the full composition range. The samples were grown by metal-organic vapor phase epitaxy and molecular beam epitaxy on m-plane freestanding GaN and AlN substrates. Spectroscopic ellipsometry up to 20eV was measured at the synchrotron Metrology Light Source (MLS) of the PTB in Berlin for each sample. Using a point-by-point fit the ordinary and the extraordinary dielectric functions were obtained.

These data were used to fit the parameters for an ordinary and extraordinary model DF $\varepsilon_{\perp,\parallel}(x, \hbar\omega)$ in the spectral range from 0.7eV to 20eV, where the AlN-concentration x can be chosen arbitrarily. The model DF compares well with previous results for the ordinary DF and with the position of the high energy interband transitions.

HL 27.11 Wed 12:15 EW 203

Effects of well width on the recombination dynamics in m-plane GaInN/GaN quantum wells — •Philipp Henning, Fedor Alexej Ketzer, Philipp Horenburg, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

In this contribution we discuss the dependence of carrier recombination dynamics on quantum well width in nonpolar structures. For this purpose a set of m-plane GaInN/GaN quantum wells (QWs) with low indium content ($\leq$ 10 %) and varying QW width (1...6 nm) is grown by MOVPE on GaN pseudo bulk substrates and measured by time-resolved photoluminescence spectroscopy. We find a single-exponential PL decay and large radiative recombination rates at low temperatures. The corresponding lifetimes of about 500 ps stay constant for all QW widths, which is expected for nonpolar structures due to the absence of internal polarization fields that would reduce the wave function overlap for wider wells. Furthermore, we discuss the behavior of the radiative recombination at elevated temperatures, where the increase in radiative lifetime varies with changing QW width. Additionally, a sharp drop in the nonradiative lifetime can be observed in the measurements, which is unexpected due to the low indium content and the high-quality substrates. The lifetimes at room-temperature are of the order of 100 ps or below, clearly showing the dominance of nonradiative recombination. Dislocations originating from the substrate and penetrating through the QW are relatively rare, indicating that defects form during the QW growth.

HL 27.12 Wed 12:30 EW 203

Time-integrated and time-resolved luminescence studies of 3D InGaN/GaN microrod and fin heterostructures — Angelina Vogt[1], Jana Hartmann[1,2], Hao Zhou[1,2], Felix Blumenröther[1], Hergo-Heinrich Wehmann[1,2], Andreas Waag[1,2], and •Tobias Voss[1] — [1]Institute of Semiconductor Technology and Laboratory for Emerging Nanometrology, TU Braunschweig, 38092 Braunschweig, Germany — [2]Epitaxy Competence Center, ec2, 38092 Braunschweig, Germany

Three-dimensional (3D) GaN-based structures allow for the integration of InGaN quantum wells (QWs) on their non-polar sidewalls while keeping the material free of extended defects. Thus, they represent a promising approach for next generation LEDs. In order to optimize the internal quantum efficiency (IQE) of the 3D heterostructures, a detailed knowledge of the radiative and non-radiative recombination channels and their rates is required. We compare the spectrally and temporally resolved photoluminescence (PL) and cathodoluminescence (CL) of InGaN QWs of 3D microrod and fin (microwalls) heterostructures. Both were grown by continuous selective area MOVPE. We analyse the homogeneity of the indium in the QWs along the height of the structures and the length of the fins with time-integrated PL and CL measurements. The dynamics are investigated by time-resolved PL measurements at different sample temperatures. The InGaN luminescence of the 3D structures show decay times in the order of 200 ps and just a weak influence of the quantum confined Stark effect due to the QW growth mainly on the non-polar sidewalls.

HL 27.13 Wed 12:45 EW 203

Fe-doped GaN a suitable material for antiferromagnetic spintronics? — •Andrea Navarro-Quezada[1,2], Thibaut Devillers[1], Tian Li[3], Andreas Grois[1], Maciej Sawicki[3], Tomasz Dietl[3], and Alberta Bonanni[1] — [1]Semiconductor and Solid State Physics, Johannes Kepler Universität, Linz, Austria — [2]Institute of Experimentalphysics, Johannes Kepler Universität, — [3]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

The control over the aggregation of magnetic ions in a non-magnetic semiconductor matrix constitutes a new way to realize semiconductor/ferromagnetic nanocomposites with yet unexplored but striking functionalities. In this work we show that it is possible to obtain a controlled and well-defined arrangement of single-phase magnetic GaxFe4-xN nanocrystals (NCs) embedded in a GaN matrix [1]. Depending on the fabrication conditions, a modification of the lattice parameter of the NCs is observed, pointing to the incorporation of Ga into the Fe4N structure and therefore, to the formation of GaFe3N. While Fe4N is a strong FM semi-metal with minority spin-polarization, GaFe3N is a weak AFM material. Our results open the perspectives of this magnetic semiconductor for the demonstration of interesting effects such as spin-pumping for spin current injectors/detectors, anisotropic magnetoresistance and the manipulation of the NCs magnetic moment via an electric field [2].

[1] A. Navarro-Quezada et al., Appl. Phys. Lett. 101, 081912 (2012)
[2] D. Sztenkiel et al., Nature Communications 7, 015034 (2017)

HL 28: 2D materials: Chalcogenides I (joint session HL/DS)

Time: Wednesday 9:30–13:15 Location: A 151

HL 28.1 Wed 9:30 A 151

Theory of Strain-Induced Confinement in Transition Metal Dichalcogenide Monolayers — •Matthew Brooks and Guido Burkard — Universität Konstanz, Konstanz

Recent experimental studies of out-of-plane straining geometries of transition metal dichalchogenide (TMD) monolayers have demonstrated sufficient band gap renormalisation for device application such as single photon emitters. Here, a simple continuum-mechanical plate-theory approach is used to estimate the topography of TMD monolayers layered atop nanopillar arrays. From such geometries, the induced conduction band potential and band gap renormalisation is given, demonstrating a potential shape that is independent of the height of deforming nanopillar. Additional, with a semi-classical WKB approximation, the expected leakage of the strain potential may be estimated as a function of the height of the deforming nanopillar. This straight forward approach is in accordance with experiment, supporting recent findings suggesting that nanopillar height improves linewidth of the single photon emitters observed at the tip of the pillar, yet has no discernible influence over the wavelengths of the emitted photons.

HL 28.2 Wed 9:45 A 151

the role of dark exciton states in magneto-exciton valley depolarisation mechanisms In monolayer transition metal dichcalcogenides — •Alexander Pearce and Guido Burkard — Universität Konstanz, Konstanz, Germany

We present a theoretical study of the valley magneto-exciton relaxation dynamics in monolayer transition metal dichcalcogenides (TMDs) using a kinetic equation approach. The TMDs are direct band gap semiconductors with strong light-matter coupling which produce optical responses dominated by tightly bound excitons. The combination of the lattice symmetry and strong spin-orbit interaction gives rise to a rich selection rules allowing for optical control of the excitons valley polarisation. Experiments have shown that due to spin-orbit interactions there are spin forbidden transitions which lead to dark exciton states, and these states are found to possess long lifetimes due to their non-radiative decay and play a role in the depolarisation dynamics of the TMDs. Using a kinetic equation approach we investigate the interplay of the exchange interaction, a perpendicular magnetic field and the dark state scattering the time evolution of the exciton valley polarisation. We find that the influence of the dark states leads to longer valley relaxation times. We also explore the effect of an in-plane magnetic, which acts to "brighten" the dark states, which leads to an even greater increase in the valley relaxation time.

HL 28.3 Wed 10:00 A 151

Strain on molybdenum disulfide sheets with defects from first principles — •Mohammad Bahmani[1], Mahdi Faghihnasiri[2], and Thomas Frauenheim[1] — [1]BCCMS, Physics Department, Bremen University, Bremen, Germany — [2]Physics Department, Shahrood University of Technology, Shahrood, Iran

Single layer of transition metal dichalcogenides(TMDCs) are under intense investigations since the discovery of unique characteristics of 2D and Vann der Waals layered materials. They are predicted to be the most promising structure for various future nanoscale devices. They have also novel applications in spintronic and optoelectronic.

As a result of thermal equilibrium and the kinetics of processing, all real materials contain structural defects which show significant effects on their electrical, optical, vibrational, magnetic, and chemical properties. Besides, mechanical strain has very much influence on the electronic properties of 2D materials, particularly TMDCs. For example, 0.5% biaxial strain force direct band gap in molybdenum disulfide(MoS2) to become indirect since it breaks the crystalline symmetry.

Therefore, I study different types of point defects such as single and double sulfur(S), single molybdenum(Mo) vacancies, and removing a Mo with its three upper S neighbors. I also substitute a Mo vacancy with one and two S atoms. Furthermore, as the second aim of this study, I showed the modification of defect states under uniaxial and biaxial compression and tensile strain. For the case of one S vacancy, this moves shallow states into the valance band and importantly breaks the degeneracy of degenerate states.

HL 28.4 Wed 10:15 A 151

Optical absorption of a mechanically strained WSe_2 monolayer — •Iris Niehues[1], Robert Schmidt[1], Robert Schneider[1], Matthias Drüppel[2], Torsten Deilmann[2], Michael Rohlfing[2], Steffen Michaelis de Vasconcellos[1], Andres Castellanos-Gomez[3], and Rudolf Bratschitsch[1] — [1]Physikalisches Insitut, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster — [3]Materials Science Factory, Instituto de Ciencia de los Materials de Madrid (ICMM-CSIC), E- 28049 Madrid

Atomically thin layers of transition metal dichalcogenides represent a new class of materials. Strain engineering allows to tune their fundamental optical transitions. We apply reversible uniaxial tensile strain of up to 1.4% to a WSe_2 monolayer. At increasing and decreasing tensile strain levels absorption spectra are recorded, and the strain-dependent energy shifts of the exciton resonances are measured[1]. Gauge factors of $-54\,\mathrm{meV/\%}$, $-50\,\mathrm{meV/\%}$, $+1\ \mathrm{meV/\%}$, and $-22\,\mathrm{meV/\%}$ are derived for the A, B, C, and D exciton, respectively. A comparison with ab initio *GW*-BSE calculations shows an excellent agreement with the measured data.

[1] R. Schmidt, I. Niehues, R. Schneider, M. Drüppel, T. Deilmann, M. Rohlfing, S. Michaelis de Vasconcellos, A. Castellanos-Gomez, and R. Bratschitsch, Reversible uniaxial strain tuning in atomically thin WSe_2 in: 2D Materials 3, 021011 (2016)

HL 28.5 Wed 10:30 A 151

Tunable electron-phonon interaction in MoS2 — •Max Bommert[1], Bastian Miller[1,2], Alexander Holleitner[1,2], and Ursula Wurstbauer[1,2] — [1]Walter Schottky Institute and Physics Department, Technical University of Munich, Am Coulombwall 4a, 85748 Garching, Germany — [2]Nanosystems Initiative Munich (NIM), Schellingstr. 4, 80799 Munich, Germany

Transition metal dichalcogenides such as MoS2 are of current interest for optoelectronic application, as well as for studying fundamental aspects of light-matter interaction and excitonic properties in strictly two-dimensional semiconductors. We explore the impact of the charge carrier density on the electron phonon interaction by non-resonant and resonant Raman spectroscopy. We utilize MoS2 field effect structures with solid electrolyte and liquid ion gates, enabling a change of the 2D electron density by more than two orders of magnitude [1]. We report unusual polarization and charge carrier dependent behavior in resonant Raman spectra that points towards strong electron-phonon coupling in MoS2 and the importance of excitonic phenomena [2]. Alongside we investigate temperature dependent phase transitions through changes in transport and optical properties.

[1] Miller et al., APL 106, 122103 (2015)
[2] Miller, Bommert et al. (2018)

HL 28.6 Wed 10:45 A 151

Theory of Exciton-Exciton Interactions in Monolayer Transition Metal Dichalcogenides — •Florian Katsch, Malte Selig, Alexander Carmele, and Andreas Knorr — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik von Halbleitern, Technische Universität Berlin, 10623 Berlin, Germany

Due to the strong Coulomb interaction in monolayers of transition metal dichalcogenides (TMDs), the optical properties are governed by tightly bound electron-hole pairs in the vicinity of the band edge. In order to allow for efficient modeling, a theoretical description in a two particle exciton basis based on the unit-operator method [1] is introduced. The formalism incorporates TMD-typical Coulomb inter- and intravalley interactions up to three correlated excitons. The developed theory is applied to access the exciton dynamics [2,3] in the so-called coherent limit as well as exciton-phonon interactions [4]. The derived TMD Bloch equations contribute to the understanding of recent pump-probe experiments observing an immediate signal in the unpumped valley [5,6].

[1] A. L. Ivanov and H. Haug, *Physical Review B* **48**, 1490 (1993).
[2] V. M. Axt and A. Stahl, *Zeitschrift für Physik B Condensed Matter* **93**, 2 (1994).
[3] M. Lindberg et. al., *Physical Review B* **50**, 18060 (1994).
[4] M. Selig et. al., *Nature communications* **7**, 13279 (2016).

[5] C. Mai et. al., *Nano letters* **14**, 202 (2013).
[6] R. Schmidt et. at., *Nano letters* **16**, 2945 (2016).

HL 28.7 Wed 11:00 A 151

Optical spectra and bound excitons in MoTe2 from monolayer to bulk by many-body perturbation theory — •Saeideh Edalati-Boostan, Caterina Cocchi, and Claudia Draxl — Physics Department and IRIS Adlershof, Humboldt-Universität zu Berlin, Germany

Among the transition-metal dichalcogenides, MoTe2 plays a relevant role as a good candidate for light-emitting devices. In the framework of GW and the Bethe-Salpeter equation as implemented in the exciting code [1], we study optical excitations in this material as a function of dimensionality, going from mono- and bilayers to the bulk. The role of spin-orbit coupling is assessed in band structures and optical spectra with respect to the number of layers. The calculated absorption spectra are characterized by a few bound excitons in the visible region with binding energies of the order of a hundred meV [2]. Bound electron-hole pairs, which are known to be both inter- and intra-layer in bulk MoTe2 [2], are analyzed in view of quantum confinement effects. This understanding is essential to eventually use this material in van der Waals heterostructures.

[1] A. Gulans, S. Kontur, C. Meisenbichler, D. Nabok, P. Pavone, S. Rigamonti, S. Sagmeister, U. Werner, and C. Draxl, JPCM 26, 36 (2014); D. Nabok, A. Gulans, and C. Draxl, PRB 94, 035118 (2016); S. Sagmeister, and C. Draxl, PCCP 11, 4451 (2009)
[2] A. Arora, M. Drüppel, R. Schmidt, T. Deilmann, R. Schneider, M. R. Molas, Ph. Marauhn, S. M. de Vasconcellos, M. Potemski, M. Rohlfing, and R. Bratschitsch, Nat Commun. 8, 639 (2017)

15 min. break.

HL 28.8 Wed 11:30 A 151

Thermal annealing effects on optical properties of 2D MoS_2 — •Oleg Gridenco, Kathrin Sebald, Christian Tessarek, Martin Eickhoff, and Jürgen Gutowski — Institute of Solid State Physics, University of Bremen, Germany

Mechanically exfoliated monolayers obtained by using natural crystals and deposited by a polymer transfer process on substrates suffer from residues on the surface which are hard to be removed. The residues as well as absorbed O_2 and H_2O at the surface of a monolayer are known to modify the optical and electrical properties resulting in a quenching of the photoluminescence (PL) and a reduction of the carrier mobility. We present a systematic thermal annealing study conducted by heating and laser annealing in order to remove such residues. The results show that the PL energy is blue-shifted and the PL intensity is enhanced by a factor of 1.8 after a thermal annealing cycle. The blue-shift points to a reduction of the trion contribution and a relative increase of free-exciton recombination. In addition, the overall PL enhancement can be related to a decrease of non-radiative recombination processes. A similar behaviour of the PL is observed after MoS_2 monolayers were exposed to UV laser irradiation for several seconds. The study provides a low-cost, large scale and effective route to enhance the PL efficiency which is important for the device performance.

HL 28.9 Wed 11:45 A 151

Spatiotemporal dynamics of the carrier capture into localized states in a TMDC monolayer — •Roberto Rosati, Frank Lengers, Doris E. Reiter, and Tilmann Kuhn — Institut für Festkörpertheorie, Universität Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

Monolayers of transition metal dichalcogenides (TMDC) have attracted wide attention due to their interesting optical and electronic properties. Local strain distributions lead to the formation of embedded 0D confinement potentials which can be exploited, e.g., as single photon sources [1]. In such hybrid 2D-0D systems, the bound states of the 0D potential may be populated through carrier capture by emission of optical phonons. Such capture processes are known to generate non-trivial spatiotemporal dynamics in hybrid 1D-0D systems [2]. In this work we study the capture of a wave packet in a MoSe2 monolayer into localized states. We find interesting spatio-temporal dynamics of the trapped charge distribution associated with the capture into specific superposition states, which can be controlled by the propagation direction of the wave packet. To calculate the dynamics we use a recently introduced Lindblad single-particle approach, which allows us to deal with the dimensionality-related computational demands and, at the same time, catches the most relevant features of the carrier capture, in particular its locality [3].

[1] Kern et al., Adv. Mater., **28**, 7101-7105 (2016)
[2] Glanemann et al., Phys. Rev. B **72**, 045354 (2005)
[3] Rosati et al., Phys. Rev. B **95**, 165302 (2017)

HL 28.10 Wed 12:00 A 151

Strong Anisotropic Spin-Orbit Interaction Induced in Graphene by Monolayer WS2 — •Taro Wakamura[1], Francesco Reale[2], Pawel Palczynski[2], Cecilia Mattevi[2], Sophie Guéron[1], and Hélène Bouchiat[1] — [1]Laboratoire de Physique des Solides, Université Paris-Sud, Orsay, France — [2]Department of Materials, Imperial College London, London, United Kingdom

We demonstrate strong anisotropic spin-orbit interaction in graphene induced by monolayer WS2. Direct comparison between graphene/monolayer WS2 and graphene/bulk WS2 system in magnetotransport measurements reveals that monolayer transition metal dichalcogenide can induce much stronger SOI than bulk. Detailed theoretical analysis of the weak-antilocalization curves gives an estimated spin-orbit energy (Eso) more than 10 meV. The dominant z to -z symmetric spin-orbit interaction demonstrates strong valley-Zeeman spin-orbit interaction induced in graphene, consistent with the recent theoretical study. Dramatic increase of resistance around the Dirac point with decreasing temperature suggests the existence of the spin-orbit gap at the Dirac point.

HL 28.11 Wed 12:15 A 151

Electronic and optical properties of group-IV transition metal dichalcogenides monolayers and their heterostructures — •Ka Wai Lau, Caterina Cocchi, and Claudia Draxl — Physics Department and IRIS Adlershof, Humboldt-Universität zu Berlin, Germany

The interest in transition-metal dichalcogenides (TMDs) monolayers as promising materials for opto-electronics has rapidly increased in the last few years [1]. The majority of studies has been devoted so far to group-VI TMDs, with MoS2 and WS2 as the most relevant examples of this material class [1]. Here, we study monolayers of group-IV TMDs focusing on ZrS2 and HfS2. We investigate their electronic and optical properties in the framework of many-body perturbation theory (GW and the Bethe-Salpeter equation) as implemented in the all-electron full-potential code exciting [2]. The optical response of these systems is characterized by intense peaks in the visible region due to tightly-bound excitons with binding energies of the order of hundreds of meV. The degeneracy of the hole state at the Γ point with different dispersion along the M-Γ-K direction and the strong spin-orbit coupling in the valence band leads to several distinct excitonic states around Γ. Finally we study van-der-Waals heterostructures obtained by combining ZrS2 and HfS2 monolayers in view of understanding how different stacking patterns influence band alignment and optical excitations.

[1] K. F. Mak and J. Shan, Nat. Photon. 10, 216 (2016)
[2] A. Gulans et al., J. Phys.: Condens. Matter 26, 363202 (2014)

HL 28.12 Wed 12:30 A 151

Persistent photoconductivity in monolayer MoS_2 field effect transistors after UV irradiation — •Antony George[1], Mikhail Fistul[2,3], Uwe Hübner[4], Nirul Masurkar[5], David Kaiser[1], Christof Neumann[1], Andreas Winter[1], Arava Leela Mohana Reddy[5], and Andrey Turchanin[1] — [1]Friedrich Schiller University Jena, Institute of Physical Chemistry, 07743 Jena, Germany — [2]Center for Theoretical Physics of Complex Systems, Institute for Basic Science, Daejeon 34051, Republic of Korea — [3]Russian Quantum Center, National University of Science and Technology "MISIS", 119049 Moscow, Russia — [4]Leibniz Institute of Photonic Technology, 07745 Jena, Germany — [5]Department of Mechanical Engineering, Wayne State University, 48202 Detroit, USA

We demonstrate long living photo-excited charge carriers in monolayer MoS_2 field effect transistors (FET) after UV irradiation. After irradiation, the FETs were found to be remaining in a high conductivity state at room temperature (RT) for a long time (ca. 30 days). We investigated the origin of the persistent photoconductivity (PPC) combining RT and low-temperature transport measurements with theoretical modeling. At low temperatures, a great enhancement of photo-induced conductivity with applied gate voltage was observed. We ascribe this to the UV irradiation of MoS_2, which results in inter-band transitions and the creation of a large number of electron-hole pairs, which are quickly spatially separated due to local variations of the band structure. Under such conditions, the recombination time drastically increases and

induces the PPC effect.

HL 28.13 Wed 12:45 A 151

Highly polarized excitons in atomically thin and bulk-like 1T'-ReSe$_2$ — •A. Arora[1], J. Noky[2], M. Drüppel[2], B. Jariwala[3], T. Deilmann[4], R. Schneider[1], R. Schmidt[1], O. Del Pozo-Zamudio[1], T. Stiehm[1], A. Bhattacharya[3], P. Krüger[2], S. Michaelis de Vasconcellos[1], M. Rohlfing[2], and R. Bratschitsch[1] — [1]Institute of Physics, University of Münster, Wilhelm-Klemm-Strasse 10, 48149 Münster, Germany — [2]Institute of Solid State Theory, University of Münster, D-48149 Münster, Germany — [3]Tata Institute of Fundamental Research, Homi Bhabha Road, Colaba, Mumbai 400005, India — [4]Department of Physics, Technical University of Denmark, DK-2800 Kongens Lyngby, Denmark

Using low-temperature polarized optical absorption and photoluminescence spectroscopy, supported by GW-BSE ab initio calculations, we investigate excitons in the van der Waals semiconductor 1T'-ReSe$_2$ [1]. A red shift of the excitonic transition energy is observed when the crystal thickness is reduced from bulk towards a monolayer. The excitons exhibit a strong polarization anisotropy within the plane of the crystal, with dipole vectors pointing towards different crystal directions. This polarization behavior persists from bulk to monolayer thickness. We find that the excitons are strongly confined within the individual crystal layers, even for the bulklike case. We find a direct band gap in 1T'-ReSe$_2$ in our calculations, regardless of the crystal thickness. Our results pave the way for polarization-sensitive applications using two-dimensional semiconductors. [1] A. Arora et al., Nano Lett. 17, 3202-3207 (2017).

HL 28.14 Wed 13:00 A 151

The Influence of the environment on monolayer tungsten diselenide photoluminescence — •Lorenz Maximilian Schneider[1], Sina Lippert[1], Jan Kuhnert[1], Obafunso Ajayi[2], Dylan Renaud[1], Young Duck Kim[2,3], Wolfram Heimbrodt[1], James C. Hone[2], and Arash Rahimi-Iman[1] — [1]Department of Physics and Material Sciences Center, Philipps-Universität Marburg, 35032 Marburg , Germany — [2]Department of Mechanical Engineering, Columbia University, 10027 New York, USA — [3]Department of Physics and Center for Humanities and Sciences, Kyung Hee University, 02447 Seoul, Republic of Korea

In recent years, two-dimensional (2D) semiconductors have drawn a lot of attention due to their special properties. Since transition metal dichalgogenides (TMDs) are a potential candidate for opto-electronic applications in the visible range, they are of major interest and subject of many studies. Recent investigations have shown that encapsulating monolayers with hBN can improve signal quality greatly compared to flakes grown or exfoliated on common substrates. Here, we present a systematic study of the effects, that such encapsulation of monolayers with mainly hBN can have on the 2D material's optical properties using WSe_2. Besides the already known narrowing of the PL-linewidth, remarkable differences are found in the time evolution. hBN supported and encapsulated samples show a significantly stronger exciton-exciton annihilation as the reference samples on bare substrate. Furthermore, we show that this effect is also obtained if the heterostructure consists of two TMDs.

HL 29: Focussed Session: Metasurfaces I

Metasurfaces are optical components, which rely on metamaterials, but are further confined below the wavelength in the direction of light propagation. The ability of metasurfaces to manipulate wavefronts arises fundamentally from the optical responses of the individual nanoparticles that comprise the surface. This response is dominated by the morphological resonances of the particles, which depend on the size, shape, material composition, and environment of the particles. For metal particles the resonances have a plasmonic character, whereas for dielectric particles several Mie-type multipoles can contribute. Such resonances can also lead to strong local optical fields near (metallic) or even inside (dielectric) the particles. Such local-field enhancement is crucial for a number of potential applications of metasurfaces, including nonlinear optics, tunable optics, and sensing.

Organizers: Isabelle Staude and Carsten Ronning (U Jena)

Time: Wednesday 15:00–18:30 Location: EW 201

Invited Talk HL 29.1 Wed 15:00 EW 201

Device Applications of Metafilms and Metasurfaces — •Mark Brongersma — Stanford

Many conventional optoelectronic devices consist of thin, stacked films of metals and semiconductors. In this presentation, I will demonstrate how one can improve the performance of such devices by nanostructuring the constituent layers at length scales below the wavelength of light. The resulting metafilms and metasurfaces offer opportunities to dramatically modify the optical transmission, absorption, reflection, and refraction properties of device layers. This is accomplished by encoding the optical response of nanoscale resonant building blocks into the effective properties of the films and surfaces. To illustrate these points, I will show how nanopatterned metal and semiconductor layers may be used to enhance the performance of solar cells, photodetectors, and enable new imaging technologies. I will also demonstrate how the use of active nanoscale building blocks can facilitate the creation of active metafilm devices.

Invited Talk HL 29.2 Wed 15:30 EW 201

Harmonic generation and photon management at the nanoscale in AlGaAs nanoantennas — •Costantino De Angelis[1], Dragomir Neshev[2], Luca Carletti[1], Lavinia Ghirardini[3], Davide Rocco[1], Valerio Gili[4], Giovanni Pellegrini[3], Marco Finazzi[3], Andrea Locatelli[1], Ivan Favero[4], Giuseppe Marino[4], Michele Celebrano[3], and Giuseppe Leo[4] — [1]Department of Information Engineering, University of Brescia, 25123 Brescia, Italy — [2]Nonlinear Physics Centre, The Australian National University, Canberra ACT 2601, Australia — [3]Department of Physics, Politecnico di Milano, 20133 Milano, Italy — [4]Matériaux et Phénomènes Quantiques, Université Paris Diderot, 75013 Paris, France

High-permittivity semiconductor resonators are emerging as potential platforms for nonlinear nanophotonics due to a rich variety of resonances, lossless operation, and strong volume nonlinearity. Harnessing these aspects can lead to efficient and controlled nonlinear light generation in nanoscale devices. In this work, we review recent advances for efficient frequency conversion and tunable control of the spatial and polarization properties of the emitted photons exploiting second order nonlinear processes in AlGaAs nanoantennas. By means of both numerical and experimental approaches, we demonstrate dynamic control over the directionality of the second harmonic radiation pattern generated in nanodisks by varying the angle of incidence of the pump beam and the shape of nanoresonator.

HL 29.3 Wed 16:00 EW 201

Broadband Laguerre-Gaussian Metasurfaces and Direct Phase Mapping — •Alexander Fassbender[1], Jiří Babocký[2], and Stefan Linden[1] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms Universität Bonn, Nußallee 12, D-53115 Bonn, Germany — [2]Institute of Physical Engineering, Brno University of Technology, Technická 2, CZ-616 69 Brno, Czech Republic

We demonstrate metasurfaces based on off-resonant optical scatterers generating Laguerre-Gaussian modes. These modes are characterized by a helical phase profile with radial discontinuities. The metasurfaces are based on gold rods with a length of 220 nm which modify the properties of circular polarized waves. More specifically, the local phase of

the scattered light with the opposite helicity can be controlled by the orientation of the rods relative to a reference axis. To accomplish a helical phase gradient, the orientation of the rods placed on a circle around the metasurface center rotates by multiples of π per turn. To achieve radial discontinuities, neighboring rods are shifted by $\pi/2$. Since the rods are not required to be driven in resonance, this metasurface allows for a broadband operation in the visible and near-infrared regime. Our interferometric measurements reveal a spiral phase distribution resulting from the introduced helical phase profile. We further present a multifunctional metasurface that coalesces the properties of two conventional optical elements. It generates a doughnut-shaped intensity pattern in combination with the focusing property of a lens. The phase distribution of the beam is measured in two and three dimensions by a holographic microscope and the method of digital holography.

HL 29.4 Wed 16:15 EW 201

Manipulation of electric and magnetic dipole emission from Eu3+ with silicon metasurfaces — •Aleksandr Vaskin[1], Soheila Mashhadi[2], Natalia Noginova[2], Katie. E. Chong[3], Stefan Nanz[4], Aimi Abass[4], Ivan Fernandez-Corbaton[4], Evgenia Rusak[3,4], Mikhail A. Noginov[2], Yuri S. Kivshar[3], David Keene[2], Carsten Rockstuhl[4], Thomas Pertsch[1], Dragomir Neshev[3], and Isabelle Staude[1] — [1]Friedrich Schiller University Jena, Jena, Germany — [2]Norfolk State University, Norfolk, USA — [3]The Australian National University, Canberra, Australia — [4]Karlsruhe Institute of Technology, Karlsruhe, Germany

Mie-resonant dielectric nanoparticles were theoretically predicted to provide a viable platform for enhancing both electric and magnetic dipole transitions. While the electric dipole transition enhancement by dielectric nanoparticles was experimentally demonstrated, the case of magnetic dipole transition remains to be explored. We study enhancement of spontaneous emission of Eu3+ ions featuring electric (at 610 nm) and magnetic-dominated (at 590 nm) transitions by Mie-resonant metasurfaces consisting of silicon nanocylinders. By fabricating a set of metasurfaces with nanocylinders of different diameter we sweep the spectral positions of the Mie resonances over the spectral range of the electric and magnetic dipole transitions. The samples were covered by a 40 nm-layer of polymer doped by Eu3+ compound. We observed an enhancement of the Eu3+ emission associated with the electric and magnetic-dominated dipole transitions. We further perform numerical simulations using two different approaches.

30 min. break.

Invited Talk HL 29.5 Wed 17:00 EW 201

Meta-optics and functional metasurfaces driven by Mie resonances — •Yuri Kivshar — Nonlinear Physics Center, Australian National University, Canberra, Australia

Rapid progress in plasmonics is associated with the ability to enhance near-field effects with subwavelength localization of light. Recently, we observed the emergence of a new branch of nanophotonics and meta-optics aiming at the manipulation of strong optically-induced electric and magnetic Mie-type resonances in dielectric nanoscaled structures with high refractive index. Unique advantages of dielectric resonant optical nanostructures over their metallic counterparts are low dissipative losses, low heating, and the enhancement of both electric and magnetic fields. In this talk, I will review this new emerging field of nanophotonics and metasurfaces and demonstrate that Mie-type resonances in high-index dielectric nanoparticles and subwavelength structures can be exploited for new physics and novel functionalities of photonic structures especially in the nonlinear regime.

Invited Talk HL 29.6 Wed 17:30 EW 201

Nonlinear Metasurface Holography — •Thomas Zentgraf — Department of Physics, University of Paderborn, Germany

For efficient nonlinear processes, the engineering of the nonlinear optical properties of media becomes important. A continuous tailoring of the phase of the nonlinear susceptibility would greatly enhance flexibility in the design of nonlinear elements. Here we will discuss a novel nonlinear metamaterial which can exhibit homogeneous linear optical properties but continuously controllable phase of the local effective nonlinear polarizability. For the demonstration, we use plasmonic metasurfaces with various designs for the meta-atom geometry together with circular polarized light states. The controllable nonlinearity phase results from the phase accumulation due to the polarization change along the polarization path on the Poincare sphere (the so-called Pancharatnam-Berry phase) and depends therefore only on the spatial geometry of the metasurface. We will demonstrate the concept of phase engineering for the manipulation of second- and third-harmonic generation from metasurfaces and the restriction with respect to symmetry and geometry of meta-atoms on a few examples.

HL 29.7 Wed 18:00 EW 201

Towards actively programmable metasurfaces: Local addressing and fine-tuning of individual nanostructures covered with phase-change material — •Andreas F. Hessler[1], Ann-Katrin U. Michel[1,2], Martin Lewin[1], Henrik Wördenweber[1], Julian Hanss[1], Thomas Kalix[1], Angela De Rose[1], Dmitry N. Chigrin[1], Matthias Wuttig[1], and Thomas Taubner[1] — [1]Institute of Physics (IA), RWTH Aachen — [2]Optical Materials Engineering Laboratory, ETH Zurich

Despite their nanometer thickness, metasurfaces offer comprehensive control over light fields and allow for the creation, detection and transformation of light. For optimal functionality, they need to be freely programmable and have low optical losses.
Phase-change materials provide an effective and convenient way to add active functionality to a metasurface post-fabrication. They characteristically have a high optical contrast between their amorphous and crystalline phases, while only suffering low optical losses in the infrared [1,2].
Here, we present on how we can fine-tune individual elements of a metasurface covered with the phase-change material $Ge_3Sb_2Te_6$ by locally addressing them with laser pulses. This work represents an advance towards actively programmable metasurfaces and the concept can be applied to a multitude of already present metasurface designs.
[1] A.-K. U. Michel et al., Nano Lett. 13, 3470 (2013).
[2] M. Wuttig et al., Nat. Photon. 11, 465 (2017)

HL 29.8 Wed 18:15 EW 201

Sub-wavelength phase coexistence patterning of phase change materials by means of ion irradiation — •Martin Hafermann, Jura Rensberg, and Carsten Ronning — Institute of Solid State Physics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Phase change materials such as the chalcogenide $GeSb_xTe_y$ (GST) enable the fabrication of reconfigurable devices like rewritable optical data storage media. In such devices switching between two states (amorphous - crystalline) is usually accomplished by applying intense laser pulses. The two states show a tremendous difference of the optical and electrical properties. Using direct laser writing GST based metasurfaces were created by structuring regular patterns of amorphous GST within the crystalline film or vice versa. However, the size of any pattern element is diffraction limited and cannot be smaller than the wavelength of laser light used. To circumvent the diffraction limit, instead of a laser we use a focused ion beam. The ion irradiation induced defect formation triggers the phase transition from crystalline to amorphous in predefined regions, which enables the patterning of GST films down to structure sizes much smaller than the wavelength of visible light. Here, we demonstrate the influence of homogenous ion irradiation on the optical properties of GST thin films. These results were used to design and fabricate sub-wavelength patterns of irradiated GST using area-selective ion irradiation. With this method we are able to create reconfigurable, inherently flat metasurfaces, which is a main desire of modern optics.

HL 30: Heterostructures, interfaces, and surfaces

Time: Wednesday 15:00–17:30 Location: EW 202

HL 30.1 Wed 15:00 EW 202

Band offset of Ga(N,As,P)/GaP heterostructures on silicon for optoelectronic integration — •Sebastian Gies[1], Florian Dobener[1,2], Robin C. Döring[1], Sarah Karrenberg[1], Khakaber Jandieri[1,3], Peter Ludewig[3], Kerstin Volz[1], Wolfgang Stolz[1,3], Sangam Chatterjee[2], and Wolfram Heimbrodt[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Germany — [2]Institute of Experimental Physics I, Justus-Liebig-University Giessen, Germany — [3]NAsP$_{III/V}$ GmbH, Marburg, Germany

Nowadays, realizing laser diodes for the optoelectronic integration on silicon is a big challenge. The quaternary, direct-gap semiconductor Ga(N,As,P) is a suitable candidate for this purpose as it can be grown pseudomorphically on silicon and laser operation at low temperatures has already been demonstrated. To further optimize the Ga(N,As,P) heterostructures profound knowledge of the band offset is important. We present a thorough study of the Ga(N,As,P)/GaP band offset based on the conjunction of experiment and theory. Using PLE spectroscopy the transition energies of the Ga(N,As,P)-QW are revealed. These are modeled by a QW-calculation taking strain and the N-induced band anti-crossing into account. Therefore, it is possible to uniquely determine the band offset with very high precision.

HL 30.2 Wed 15:15 EW 202

First Principle Calculations of Interlayer Electronic Excitations in MoS2-WS2-MoSe2 van der Waals Trilayer Semiconductor — •Anders Christian Riis-Jensen and Kristian Sommer Thygesen — Technical university of Denmark, Department of Physics

van der Waals bonded heterostructures based on transition metal dichalcogenides or other 2D materials, represent an ideal playground for studying light-matter interactions at the nano-scale, and for benchmarking first principles excited state calculations against well defined experiments. Here we combine many-body perturbation theory with classical electrostatic models to calculate the electronic structure of the trilayer MoS2-WS2-MoSe2. The band alignment and interlayer excitons obtained using different self-energy approximations (with and without vertex corrections) and pseudopotentials (norm conserving and ultrasoft) are compared and discussed in relation to recent experimental results.

HL 30.3 Wed 15:30 EW 202

Hole carrier profiles at the surface of p-type Ge measured by low-energy muon spin spectroscopy — •Thomas Prokscha[1], Kim Chow[2], Elvezio Morenzoni[1], Zaher Salman[1], Evelyn Stilp[1,3], and Andreas Suter[1] — [1]LMU, Paul Scherrer Institut, 5232 Villigen, Switzerland — [2]University of Alberta, Edmonton, T6G 2E1, Canada — [3]Physics Institute, University of Zurich, 8057 Zurich, Switzerland

Macroscopic transport measurements and modelling are usually used to determine the charge carrier profiles across semiconductor interfaces. A local probe technique, capable of detecting the variation in carrier concentration, offers the unique possibility of measuring carrier profiles and manipulation directly without the need of model assumptions. Here we use for the first time the low-energy μ^+ beam at PSI with tunable energies in the keV range to investigate charge carrier profiles and their manipulation by illumination in commercial p-type Ge wafers at varying mean implantation depths from 10 nm to 150 nm. In p-type Ge with doping levels of 10^{15} cm^{-3} and 10^{16} cm^{-3} we observed a depletion of holes in the top 150 nm and 50 nm, respectively. The depletion zone can be persistently removed by illumination with blue light due to filling of empty surface acceptor states with photo-generated electrons [1]. By illumination with red light the photo-generated electrons have not sufficient energy to overcome the surface barrier of about 1 eV [1], and a dynamic equilibrium concentration of holes is observed, which increases as a function of depth.

[1] T. Prokscha et al., Sci. Rep. 3, 2569 (2013).

HL 30.4 Wed 15:45 EW 202

NiSi$_2$-Si interfaces and their role in tunneling based field-effect transistors: from the atomic structure to device characteristics — •Florian Fuchs[1,2,3,4], Sibylle Gemming[1,2,3], and Jörg Schuster[2,4] — [1]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany — [2]Center for Advancing Electronics Dresden (cfaed), Dresden, Germany — [3]Institute of Physics, Technische Universität Chemnitz, Chemnitz, Germany — [4]Fraunhofer Institute for Electronic Nano Systems (ENAS), Chemnitz, Germany

The electron transport across metal-semiconductor interfaces is crucial for the functionality of field-effect transistors (FETs) built from such contacts. By using a multiscale simulation approach we simulate single-gate FETs and so called reconfigurable FETs, where the latter design allows switching between electron and hole conduction by applying a second gate electrode. Our simulation approach combines NEGF-DFT modeling of the contact physics and a compact model to describe the device switching.

Our transistor model consists of a silicon channel sandwiched between two NiSi$_2$ contacts. We systematically apply strain and vary the crystal orientation. It is demonstrated that strain has, depending on the crystal orientation, a very different influence on the ratio between electron and hole current. These differences are compared with the change of the effective mass and the work function of the isolated materials. We show that the properties of the isolated materials cannot explain the discovered modification of the current alone and that the interface chemistry needs to be taken into account as well.

HL 30.5 Wed 16:00 EW 202

Spectroscopic examination and theoretical modelling of fluorescence spectral diffusion of CdSe/CdS dotrods — •Sven-Hendrik Lohmann, Philip Harder, Felix Bourier, Christian Strelow, Tobias Kipp, and Alf Mews — Institute für Physikalische Chemie ,Universität Hamburg, Grindelallee 117, 20146 Hamburg, Deutschland

Here we investigate the photoluminescence properties, more specifically the spectral diffusion, of individual chemically-synthesized CdSe/CdS nanoparticles, which consist of a spherical core enclosed by an elongated shell. Time- and energy-resolved photoluminescence data were collected at low temperature to analyze the spectral diffusion of the emission. The observed correlation between the energy and the decay time of the emission was used to develop a theoretical model, which includes migrating surface charges to describe the fluorescence jittering. Our initial model calculations already show a good agreement with our experimental studies.[1] In the next step, the model was refined by the incorporation of strain effects and the geometric parameters as well as different material compositions were investigated in respect to spectral diffusion.

[1] S.-H. Lohmann, C. Strelow, A. Mews, T. Kipp, ACS Nano 2017, DOI 10.1021/acsnano.7b05303.

15 min. break.

HL 30.6 Wed 16:30 EW 202

Fluorescence behaviour of semiconductor nanoparticles in vicinity of plasmonic metals — •Simon Schneider, Phillip Witthöft, Jannik Rebmann, Tobias Kipp, Christian Strelow, and Alf Mews — Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Interactions of plasmonic metal nanoparticles with semiconductor nanoparticles greatly influence the fluorescence behaviour of the latter. If introduced to a plasmonic resonant system, the rate of spontaneous emission can be enhanced (Purcell effect). Here, the distance between the metal- and semiconductor nanoparticles, as well as the geometry of the system, has a huge influence on the fluorescence behaviour of the whole system, i.e. direct contact of the two parts leads to complete fluorescence quenching. We control the distance between plasmonic metals and CdSe/CdS semiconductor dot-in-rod (DR) structures on a nanometer scale using a silica shell around the DRs as a dielectric spacer and investigate the effect of attached plasmonic metals (Ag & Au) on the fluorescence behaviour of the DRs. By using different geometries (i.e. spherical nanoparticles or nanorods) we can tune the spectral overlap as well as the dispersion of the electric field generated through the surface plasmon resonances, thereby influencing the fluorescence behaviour of the system.

HL 30.7 Wed 16:45 EW 202

Tracing dark exciton dynamics with optical bistable exci-

ton polaritons in planar microcavities — •Daniel Schmidt[1], Bernd Berger[1], Manfred Bayer[1], Christian Schneider[2], Sven Höfling[2], and Marc Assmann[1] — [1]Technische Universität Dortmund, 44227 Dortmund, Deutschland — [2]Technische Physik, Universität Würzburg, 97074 Würzburg, Deutschland

In the quickly thriving field of quantum computation exists a demand in systems that can be derived by using quantum mechanical methods. To fulfill such demands, various research has been done on exciton polaritons in semiconductor microcavities that arise due to the strong coupling of cavity photons and quantum well excitons. Furthermore, their ability to be reconfigured by controlling them all-optically makes them even more promising candidates. Another striking feature of exciton polaritons is the nonlinear polariton-polariton interaction. At high pumping densities these interactions may induce various phenomena, such as Bose-Einstein condensation, superfluidity or optical bistability. The latter is created by using slightly off-resonant CW excitation that generates a blueshift of the lower polariton branch, resulting in a hysteresis of the input-output behavior of the exciton polaritons. Utilizing this behavior, we use an additional short far off-resonant laser pulse to perturb the bistable system, enabling access to the dynamics of the lower polariton branch. Here, these dynamics show surprisingly long recovery times, which hints the presence of a reservoir of dark excitons involved in this process.

HL 30.8 Wed 17:00 EW 202

Exceptional Carrier Diffusion on CdTe Surfaces Revealed by 4D Electron Microscopy — •Ahmed M. El-Zohry, Basamat S. Shaheen, Jun Yin, Boon Ooi, Osman M. Bakr, and Omar F. Mohammed — King Abdullah University of Science and Technology

To further develop any real-world-energy devices, light light-triggered charge carrier dynamics near the surface of the absorber layers need to be visualized in space and time. Such spatial and dynamical information can only be accessed using the one of-a-kind technique of scanning ultrafast electron microscopy. Here, we clearly demonstrate not only that charge transport on material surfaces behaves very differently from that of the bulk, but also the surface orientation can control the overall charge carrier dynamics. More specifically, in CdTe single crystal with orientation of (110), we found that shows a the diffusion coefficient at surfaces of 3-4 order of magnitude higher than in bulk. The detected charges for the first time can move up to ~ 60 nm within 6 nanosecond time scale. Moreover, the X-ray photoelectron spectroscopy experiments and Density functional theory (DFT) calculations show that the surface diffusion process relay mostly on the crystal orientation and termination, in which other crystal with (211) orientation, highly tends to form ultrathin-oxidative layers that in turn suppress the charge transport through formation of mid surface-trap states

HL 30.9 Wed 17:15 EW 202

Template-Assisted Fabrications of Regular Arrays of Nanostructures for Sensitive Gas-Sensing — •Shipu Xu, Huaping Zhao, Yang Xu, Rui Xu, Huanming Zhang, and Long Liu — Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, Germany

Sensitive gas-sensing is a constant pursue for the development of gas sensors. Herein we show a gas sensor formed by a regular array of nanostructures to efficiently fulfill sensitive gas-sensing, where the regular array is prepared by template-assisted methods. The morphologies of the gas-sensors involve regular arrays of nanopores and nanorods, which are respectively prepared from the templates of colloidal monolayer and anodic aluminum oxide. An optimized sensitivity of the gas-sensor is achievable by adjusting structure parameters of the gas sensors: (i) the pore size for the nanoporous-film-based sensor and (ii) the nanorod length for the nanorod-array-based sensors. In a detection of ethanol gas, the optimized sensitivity of the SnO2 porous film and the SnO2 nanorod array can be characterized by a low detection limit at a ppm level. Base on the above, we confirm that the regular arrays of nanostructures prepared by template-assisted methods can realize the sensitive gas-sensing.

HL 31: Quantum information systems (joint session HL/TT)

Time: Wednesday 15:00–17:30 Location: EW 203

HL 31.1 Wed 15:00 EW 203

Input-output theory for spin-photon coupling in Si double quantum dots — •Mónica Benito[1], Xiao Mi[2], Jacob M. Taylor[3], Jason R. Petta[2], and Guido Burkard[1] — [1]University of Konstanz — [2]Princeton University — [3]Joint Quantum Institute/NIST

The interaction of qubits via microwave frequency photons enables long-distance qubit-qubit coupling and facilitates the realization of a large-scale quantum processor. However, qubits based on electron spins in semiconductor quantum dots have proven challenging to couple to microwave photons. In this theoretical work [1] we show that a sizable coupling for a single electron spin is possible via spin-charge hybridization using a magnetic field gradient in a silicon double quantum dot. Based on parameters already shown in recent experiments, we predict optimal working points to achieve a coherent spin-photon coupling. Our predictions are in good agreement with recent measurements [2] which demonstrate strong coupling with spin-photon coupling rates of more than 10 MHz. These results open a direct path towards entangling single spins using microwave frequency photons. Furthermore, we employ input-output theory to identify observable signatures of spin-photon coupling in the cavity output field, which can provide guidance to the experimental search for strong coupling in such spin-photon systems and opens the way to cavity-based readout of the spin qubit.

[1] M. Benito, X. Mi, J. M. Taylor, J. R. Petta, and G. Burkard. arXiv:1710.02508.

[2] X. Mi, M. Benito, S. Putz, D. M. Zajac, J. M. Taylor, G. Burkard, and J. R. Petta. arXiv:1710.03265.

HL 31.2 Wed 15:15 EW 203

Synchronized high-fidelity quantum gates in Si/SiGe double quantum dots — •Maximilian Russ[1], D. M. Zajac[2], A. J. Sigillito[2], F. Borjans[2], J. M. Taylor[3], J. R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — [2]Department of Physics, Princeton University, Princeton, NJ 08544, USA — [3]JQI and QuICS, NIST and University of Maryland, College Park, MD 20742, USA

Motivated by recent experiments [1], we theoretically describe a high-fidelity controlled-NOT (CNOT) gate using the exchange interaction between the spins in neighboring quantum dots subject to a magnetic field gradient from a micromagnet. We use a combination of analytical calculations and numerical simulations to provide the optimal pulse sequences and parameter settings for the gate operation [2]. We present a synchronization method which avoids detrimental spin flips when the state of the control qubit is $|0\rangle$, and provide details about phase mismatches accumulated during the two-qubit gate. By synchronizing the resonant and off-resonant transitions and compensating these phase mismatches by phase control the overall gate fidelity can be increased significantly. Numerical simulations demonstrate a high tolerance towards charge noise coupled to the two spins due to a partial intrinsic refocussing mechanism.

[1] D. M. Zajac, A. J. Sigillito, M. Russ, F. Borjans, J. M. Taylor, G. Burkard, and J. R. Petta, arXiv:1708.03530 (2017)

[2] M. Russ, D. M. Zajac, A. J. Sigillito, F. Borjans, J. M. Taylor, J. R. Petta, and G. Burkard, arXiv:1711.00754 (2017)

HL 31.3 Wed 15:30 EW 203

Engineering of Coherent Defects in Silicon Carbide with Varying Irradiation Methods — •Christian Kasper[1], Victor Soltamov[1], Dmitrij Simin[1], Takeshi Ohshima[2], Vladimir Dyakonov[1,3], and Georgy Astakhov[1] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]National Institutes for Quantum and Radiological Science and Technology, Takasaki, Japan — [3]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Out of the many possible material systems, quantum centers in silicon carbide (SiC) have proven themselves to be promising candidates for qubits [1]. Whereas a wide availability and easy handling are crucial for a functioning device, long-preserving spin coherence is also essential for such systems [2]. By using the pulsed-ODMR technique

we compare the coherence properties of silicon vacancies created with two common methods: Neutron and electron irradiation. Particularly, the spin-lattice relaxation time (T1) and spin coherence time (T2) are measured in a broad range of the silicon vacancy density for each of the two irradiation methods. Additionally, Ramsey-fringes were measured while selecting a coherent spin package by applying a second microwave frequency.

[1] D. Riedel et al., Phys. Rev. Lett. 109, 226402 (2012)
[2] Simin et al., Phys. Rev. B 95, 161201(R) (2017)

HL 31.4 Wed 15:45 EW 203

Simulating high-fidelity two-qubit gates with singlet-triplet qubits generated by capacitive coupling and interqubit exchange interaction — •Michael Wolfe[1], Pascal Cerfontaine[1], Fernando Calderon-Vargas[2], Jason Kestner[3], and Hendrik Bluhm[1] — [1]JARA-Institute for Quantum Information, RWTH Aachen University, D-52074 Aachen, Germany — [2]Department of Physics, Virginia Tech, Blacksburg, VA 24061, USA — [3]Department of Physics, University of Maryland Baltimore County, Baltimore, MD 21250, USA

Two-qubit gates in singlet-triplet qubits can be generated via capacitive coupling or interqubit exchange interaction. Both methods suffer considerably from charge noise and nearly all approaches to mitigate this effect rely on the fact that the noise is slow compared to the gate time. We show that in the strictly capacitive case where gate times are much slower, maximally entangling gates with fidelities above 99% are achievable by operating the qubit in a sweet spot regime that is predicted by a Hund-Mulliken model [1]. In addition, we find comparable fidelities when both interqubit exchange and capacitive interactions are simultaneously used to generate entanglement. We compare these theoretical results with gates that are found using an optimization technique that numerically searches for high-fidelity two-qubit gates using a full-noise and control error model [2]. [1] Wolfe et al., arXiv:1709.09165 (2017) [2] Cerfontaine et al., PRL 113, 150501 (2014)

HL 31.5 Wed 16:00 EW 203

Microwave saturation spectroscopy of silicon vacancies in SiC — •Victor Soltamov[1], Christian Kasper[1], Georgy V. Astakhov[1], Sergej A. Tarasenko[2], Alexander V. Poshakinskiy[2], Andrey N. Anisimov[2], Pavel G. Baranov[2], and Vladimir Dyakonov[1,3] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Ioffe Institute, 194021 St.Petersburg, Russia — [3]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Negatively charged silicon vacancy (V_{Si}) center in Silicon Carbide (SiC) has been attracting growing attention due to their use in quantum sensing with optical pumping [1]. The core of the sensing methods is to precise measurement of the optically detected magnetic resonance (ODMR) signal frequency shift, induced by the external fields. A sensitivity of the measurement improves when the V_{Si} ground-state microwave transitions are narrow. That is why, understanding of the mechanisms responsible for inhomogeneous broadening of the ODMR line is of great importance. To establish the mechanisms we provided the study of the V_{Si} ODMR linewidth by means of microwave saturation spectroscopy. We revealed the presence of two types of broadening namely induced by randomly distributed strain fields and by randomly distributed local magnetic fields. The results allowed deeper understanding of the V_{Si} ground spin state properties and to propose new measurement protocols for quantum sensing with the V_{Si} centers.

[1] H. Kraus et al., Sci. Rep. 4, 5303 (2014).

15 min. break.

HL 31.6 Wed 16:30 EW 203

Fabrication and Characterization of a Quantum Bus Prototype in Si/SiGe — •Inga Seidler[1], Arne Hollmann[1], Veit Langrock[1], Stefan Trellenkamp[2], Christian Neumann[3], Dominique Bougeard[3], Hendrik Bluhm[1], and Lars R. Schreiber[1] — [1]JARA-FIT Institute for Quantum Information, RWTH Aachen University, Germany — [2]Helmholtz Nano Facility, Forschungszentrum Jülich GmbH, Germany — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany

Silicon based spin qubits in electrostatically defined quantum dots are well established and 1-qubit and 2-qubit gates are shown with high fidelities [1,2]. The missing link for building a large scale quantum computer is a long range coherent coupling mechanism. A candidate for a coupling mechanism is a 10 micron long quantum bus (QuBus), which transfers a single electron spin qubit along a 1D channel. We will present the concept of a QuBus that consists of a dense metal gate array required to appropriately shape the electrostatic potential within the channel. We optimized the fabrication yield of the three-layer metal gate pattern of the 320 nm long Si QuBus prototype. In addition, 10 mK transport measurements of a single electron transistor which operates as the charge sensor at the ends of a QuBus are shown.

[1] J. Yoneda ea., arXiv:1708.01454 [2] D. M. Zajac ea., arXiv:1708.03530

HL 31.7 Wed 16:45 EW 203

Towards atomic vapor based memories for quantum dot single photons - A variable EIT delay in Cesium — •Tim Kroh[1], Esteban Gomez Lopez[1], Janik Wolters[2], Alexander Thoma[3], Stephan Reitzenstein[3], Joahnnes S. Wildmann[4], Rinaldo Trotta[4], Eugenio Zallo[5], Armando Rastelli[4], Oliver G. Schmidt[6], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin — [2]Universität Basel — [3]Technische Universität Berlin — [4]Johannes Kepler Universität Linz — [5]Paul-Drude-Institut für Festkörperelektronik, Berlin — [6]IFW Dresden

Quantum memories will play a central part in synchronizing operational events in quantum networks, e.g. joint measurements between photons from different sources in order to implement entanglement swapping in quantum repeater protocols [1].

Here, we interface quantum light sources with an electromagnetically induced transparency (EIT) system, in principle suitable for quantum memory. First, we demonstrate precise strain-tuning of InGaAs quantum dot emission between the two 1.2 GHz hyperfine-split levels in the Cesium D1 transitions. Proceeding from this we explore the potential of EIT for variable delays for single photons [2]. In addition to application in synchronization of heralded single photon sources, these experiments lay the ground for atomic vapor-based quantum memories in hybrid quantum networks [3].

[1] Kimble, Nature 453, 1023 (2008)
[2] D. Höckel et al., Phys. Rev. Lett. 105, 153605 (2010)
[3] J. Wolters et al., Phys. Rev. Lett. 119, 060502 (2017)

HL 31.8 Wed 17:00 EW 203

Theory of long-range coherent electron shuttling devices in Silicon/Silicon-Germanium quantum wells — •Veit Langrock, Arne Hollmann, Inga Seidler, Lars R. Schreiber, and David P. DiVincenzo — JARA-FIT Institute for Quantum Information, RWTH Aachen University, Germany

Silicon quantum computing is at a stage where single qubits confined in electrostatically formed quantum dots with very long coherence times can be manufactured. To make the transition to large scale quantum computing, long range on chip coupling (over micrometer distances) is a building block that is currently still missing. A concept currently pursued experimentally is the coherent shuttling of electrons via moving electrostatic quantum dot configurations, with information encoded in the electron's spin state. In this talk, we present theoretical considerations and simulations regarding moving electrostatically formed quantum dots through a Silicon/Silicon-Germanium (Si/SiGe) quantum well. Emphasis will be put on the effects that interface disorder in the form of miscut steps along the Si/SiGe quantum well interfaces will have on the moving electron's spin environment, with the valley dependence in silicon playing a crucial role.

HL 31.9 Wed 17:15 EW 203

Spin-orbit interaction isotropy for holes in rectangular Si nanowires — •Marko J. Rancic, Christoph Kloeffel, and Daniel Loss — Department of physics, University of Basel

In this study we develop a model describing holes in rectangular nanowires in silicon (Si). In similarity with cylindrical nanowires, an electric field of intermediate strength can induce a sizable direct Rashba spin-orbit interaction (DRSOI). Our findings suggest that the magnitude of DRSOI is isotropic in case of germanium (Ge) due to the high degree of symmetry which Ge has. In contrast to that DRSOI is highly anisotropic in Si, dependant on the growth direction of the Si nanowire with respect to the main crystallographic axes. Still the DRSOI in si can be made significant ($\sim$ 0.5 meV) when the growth direction of the nanowire is chosen optimally, different to recent experimental studies.

HL 32: Quantum dots and wires: Optical properties II

Time: Wednesday 15:00–17:30 Location: A 151

HL 32.1 Wed 15:00 A 151

Tuning Radiation Pattern and Polarization Anisotropy of Stacked Quantum Dots — •Ludwig Albrecht Thorsten Greif, Stefan Thomas Jagsch, and Andrei Schliwa — Technische Universität Berlin, Institut für Festkörperphysik

Control over the spatial radiation characteristics of individual photon emitters constitutes a promising way of optimizing various kinds of photonic devices. We show that the direction of predominant emission of stacked InGaAs quantum dots (QDs) as well as their polarization anisotropy can be tuned via two parameters: The number of stacked dots n and the height of the barrier layer h_b. Our simulations in the framework of 8-band $\mathbf{k}\cdot\mathbf{p}$-theory reveal that the wavefunctions form delocalized states when the separating barrier thickness is smaller than the height of a QD. We demonstrate how the collective aspect ratio AR_col of such closely stacked QDs can be used to tailor the average biaxial strain in the wavefunction region and consequently the radiation pattern itself.

HL 32.2 Wed 15:15 A 151

Multi-particle electronic structure of $\mathbf{In_{1-x}Ga_xAs_ySb_{1-y}/GaP}$ quantum dots — •Petr Klenovský[1,2], Petr Steindl[1,2], Elisa Maddalena Sala[3], Benito Alén[4], and Dieter Bimberg[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 2, 61137 Brno, Czech Republic — [2]Central European Institute of Technology, Masaryk University, Kamenice 753/5, 62500 Brno, Czech Republic — [3]Institut für Festkörperphysik Technische Universität Berlin, Hardenbergstraße 36 10623 Berlin, Germany — [4]Instituto de Micro y Nanotecnología, IMN-CNM, CSIC Isaac Newton, 8 PTM Tres Cantos 28760 Madrid

We investigate the multi-exciton structure of InGaAsSb/GaP quantum dots for different Ga and As compositions using the configuration interaction method with basis single-particle states obtained within the envelope function approximation based on k.p method. Depending on the dot composition the system is found to be of type-I or type-II nature. The type of transition in case of electrons originating from Γ, L, and X points of k-space and holes from Γ is, furthermore, calculated for different excitation intensities. Obtained emission energies and oscillator strengths of the transitions are compared to results of pumping-dependent photoluminescence measurements.

HL 32.3 Wed 15:30 A 151

GaN Nanowires for Optoelectronic Control of Nitrogen Vacancy Centers in Diamond — •Theresa Hoffmann[1], Martin Hetzl[1], Jakob Wierzbowski[1], Max Kraut[1], Verena Zuerbig[2], Christoph E. Nebel[2], Jonathan J. Finley[1], and Martin Stutzmann[1] — [1]Walter Schottky Institut and Physics Department, Technische Universität München, Garching, Germany — [2]Fraunhofer-Institut für Angewandte Festkörperphysik IAF, Freiburg, Germany

Nitrogen vacancy centers (NVs) are color centers in diamond with highest coherence times of their excited states which makes them promising candidates for quantum computing applications. However, charge state instabilities of surface-near NVs lead to optical blinking and spin state instabilities. Moreover, the high refractive index of diamond is unfavorable for their optical read-out.

We demonstrate an efficient method for the optical read-out of the NVs via GaN nanowire (NW) arrays as optical waveguides. Selective area growth of n-GaN NW arrays on a i-p-diamond (111) by molecular beam epitaxy allows the variation of the NW dimensions and position. Numerical simulations of the light propagation have been performed to optimize these parameters to obtain a maximum extraction efficiency of the NV PL signal through the NW array. In addition, p-i-diamond/n-GaN nano diodes have been implemented to stabilize and control the NV charge state via an externally applied voltage.

HL 32.4 Wed 15:45 A 151

Dynamical Tuning of Nanowire Laser Spectra [1] — •Maximilian Zapf[1], Robert Röder[1], Karl Winkler[2], Lisa Kaden[1], Johannes Greil[2], Marcel Wille[3], Marius Grundmann[3], Rüdiger Schmidt-Grund[3], Alois Lugstein[2], and Carsten Ronning[1] — [1]Institute for Solid State Physics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena — [2]Institute of Solid State Electronics, TU Wien, Floragasse 7, A-1040 Vienna, Austria — [3]Felix Bloch Institute for Solid State Physics, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany

The availability of coherent light sources on the nanoscale has recently brought up visionary concepts of integrated photonic circuits, nanospectroscopy, and nanosensing. These concepts will tremendously benefit from a dynamically tunable laser spectrum. Semiconductor nanowires (NWs) can provide both continuous wave laser emission and ultrafast modulation capabilities but individual NW laser devices currently suffer from fixed emission spectra determined by the material band gap. Therefore, we demonstrate an individual nanowire laser based device, which can be gradually tuned by reversible length changes of the nanowire such that uniaxial tensile stress is applied to the respective semiconductor gain material. By straining the device, the spontaneous excitonic emission of the nanowire shifts to lower energies caused by the bandgap reduction of the semiconductor. Moreover, the optical gain spectrum of the nanolaser can be precisely strain-tuned in the high excitation regime. [1] Zapf et al. Nano Lett., 17, 6637 (2017)

HL 32.5 Wed 16:00 A 151

Atomistic pseudopotential calculations of the excitonic fine structure of InP and CdSe quantum dots — •Hanh Bui[1,2], Anastasia Karpulevich[1,2], and Gabriel Bester[1,2] — [1]Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, D-20146 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, Germany

Using the atomic effective pseudopotentials (AEPs) [1,2] and a small modification of the non-local part of pseudopotential to obtain the correct band-gaps, we perform the screened configuration interaction (CI) calculations and study the exciton fine structure of InP and CdSe quantum dots with hundreds to thousands of atoms. The strong confinement of particles in quantum dots enhances the electron-hole exchange interaction which splits the band-edge exciton into bright and dark exciton states, resulting in the so-called exciton fine structure. Our results fit well with experimental data.

[1] J. R. Cardenas and G. Bester, Phys. Rev. B 86, 115332 (2012).
[2] A. Karpulevich, H. Bui, D. Antonov, P. Han, G. Bester, Phys. Rev. B 94, 205417 (2016).

15 min. break.

HL 32.6 Wed 16:30 A 151

Coherence of a dynamically decoupled quantum-dot hole spin — •Lukas Huthmacher, Robert Stockill, Claire Le Gall, and Mete Atatüre — Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, UK

Single spins in self-assembled InGaAs quantum dots are promising candidates for the implementation of distributed quantum information processing. For the electron the strong hyperfine coupling to the surrounding nuclei dephases the spin states in a few ns, hindering the quality of the spin-photon interface. In contrast, a hole spin is expected to couple less to the nuclear spin bath, providing a promising alternative. While it has been shown that holes can offer a longer dephasing time, T_2^* [1], future progress hinges on what coherence times can be achieved through decoupling.

In this work, we establish the regimes that allow for a highly coherent hole spin in this system. We observe a pick-up and decay with external magnetic field for both the inhomogeneous dephasing time, T_2^*, as well as the coherence time, T_2. We show that the decoherence of the hole is still dictated by the hyperfine coupling to the nuclear spin environment for fields up to a few Tesla, whereas electrical noise dominates at higher fields. We implement dynamic decoupling in the latter regime to actively protect the hole spin, allowing us to achieve $T_2 = 4.4\,\mu$s, the longest for any spin in this system. Finally, we independently determine the local electrical environment which quantitatively supports the improvement of coherence we achieve with dynamic decoupling.
[1] D. Brunner *et al.* Nature **456**, 218 (2008)

HL 32.7 Wed 16:45 A 151

Indirect (In,Al)As/AlAs quantum dots: Carrier spin dynamics and recombination — •Janina Rautert[1], Sergey Nekrasov[2], Timur Shamirzaev[3], Jörg Debus[1], Dmitri

Yakovlev[1,2], Yuri Kusrayev[2], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, Germany — [2]Ioffe Institute, St. Petersburg, Russia — [3]Rzhanov Institute of Semiconductor Physics, Novosibirsk, Russia

Spin memory systems realized within a semiconductor application require structures that provide both long carrier lifetimes and spin relaxation times in the range of microseconds. Promising but little known candidates for that aim are (In,Al)As quantum dots (QDs) with an indirect band gap in the k-space. Here the direct band gap material is transformed to an indirect one by decreasing the QD size. Samples with a broad distribution of dot diameters allow the investigation of both types of QDs under selective excitation. Photoluminescence (PL) measurements in which the laser energy is tuned through the inhomogenously broadened dot ensemble show an increasing circular polarization degree up to 40% for indirect QDs speaking for a high spin relaxation time. Polarization degrees up to 90% can be reached by applying a small longitudinal field (mT-range) that suppress the nuclear spin fluctuations. In transverse magnetic fields however, the width of the Hanle curve corresponds to spin relaxation times of only a few nanoseconds. Therefore direct measurements of the spin dynamics and the exciton lifetime via time resolved PL are planned for the near future.

HL 32.8 Wed 17:00 A 151

Prospects of Quantum Dot based Quantum Cascade Lasers — •Alexander Mittelstädt and Andrei Schliwa — Technische Universität Berlin, Institut für Festkörperphysik

The examination of the electronic structure of stacked and strongly coupled quantum dots (QDs) serves as groundwork for the development of quantum cascade lasers [1] consisting of quantum dot chains as gain material [2]. We show intradot excited state to ground state transitions in stacks of 14 and 20 InGaAs QDs embedded in a GaAs matrix. Simulations of large scale systems at various biases are accomplished via a 'linear combination of atomic orbitals' type of approximation based on single quantum dot eight-band k*p-wavefunctions.

[1] J. Faist, F. Capasso, et al. Science, 264(5158):553-556, 1994.
[2] R. A. Suris. In Future Trends in Microelectronics, pp. 197-208. Springer Netherlands, 1996.

HL 32.9 Wed 17:15 A 151

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

For the case of pulsed laser fields and in the absence of decoherence, an exciton in a single QD represents a qubit, which can be tuned by electric fields. Robust state preparation has been achieved so far by using polarization tailored pulses [1] or chirped pulses for the realization of a rapid adiabatic passage (RAP) [2,3].

Here we demonstrate state preparation by RAP, using fast transient Stark shift of the exciton energy. Our system is based on self-assembled InGaAs QDs embedded in a low capacitance Schottky-photodiode. The photodiode is closely connected to a SiGe:C BiCMOS chip, which delivers transients as fast as 4.7 mV/ps at low temperature. The ps electric transient is synchronized to the optical pulse. The occupancy of the QD can be read out by photocurrent detection. We are able to observe the transition from an un-chirped Rabi scenario to a clear RAP signature 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 33: Poster Session III

Time: Wednesday 17:30–19:30 Location: Poster F

HL 33.1 Wed 17:30 Poster F

Investigation of the effects of Mg-doping on the structural and electrical properties of(In,Ga)N/GaN superlattices — •Erdi Kuşdemir, Caroline Chèze, and Raffaella Calarco — Paul-Drude-Institut für Festkörperelektronik, 10117 Berlin, Germany

Optimization of the p-type area is one of the challenges for the realization of more efficient light emitters based on group III-nitrides. A self-compensation mechanism limits the hole density in the Mg-doped (In, Ga)N layers usually constituting the p-type area. Instead of directly increasing the hole concentration on the topmost contact layer, the hole injection may be promoted by utilizing (In, Ga)N/GaN superlattices (SLs) neighboring the active region. To this aim, we investigate the influence of Mg on the structural and electrical properties of (In, Ga)N/GaN SLs and (In, Ga)N layers grown by PAMBE. SL samples with 10 periods of (In, Ga)N/GaN were fabricated at 610°C and doped with Mg at different steps of the period. In-situ monitoring of the In desorption by QMS indicated a decrease in In incorporation in the SLs with the amount of Mg supplied. XRD was employed to assess this effect, as well as the structural quality of the SLs. Significant improvement of the surface morphology was achieved by the SL formation compared to the random alloy. In addition, the electrical characterization confirmed the p-type nature of some of the SLs. Our results pave the way for improved hole injection efficiency in III-N emitters.

Financial support of this work within from the European Union program Horizon2020 under grant agreement No. 642574 (SPRInG) is gratefully acknowledged.

HL 33.2 Wed 17:30 Poster F

Band offset at the Ga(N,As,P)/GaP Heterointerface — •Florian Dobener[1,3], Sebastian Gies[1], Robin C. Döring[1], Kahkaber Jandieri[1], Peter Ludewig[2], Kerstin Volz[1], Wolfgang Stolz[1,2], Wolfram Heimbrodt[1], and Sangam Chatterjee[3] — [1]Faculty of Physics and Materials Science Center, Philipps-Universität Marburg, D-35032 Marburg, Germany — [2]NAsPIII/V GmbH, Am Knechtsacker 19, D-35041 Marburg, Germany — [3]Institute of Experimental Physics I, Justus-Liebig-University Giessen. D-35392 Gießen, Germany

The realization of monolithically integrated on-chip laser sources for optical data transmission remains to be one of the major goals of optoelectronic integration. The quaternary III-V material system Ga(N,As,P) promises to fulfil this task. Composition variations through the control of nitrogen and phosphorous incorporation allow for both, bandgap engineering, potentially covering the near-infrared regime as well as the telecom wavelength and matching the lattice constant to Si. Here, we investigate a series of Ga(N,As,P) multiple quantum well samples. The well thickness is varied while the composition is kept quasi-constant. The samples are examined by photoluminescence excitation spectroscopy. Besides higher states, we find two clear peaks slightly above the band-gap energy, which we attribute to the heavy-hole and light-hole valence band to conduction band energy transitions of the samples. Consequently, we are able to model the band offset at the Ga(N,As,P)/GaP heterointerface with a band anti-crossing model and the model solid theory.

HL 33.3 Wed 17:30 Poster F

Characterization of electro-chemical treated GaN-Nanowires — •René Couturier[1], Jan Philipps[1], Pascal Hille[2], Jörg Schörmann[1], Martin Eickhoff[2], Sangam Chatterjee[1], and Detlev Hofmann[1] — [1]I. Physikalisches Institut, Heinrich-Buff-Ring 16, Justus-Liebig-Universität-Gießen, D-35392-Gießen — [2]Institute of Solid State Physics, Otto-Hahn-Allee NW1, University of Bremen, D-28359

Due to its large surface to volume ratio GaN nanowires show excellent properties for bio-sensing and water-splitting applications. Therefore, the optical, structural and electrochemical properties of photoelectrochemically treated and untreated GaN nanowires were investigated. The GaN nanowires ensembles were immersed in an aqueous phosphate buffered saline solution (PBS) and treated under various bias and illumination conditions. Photoluminescence measurements show that anodic biases induce a permanent decrease in the radiative recombination intensity. The structural properties of the treaded samples changed from free standing nanowires to more tilted structures, as can be seen in scanning microscopy images. We find that the effects are stronger for higher anodic biases and longer treatment times. En-

ergy dispersive x-ray spectroscopy shows that the surface of the nitride nanowires is oxidized as a consequence of the treatments.

HL 33.4 Wed 17:30 Poster F

Raman spectrosopic characterization of GaN grown by high-temperature vapor phase epitaxy — •Christian Röder[1], Mykhailo Barchuk[2], Tom Schneider[3], Gleb Lukin[3], Friederike Zimmermann[4], and Jens Kortus[1] — [1]TU Bergakademie Freiberg, Institute of Theoretical Physics, D-09599 Freiberg, Germany — [2]TU Bergakademie Freiberg, Institute of Materials Science, D-09599 Freiberg, Germany — [3]TU Bergakademie Freiberg, Institute of Nonferrous Metallurgy and Purest Materials, D-09599 Freiberg, Germany — [4]TU Bergakademie Freiberg, Institute of Applied Physics, D-09599 Freiberg, Germany

High-temperature vapor phase epitaxy (HTVPE) [1] is considered as a cost-efficient technology for fabrication of GaN templates. In this work, recent results on structural and optical characterization of GaN layers grown by HTVPE at various growth conditions will be presented. Analysing reciprocal space maps recorded by HRXRD, the threading dislocation density of the investigated samples was assessed. In order to monitor residual stress within the GaN layers confocal Raman spectroscopic measurements at room temperature with high lateral and spatial resolution were performed. The spectral position of the non-polar E_2(high) Raman mode indicates compressive in-plane strain, which is reduced with increasing GaN layer thickness. This work is financially supported by the European Union (European Social Fund) and by the Saxonian Government (grant no. 100231954).

[1] G. Lukin et al. Phys. Stat. Solidi A **65** (2017) 1600753

HL 33.5 Wed 17:30 Poster F

Cathodoluminescence characterization of stacking faults in GaN — •Anja Ipsen[1], Matthias Hocker[1], Ingo Tischer[1,3], Tobias Meisch[2], Ferdinand Scholz[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter, Semiconductor Physics Group, Ulm University, Germany — [2]Institute of Optoelectronics, Ulm University, Germany — [3]Richter Lighting Technologies GmbH, Heubach, Germany

Semipolar GaN samples, heteroepitaxially grown by metal organic vapor phase epitaxy on pre-structured sapphire substrates, are possible substrates for efficient optoelectronic devices. Due to the sophisticated growth mode on pre-structured sapphire substrates, defects in the epitaxial GaN layer are formed. These include basal plane stacking faults in various types, such as I_1, I_2 and terminating prismatic dislocations. Mostly, these defects are created at an early stage of growth, but also they form during coalescence.

In this study we present spatially and spectrally resolved low-temperature cathodoluminescence (SEM-CL) investigations from a semipolar coalesced $(10\bar{1}1)$ GaN sample, grown on a pre-structured r-plane sapphire substrate. This sample shows complex luminescence signatures from several types of crystal defects.

HL 33.6 Wed 17:30 Poster F

Polarisation resolved PL-studies of thin AlBGaN-layers — •Natja Steiger[1], Sebastian Bauer[1], Markéta Zíková[2], Oliver Rettig[3], Anja Ipsen[1], Yueliang Li[4], Johannes Biskupek[4], Ute Kaiser[4], Ferdinand Scholz[3], and Klaus Thonke[1] — [1]Institute of Quantum Matter/Semiconductor Physics Group, Ulm University, Ulm — [2]The Czech Academy of Sciences, Prague — [3]Institute of Optoelectronics, Ulm University, Ulm — [4]Electron Microscopy Group of Materials Science, Ulm University, Ulm

We try to incorporate small amounts of boron into AlGaN to reduce the lattice mismatch to AlN. This enables strain management in the material system and should help to reduce the quantum confined Stark effect in quantum well structures, hence increasing the external quantum efficiencies of UV-LEDs. However, strain reduction can also have negative impact. By inverting the valence band order and thus switching the emission from TE to TM Mode. In the ternary compound AlGaN, this polarisation switching occurs at a specific composition, which is strongly strain dependent. For high Al content, for which the TM-polarisation is predominant, higher strain enhances TE polarisation. To study the influence of boron on strain and polarisation, mainly optical spectroscopy and X-Ray diffractometry were used, alongside with other characterisation methods. Even for reduced strain, enhanced TE polarisation was observed for boron containing samples.

HL 33.7 Wed 17:30 Poster F

Determination of polarization fields in group III-nitride heterostructures by capacitance-voltage measurements — •Marcel Schilling, Norman Susilo, Luca Sulmoni, Martin Guttmann, Tim Wernicke, and Michael Kneissl — Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany

Due to changes in the spontaneous and piezoelectric polarization, group III-nitride heterostructures exhibit strong polarization fields at heterointerfaces in the order of MV/cm. For quantum wells, the polarization fields lead to a strong band bending and a redshift of the emission wavelength, known as quantum-confined Stark effect. In order to study the influence of polarization fields in group III-nitride-based semiconductor devices, an accurate determination of the magnitude and direction of the polarization fields is of great importance.

We demonstrate a new method to precisely determine the polarization fields in group III-nitride heterostructures based on capacitance-voltage measurements. By evaluating the changes in the depletion region width of a pin diode or Schottky diode, we are able to determine the polarization fields with high accuracy. For this approach, it is necessary to compare the depletion region width of a reference sample without the heterostructure (i.e. homojunction) to a sample with a quantum well structure. Finally, we will discuss the accuracy and possible sources of errors for this method.

HL 33.8 Wed 17:30 Poster F

Optical properties of metamorphic semipolar group III-nitride quantum well structures — •Daniel Schmid[1], Philipp Henning[1], Philipp Horenburg[1], Fedor Alexej Ketzer[1], Heiko Bremers[1], Uwe Rossow[1], Florian Tendille[2], Philippe De Mierry[2], Philippe Vennéguès[2], Jesús Zúñiga-Pérez[2], and Andreas Hangleiter[1] — [1]Institut für Angewandte Physik, Technische Universität Braunschweig — [2]Centre de Recherche sur l'Hétéro-Epitaxie, Valbonne, France

In this contribution we discuss the carrier dynamics in semipolar $(11\bar{2}2)$ quantum well structures. In particular we study the influence of reduced strain in metamorphic structures on recombination processes. For this purpose we control the strain of our samples with AlInN buffer layers to adjust our lattice parameters. Via temperature dependent time-resolved photoluminescence we took a deeper look into the relation between radiative and nonradiative recombination processes of thin (1.5 nm) metamorphic semipolar $(11\bar{2}2)$ GaInN/GaN MQW structures. Our samples were grown with low pressure MOVPE on high quality pseudo bulk GaN substrates as well as on templates grown on patterned sapphire. We measured radiative lifetime of 0.32 ns at 5 K and 1.44 ns at RT. The non radiative lifetime of the sample grown on pseudo bulk GaN was higher compared to samples grown on patterned sapphire, which leads to the idea of fewer defects inside the QW and therefore less non radiative recombination centres. In addition we discuss the effect of the band structure as derived by $\mathbf{k} \cdot \mathbf{p}$ calculations.

HL 33.9 Wed 17:30 Poster F

Transport properties and structural characteristics of thin AlGaN/(AlN)/GaN heterostructures and their built-in 2D electron gases — •Dennis Mauch, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik, TU Braunschweig, Germany

We present transport properties of ultrathin AlGaN/AlN/GaN heterostructures, grown on c-oriented sapphire substrates in our commercial MOVPE system. These heterostructures form a two-dimensional electron gas (2DEG) with high mobilities, showing values exceeding $15000\,\mathrm{cm}^2/\mathrm{Vs}$ at 4K with observed sheet carrier densities ranging from $3 - 12 \times 10^{12}\,\mathrm{cm}^{-2}$. As a consequence of the noncentrosymmetry of the wurtzite structure in group-III nitrides, a large spontaneous polarization is oriented along the hexagonal c-axis. In addition, group-III nitrides are highly piezoelectric. Hence, in AlGaN/GaN heterostructures, where the AlGaN layer is grown pseudomorphically on top of GaN, strain leads to piezoelectric polarization in this AlGaN epitaxial layer. The electric field, induced by the polarization discontinuity at the heterointerface, then gives rise to the formation of a 2DEG ("polarization doping"). We also investigated the influence of an additional AlN interlayer at the AlGaN/GaN interface in order to reduce alloy disorder scattering and thus to reach higher 2DEG mobilities. The transport properties were analysed via Hall effect measurements at room temperature and also by Shubnikov-de Haas measurements at 4K. The structural details were obtained from high-resolution X-ray diffraction and X-ray reflectivity.

HL 33.10 Wed 17:30 Poster F

Investigation of the optical polarization of AlGaN multiple quantum wells using photoluminescence spectroscopy — •Bettina Neuschulz[1], Christoph Reich[1], Johannes Enslin[1], Baran Avinc[1], Frank Mehnke[1], Norman Susilo[1], Christian Kuhn[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 valence band order in AlGaN quantum wells (QW) is strongly effected by the aluminum mole fractions in QW (x) and barrier (y) as well as the QW width. This can lead to a switching of the polarization $P = (TE - TM)/(TE + TM)$ of the emitted light from mainly transverse-electric (TE) to transverse-magnetic (TM). The symmetry and order of the respective valence bands can be probed by polarization resolved photoluminescence (PL) as the degree of optical polarization is directly linked to the valence band properties. Using PL spectroscopy, the optical polarization of the in-plane AlGaN QW emission at room temperature has been investigated, and in a systematic study, the aluminum mole fractions of the QWs and barriers as well as the QW width have been varied. Measurements show that for 1.5 nm thin Al_xGaN/AlN QWs the degree of polarization is changing from 0.33 (TE) for $x = 0.6$ to -0.13 (TM) for $x = 0.81$. Using 2 nm wide QWs with $x = 0.6$ and $y = 0.81$ strongly TE polarized light $P = 0.7$ can be obtained. The transition from TE to TM polarized emission has been observed at a wavelength of ~ 240 nm in good agreement to simulations based on $\boldsymbol{k \cdot p}$ -perturbation theory.

HL 33.11 Wed 17:30 Poster F

Optical and structural properties of latticed matched AlInN/GaN heterostructures — •Savutjan Sidik, Philipp Horenburg, Fedor Alexej Ketzer, Philipp Henning, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institute of Applied Physics, TU Braunschweig, Germany

It is well known that AlInN can be grown lattice-matched on c-plane GaN. In contrast, on non- and semipolar GaN surfaces, one-dimensional lattice matching can be achieved due to diffrent a/c lattice ratios. This opens up new opportunities to manipulate the strain states in the GaInN/GaN quantum well based light emitting diodes which are suffering from strongly reduced efficiencies towards longer wavelength emissions. However, the basic optical properties of AlInN are not yet well known which are of significant importance not only in accurate characterization of the optoelectronic devices but also in evaluation of the structural quality and homogeneity of the samples. In this contribution, we present first results on the optical investigation of lattice matched AlInN heterostructures grown by MOVPE on c-plane, m-plane and semipolar GaN buffer layers grown on various substrates. Photoluminescence spectroscopy is used to characterize the samples with 266 nm laser excitation in the temperature range of 5 K to 300 K. As an initial step, we observe strong polarization-dependent defect related AlInN emission from the sample grown on semipolar orientation at room temperature. An accurate analysis of the strain state of the epitaxial layers by high resolution XRD is combined with the optical characterization.

HL 33.12 Wed 17:30 Poster F

Structural and opto-electrical investigation of InGaN/GaN nanoLED arrays — •Jan Gülink[1,2], Hendrik Spende[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

In recent years, gallium nitride-based LEDs have been continuously developed and employed in not only solid state lighting but also for bio-imaging and optical sensor applications. By integrating them with CMOS control electronics, matrix-addressed GaN microLED arrays could be utilized as a new microscope technique in life sciences. Although those optoelectronic devices exhibit promising results, their spatial resolution is still low, which results from the LED dimensions with pixel and pitch sizes in the range of several tens of micrometers.

In this work, InGaN/GaN nanoLED arrays were designed and fabricated to be used as a nanoillumination source inside an on-chip microscope. As the LED pixel dimensions are scaled down to the sub-micron range, the relationship between the nanoscale size and performance of a LED is of interest. Opto-electrical measurements of nanoLEDs were conducted with nanoneedle probing tips inside an SEM. Hence, I-V and electroluminescence characteristics of light sources with dimensions of smaller than one micrometer could be extracted. Technological details of the challenging processing of these structures will also be presented.

HL 33.13 Wed 17:30 Poster F

Dose and bias dependend cathodoluminescence efficiency of InGaN/GaN MQWs — •Hendrik Spende[1], Johannes Ledig[1,2], Christoph Margenfeld[1], Angelina Vogt[1], Sönke Fündling[1], Hergo-Heinrich Wehmann[1], Tobias Voss[1], and Andreas Waag[1] — [1]Institute of Semiconductor Technology and Laboratory for Emerging Nanometrology, Braunschweig University of Technology, 38092 Braunschweig — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

Cathodoluminescence (CL) inside a scanning electron microscope (SEM) is a powerful tool to probe optical properties of semiconductor microstructures with high spatial resolution. The primary electron probe is scattered and the generated e-h pairs undergo sample related drift and diffusion. Therefore, the radiative recombination inside the material is spatially inhomogeneous and although resolving local electro-optical properties a quantitative interpretation is difficult.

This work aims at understanding the underlying mechanisms to pave the way for a quantiative interpretation. Dedicated MOVPE grown InGaN/GaN test samples were analyzed by CL at room and LN2 temperatures inside a SEM. Each sample contains MQWs emitting at different wavelengths stacked in growth direction. Thus, spectra taken with different electron beam energies provide depth dependent information on the recombination from different MQWs. We observe unexpected time and temperature dependent changes in the CL emission of the samples which suggest electron beam induced changes in carrier dynamics inside the MQW region which is verified by voltage biased CL.

HL 33.14 Wed 17:30 Poster F

Effect of AlGaN quantum well barrier composition on electro-optical properties of 270 nm light emitting diodes — •Jakob Höpfner[1], Martin Guttmann[1], Christoph Reich[1], Luca Sulmoni[1], Christian Kuhn[1], Pascal Röder[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 ultraviolet (UV) light emitting diodes (LEDs) with emission wavelengths around 270 nm have a wide range of applications such as water purification, sterilization of medical equipment and gas sensing. By varying the composition of the AlGaN quantum well barriers (QB), many properties of the LED can be affected: The injection efficiency, the internal quantum efficiency and the light extraction efficiency. To investigate these properties, current and polarization dependent electroluminescence measurements of emission spectrum and output power are performed which are then compared to **k·p** and drift diffusion model calculations. A maximum external quantum efficiency (EQE) was obtained for LEDs with an Al mole fraction of 0.69 in the QB. Furthermore, it was found that the fraction of transverse electric polarized light emission increases and the emission wavelength decreases with increasing Al mole fraction in the QB. This is consistent with **k·p** calculations, attributing the changes of EQE to changes in the transition probabilities. Drift diffusion model calculations are used to investigate the influence of the properties of the heterostructure on the EQE. Finaly, it will be discussed how to balance the different effects.

HL 33.15 Wed 17:30 Poster F

Sub 240 nm UVC LEDs featuring low contact resistance V-based electrodes on n-$Al_{0.9}Ga_{0.1}N$ — •Luca Sulmoni[1], Frank Mehnke[1], Martin Guttmann[1], Christian Kuhn[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 design and fabrication of III-nitride-based heterostructures is particularly demanding for deep UV LEDs emitting below 240 nm as the external quantum efficiency drastically decreases with decreasing wavelength. In addition, ohmic contacts to n-$Al_xGa_{1-x}N$ are extremely challenging for very high Al mole fractions mainly due to the low electron affinity and to limitations in the ionized donor concentration. This results in high operating voltages and resistive heating.

$Al_{0.9}Ga_{0.1}N$:Si layers were grown on low defect density AlN by MOVPE with a specific sheet resistivity of 0.3 Ω cm. In this study, we achieved ohmic contacts on n-$Al_{0.8}Ga_{0.2}N$ with estimated specific contact resistivities of $9{\cdot}10^{-4}$ Ω cm^2. By further optimizing the four-

metal electrode V/Al/Ni/Au configuration and the rapid thermal annealing procedure, we were able to sensibly reduce also the contact resistivities as well as the Schottky behavior of our n-contacts on n-$Al_{0.9}Ga_{0.1}N$. The V/Al/Ni/Au n-contacts on n-$Al_{0.9}Ga_{0.1}N$ annealed at 750°C exhibited moderate rectifying characteristics with estimated specific contact resistivities as low as $3{\cdot}10^{-3}$ Ω cm^2 at a current density of 0.1 kA/cm^2. Finally, we fabricated UVC LEDs emitting at 234 nm with output power of 40 μW at 20 mA and 12.5 V in cw operation.

HL 33.16 Wed 17:30 Poster F

Instability of the Sb vacancy in GaSb — •Natalie Segercrantz[1,2], Jonatan Slotte[2], Filip Tuomisto[2], Kenichiro Mizohata[3], and Jyrki Räisänen[3] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Germany — [2]Department of Applied Physics, Aalto University School of Science, Finland — [3]Department of Physics, University of Helsinki, Finland

The narrow-gap semiconductor GaSb can be used in various optoelectronic devices. Undoped, GaSb is of p-type and the Ga antisite and the Ga vacancy have been shown to be responsible for the residual hole concentration. Self-diffusion experiments in GaSb have revealed another unusual asymmetry of GaSb. The Ga atom was found to diffuse three orders of magnitude faster in the material than the Sb atom. The Sb vacancy has been proposed to be unstable, exchanging sites with a neighboring Ga atom. This mechanism would enhance Ga diffusion due to the increased Ga vacancy defects while at the same time suppressing Sb diffusion.

We have studied the instability of the Sb vacancy by irradiating undoped, p-type GaSb and performing positron annihilation spectroscopy in the temperature interval 35-300 K. The Sb vacancy is shown to be unstable above temperatures of 150 K and undergoes a transition resulting in a Ga vacancy and a Ga antisite leading to a further increase in the acceptor-type defect distribution in proton irradiated material. The activation energy of this transition is determined to be 0.6 eV ± 0.1 eV. Our results prove that the instability of the Sb vacancy in GaSb has a profound role on the native defect distribution in GaSb.

HL 33.17 Wed 17:30 Poster F

Emission and Disorder Properties of Quaternary GaInAsBi Semiconductor Alloys — •Julian Veletas[1], Thilo Hepp[2], Lukas Nattermann[2], Kerstin Volz[2], and Sangam Chatterjee[1] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Giessen, D-35392 Giessen, Germany — [2]Faculty of Physics and Materials Science Center, Philipps-Universität Marburg, D-35032 Marburg, Germany

Dilute bismuth-containing semiconductor alloys such as Ga(As,Bi) are attracting significant attention due to their promising characteristics in near- and mid-infrared laser applications. The incorporation of bismuth leads to a strong reduction of the bandgap commonly described by an anti-crossing model of the Bi-level with the valence bands of the host material. Consequently, the band gap narrows and the separation Δ_{SO} between the valence band edge and the split-off band increases. If Δ_{SO} surpasses E_{gap}, this leads to a suppression of non-radiative Auger recombination and, thus an enhanced performance of future devices. For example, Δ_{SO} surpasses the bandgap energy E_{gap} for more than 4% bismuth incorporation in (Ga,In)(As,Bi) alloys with In concentrations of about 50%. Here, we study a series of (Ga,In)(As,Bi)/(Ga,In)As/InP epilayers grown by metal-organic vapor-phase epitaxy. Modulation spectroscopy is applied to identify the optical transitions in the quaternary alloy. Comparing the results with temperature-dependent photoluminescence data measurements reveals only a small Stokes Shift and very little disorder signatures.

HL 33.18 Wed 17:30 Poster F

Single Quantum Dot with Microlens and 3D-Printed Microobjective as Integrated Bright Single-Photon Source — •Jan Hausen[1], Sarah Fischbach[1], Timo Gissibl[2], Simon Ristok[2], Ksenia Weber[2], Simon Thiele[3], Tobias Heindel[1], Sven Rodt[1], Alois Herkommer[3], Harald Giessen[2], and Stephan Reitzenstein[1] — [1]Institute of Solid State Physics, Technische Universität Berlin, Berlin, Germany — [2]4th Physics Institute and Research Center SCoPE, Stuttgart, Germany — [3]Institute for Applied Optics and Research Center SCoPE, Stuttgart, Germany

In recent years, semiconductor quantum dots (QD) have proven to work as close to ideal single-photon sources. In order to apply such sources in future quantum communication systems, it will be crucial to further increase the photon-extraction efficiency. Here we report on deterministically fabricated QD-microlenses combined with 3D printed microobjectives (MO). Monolithic microlenses were fabricated in a deterministic way by in-situ electron beam lithography allowing for spacial and spectral pre-selection of suitable QDs. Two-photon 3D direct laser writing enabled the realization of multilens MOs precisely aligned to the brightest microlens structures. A micro photoluminescence characterisation of the resulting combination shows an enhancement of the photon-extraction efficiency by a factor of two. The device also exhibits a high suppression of multiphoton events with $g^{(2)}(\tau = 0) < 0.02$.

HL 33.19 Wed 17:30 Poster F

A first-principles investigation of the cubic ternary AlxB1-xBi alloys for infrared optical devices — •BELABBAS Mawloud[1], arbouche omar[2], benallou yacine[1], and bentayeb abdelkader[1] — [1]Laboratory of Technology of Communications, Faculty of Technology, University of Saïda Dr Tahar Moulay, P. O. Box 20000, Saïda, Algeria — [2]Laboratory of physico-chemistry of advanced materials, Faculty of Sciences, University of Djillali Liabes, P. O. Box 22000, Sidi Bel Abbes, Algeria

In this study, We propose the cubic AlxB1-xBi ternary alloy as a promosing infrared material. we used the full potential-linearized augmented plane wave (FP-LAPW) method within the Density Functional Theory (DFT) to predict the structural, electronic and optical properties of the AlxB1-xBi ternary alloys. The structural properties such as the equilibrium lattice parameter, bulk modulus and its pressure derivative are investigated with the effect of the concentration variation of Al atom, x (x=0, 0.25, 0.50, 0.75 and 1). We found that the equilibrium lattice parameter of AlxB1-xBi ternary alloys increases when increasing the doping concentration of the Al atom, while its bulk modulus decreases. The energy band gap of the AlxB1-xBi ternary alloys decreases with the increase in the Al doping concentration. Our results show the direct nature of the energy band gap of the ternary AlxB1-xBi alloy for all composition of Al substitution, Furthermore, investigation of the dielectric function and refractive index shows that our materials are active in infrared and visible energy regions.

HL 33.20 Wed 17:30 Poster F

Subsecond nuclear spin dynamics in n-doped GaAs — •Pavel Sokolov[1,2], Mikhail Petrov[2], Kirill Kavokin[2,3], Maria Kuznetsova[2], Sergey Verbin[2], Dmitri Yakovlev[1,3], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, TU Dortmund, Dortmund, Germany — [2]Spin Optics Laboratory, Saint Petersburg State University, St. Petersburg, Russia — [3]Ioffe Physical Technical Institute, Russian Academy of Sciences, St. Petersburg, Russia

In this work, we report experimental studies of the Nuclear Spin (NS) relaxation in presence of optical excitation in n-doped GaAs ($n_d = 4 \cdot 10^{15}$). The time-resolved photoluminescence study allows us to address a fast subsecond NS dynamics. The NS relaxation time, T_S, is extracted by the time-of-flight method commonly used for investigation the kinetics of the photoluminescence decays. Extrapolation of the subsecond spin relaxation times a weak power of excitation allows us to conclude on the existence of the fast NS relaxation dynamics, which has not been studied so far. We show, that the process is governed by the dynamic polarization of NSs subject to an external magnetic field a time-dependent Knight field of photo-generated electrons encourage also the warm-up of NS bath and relaxation of the non-equilibrium NS. We find that the spin relaxation time T_S is observed in a subsecond time range showing a decrease of T_S from 75 ms down to 40 ms with the pumping power varied by an order of magnitude. The experimental results are interpreted within the developed model predicting a drop of the NS polarization when the light helicity modulation rate reaches a characteristic value determined by ratio $1/\sqrt{T_1 T_2}$.

HL 33.21 Wed 17:30 Poster F

In-situ atomic layer deposition of high-k dielectrics on MBE-grown GaAs — •Soraya Karimzadah[1], Torsten Rieger[1], Nils von den Driesch[1], Lidai Kibkalo[1], Gregor Mussler[1,2], Detlev Grützmacher[2], and Mihail Ion Lepsa[2] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich GmbH & JARA-FIT, 52425 Jülich — [2]Peter Grünberg intsitute (PGI-10), Forschungszentrum Jülich GmbH & JARA-FIT, 52425 Jülich

The deposition of high-k dielectrics on III-V compound semiconductors by atomic layer deposition (ALD) is a promising approach to fabricate gate oxides of Nano devices as well as surface passivation of nanowires (NWs). Employing ALD allows for conformal overgrowth of high aspect ratio structures such as NWs. Here, we have investigated the in-situ ALD of Al2O3 and HfO2 on MBE grown GaAs layers. The experiments were carried out in a state of the art multi-material cluster tool composed of UHV growth and deposition systems. The quality of

the ALD layers was first determined. Later on, the in-situ deposition of Al2O3 and HfO2 on GaAs substrates has performed. The MBE-grown GaAs layers transferred directly to the ALD chamber without exposing the samples to air. In this way, the formation of the native oxide and other contamination on the GaAs surface is avoided improving the quality of the semiconductor interface.

The samples were characterized by Ellipsometry, XRR, AFM, RBS, TEM, and CV measurements. High quality high-k dielectrics on III-V semiconductors open the way to nanoscale devices.

HL 33.22 Wed 17:30 Poster F

LH-HH Splitting in Ga(As,Bi) Semiconductor Alloys — •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 Science Center, Philipps-Universität Marburg, Hans-Meerwein-Str., D-35032 Marburg, Germany

The dilute bismuthide III-V semiconductors are of great interest for a wide range of applications as they offer significant potential for band gap engineering. The anti-crossings of the isovanlent Bi level in the uppermost valence bands of the host material potentially allow for the suppression of non-radiative Auger recombination, thus enhancing radiative output characteristics important for the efficiency of semiconductor lasers. In addition, the incorporation of Bismuth causes a splitting of the heavy-hole (hh) and the light-hole (lh) bands at the Γ-point due to a reduction in tetrahedral symmetry of the zinc-blende structures. We investigate a series of Ga(As,Bi)-samples with varying Bismuth concentration and known strain grown by metal-organic vapor-phase epitaxy. We perform low-temperature photomodulation reflectance spectroscopy in order to get detailed information about the optical properties and to quantify the lifting of the hh-lh degeneracy at the Γ-point.

HL 33.23 Wed 17:30 Poster F

Inverted HEMT structure with electric field induced 2DEG — •Ismail Bölükbasi, Julian Ritzmann, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, D-44780 Bochum, Germany

Two-dimensional-electron gases (2DEG) have interesting physical properties and allow studies in reduced dimensions. For example they can function as a host material for electrostatic qubit systems, like quantum dots. These 2DEGs are mostly created in high-electron-mobility transistors with modulation doping.

However, there are deep donor levels, that hinder compatibility with photonic applications. Approaches like short-period-superlattice doping[1] lead to unwanted gate hysteresis. All structures seem to be plagued by charge noise, probably arising from the dopands in the modulation doped region. To avoid the interference with the impurities, the 2DEG can alternatively be induced with an electric field.

An issue with these structures is to produce reliable ohmic contacts to the 2DEG without short-circuits to the inducing gate. Here we use an approach with alloyed ohmic contacts to a global backgate, inducing the 2DEG. The 2DEG is then contacted with non-alloyed epitaxial contacts.

[1] Umansky, V., et al. "MBE growth of ultra-low disorder 2DEG with mobility exceeding $35*10^6 cm^2/Vs$." *Journal of Crystal Growth* 311.7 (2009): 1658-1661.

HL 33.24 Wed 17:30 Poster F

Formation and characterization of shallow junction in GaAs made by ion implantation and ms-range flash lamp annealing — •juanmei duan and mao wang — Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, D-01328 Dresden, Germany

With the demand of aggressive scaling in MOS device the further progress can be realized by integration of high mobility semiconductors with CMOS technology. III-V compound semiconductors are characterized not only by the high carrier mobility but most of them are also direct band gap semiconductors. In this paper we present the formation of shallow junctions in both p-type and n-type GaAs utilizing ion implantation of S and Zn, respectively, followed by millisecond-range flash lamp annealing (FLA). The distribution of implanted elements obtained by SIMS shows that the FLA process suppressed the diffusion of dopants and simultaneously the ms-range annealing is sufficient to recrystallize the implanted layer. The effective carrier concentration is in the range of 5*1018 cm-3 suggesting full activation of implanted elements. Formation of p-n and n-p junction is confirmed by current-voltage characteristics and photoluminescence spectroscopy where the main emission peak from the implanted GaAs layer exhibits red and blue shift, respectively. The observed shift is due to the Burstein-Moss-Effect. Moreover, the Raman active LO-like phonon mode in Zn doped GaAs exhibits a strong asymmetry on the left side due to a coupling with the plasmon mode. This is typical for p-type GaAs with a carrier concentration higher than 1018 cm-3.

HL 33.25 Wed 17:30 Poster F

Rotational twins in III-V/Si(111) virtual substrates and their impact on subsequent III-V nanowire growth — •Matthias Steidl[1], Christian Koppka[1], Lars Winterfeld[2], Marsel Karmo[2], Katharina Peh[1], Oliver Supplie[1], Peter Kleinschmidt[1], Erich Runge[2], and Thomas Hannappel[1] — [1]Photovoltaics Group, Institute of Physics, Technische Universität Ilmenau, 98693 Ilmenau, Germany — [2]Theoretical Physics I, Institute of Physics, Technische Universität Ilmenau, 98693 Ilmenau, Germany

The epitaxial integration of III-V nanowires (NWs) with Si combines the tunable, high-performance properties of III-V materials with the well-established Si technology. In particular the combination of (111) oriented epilayers/transition layers with the vapor-liquid-solid (VLS) growth of doped, NW-based III-V structures is a subject of intense research. However, the epitaxy on (111) orientation is generally accompanied by the formation of rotational twins. In the present study, we thoroughly investigate the twin suppression in GaP/Si(111) virtual substrates below 5 vol%. In particular, the misorientation of the vicinal Si substrate has a crucial influence on the resulting twin density. We explain the underlying mechanism by a DFT and KMC based nucleation model and show the impact of rotational twin boundaries (RTBs) in GaP/Si on the subsequent NW growth both for GaP and GaAs NWs. RTBs can suppress NW growth entirely or lead to different undesired growth directions, such as horizontal and diagonal growth. To explain the similarities and differences of GaP and GaAs NW growth, we developed a second model based on classical nucleation theory.

HL 33.26 Wed 17:30 Poster F

A series of "fractional" peaks in multiple paramagnetic resonance Raman scattering by (Cd,Mn)Te quantum wells — Alexei Koudinov[1,2], Alexander Knapp[3], Grzegorz Karczewski[4], •Sebastian Elsässer[3], and Jean Geurts[3] — [1]Spin Optics Laboratory, St.-Petersburg State University, St.-Petersburg, Russia — [2]A.F. Ioffe Physico-Technical Institute of RAS, Russia — [3]Physikalisches Institut (EP3), Universität Würzburg, Germany — [4]Institute of Physics, Polish Academy of Sciences, Warsaw, Poland

Diluted magnetic semiconductors (DMS) are employed as a ground for the analysis of spin interactions between the band charge-carriers and the localized spin moments of magnetic ions. In 1995, multiple paramagnetic resonance (MPR) Raman scattering was discovered in narrow QWs of the (Cd,Mn,Mg)Te family: a large number of equidistant Raman repetitions, with energy shifts being integer multiples of the Zeeman splitting of the intra-shell Mn 3d5 electrons. We report on a previously unknown series of B-field dependent Raman lines in MPR conditions in a model DMS QW nanostructure. The observed series of lines shows up in the gaps between the main MPR peaks in a narrow range of B-fields (around 6 T) and seems to manifest a fractional effect: a spin flip of a half-integer number of Mn 3d5 electrons. The peaks reveal remarkably weak dependence of the intensity on the peak number. We demonstrate some main peculiarities of the observed series of lines, discuss the appropriateness of the fractional- as well as alternative interpretations and we discuss steps towards a further exploration of the effect.

HL 33.27 Wed 17:30 Poster F

Optical and magnetic studies of MBE-grown ferromagnetic CrSe and CrS layers in zincblende structure — •Johannes Röder[1], Richard T Moug[2], Kevin A Prior[2], and Wolfram Heimbrodt[1] — [1]Department of Physics and Material Science Center, Philipps University, Marburg, Germany — [2]Institute of Photonics and Quantum Sciences, SUPA, School of Engineering and Physical Sciences Heriot-Watt University, Edinburgh, United Kingdom

Theoretical calculations predicted chromium chalcogenides in the zinc blende (ZB) structure to be promising candidates for half-metallic spin-aligner at room temperature. Unfortunately, the thermodynamically stable phase of CrSe and CrS is the hexagonal NiAs-structure. Different approaches have been tested to stabilize the ZB state. Most

promising were CrSe layers grown on GaAs substrates with either ZnSe or ZnSe/MgS as buffer layers and CrS-layers embedded between ZnMgS layers. All samples have been grown by MBE. We investigated the ferromagnetic properties and magnetic phase transitions and the respective optical properties of these films by temperature dependent SQUID and time resolved photoluminescence measurements. Ferromagnetic phase transitions have been found. The highest yet observed Curie temperature was at 255 K. Optical measurements revealed excitonic transitions of ZnSe, CrSe as well as the type-II CrSe-ZnSe interlayer transition.

HL 33.28 Wed 17:30 Poster F

Towards electrostatically defined Quantum Dots in ZnSe — •Christian Julien Kamphausen[1], Arne Hollmann[1], Felix Hartz[1], Lars Reiner Schreiber[1], Johanna Janssen[2], Torsten Rieger[2], and Alexander Pawlis[2] — [1]JARA - Institute for Quantum Information, RWTH Aachen University, Germany — [2]Peter Grünberg Institute 9 and JARA - FIT, Forschungszentrum Jülich GmbH, Germany

ZnSe is a promising material for realizing electrostatically defined electron spin qubits combining both long coherence and optical activity. Unlike the current materials (Ga,Al)As and SiGe, our ZnSe/(Zn,Mg)Se quantum wells exhibit neither valley splitting nor a nuclear magnetic field if isotopically purified combining their strengths. As the effective mass of ZnSe is three times higher compared to GaAs, small gate patterns are required for single electron trapping.

Therefore, we demonstrate lift-off gate pattern for double quantum dots with feature size of less than 20 nm on Si substrates, which are sufficient for our ZnSe/(Zn,Mg)Se heterostructure according to simulations. In order to avoid electrical noise from doping, we implant dopants below ohmic contacts and heal/activate them by annealing. Heating ZnSe appears to be problematic due to the loss of Zn, which compensates our n-doping. Therefore, we present our studies on annealing in a Zn atmosphere using different implantation energies and species.

HL 33.29 Wed 17:30 Poster F

Optical spectroscopy on single semiconducting hetero dot-in-rod nanostructures: A comparison of type-I (CdSe/CdS) and type-II (ZnSe/CdS) systems — •Hans Werners, Sven Lohmann, Alexandra Hinsch, Christian Strelow, Tobias Kipp, and Alf Mews — Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Single CdSe/CdS dot-in-rod nanostructures are well researched in terms of their optical properties. The band offset of these structures characterizes CdSe/CdS as Type-I semiconductors. Here, we compare recent results obtained in single-nanocrystal spectroscopy of CdSe/CdS dot-in-rods [1] to results on type-II systems.

For this approach we successfully synthesized ZnSe/CdS dot-in-rods. Single ZnSe/CdS dot-in-rod structures were investigated by confocal fluorescence spectroscopy at room and cryogenic temperatures. We measured lifetimes, intensity time traces, emission spectra, and polarization properties of these dot-in-rods for different excitation wavelengths. Our first data indicate a type-II behavior leading to considerably longer lifetimes as compared to the CdSe/CdS case.

[1] S. Lohmann et al., ACS Nano Article ASAP DOI: 10.1021/acsnano.7b05303

HL 33.30 Wed 17:30 Poster F

Transparent UV-active solar cells based on NiO/ZnO heterostructures: Supression of interface recombination currents — •Robert Karsthof, Holger von Wenckstern, and Marius Grundmann — Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany

Visible-light-transparent photovoltaic cells open new fields of application for solar cells, such as energy harvesting on windows, glass roofs or displays of mobile devices. It has been shown [1] that p-NiO/n-ZnO heterojunctions show photovoltaic activity in the UV spectral range. They suffer, however, from a severe illumination-induced increase of the carrier recombination rate at the type-II heterointerface. Because of the strong offsets in valence and conduction bands of the heterostructure, recombination through interface gap states is the dominating transport mechanism under both dark and illuminated conditions.
In this work, we studied the effect of the inclusion of a few-nm-thin insulating layer of HfO_2 between NiO and ZnO, aiming at a suppressed interface recombination by widening the interface gap and reducing the density of states within it. At the same time, it should allow an unhindered transport of photogenerated carriers across.
NiO and ZnO layers were grown by pulsed laser deposition, the HfO_2 buffer layers were deposited by RF sputtering. Device characterization was done by current-voltage, capacitance-voltage and quantum efficiency measurements as well as carrier collection analysis.

[1] R. Karsthof, H. von Wenckstern, M. Grundmann: *J. Vac. Sci. Technol. B* **34**, 04J107 (2016)

HL 33.31 Wed 17:30 Poster F

Towards transparent and flexible photovoltaic devices: optimized growth parameters of NiO/ZnO-based UV solar cells in superstrate configuration — •Fabian Schöppach, Robert Karsthof, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstraße 5, 04103 Leipzig, Germany

Visible-light transparent solar cells open new areas for photovoltaic energy harvesting, such as on windows, glass roofs or displays of mobile devices. In the work of Karsthof et al. [1], ZnO/NiO heterojuntions were used as prototypes of transparent UV active solar cells. The transparency of these cells is mostly limited by the electrode deposited on top of the *p*-type NiO contact. Thin metallic layers are usually employed for this purpose.

In this work we present an approach to tackle this by replacing the hitherto used ohmic contact with a tunnel junction between the *p*-type NiO and a TCO electrode, namely indium tin oxide (ITO). Additionally, the overall structure shall be changed to a superstrate configuration to circumvent the necessity of encapsulation. Moreover, flexible instead of rigid glass substrates were used in order to test for the portability into a roll-to-roll fabrication process. *p*-type NiO and *n*-type ZnO were grown on ITO-coated flexible glass substrates by pulsed laser deposition. The cells were characterized by means of optical transparency, X-ray diffraction and both, dark and illuminated current-voltage measurements.

[1] Karsthof et al. *physica status solidi (a)*, 213.1 (2016): 30–37

HL 33.32 Wed 17:30 Poster F

CVD-growth and characterization of crystalline zinc oxide layers and nanowires — •Florian Huber, Anouk Puchinger, Waleed Ahmad, Manfred Madel, Sebastian Bauer, Raphael Müller, and Klaus Thonke — Institute of Quantum Matter / Semiconductor Physics Group, Ulm University

For the growth of zinc oxide (ZnO) by chemical vapor deposition (CVD), the commonly used graphite powder as reducing agent is replaced by the gaseous precursor methane (CH_4). By this, the controllability of the growth processes can be significantly improved. Specifically the consumption of the source material (a commercially available ZnO powder) and the II-VI ratio can be varied very precisely.

Using this new growth method, high quality ZnO layers have been grown both on gallium nitride (GaN) substrates and on c-plane sapphire with an intermediate aluminum nitride (AlN) nucleation layer. By adjusting the growth conditions accordingly, it is possible to switch from layer growth to catalyst-free growth of ZnO nanowires on a-plane and c-plane sapphire. The excellent quality of the resulting material is proven by high resolution X-ray diffraction (HRXRD) measurements and low-temperature photoluminescence (PL) spectroscopy.

With the presented method high growth rates can be realized, while keeping the technical setup as simple as possible. Together with the high controllability and the low-cost precursors used, the method has great potential for industrial up-scaling.

HL 33.33 Wed 17:30 Poster F

Optical Characterization of iron-doped ZnO — •Sebastian Bauer[1], Florian Huber[1], Benjamin Neuschl[1], Matthias Schreck[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter, Semiconductor Physics Group, University Ulm, Germany — [2]Institute of Physics, University Augsburg, Germany

Iron is a pertinent impurity even in high-quality II-VI-semiconductor materials. In ZnO, iron on a Zn lattice site acts as a deep donor and can not be used to compensate excess carriers. However, ZnO:Fe is an interesting candidate for the realization of ferromagnetic semiconductors for spintronics applications.

In this study we present results on the preparation of iron containing ZnO layers grown by chemical vapour deposition. Iron has been incorporated into high-quality crystalline wurtzite ZnO layers both by ion implantation and by a CVD-based seed growth technique adding iron(II) acetate as a precursor. Optical Raman spectroscopy, photoluminescence, and magneto-optical photoluminescence investigations

on the iron atom and its optical band at 1.78 eV are presented. This band emerges for Fe^{3+} from the spin-forbidden electric-dipole transition from the excited state $^4T_1(G)$ to the ground state $^6A_1(S)$ transition.

HL 33.34 Wed 17:30 Poster F

Raman spectroscopy of the copper oxide phases Cu_4O_3 and CuO: A first principles study — Marcel Giar, Markus Heinemann, and •Christian Heiliger — Institute of Theoretical Physics, Justus-Liebig-University, Heinrich-Buff-Ring 16, 35392 Giessen, Germany

We present first principles Raman spectroscopic investigations of the binary oxides Cu_4O_3 and CuO. For monoclinic CuO different (magnetic) unit cells must be considered at room temperature and below 213 K. These structures particularly differ by their local symmetry. The resulting effects on the Raman spectrum are discussed in detail and experimental observations [1] are explained. We further study the laser energy dependence of the Raman spectrum of both the room temperature and the low temperature structure. For tetragonal Cu_4O_3 experimental Raman spectra have only recently been obtained [2,3]. For this material we present a detailed analysis of the Raman scattering properties with particular emphasis on the crystal orientation and the angular dependence of the Raman intensities.

[1] X. K. Chen, J. C. Irwin, and J. P. Franck, Phys. Rev. B 52, R13130 (1995)

[2] B. K. Meyer, A. Polity, D. Reppin, M. Becker, P. Hering, P. J. Klar, T. Sander, C. Reindl, J. Benz, M. Eickhoff, C. Heiliger, M. Heinemann, J. Bläsing, A. Krost, S. Shokovets, C. Müller, and C. Ronning, Phys. Status Solidi B 249, 1487 (2012)

[3] L. Debbichi, M. C. M. de Lucas, J. F. Pierson, and P. Krüger, J. Phys. Chem. C 116, 10232 (2012)

HL 33.35 Wed 17:30 Poster F

H_2S-sensing in the sub-ppm region with a ZnO nanowire ChemFET — •Angelika Kaiser, Florian Huber, Yujia Liu, Klaus Kolb, Manfred Madel, and Klaus Thonke — Institute of Quantum Matter / Semiconductor Physics Group, Ulm University

The medical role of hydrogen sulfide (H_2S) has been extensively studied over the past few years, revealing a variety of crucial medical applications. These are reaching from cancer therapeutics to medical diagnostics via breath analysis. Such a reliable breath analysis, which is selectively aiming at the detection of ppb-range concentrations of the biomarker H_2S, requires a gas sensing device with a well understood and effective sensing mechanism.

We investigated resistive gas sensors based on the conductivity change of ZnO NWs under different gas exposure, which effectively act as ChemFETs with open gate. The sensitive element is formed by the surface of ZnO NWs, and operates as a transducer between ongoing adsorption reaction on the NW sensor surface and the resistivity change in the NWs leading to a measurable electrical signal. The goal of our work is to design a stable sensor with an optimal translation of the chemical surface reactions into a detectable electrical signal. Therefore, we grew and electrically compared various sets of VLS grown ZnO NWs, which additionally were characterized by SEM micrographs and analysed by low-temperature PL-spectroscopy.

HL 33.36 Wed 17:30 Poster F

Molecular Dynamics Simulation of the Oxidation Process of thin Silicon Nanowires — •Georg Heinze[1,2], Florian Fuchs[1,2,3,4], Sibylle Gemming[2,3,4], and Jörg Schuster[2,4] — [1]Institute of Physics, Technische Universität Chemnitz, Chemnitz, Germany — [2]Fraunhofer Institute for Electronic Nano Systems (ENAS), Chemnitz, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany — [4]Center for Advancing Electronics Dresden (cfaed), Dresden, Germany

Silicon nanowires (SiNWs) are promising building blocks for the development of small nanoelectronic devices, such as ultra-scaled field-effect transistors or sensors. The oxidation of the wires has a large impact on their electronic properties. With shrinking device sizes an atomistic modelling of the oxidation process has become increasingly important.

Using molecular dynamics with a reactive force field potential we analyse the beginning of the oxidation process of thin SiNWs. Wires of variing diameters with the orientations <100> and <110> are examined regarding the speed of the oxidation at different temperatures. We will show how the mass density, the stochiometry and the mechanical strain evolve during the oxidation process. The observation of multiple different subphases during the oxidation is one exemplary finding.

HL 33.37 Wed 17:30 Poster F

Irradiation Effects on β-Ga2O3 Single Crystal: Vacancy vs. Optical Properties — •Chaoming Liu[1], Yidan Wei[1], Mao Wang[2,3], Yonder Berencén[2], Jianqun Yang[1], Xingji Li[1], and Shengqiang Zhou[2] — [1]Harbin Institute of Technology, School of Materials Science and Engineering, 150001, Harbin, China — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, D-01328, Dresden, Germany — [3]Technische Universität Dresden, D-01062, Dresden, Germany

Monoclinic beta-phase gallium oxide (β-Ga2O3) is a versatile transparent conducting oxide with excellent chemical and thermal stability and a wide bandgap of 4.85 eV. In β-Ga2O3, vacancies play a crucial role, largely influencing the optical properties. However, the optical response induced by vacancy-engineering in β-Ga2O3 has so far been only investigated under quasi-stationary conditions. Therefore, the research on the dynamic correlation between the optical properties and vacancies of β-Ga2O3 is of great interests. In this work, n-type β-Ga2O3 single crystals are irradiated by 25 MeV O ions with different fluences to investigate the effect of vacancies. The correlation between the vacancy concentration and the optical properties is investigated by Raman spectra and photoluminescence experiments. We show that the symmetric stretching modes and bending vibrations of GaO4 and GaO6 units are weakened to a certain extent upon increasing irradiation fluence. Moreover, the emission at the blue and green regions is enhanced upon raising the vacancy density, while the UV emission is strongly reduced.

HL 33.38 Wed 17:30 Poster F

The Effect of Oxygen Vacancies on the Creation and Migration of Ti Interstitials in r-TiO2 — •Julian Gaberle and Alexander Shluger — University College London, WC1E 6BT London, UK

Titanium dioxide finds a wide range of applications from catalysis, electronics, gas sensing to paint. Its broad range of uses is due to its exceptional physical properties i.a. high refractive index, high dielectric and hardness. In its stoichiometric form TiO_2 is a wide bandgap insulator. However, defects and impurities can create states, which lie in the bandgap, thus altering its physical properties. Understanding these defect states is imperative to building new technologies and other future applications.

The two most important defects in TiO_2 are oxygen vacancies and titanium interstitials. Both defects create a defect state just below the conduction band. This defect state is commonly attributed to the formation of polarons on titanium sites, creating a Ti^{3+} species.

In this work, we used ab initio methods to investigate the interplay between oxygen vacancies and Ti interstitials. It was found that the barrier for Frenkel defect formation is significantly reduced in the presence of O vacancies. Furthermore the diffusion barrier of Ti interstitials is dependent on the degree of reduction.

HL 34: Carbon: Diamond, nanotubes, Buckyballs

Time: Thursday 9:30–10:30 Location: EW 015

HL 34.1 Thu 9:30 EW 015

Tunable carrier density of two-dimensional hole gases on diamond — •Dennis Oing, Martin Geller, Nicolas Wöhrl, and Axel Lorke — University of Duisburg-Essen, 47057 Duisburg, Germany

Since diamond has a large band gap of 5.45 eV, it shows a vanishing intrinsic charge carrier density at room temperature. However, surface conductivity, induced by a two-dimensional hole gas on the surface, can be established by hydrogen termination and accumulation of an adsorbate layer.
Here, we investigate two-dimensional hole gases (2DHGs) on chemical-vapor-deposition-(CVD)-grown diamond after hydrogen plasma treatment and exposure to ambient atmosphere. The 2DHGs are characterized using temperature-dependent Hall experiments. The influence of the surface functionalization, determined by X-ray photoelectron spectroscopy (XPS), on the carrier density and mobility is evaluated. Hall measurements reveal that the carrier density is increasing from $7.6 \cdot 10^{11}\,\mathrm{cm}^{-2}$ to $1.5 \cdot 10^{13}\,\mathrm{cm}^{-2}$ with increasing amounts of oxygen adsorbed at the surface. In this range, the carrier density remains constant over a temperature range between 4.2 K and 325 K. For oxygen concentrations above 2.2 % (relative XPS signal), the charge carrier density decreases again and becomes temperature dependent. This supports a model based on oxygen-related centers that lead to the transfer of electrons from the surface to the adsorbate layer.

HL 34.2 Thu 9:45 EW 015

Buckyball spin networks controlled using qubits in diamond — •Dinesh Pinto[1,2], Domenico Paone[1], Lukas Schlipf[1], Bastian Kern[1], Markus Ternes[1], Amit Finkler[3], Jörg Wrachtrup[1,2], and Klaus Kern[1,4] — [1]Max Planck Institute for Solid State Research, D-70569 Stuttgart, Germany — [2]3. Physikalisches Institut, Universität Stuttgart, D-70569 Stuttgart, Germany — [3]Department of Biological and Chemical Physics, Weizmann Institute of Science, Rehovot 7610001, Israel — [4]Institut de Physique de la Matière Condensée, École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

The nitrogen vacancy (NV) center in diamond is a model single qubit. It can be optically initialized, coherently controlled and read out. However, controlling multi-qubit NV systems can be challenging as their distribution is generally stochastic. Molecular spin systems, especially N@C_{60} (atomic nitrogen inside C_{60}), show great promise for quantum technologies: single endohedral nitrogen spins have long coherence times, and the scalability of fullerene networks allows for construction of complex nanoscale devices [1]. Coupling N@C_{60} and single NV spins at ultra-high vacuum and cryogenic temperatures allowed us to observe the hyperfine splitting of endohedral nitrogen, which we used to implement quantum gate operations. Another possibility is the emergence of discrete time-crystalline order [2] in our disordered and strongly interacting molecular network.

1. Benjamin, S. C. *et al. J. Phys-Condens. Mat.* **18,** S867 (2006).
2. Choi, S. *et al. Nature* **543,** 221-225 (2017).

HL 34.3 Thu 10:00 EW 015

Fano effect in an ensemble of nitrogen vacancies in diamond under resonant excitation conditions — •Dion Braukmann[1], Vladimir P. Popov[2], Evan R. Glaser[3], Thomas A. Kennedy[3], Manfred Bayer[1,4], and Jörg Debus[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany — [2]Rzhanov Institute of Semiconductor Physics, SB RAS, 630090 Novosibirsk, Russia — [3]Naval Research Laboratory, Washington, DC 20375, USA — [4]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia

Photoluminescence excitation (PLE) enables the observation of the Fano effect in an ensemble of nitrogen vacancy (NV) centers in diamond. We see a Fano resonance at resonant excitation of the NV center. Due to ensemble effects the impact of the resonance is not seen in the intensity of the NV zero phonon line (ZPL), but in a distinct energy shift. The ZPL intensity however shows a different resonance, which can be associated with a recharging process between neutral NV^0 and the negatively charged NV^- centers. In fact, resonant excitation of the NV^0 center at 2.156 eV leads to a strong increase in the NV^- ZPL emission at 1.946 eV. Temperature and excitation power dependent, spectrally resolved PLE measurements show, that due to effective recharging, the ZPL intensity can be increased about a factor of 25. Moreover, time resolved measurements reveal that the charge state can be selectively addressed in timescales of up to one hour.

HL 34.4 Thu 10:15 EW 015

Fully integrated quantum photonic circuit with an electroluminescent nanotube light source — •Felix Pyatkov[1,2], Svetlana Khasminskaya[1], Benjamin Flavel[1], Frank Hennrich[1], Manfred Kappes[1,3], Wolfram Pernice[4], and Ralph Krupke[1,2] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany — [2]Department of Materials and Earth Sciences, Technische Universität Darmstadt, Germany — [3]Institute of Physical Chemistry, Karlsruhe Institute of Technology, Germany — [4]Institute of Physics, University of Münster, Germany

Optically excited semiconducting carbon nanotubes (CNTs) can serve as quantum emitters operating in the telecommunication wavelength range. From the other side, dielectrophoretically deposited CNTs appear as waveguide-integrated electrically driven light sources [1]. The optical properties of such emitters can be tuned by photonic circuit design [2]. In the presented work we demonstrate non-classical properties of electroluminescent CNTs [3]. The electrically generated light efficiently couples and propagates into waveguide, and is recorded with integrated single photon detectors at cryogenic conditions. Correlation function demonstrates pronounced antibunching, which is a clear signature of non-classical nature of light. Therefore, we realized a CNT-based fully integrated photonic quantum circuit with purely electrical drive. [1] S. Khasminskaya, F. Pyatkov et. al., Advanced Materials 26, 3465 (2014). [2] F. Pyatkov, V. Fütterling et. al., Nature Photonics 10, 420 (2016). [3] S. Khasminskaya, F. Pyatkov et. al., Nature Photonics 10, 727 (2016).

HL 35: Focussed Session: Metasurfaces II

Organizers: Isabelle Staude and Carsten Ronning (U Jena)

Time: Thursday 9:30–10:45 Location: EW 201

HL 35.1 Thu 9:30 EW 201

Mie-resonant all-dielectric metasurfaces with tailored positional disorder — •Dennis Arslan[1], Aso Rahimzadegan[2], Stefan Fasold[1], Matthias Falkner[1], Carsten Rockstuhl[2], Thomas Pertsch[1], and Isabelle Staude[1] — [1]Friedrich Schiller University Jena, 07745 Jena, Germany — [2]Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany

Optical metasurfaces typically consist of subwavelength-sized scattering particles placed deterministically on top of a flat surface. The tuning of the metasurface's structural parameters allows for a fine control over the modulation of the wavefront, polarization, and spectrum of a given incident light field.

So far, most of the realized metasurfaces were based on a periodic arrangement of the scattering particles, as the introduction of disorder in the particle position, shape, or orientation inevitably leads to an increase of incoherent scattering and thus to a deterioration of the metasurface's optical properties. More recently, however, it was recognized that the controlled introduction of disorder can, for example, decrease unwanted anisotropy in the optical response and enhance the channel capacity of wavefront-shaping metasurfaces.

In this study, we investigate disordered silicon metasurfaces exhibiting electric and magnetic dipolar Mie-type resonances. We systematically investigate how the introduction of different types of positional disorder influences the phase and intensity transmitted by these meta-

surfaces, showing that disorder can serve as a new degree of freedom in the design of wavefront-shaping devices.

HL 35.2 Thu 9:45 EW 201

Multiphysics Simulation of Phase Change Material based Metasurfaces — •Sebastian Meyer and Dmitry N. Chigrin — Institute of Physics (IA) RWTH Aachen

Meta-surfaces, despite their small length scale, provide immense control over the phase, amplitude and direction of electromagnetic waves. Adding phase-change materials as an active medium promises high flexibility in designing meta-surfaces, which can be reversibly reconfigured in the post-production. Being able to accurately describe the phase change process at the individual meta-atom level is fundamental for understanding and improving functional meta-surface designs.

This presentation deals with the implementation of a self-consistent model combining electromagnetic, thermal and phase transition kinetics simulations. The model is applied to study an all-optically induced resonance shift in a perfect absorber meta-surface. The multiphysics simulations enable design optimisation leading to a significant improvement in the tunability range of the perfect absorber.

HL 35.3 Thu 10:00 EW 201

Control of the Ge(Si) quantum dot emission by Mie resonances in silicon nanostructures — •Viktoriia Rutckaia[1], Mihail Petrov[2], Alexey Novikov[3], Mikhail Shaleev[3], Frank Heyroth[4], and Joerg Schilling[1] — [1]Centre for Innovation Competence SiLi-nano, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany — [2]Department of Nanophotonics and Metamaterials, ITMO University, St. Petersburg, Russia — [3]Institute for Physics of Microstructures of the Russian Academy of Sciences (IPM RAS), 603950 Nizhniy Novgorod, Russia — [4]Interdisciplinary center of material science, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany

Light manipulation at the nanoscale can be achieved using all-dielectric resonant nanostructures. We show an active photonic system based on Ge(Si) quantum dots coupled to silicon nanodisks. We show that Mie resonances govern the enhancement of the photoluminescent signal from embedded quantum dots due to a good spatial overlap of the emitter position with the electric field of Mie modes. We identify the coupling mechanism, which allows for engineering the resonant Mie modes through the interaction of several nanodisks. In particular, the mode hybridization in a nanodisk trimer results in an up to 10-fold enhancement of the luminescent signal due to the excitation of resonant anti-symmetric magnetic and electric dipole modes. Results of the time-resolved measurements show the modification of the QD spontaneous emission rate governed by the Purcell effect in the Mie resonators.

HL 35.4 Thu 10:15 EW 201

Fundamental mode decomposition in a patch-wire metasurface stack — •Jan Sperrhake, Matthias Falkner, Stefan Fasold, and Thomas Pertsch — Friedrich-Schiller Universität Jena, Institute of Applied Physics, Abbe Center of Photonics, Albert-Einstein-Str. 6, 07745 Jena

A widely studied class of optical materials in modern photonics are artificially structured dielectric or metallic surfaces with geometric parameters in the subwavelength regime of impinging electromagnetic waves. If the optical far-field response of these so called metasurfaces is solely determined by their fundamental mode, they can be considered to be homogeneous in the sense of an effective medium. Then, it is furthermore possible to stack different kinds of metasurfaces and achieve a wide range of artificial optical properties.

In our contribution we demonstrate the decomposition of both amplitude and phase of a transmitted fundamental mode into leading transmissive and contributing interferometric parts. We will apply our approach to a fabricated metasurface stack comprised of a lower layer of gold nano-wires and an upper layer of gold nano-patches. Both are differently periodic such that the stacked layers form a super-cell structure. Usually, these have to be handled employing rigorous numerics albeit covering up some of the finer details of the underlying physics. Instead, we employ a faster semi-analytic algorithm that allows for a deeper analysis.

HL 35.5 Thu 10:30 EW 201

Towards macroscopic non-reciprocal light propagation by colloidal self-assembly of gain and loss nanoparticles — Max Schnepf[1,3], Fabian Gossler[1,3], Vaibhav Gupta[1,3], and •Tobias König[1,2,3] — [1]Leibniz-Institut für Polymerforschung Dresden e.V., Institute of Physical Chemistry and Polymer Physics — [2]Technische Universität Dresden, Physical Chemistry, Technische Universität Dresden — [3]Cluster of Excellence Centre for Advancing Electronics Dresden (cfaed), Technische Universität Dresden

For the next generation of optical computing, a novel and cost efficient approach is needed. This future development requires both tailored control over nanometer-sized building blocks on large area and a fundamental understanding of the strong as well as coherent coupling mechanisms. Currently, practical demonstrations are scarce, and are limited in terms of how many devices may be fabricated in parallel. To realize fabrication on a larger scale, a synergy between optical metamaterials and colloidal self-assembly will be leveraged. This requires, on the one hand, applying concepts from parity-time symmetry metamaterials and, on the other hand, using pre-existing gain and loss building blocks, which form an organized structure on large area by reducing their free energy [Nano Lett. 2014, 14, 6863.; Faraday Discuss. 2016, 191, 159.]. We discuss our recent achievements in finite-difference time-domain modelling, large area self-assembly of tailored building blocks as well as time and space resolved optical characterization to fabricate cost-efficient, programmable and up-scalable photonic diodes.

HL 36: Focussed Session: Frontiers in Laser Diode Physics I

Since the first demonstration in 1962, laser diodes experienced tremendous developments. Today, laser diodes find widespread use as small, cheap, robust and reliable sources of coherent light. They are available in a very wide wavelength range with extreme output powers, short pulse width, small energy consumption, special beam properties, or extremely small sizes. Nevertheless,design, fabrication, and analysis of laser diodes to achieve novel or improved properties compose very active, interdisciplinary fields spanning over semiconductor physics, electrical engineering, and materials science. This focus session brings together leaders from industry, internationally renowned expert scientists, and young and active researchers in the field.

Organizers: Tim Wernicke(TU Berlin), and André Strittmatter (OvGU Magdeburg)

Time: Thursday 9:30–13:00 Location: EW 202

Invited Talk HL 36.1 Thu 9:30 EW 202

Semiconductor laser diodes: applications, trends and their technological challenges — •Werner Bergbauer, Andre Somers, Teresa Wurm, Matthias Peter, Christoph Eichler, Sven Gerhard, Georg Bruederl, Soenke Tautz, Bernhard Stojetz, Andreas Loeffler, Martin Mueller, Harald Koenig, and Uwe Strauss — OSRAM Opto Semiconductors GmbH, Leibnizstr. 4, 93055 Regensburg, Germany

The variety of applications using semiconductor lasers is strongly increasing. Especially the tremendous performance increase over the past years is enabling new designs. For example, nitride based laser diodes are used for augmented reality and business projection as well as for phosphor based automotive headlamps. Thus both, efficient low power single mode as well as high power multi-mode lasers, have to be addressed in development and production. In parallel, applications like gesture recognition and autonomous driving powered by infrared

lasers based on the arsenide material system will strongly increase. Next to the performance, reliability and finally the cost reduction of the devices are key factors for success. During the presentation we will discuss the current status, actual technological challenges and future perspectives for laser diodes.

Invited Talk HL 36.2 Thu 10:00 EW 202

Recent progress on VCSELs for the near- to mid-infrared spectral region — •Markus Amann — Walter Schottky Institut, TU München, 85748 Garching, Am Coulombwall 4

Previously, near-infrared Vertical-Cavity Surface-Emitting Lasers (VCSELs) have emerged as versatile single-mode, wavelength-tunable and high-speed laser diodes for numerous applications in communications and sensing. This is because of their intrinsic advantages against edge-emitting lasers such as sub-milliamp threshold currents, high slope efficiencies, low beam divergence and corresponding simple fiber-coupling. Extending the lasing regime further into the mid-infrared, however, is challenged by strong increase ($\propto \lambda^2$) of free-carrier absorption, enhanced Auger recombination, and low thermal conductivity of the underlying quaternary and quinternary alloys.

Recently, the operation wavelengths of VCSELs were significantly increased further into the near- and even mid-infrared by the introduction of the Buried-Tunnel-Junction (BTJ) technology and the application of new materials and quantum well designs. We present InP-based BTJ-VCSELs that operate at wavelengths up to 2.6μm by using type-II heterostructure active regions. With active regions based on the AlGaInAsSb material system, optimized type-I and type-II heterostructures yield emission wavelengths in the entire 3-4μm wavelength range. All devices operate in continuous-wave at room temperature, show an excellent single-mode emission with SMSR of 30dB and a continuous electro-thermal wavelength tunability up to about 20nm.

HL 36.3 Thu 10:30 EW 202

Self-mode locking of VECSELs in the red spectral range — •Marius Grossmann[1], Roman Bek[1], Hermann Kahle[1], Arash Rahimi-Iman[2], Martin Koch[2], 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]Department of Physics and Materials Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg

Since the first demonstration of a mode-locked vertical external-cavity surface-emitting laser (VECSEL) using a saturable absorber (SA) in 2000, these lasers have shown diffraction limited beam quality as well as high output powers across multiple emission wavelengths. In 2011, a new technique termed self-mode locking (SML) emerged in the infrared spectral range by abandoning the SA and thereby creating a cavity with outstanding simplicity, which allows emission with pulse lengths down to the sub-picosecond regime.

We recently showed the self-mode locked operation of a red-emitting VECSEL with the gain structure based on the AlGaInP material system. The linear cavity formed by the AlAs/AlGaAs distributed Bragg reflector and a curved outcoupling mirror delivers up to 35 mW of average output power at a repetition rate of 3.5 GHz. Additional measurements are presented with focus on laser pulse properties visible in the radio frequency power spectrum as well as the intensity autocorrelation of the noise-like pulse.

HL 36.4 Thu 10:45 EW 202

Characteristics of InAsSb/GaAs submonolayer lasers — •David Quandt[1], Dejan Arsenijević[1], Dieter Bimberg[1], and André Strittmatter[2] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany — [2]Otto-von-Guericke Universität Magdeburg, Universitätsplatz 2, D-39106 Magdeburg, Germany

The addition of Sb to the growth of InAs/GaAs submonolayer stacks results in a stronger charge carrier localization and a broader photoluminescence emission spectrum. Thereby an additional degree of freedom for the tailoring of the emission properties is gained. The static and dynamic characteristics of ridge-waveguide laser diodes containing submonolayer stacks with and without Sb have been investigated in detail. While the static characteristics show a slight degradation upon the addition of Sb, broader gain spectra and increased large signal modulation speeds could be realized.

HL 36.5 Thu 11:00 EW 202

Time dependent correlation dynamics and stochastical bifurcations in high-β quantum-dot mircopillar lasers — •Christoph Redlich, Benjamin Lingnau, and Kathy Lüdge — Institut für theoretische Physik, TU Berlin

We theoretically investigate semiconductor quantum-dot (QD) micropillar lasers with respect to the dynamics of their photon statistics and correlation functions. Semiconductor micropillar lasers show a two mode polarization degeneracy and high spontaneous emission noise (β-factor). This combination yields a strong mode interaction via the common gain medium and consequently, these lasers can show frequent mode switching and super-thermal emission characteristics.

During dynamic relaxation processes that occur far from thermodynamic equilibrium e.g. after optical perturbations or turn-ons, the second order correlation function $g^{(2)}(0)$ can yield valuable information about the laser behavior.

We describe the emission dynamics of the laser with a simple semiclassical model that contains a Langevin noise source for spontaneous emission. Using the ergodicity of the system, time-dependent intensity correlation functions can be evaluated by means of the variations from an ensemble of noise realizations. In contrast to fully quantum mechanical evaluation of $g^{(2)}$, we do not need a fully quantized approach to calculate these correlations. Particularly interesting are cases of relaxation oscillations or mode switching where we find strong oscillations in $g^{(2)}(0)$.

15 min. break.

Invited Talk HL 36.6 Thu 11:30 EW 202

Simplicity VCSELs — •James A. Lott[1], Nasibeh Haghighi[1], Gunter Larisch[1], Ricardo Rosales[1], and Martin Zorn[2] — [1]Technische Universtität Berlin, Berlin, Germany — [2]JENOPTIK Diode Labs GmbH, Berlin, Germany

We experimentally and theoretically investigate the optical, electrical, and thermal physics of vertical-cavity surface-emitting lasers (VCSELs) grown on gallium-arsenide substrates with epitaxial structures based on simplicity-in-design principles. We aim to minimize the complexity of our VCSEL epitaxial designs while simultaneously improving our VCSEL performance and reliability for specific resurgent, mainstream, and new VCSEL applications in sensing, communication, heating, and illumination. Our reduced epitaxial design complexity is expected to greatly reduce the cost to produce massive quantities of VCSELs on ever larger diameter starting wafers, and we believe similar Simplicity principles may be applied to the processed VCSEL device geometries to further reduce commercial VCSEL production costs. We demonstrate 980 nm Simplicity VCSELs with a wide range of emitting aperture diameters with record performance that exceeds the performance or our previous more complex VCSEL designs in common figures-of-merit including optical output power, efficiency and small-signal modulation bandwidth

HL 36.7 Thu 12:00 EW 202

High bandwidth versus high optical output power in 980 nm VCSELs — •Nasibeh Haghighi[1], Gunter Larisch[1], Ricardo Rosales[1], Martin Zorn[2], and James A. Lott[1] — [1]Technische Universtität Berlin, Berlin, Germany — [2]JENOPTIK Diode Labs GmbH, Berlin, Germany

Vertical-cavity surface-emitting lasers (VCSELs) are a key optical source for modern and future high bit rate optical interconnects in data centers, supercomputers, and silicon photonic integrated circuits, and for data communications across multimode optical fiber and across free (terrestrial) space. We study the trade-offs in VCSEL design between high bandwidth and high optical output power. At room temperature with our small (about 4 micrometers and smaller) oxide-aperture diameter VCSELs we achieve record small-signal modulation bandwidths exceeding 34 gigahertz with single-mode optical output powers exceeding 4 milliwatts. In contrast with our large (about 10 micrometers and larger) oxide-aperture diameter VCSELs we achieve bandwidths exceeding 20 gigahertz with multiple-mode optical output powers up to about 30 milliwatts. We compare our VCSEL designs for use in example near-term practical applications including arrays for free-space data communications and as illumination and sensing sources for smart mobile telephones.

HL 36.8 Thu 12:15 EW 202

Optimization upon AlGaInP-based membrane lasers — •Thomas Klumpp, Roman Bek, Hermann Kahle, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funk-

tionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart

Vertical external-cavity surface-emitting lasers (VECSELs), also known as optically pumped semiconductor disc lasers (OPSDLs), are becoming more and more popular due to their simplicity and excellent emission properties. Improvements regarding the output power can be obtained by optimized semiconductor gain structures, but also by advanced methods for heat extraction from the active region. Especially for AlGaInP-based VECSELs emitting in the red spectral range, one of the main limitations is the low charge carrier confinement in combination with heat incorporated into the active region by optical pumping. The thermal management can be particularly improved by a membrane laser concept, the membrane external-cavity surface-emitting laser (MECSEL). Furthermore, with the active region sandwiched between two transparent intracavity heat spreaders, growth of a distributed Bragg reflector is avoided. We present our current work on the progress of AlGaInP-based MECSELs aiming on high output power and wavelength versatility.

HL 36.9 Thu 12:30 EW 202

Stability of Two-State Quantum-Dot Lasers with Optical Feedback — Lucas Kluge, •Stefan Meinecke, and Kathy Lüdge — Institut für Theoretische Physik, Technische Universtität Berlin, Berlin, Germany

Semiconductor lasers based upon self-assembled quantum-dots (QDs) are promising sources for applications in optical networks used e.g. for data transmission via optical fibers. Recently, their ability to show simultaneous two-state lasing became the focus of diverse investigations.

We theoretically study a two-state quantum-dot laser with optical self-feedback. Our modeling approach is based on microscopically based rate-equations and goes beyond the constant alpha-factor approximation by including carrier dependent frequency shifts obtained from a full Bloch-equation approach.

In our previous work [1], we demonstrated that two-state lasing, although increasing the dynamical degrees of freedom, stabilizes the response of a QD laser to optical injection. We now report, that in the case of time-delayed feedback, a similar mechanism also increases the dynamical stability of a two-state laser. Regions of complex dynamics, which are predicted for single-color QD lasers, are greatly reduced, if lasing from the excited state is possible.

This behavior makes two-state QD lasers suitable for applications where a high tolerance for unwanted back-reflections is crucial for stable operation.

[1] S. Meinecke, B. Lingnau, A. Röhm, K. Lüdge, Ann. d. Physik (2017)

HL 36.10 Thu 12:45 EW 202

Towards mode locking of a semiconductor membrane laser — •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

Optically pumped semiconductor disk lasers (SDLs) provide several advantageous properties like near-diffraction-limited beam profile and the flexibility to add optical components inside the cavity. However, due to the incorporated heat in the active region by the pump laser, the output power of SDLs is limited by the thermal management. A new concept, the membrane external-cavity surface-emitting laser (MECSEL), first presented in 2016, uses an active region sandwiched between heat spreaders for optimized heat dissipation. Furthermore, it enables new material combinations for new laser wavelengths, which are not possible with the Bragg reflector in the conventional disk laser. Especially attractive is the combination of this new laser device with semiconductor saturable absorbers for ultrafast pulse generation.

In this contribution, we investigate the characteristics of an AlGaInP-based MECSEL emitting in the red spectral range. Current research focuses on time and frequency domain measurements with and without an absorbing semiconductor intracavity component and evaluates the possibility of mode-locked operation.

HL 37: Oxide Semiconductors

Time: Thursday 9:30–13:00 Location: EW 203

HL 37.1 Thu 9:30 EW 203

Polaronic entropy stabilizes mixed-valence compound K_4O_6 — Patrick Merz[1], Claudia Felser[1], Martin Jansen[1,2], •Christoph Freysoldt[3], and Jörg Neugebauer[3] — [1]Max-Planck-Institut für Chemische Physik fester Stoffe, Nöthnitzer Str. 40, 01187 Dresden — [2]Max-Planck-Institut für Festkörperforschung,Heisenbergstr. 1, 70569 Stuttgart — [3]Max-Planck-Institut für Eisenforschung GmbH, Max-Planck-Str. 1, 40273 Düsseldorf

Alkali sesquioxides, M_4O_6, contain peroxide O_2^{2-} and superoxide O_2^- ions and are prime examples of correlated open-shell p-electron systems. They show a rich phase diagram arising from the interplay of magnetic, orbital, and charge ordering depending on temperature and the cation size (chemical pressure). We report on the reversible endothermic formation of K_4O_6 from the separate peroxide and superoxide phases at ≈350° C. Rapid cooling leads to a metastable, charge-ordered phase, that decomposes when heated to 100° C. In order to better understand thermodynamic stability by means of density-functional theory (DFT) calculations, we have developed a scheme to include Hubbard-U corrections to account for correlations between the molecular sites. The calculations suggest that the stability at elevated temperatures is driven by the polaronic entropy associated with charge hopping between the O_2 molecular units. The ionic displacements associated with polaron hopping are complex and large, sometimes >1 Å in distance. Our findings highlight that the commonly used separation between electronic and phononic excitations in finite-temperature materials modelling may miss crucial stabilization mechanisms.

HL 37.2 Thu 9:45 EW 203

Controlling and Analyzing the Conductivity of TiO2 Nanorod Arrays — •Carola Ebenhoch, Julian Kalb, Elise Sirotti, Domenik Vögel, and Lukas Schmidt-Mende — Department of Physics, University of Konstanz, Germany

Besides being an important semiconducting material in industry for electrical components such as transistors, diodes, sensors, solar cells, and many more [1], TiO2 can easily be grown in nanometer dimensions (e.g. thin films via SALD and nanowires via hydrothermal growth), which enables the access to nanodevices. Due to an increased surface to bulk ratio for nanowires, effects from surface states become even more important for electronic properties, which still require extensive investigations. In this regard, we present conductivity measurements on nanorod arrays grown on a FTO substrate via hydrothermal growth, contacted with a gold tip as top electrode. The density of defect states at the surface, e.g. oxygen vacancies, were modified using a post annealing process in different atmospheres. With this method, temperature dependent conduction mechanisms for highly conductive nanowires, containing a large amount of oxygen vacancies at the surface [2], or rather low conductive nanowires could be identified.

[1] Yu, X., et al., Metal oxides for optoelectronic applications. Nat Mater, 2016. 15(4): p. 383-96.

[2] Folger, A., et al., Tuning the Electronic Conductivity in Hydrothermally Grown Rutile TiO(2) Nanowires: Effect of Heat Treatment in Different Environments. Nanomaterials (Basel), 2017. 7(10).

HL 37.3 Thu 10:00 EW 203

Spray Coating of Transparent Oxide Semiconductors - β-Ga_2O_3, In_2O_3-Ga_2O_3-ZnO, and ZnO Thin Films — •Constance Schmidt, Axel Fechner, and Dietrich R.T. Zahn — Semiconductor Physics, Technische Universität Chemnitz, 09107 Chemnitz, Germany

Transparent, semiconducting materials offer new opportunities for optoelectronic devices, like flat panel displays. The most remarkable property of these transparent oxide semiconductors (TOSs) is their wide band gap (>3 eV). Besides established deposition methods like MBE and CVD, cost efficient preparation methods are of great interest. Spray coating, the deposition technique of our choice, is one of these cost efficient methods to prepare TOS thin films. Samples were prepared by spray coating using a solution containing $Ga(NO_3)_3$, $Zn(NO_3)_2$, and In_2O_3, Ga_2O_3, or ZnO. For Ga_2O_3 and ZnO we solved

their nitrates in H_2O and Ethanol, for In_2O_3-Ga_2O_3-ZnO thin films we used isopropyl alcohol as solvent. N_2 is always used as carrier gas. Post annealing (300 °C - 1300 °C) needs to be applied to all thin films prepared. Optical respectively vibrational properties were studied using spectroscopic ellipsometry and Raman spectroscopy. X-ray diffraction was employed to investigate structural and phase purity. Topological and morphological characterization was performed using scanning electron microscopy. Finally, the conductivity was determined by the four-point probe method. It is demonstrated that high quality TOSs thin films using cost efficient spray coating.

HL 37.4 Thu 10:15 EW 203

Excitonic absorption and optical properties of ZnO films — •Stefan Zollner[1], Nuwanjula Samarasingha[1], Zachary Yoder[1], Dipayan Pal[2], Aakash Mathur[2], Ajaib Singh[2], Rinki Singh[2], and Sudeshna Chattopadhyay[2] — [1]New Mexico State University, Las Cruces, NM, USA — [2]IIT Indore, Indore, India

Using spectroscopic ellipsometry from 0.5 to 6.5 eV, we have investigated the thickness dependence of the optical constants (complex refractive index, dielectric function) of zinc oxide thin films grown on Si and SiO2 by atomic layer deposition. Independent characterization of the films was carried out using powder x-ray diffraction (texture, grain size), x-ray reflectance (density, thickness, roughness), and atomic force microscopy (roughness). The validity of the ellipsometry results was verified with careful error analysis, including a uniqueness fit for the thickness parameter, and comparison of the thickness with XRR. The dielectric function of ZnO layers was described with an oscillator model guided by measurements for bulk ZnO. Our results show convincingly that both the real and imaginary part of the dielectric function of ZnO on Si decrease with decreasing film thickness. We attribute this thickness dependence to the optical transition matrix element (electron-hole overlap) modified by the interface. The results are not so clear for ZnO on SiO2.

HL 37.5 Thu 10:30 EW 203

Tunable intersubband transitions in ZnO/ZnMgO multiple quantum wells in the mid infrared spectral range — •Laura Orphal, Sascha Kalusniak, Oliver Benson, and Sergey Sadofev — Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

ZnO is considered as a promising material for mid IR intersubband devices, and possibly also for the THz regime [1]. We demonstrate the ability to control intersubband transition (ISBT) energies in O-polar $ZnO/Zn_{0.60}Mg_{0.40}O$ multiple quantum well structures grown by molecular beam epitaxy on sapphire [2]. The ISBT between the first and the second electronic energy state within the conduction band are observed by infrared spectroscopy at room temperature. Absorption features due to the ISBT occur only for light polarized normal to the quantum well plane (p-polarized) according to the polarization selection rules. By variation of the quantum well width the ISBT energies can be tuned from 290 to 370 meV. The experimental results are in good agreement with theoretical calculations assuming the presence of internal electric fields of 2 MV/cm.

[1] E. Bellotti, K. Driscoll, T. D. Moustakas, and R. Paiella, Journal of Applied Physics **105**, 113103 (2009).
[2] L. Orphal, S. Kalusniak, O. Benson, S. Sadofev, AIP Advances **7**, 115309 (2017).

HL 37.6 Thu 10:45 EW 203

Towards high-performance printed in-plane and vertical MOSFETs — •Felix Neuper, Robert Kruk, Horst Hahn, and Ben Breitung — Institute of Nanotechnology, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

Integrating printed MOSFETs in complex circuits has been successfully demonstrated recently by our group [1] and novel transistor architectures are under development to further improve their performance. As one way to optimize device behaviour a printed vertical porous channel approach has been shown [2], enhancing key parameters such as channel length, on-off-ratio, and high current densities.

As Atomic layer deposition (ALD) is able to coat complex porous structures with high aspect ratios, in this presentation we show how changing from electrolyte gating to ALD-processed dielectric gating in printed MOSFETs vastly increases switching speeds and reduces leakage currents, as well as providing long-term reliability and stability towards environmental influences. Despite the usage of dielectrics, the devices are fully operational at low voltages (<= 1V) allowing applications such as smart packaging and wearable devices.

[1] Gabriel C M et al.Appl. Phys. Lett. 111, 102103 (2017) [2] Tessy. Baby et al., Advanced Materials, 29 (4), 1603858 (2017)

15 min. break.

HL 37.7 Thu 11:15 EW 203

Influence of parameters on the properties of pulsed radiofrequency magnetron sputtered Ga_2O_3 — •Philipp Schurig, Fabian Michel, Martin Becker, Angelika Polity, and Peter Klar — 1. Physikalisches Insitut und Zentrum für Materialforschung (LaMa), Justus-Liebig-Universität Giessen, Giessen, Deutschland

The advantages of high power impulse magnetron sputtering (HiPIMS) on the deposition of materials is well known, but a combining an impulse method with radio frequency sputtering is not straightforward. With Ga_2O_3 as a transparent oxide with a band gap of about 4.9 eV the influence of the duty cycle or the sputter power on the layer properties of pulsed radio frequency magnetron assisted sputtered films is investigated. The idea behind this transfer is to be able to lower the growth temperature of about 650 °C for good quality Ga_2O_3 by increasing the particle energy. For industrial applications and flexible substrates high substrate temperatures are a drawback. HiPIMS studies [1] have shown that pulsed sputter deposition allows an increase of the coupled power and at the same time a decrease of the growth temperature without severe structural degradation of the material. However, post growth annealing was still necessary and was executed at a temperature of 1000 °C in ambient atmosphere. Optical, crystallographic and compositional analysis was performed after deposition and thermal treatment.

[1] E. Nakamura et al.: Appl. Phys. Lett. 104, (2014) 051121

HL 37.8 Thu 11:30 EW 203

Optical properties of amorphous Zn-Sn-Ti oxides: A combined molecular dynamics and density functional theory study — •Daniel Fritsch — Department of Chemistry, University of Bath, BA2 7AY Bath, UK

Amorphous transparent conductive oxides (TCOs) are widely used in technological applications due to their high transparancies, charge carrier mobilities, and flexibility. Active research is under way to find materials to replace the up-to-now industry standard amorphous In-Ga-Zn oxide (a-IGZO). A promising material combination has been identified within the $(ZnO)_x(SnO_2)_y(TiO_2)_z$ solid-solution. The immense parameter space for fabrication of this system (x:y:z ratio) makes computational screening and insights highly desirable.

Here, we report on our combined ab initio molecular dynamics (MD) and density functional theory (DFT) study of amorphous Zn-Sn-Ti oxide solid-solutions. Covering the whole parameter space (x:y:z ratio) we generated amorphous structures using a well-established melt and quench approach. Based on the resultant structures, structural, electronic, and optical properties are analysed and compared with available experimental and theoretical data. The electronic properties are calculated using a self-consistent hybrid functional, which has been proven to yield improved results for bulk oxide semiconductors [1].

[1] D. Fritsch, B. J. Morgan, and A. Walsh, Nanoscale Research Letters 12, 19 (2017).

HL 37.9 Thu 11:45 EW 203

Interactions of Rydberg Excitons in Cu_2O — •Felix Föst[1], Julian Heckötter[1], Rico Schwartz[2,1], Marc Assmann[1], Dietmar Fröhlich[1], and Manfred Bayer[1] — [1]Experimentelle Physik 2, TU Dortmund, Germany — [2]Institut für Physik, Universität Rostock, Germany

In this work we present absorption measurements on highly excited Rydberg excitons in cuprous oxide with principal quantum numbers n up to 25 and odd angular momentum (p, f,..., in analogy to the hydrogen atom). These excitons have a large orbital extension of up to 2 microns [1], covering over 10^9 unit cells, which leads to a strong dipole moment and therefore a giant dipole-dipole interaction.

We investigate the interaction of these highly excited Rydberg states with other exciton states, e.g. p-excitons with low n or the 1s exciton. To accomplish this, we use 2 CW lasers in a conventional two-colour pump-probe setup to pump different fixed exciton resonances and simultaneously probe the absorption spectrum. With increasing pump laser power density, we find a decrease of absorption efficiency for large quantum numbers n in accordance with theory [1]. In addition, we also see an initial increase in absorption for small n for both p- and

f-excitons, which is larger for higher pump energies.

[1] T. Kazimierczuk et al., Nature **514**, (2014), p. 343

HL 37.10 Thu 12:00 EW 203

A Unifying Perspective on Oxygen Vacancies in Wide Band Gap Oxides — •Christopher Linderälv, Anders Lindman, and Paul Erhart — Chalmers University of Technology, Gothenburg, Sweden

Wide band gap oxides are versatile materials with numerous applications in research and technology. Many properties of these materials are intimately related to defects with the most important defect being the oxygen vacancy. Here, using electronic structure calculations, we show that the charge transition level (CTL) and the eigenstates associated with oxygen vacancies, which to a large extent determine their electronic properties, are confined to a rather narrow energy range, even while band gap and the electronic structure of the conduction band vary substantially. The vacancies are classified according to their character (deep and shallow), which shows that the alignment of electronic eigenenergies and CTL can be understood in terms of the transition between cavity-like localized levels in the large band gap limit and strong coupling between conduction band and vacancy states for small to medium band gaps. We consider a semi-local as well as a hybrid functional and, complementing earlier work, demonstrate that the former yields results in very good agreement with the latter provided that band edge alignment is taken into account.

HL 37.11 Thu 12:15 EW 203

Defect induced magnetism and polaronic states in ZnO — Sanjeev K. Nayak[1], •Waheed A. Adeagbo[2], Martin Hoffmann[3], Matthias Geilhufe[4], Hichem Ben Hamed[2], Arthur Ernst[3,5], and Wolfram Hergert[2] — [1]Department of Materials Science & Engineering, University of Connecticut, USA — [2]Institute of Physics, Martin Luther University Halle-Wittenberg, Germany — [3]Institute for Theoretical Physics, Johannes Kepler University Linz, Austria — [4]Nordita, Center for Quantum Materials, KTH Royal Institute of Technology and Stockholm University, Sweden — [5]Max Planck Institute of Microstructure Physics, Halle, Germany

Crucial issue on magnetism in ZnO in scientific literature with transition metal doped ZnO has been to identify the mechanism for magnetic interaction. However, recent reports on ferromagnetism in pure defected ZnO and Li doped ZnO have brought back our attention to examine the electronic structure of doped ZnO more carefully in order to justify the origin of magnetic moment in p-orbital system. Present understanding goes in the line that localization of holes created from some point defects, such, as Zn-vacancy V_{Zn}, is responsible for the magnetic moment. The question about the interpretation of first-principles calculations for such a problem is the interest of the present work. We propose that the hole localization in V_{Zn}, could be achieved by treating the $V_{\mathrm{Zn}}{-}O_4$, as a single complex unit of point defect, where the four O are treated separately through a Hubbard-U correction. The treatment gives identical results as in hybrid-functional treatment and non-local external potential functional and is more intuitive.

HL 37.12 Thu 12:30 EW 203

Identification of switching modes in Y_2O_3 transition metal oxide RRAM devices — •Eszter Piros[1], Stefan Petzold[1], Benjamin Krah[1], Sharath Sankaramangalam Ulhas[1], Tom Blomberg[2], Marko Tuominen[2], Hessel Sprey[3], Christian Wenger[5], Eric Jalaguier[4], Sophie Bernasconi[4], Etienne Nowak[4], Erwin Hildebrandt[1], and Lambert Alff[1] — [1]Institute for Materials Science, Advanced Thin Film Technology, Technische Universität Darmstadt, Alarich-Weiss-Str. 2 D-64287 Darmstadt, Germany — [2]ASM Microchemistry Ltd. Väinö Auerin katu 12 A, 00560 Helsinki, Finland — [3]ASM Belgium NV Kapeldreef 7, 3001 Leuven, Belgium — [4]CEA Leti 17 avenue des Martyrs, 38054 Grenoble, France — [5]IHP Im Technologiepark 25, 15236 Frankfurt (Oder), Germany

Resistive random access memory (RRAM) devices offer a new solution to the current problems of scalable non-volatile data storage. Here we report the stabilized resistive switching modes [1] in yttrium oxide-based RRAM devices. In the bipolar device, stable intermediate resistance states are achieved by varying either the voltage sweep values during reset or by varying the compliance current in the set process. This opens up the possibility of multibit programming and neuromorphic applications. The conduction mechanism of bipolar and unipolar devices was also investigated. The high endurance that exceeds several hundred DC switching cycles and very good data retention (extrapolated to 10 years at 85°C) make both bi- and unipolar devices suitable candidates for next generation non-volatile memory devices. [1] S. U. Sharath, Adv. Funct. Mater. 27, 1700432 (2017)

HL 37.13 Thu 12:45 EW 203

Solution processed hybrid field effect transistors based on graphene electrodes — •Surya Abhishek Singaraju[1], Tessy Theres Baby[1], Jasmin Aghassi-Hagmann[1,2], Horst Hahn[1], and Ben Breitung[1] — [1]Institue of Nanotechnology, Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen 76344, Germany — [2]Department of Electrical Engineering and Information Technology, Offenburg University of Applied Sciences, Offenburg 77652, Germany

In our work we target solution-processable, electrolyte-gated field-effect transistors (EGFETs) based on an In2O3 precursor channel material and graphene for the passive electrodes. The EGFETs were prepared on glass substrates by printing crystalline In2O3 as active material, graphene ink for passive structures and a composite solid polymer electrolyte (LiClO4/PC/PVA/DMSO) as gating compound. Good printing resolution could be achieved by ink-jet printing the In2O3 precursor and the electrolyte and by microplotting the graphene electrodes using an ultrasonic-controlled fluid dispensing microplotter. The chemical properties and the interaction of different transistor components was analyzed using methods like XPS and cyclic voltammetry. The interface between source/drain and the channel plays a major role in the device performance and was investigated regarding the electrical contact. We observed that the devices exhibited relatively high output current values for a fully printed transistor. Also, the on/off ratio from the transfer curve was measured to be in the range of 105-107.

HL 38: 2D materials: Chalcogenides II (joint session HL/DS)

Time: Thursday 9:30–13:15 Location: A 151

HL 38.1 Thu 9:30 A 151

Excitation-induced transition from direct to indirect band gaps in monolayer TMDCs — •Daniel Erben[1], Alexander Steinhoff[1], Tim Wehling[1,2], Christopher Gies[1], and Frank Jahnke[1] — [1]Insitute for Theoretical Physics, University of Bremen, Germany — [2]Bremen Center for Computational Materials Science, University of Bremen, Germany

Monolayer transition metal dichalcogenides (TMDCs) are atomically thin semiconductors with a direct band gap, which allows their use as active material in optoelectronic devices. Often photoluminescence or photoemission spectroscopy experiments are employed for the characterization of TMDCs. Via laser pulse excitation these methods provide excited charge carriers that populate the valleys of the band structure. The Coulomb interaction of these excited carriers causes strong many-body renormalizations in the band structure, which consequently shift the valleys and the excitonic resonances by several hundred meV.
In this talk we give detailed insight into the many-body effects in monolayer MoS_2, $MoSe_2$, WS_2 and WSe_2 by evaluating the semiconductor Bloch equations including DFT-band structures and interaction-matrix elements. This provides a precise description for the interplay of the Coulomb interaction with the electron and hole populations. We describe the impact of these effects on the K- and Σ-valley in the band structure. Our calculations show a clear tendency to a direct-to-indirect band gap transition due to the renormalizations. Being reminiscent of the effect of strain on monolayers, this transition should also lead to a quenching of the photoluminescence.

HL 38.2 Thu 9:45 A 151

Microscopic description of localized quantum-dot-like states in MoS2 nanobubbles — •Christian Carmesin, Matthias Florian, Michael Lorke, Daniel Erben, and Frank Jahnke — Institute for Theoretical Physics, University of Bremen, Germany

Atomically thin layers of transition metal dichalcogenides (TMDCs) have emerged as a new class of optically active materials with recent applications reaching into the quantum-information technologies. The

systematic engineering of local confinement potentials opens the possibility of the deterministic generation of single-photons. A possible platform are TMDC nanobubbles that develop if air is enclosed during the stacking of layers. We report on results of atomistic tight-binding calculations of different sizes and height-to-diamter ratios of these nanostructures and show that the formation of confined quantum-dot-like single-particle states is caused by an interplay of strain and dielectric screening.

HL 38.3 Thu 10:00 A 151

Optical properties of TMDC semiconductors in the 1,55μm telecom wavelength range — •Michael Lorke and Frank Jahnke — Institute für theoretische Physik, Universität Bremen

In the context of the current interest in atomically thin semiconductors, we study optical properties of highly excited and/or highly doped transition-metal dichalcogenides (TMDCs). We show that under such excitation conditions, transitions between the first and higher conduction bands are possible. These transitions are analogous to intersubband transitions in conventional quantum well devices. In this work we discuss the carrier density and temperature dependence of such transitions and show that they can be tuned into the technologically relevant 1,55μm telecom wavelength range. This opens the possibility to utilize TMDCs in novel devices ranging from quantum cascade lasers to novel infra-red photodetectors.

HL 38.4 Thu 10:15 A 151

Coupling of a monolayer of WSe2 to an InGaP bullseye cavity — •Oliver Iff[1], Vasilij Baumann[1], Monika Emmerling[1], Marcelo Davanco[2], Kartik Srinivasan[2], Sven Hoefling[1,3], and Christian Schneider[1] — [1]Technische Physik, Universitaet Wuerzburg, Am Hubland, Wuerzburg, Germany — [2]Center for Nanoscale Science and Technology, National Institute of Standards and Technology, Gaithersburg, Maryland, U.S.A. — [3]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Photonic cavities based on circular gratings can be used to enhance the emission of optically active materials. Here, we investigate the optical properties of such a cavity consisting of centric rings of InGaP which are completely surrounded by air, forming a floating membrane. The characterization was done via photoluminescence measurements using embedded quantum dots as light source and spatially mapping out the near field emission. Strikingly, the grating membrane can also be transferred via the dry-stamp method onto a given substrate without disturbing its optical modes and therefore opening up new ways of building coupled systems. Furthermore, the structures are optimized for wavelengths near 750nm, making it suitable for coupling to different kinds of 2D materials like WSe2 or MoSe2. A monolayer of WSe2 has been transferred onto the cavity showing improved photoluminescence of the charged exciton right at the centre position. This enables a new path to couple monolayer of 2D materials to photons in order to gain access to quantum electrodynamic effects including strong light-matter coupling.

HL 38.5 Thu 10:30 A 151

Exciton-phonon coupling in mono- and bilayer $MoTe_2$ — •Sophia Helmrich[1], Robert Schneider[2], Alexander W. Achtstein[1], Ashish Arora[2], Bastian Herzog[1], Steffen Michaelis de Vasconcellos[2], Mirco Kolarczik[1], Oliver Schöps[1], Rudolf Bratschitsch[2], Ulrike Woggon[1], and Nina Owschimikow[1] — [1]Institut für Optik und Atomare Physik, Technische Universität Berlin, Germany — [2]Physikalisches Institut, Westfälische Wilhelms-Universität Münster, Germany

We investigate excitonic transitions of mechanically exfoliated monolayer and bilayer molybdenum ditelluride ($MoTe_2$) by temperature-dependent photoluminescence spectroscopy. Based on identical scaling of the excitonic optical bandgap and the integrated area of the emission with temperature we conclude that ML and BL $MoTe_2$ have similar band alignment and excitonic behavior. Our experiments show that for identical excitation laser power the bilayer yields twice the intensity as the monolayer unlike for other transition metal dichalcogenides. From the emission lines we extract key parameters for exciton-phonon coupling processes demonstrating an unusually small coupling with acoustical phonons of $\gamma_{\mathrm{LA}} = (28 \pm 4)\,\mu\mathrm{eV\,K^{-1}}$ and $(14 \pm 4)\,\mu\mathrm{eV\,K^{-1}}$ for ML and BL $MoTe_2$, respectively, where the interactions with longitudinal optical phonons of $\Gamma_{LO} = (40.1 \pm 5.6)\,\mathrm{meV}$ ($(86.4 \pm 12.6)\,\mathrm{meV}$) for ML (BL) $MoTe_2$ are comparable to values of other TMDs. These observations make $MoTe_2$ an attractive and robust material with a large luminescence yield for applications in the technically relevant near-infrared region.

HL 38.6 Thu 10:45 A 151

Giant Gap-Plasmon Tip-Enhanced Raman Scattering of MoS2 Monolayers on Au Nanocluster Arrays — •Mahfujur Rahaman[1], Alexander G. Milekhin[2,3], E. E. Rodyakina[2,3], A. V. Latyshev[2,3], Volodymyr M. Dzhagan[1,4], and Dietrich R.T. Zahn[1] — [1]Semiconductor Physics, Chemnitz University of Technology, D-09107, Chemnitz, Germany — [2]Novosibirsk State University, Pirogov 2, 630090, Novosibirsk, Russia — [3]Rzhanov Institute of Semiconductor Physics RAS, Lavrentiev Ave. 13, 630090, Novosibirsk, Russia — [4]V. Lashkaryov Institute of Semiconductors Physics, Nat. Acad. of Sci. of Ukraine, 03028, Kyiv, Ukraine

We present the results on a gap-plasmon tip-enhanced Raman scattering study of MoS2 monolayers deposited on a periodic array of Au nanostructures on a silicon substrate forming a two dimensional (2D) crystal / plasmonic heterostructure. We observe a giant Raman enhancement of the phonon modes of the MoS2 monolayer located in a plasmonic gap between Au tip apex and Au nanoclusters. Tip-enhanced Raman (TER) mapping allowed us to determine the gap-plasmon field distribution responsible for the formation of hot spots. These hot spots provided an unprecedented giant Raman enhancement of 5.6 * 108 and a spatial resolution as small as 2.3 nm at ambient conditions. Moreover, due to strong hot electron doping in the order of 1.8 * 1013 cm-2, we observed a structural change of MoS2 from 2H to 1T phase. Thanks to the very good spatial resolution, we were able to spatially resolve those doping sites. Our results open the perspectives of optical diagnostics in nanoscale for many other 2D materials.

HL 38.7 Thu 11:00 A 151

Doping dependent photoluminescence of ML WSe2 — Jhih-Sian Tu, •Sven Borghardt, Detlev Grützmacher, and Beata Kardynał — Peter Grünberg Institute 9 (PGI-9), Forschungszentrum Jülich, Germany

While free exciton states of monolayer transistion meatal dichalcogenides are well understood, photoluminescence spectra of WSe_2 contain number of low energy features that are not understood and collectively referred to as localized states. Such signal is not observed in spectra of materials with the lowest energy state being bright for example in the spectra of monolayer MoSe_2. In order to shed light on the origin of the sub-bandgap emission from WSe_2, we measured low temperature photoluminescence at a very wide range of both electron and hole doping levels. The spectra appear rich in structure which is very strongly doping dependent. The spectral, polarization and spatial correlations between the long wavelength emission features with the signal from the recombination of the bright exciton and trion states are consistent with the brightening of momentum-dark states either by phonon-mediated processes or by interactions of excitons with electrons or plasmons. Unexpectedly, while majority of the spectral features share polarization properties of excitons and trions, some show cross-polarization with the excitation laser.

15 min. break.

HL 38.8 Thu 11:30 A 151

Effective theory of monolayer TMDC double quantum dots — •Alessandro David, Andor Kormányos, and Guido Burkard — Department of Physics, University of Konstanz, D-78464, Germany

Monolayer Transition Metal Dichalcogenides (TMDCs) are promising candidates for the creation of quantum dots, because they are truly two-dimensional semiconductors with a direct band gap. One of their features is an intrinsic spin-orbit interaction that splits the spins in the conduction and valence band. In this work, we analyse theoretically the behaviour of a double quantum dot (DQD) system created in the conduction band of these materials, with two electrons in the regime of the (1,1) charge configuration. Motivated by recent experimental progress, we consider several scenarios, such as when the spin splitting is different in the two dots or when the the valley degeneracy in the TMDC is removed due to a ferromagnetic insulator substrate. Finally, we discuss in which cases it is possible to reduce the low energy subspace to the lowest Kramer's pairs, where novel interactions appear.

HL 38.9 Thu 11:45 A 151

transport properties of high-quality ultrathin two-dimensional superconducting Mo2C crystals and Het-

erostructures — •N. KANG[1], L.B WANG[1], C. XU[2], S. SONG[1], and W.C. REN[2] — [1]Peking University, Beijing, P. R. China. — [2]Institute of Metal Research, Shenyang, P. R. China.

There is particularly interesting in the studies on highly crystalline 2D superconductors. Recently, we have obtained high-quality ultrathin Mo2C crystals and graphene/Mo2C heterostructures by means of chemical vapor deposition method [1-3]. Here, we report on transport measurements on superconducting Mo2C crystals and heterostructures in the 2D limit. We observe magnetoresistance (MR) oscillations and negative MR at low magnetic fields for temperature far below superconducting transition temperature[2,3]. We discuss that these anomalous behaviors can be understood quantitatively by including the effects of inhomogeneous superconducting phase and quantum fluctuations. For graphene/ Mo2C heterostructures, we demonstrate the realization of highly transparent Josephson junction devices based on these strongly coupled heterostructures[3].

[1]. C. Xu, L. B. Wang, Z. B. Liu, L. Chen, J. K. Guo, N. Kang*, X, L. Ma, H. M. Cheng, and W. C. Ren*, Nature Mater, 14, 1135(2015).

[2] L. B. Wang, C. Xu, Z. B. Liu, L. Chen, X, L. Ma, H. M. Cheng, W. C. Ren*, and N. Kang*, ACS NANO, 10, 4504(2016).

[3] C. Xu, S. Song, Z. B. Liu, L. Chen, L. B. Wang, D. X. Fan, N. Kang*, X, L. Ma, H. M. Cheng, and W. C. Ren*, ACS NANO, 11, 5906 (2017).

HL 38.10 Thu 12:00 A 151

Nanoplatelets - a material system between strong confinement and weak confinement — •MARTEN RICHTER — Institut für Theoretische Physik, Technische Universität Berlin, Germany

Recently grown CdSe Nanoplatlets are often described to have a similar electronic structure as two-dimensional quantum wells and are promoted as colloidal quantum wells with monolayer precision width. Here we show, that nanoplatelets are not ideal quantum wells, but cover (depending on their size a strong confinement) an intermediate and a Coulomb interaction dominated regime [1]. For the analysis we show results from a solution of the full four dimensional exciton wave function and analyze different confinement regimes.

[1] Phys. Rev. Materials 1, 016001 (2016)

HL 38.11 Thu 12:15 A 151

Giant magnetic splitting inducing near-unity valley polarization in van der Waals heterostructures — •PHILIPP NAGLER[1], MARIANA V. BALLOTTIN[2], ANATOLIE A. MITIOGLU[2], FABIAN MOOSHAMMER[1], JOHANNES HOLLER[1], JONAS ZIPFEL[1], MICHAEL KEMPF[1], NICOLA PARADISO[1], CHRISTOPH STRUNK[1], RUPERT HUBER[1], ALEXEY CHERNIKOV[1], PETER C. M. CHRISTIANEN[2], CHRISTIAN SCHÜLLER[1], and TOBIAS KORN[1] — [1]Department of Physics, University of Regensburg, Regensburg, Germany — [2]High Field Magnet Laboratory (HFML), Radboud University, The Netherlands

Atomically thin van der Waals heterostructures enable solid-state systems in the ultimate thickness limit. Type II band alignment of transition metal dichalcogenides (TMDCs) leads to the formation of interlayer excitons, which stem from spatially separated electron-hole pairs. These species are highly promising for future valleytronic devices since they combine ultra-long lifetimes with the peculiar spin-valley physics of the constitutent monolayers. Here, we demonstrate strong magnetic coupling of interlayer excitons in a $WSe_2/MoSe_2$ heterostructure to an external magnetic field up to 30 T. The observed g factor of -15 by far exceeds typical values of the g factor in TMDC monolayers and enables near-unity valley polarization of long-lived interlayer excitons at high fields. Our findings can be made plausible by taking into account the AB-stacking configuration of the heterostructure where K+ and K− valleys align in momentum space, leading to spin-allowed inter-valley optical transitions.

HL 38.12 Thu 12:30 A 151

Effective passivation of ultra-thin layers of InSe to enhance electrical properties — •HIMANI ARORA[1,2], YOUNGHUN JUNG[3], SANGHOON CHAE[3], DANIEL RHODES[3], GHIDEWON AREFE[3], TAKASHI TANIGUCHI[4], JAMES HONE[3], and ARTUR ERBE[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Department of Mechanical Engineering, Columbia University, New York, NY, 10027, USA — [4]Advanced Materials Laboratory, National Institute for Materials Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

We report electrical properties of ultrathin layers of Indium Selenide (InSe), a member of the III-VI chalcogenides family, which has shown a mobility two orders of magnitude higher than MoS2, alongside better stability than black phosphorus.

InSe has light electron effective mass and high mobility enabling its usage for fast, high performance electronics. State-of-the-art InSe transistors reported so far, consist of 6 nm thick InSe flake contacted using graphene edge contacts and reaching a mobility of 1500 cm2V-1s-1 at RT in top-gate configuration. However, InSe being an air-sensitive material loses its conductance over time, resulting the transistor to become unfunctional.

In this study, we report an InSe-based transistor fully encapsulated in h-BN layers which enhanced its electrical properties compared to an un-encapsulated device. The transistor reached a high Hall mobility at RT, while retaining its performance for a long period of time.

HL 38.13 Thu 12:45 A 151

Impact of layer separation on the optoelectronic properties of van der Waals heterostructures — •MALTE HARTMANN[1], MATTHIAS FLORIAN[1], ALEXANDER STEINHOFF[1], FRANK JAHNKE[1], JULIAN KLEIN[2], ALEXANDER HOLLEITNER[2], JONATHAN FINLEY[2], TIM WEHLING[1], MICHAEL KANIBER[2], and CHRISTOPHER GIES[1] — [1]Institut für theoretische Physik, Bremen, Deutschland — [2]Walter Schottky Institut, München, Deutschland

Dielectric screening plays an important role in the field of atomically thin transition-metal dichalcogenides (TMDs) and van der Waals heterostructures consisting of stacked 2D-materials. In each layer the field lines of the Coulomb interaction are screened by the adjacent material, which reduces the single-particle band gap as well as binding energies of exciton complexes and can be used to tailor the optoelectronic properties. By combining an electrostatic model for a dielectric hetero-multi-layered environment with semiconductor many-particle methods, we demonstrate that the electronic and optical properties are sensitive to the interlayer distances on the atomic scale. Spectroscopical measurements in combination with a direct solution of a three-particle Schrödinger equation reveal trion binding energies that correctly predict recently measured interlayer distances.

HL 38.14 Thu 13:00 A 151

Band Gaps and Carrier Relaxation 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 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. Measurements of charge carrier relaxation are described by a power-law dependence and reveal unexpectedly long relaxation times.

[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 39: Group IV (other than C): Si/Ge/SiC

Time: Thursday 11:00–13:00 Location: EW 015

HL 39.1 Thu 11:00 EW 015

investigation of 3C-SiC/SiO2 interfacial point defects from first principles calculations and electron paramagnetic resonance measurements — •Taufik Adi Nugraha[1,2], Martin Rohrmüller[2], Uwe Gerstmann[2], Siegmund Greulich-Weber[3], Jean-Louis Cantin[4], Jurgen von Bardeleben[4], Wolfgang Gero Schmidt[2], and Stefan Wippermann[1] — [1]Max-Planck-Institut für Eisenforschung — [2]University of Paderborn — [3]Solar Weaver GmbH — [4]University Pierre and Marie Curie

SiC is widely used in high-power, high-frequency electronic devices. It has also been used as a building block in hybrid nanocomposites for photovoltaics. Analogous to Si, SiC features SiO2 as native oxide that can be used for passivation and insulating layers. However, a significant number of defect states are reported to form at SiC/SiO2 interfaces, limiting mobility and increasing recombination of free charge carriers. Combining ab initio g-tensor and hyperfine interactions calculations with electron paramagnetic resonance (EPR) measurements, we show that carbon antisite dangling bond (Csi-db) defects explain the measured EPR signatures. Csi-db is found to be strongly stabilized at the interface, because carbon changes its hybridization from sp3 in the SiC- bulk to sp2 at the interface, creating a dangling bond inside a porous region of the SiO2 passivating layer. The calculated energy level of a neutral Csi-db coincides with the barrier height of the interface states from internal photoemission (IPE) of SiC/SiO2 interfaces, indicating a contribution of Csi-db to the measured interface states.

HL 39.2 Thu 11:15 EW 015

Towards room-temperature extended infrared Si-based photoresponse: A case study of Te-hyperdoped Si — •Mao Wang[1,2], Yonder Berencén[1], Slawomir Prucnal[1], Eric García-Hemme[3], René Hübner[1], Ye Yuan[1,2], Chi Xu[1,2], Lars Rebohle[1], Roman Böttger[1], René Heller[1], Harald Schneider[1], Wolfgang Skorupa[1], Manfred Helm[1,2], and Shengqiang Zhou[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstr. 400, 01328 Dresden, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstr. 400, 01328 Dresden, Germany — [3]Univ. Complutense de Madrid, Departamento de Física Aplicada III (Electricidad y Electrónica), 28040 Madrid, Spain

Presently,room-temperature broadband Si-based photodetectors are required for Si photonic systems.Here,we demonstrate room-temperature sub-band gap photoresponse of photodiodes based on Si hyperdoped with Te.The epitaxially recrystallized Te-hyperdoped Si layers are developed by ion implantation combined with pulsed laser melting and incorporate Te concentrations beyond the solid solubility limit.An insulator-to-metal transition driven by increasing Te concentration accompanied with a band gap renormalization is observed.The optical absorptance is found to increase monotonically with increasing Te concentration and extends well into the mid- and far- infrared regions.This work contributes to establish room temperature Si-based broadband infrared photonic system.

HL 39.3 Thu 11:30 EW 015

Crystal phase effects in group IV nanowire polytypes and their homojunctions — •Michele Amato — Laboratoire de Physique des Solides (LPS) Centre de Nanosciences et de Nanotechnologies (C2N) Université Paris-Sud, Orsay (France)

Recent experimental investigations have confirmed the possibility to synthesize and exploit polytypism in group IV nanowires. Indeed, while the crystal structure of Si and Ge nanowires (NWs) at standard conditions usually takes a well-defined cubic-diamond phase (as for their bulk counterparts), in the last few years several experimental observations of NWs exhibiting other phases - i.e. the hexagonal-diamond one - have been reported [1-2]. Driven by this promising evidence, here I will discuss recent first-principles calculations of the electronic and optical properties of hexagonal-diamond and cubic-diamond Si and Ge NWs as well as their homojunctions [3-4]. I will outline how a change in the crystal phase can strongly modify the electronic structure and optical response of the NW inducing novel and fascinating properties. Furthermore, I will show that, in the case of homojunctions, playing on crystal phase, size and length of the junction is an efficient tool to modulate band offsets and electron-hole separations.

References
[1] S. Assali et al., Nano Lett. 15, 8062-8069 (2015)
[2] J. Tang et al., Nanoscale, 9, 8113-8118 (2017)
[3] M. Amato et al., Nano Lett. 16, 5694-5700 (2016)
[4] T. Kaewmaraya et al., J. Phys. Chem. C 121, 5820-5828 (2017)

HL 39.4 Thu 11:45 EW 015

Shell-Thickness Controlled Semiconductor-Metal Transition in Si-SiC Core-Shell Nanowires — •Michele Amato — Université Paris-Sud, Orsay, France

Today Si nanowires (NWs) represent a viable solution to realize high-performance sensors due their potential for fabrication into high density nanoscale devices [1]. The large surface-to-volume ratio and the possibility to tune their properties at growth time controlling the composition, crystal orientation, and diameter make Si NWs bound to outperform any other conventional alternative in a large class of sensing environments [1]. On the other hand, because of its excellent chemical and mechanical stability, high hardness and low density it is widespread belief that SiC is a much better biocompatible material than Si. The combination of Si and SiC in a nanostructure, as shown by recent experiments [2], could lead therefore to a material with the smart properties of Si and the biocompatibility of carbon-based systems. We study Si-SiC core-shell NWs by means of electronic structure first-principles calculations [3]. We show that the strain induced by the growth of a lattice mismatched SiC shell can drive a semiconductor-metal transition. Core-shell nanowires with thicker cores, however, remain semiconducting even when four SiC monolayers are grown, paving the way to versatile, biocompatible nanowire-based sensors.

[1] M. Amato and R. Rurali, Prog. Surf. Sci. 91, 1-28 (2016) [2] L. Latu-Romain and M. Ollivier, J. Phys. D, 47, 203001 (2014) [3] M. Amato and R. Rurali, Nano Lett. 15, 3425 (2015)

HL 39.5 Thu 12:00 EW 015

Sub-Bandgap Photoluminescence Study on Implantation-Induced Color Centers in 4H-SiC — •Maximilian Rühl, Christian Ott, Michael Krieger, and Heiko B. Weber — Department of Physics, Chair of Applied Physics, FAU Erlangen-Nürnberg, Germany

Silicon carbide (SiC) is a promising host material for novel quantum technology based on single photon sources such as color centers in crystals [1]. In this study, we report on low temperature photoluminescence (PL) spectra related to color centers created by proton implantation and subsequent annealing. Particularly, we monitor the dependence of PL spectra on the implantation dose and the annealing temperature in a wide parameter range. Among the well known defect signatures related to the silicon vacancy (V_{Si}) defect and the carbon vacancy antisite (C_{Si}-V_C) defect we observe several omnipresent and highly temperature stable spectral lines (TS lines) three of which (at 768 nm, 811 nm and 813 nm) show strongly correlated PL intensities through all measurement parameters. This suggests a common underlying microscopic defect. Further, the intensities of the TS lines turn out to be clearly dependent on the initial implantation dose where the PL lines do not increase until an annealing temperature of 1200°C. At this temperature the initially created V_{Si} defects are basically annealed, hence the defect responsible for the TS signature could be a transformation product of the afore-mentioned.

[1] S. Castelletto *et. al.* nature materials 13, 151-156 (2013)

HL 39.6 Thu 12:15 EW 015

electronic and optical properties of hexagonal germanium: influence of echange and correlation — •valerio armuzza, jürgen furthmüller, claudia rödl, friedhelm bechstedt, and silvana botti — Institut für Festkörpertheorie und Optik der Friedrich-Schiller-Universität, Jena, Jena, Germany

Using ab initio density functional calculations, we study the effect of several Exchange and Correlation (XC) potentials on geometry, electronic and optical properties of Cubic (C) and Lonsdaleite (L) Germanium (Ge), including spin-orbit interaction and d-electrons. Given the importance of Ge in semiconductor technology, this work is directed to the best approach comparing with the well-known experimental results for C-Ge. It is applied on the L-Ge polytype. We initially obtain the

lattice parameters, cohesive energies and bulk moduli with the LDA, PBE, PBEsol and AM05 potentials, while, subsequently the energy band gaps, band structures, optical transitions and radiative lifetimes are calculated with the PBEsol, a *hybrid* XC-funcional (HSE06) and a *meta*-GGA functional (MBJLDA). The atomic geometry for PBEsol and AM05 are consistent with experimental results. Band gaps are slightly overstimated (underestimated) for HSE06 (MBJLDA) in C-Ge, while we have the opposite situation in L-Ge. The small lonsdaleite gap and the symmetry of the lowest conduction bands are explained in terms of folding of the diamond-structure bands.

HL 39.7 Thu 12:30 EW 015

Phase separation in metastable $Ge_{1-x}Sn_x$ epilayers induced by free running Sn precipitates — •Heiko Groiss[1,2,3], Martin Glaser[2], Magdalena Schatzl[2], Moritz Brehm[2], Dagmar Gerthsen[3], and Friedrich Schäffler[2] — [1]Center of Surface and Nanoanalytics, Johannes Kepler University Linz, Austria — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Austria — [3]Laboratory for Electron Microscopy, Karlsruhe Institute of Technology, Germany

Recently, optical gain was demonstrated in $Ge_{1-x}Sn_x$ alloys [1], which are the only known group-IV materials that assume a direct band gap. However, Ge and Sn are immiscible over 98% of the composition range, which renders these epilayers inherently metastable. We investigated the temperature stability of pseudomorphic $Ge_{0.9}Sn_{0.1}$ films grown by MBE [2]. We observed that decomposition of the epilayers sets in above 230°C, the melting point of Sn. Videos taken during annealing in a scanning electron microscope reveal the crucial role of liquid Sn precipitates. Driven by a gradient of the chemical potential, the Sn droplets move on the surface and behave like microscopic liquid-phase epitaxy reactors: The strained and metastable GeSn film on the one side acts as a feeding medium for the supersaturation of the Sn melt with Ge. From this Sn melt Ge precipitates epitaxially in a trail region, where it develops low energy facets. Overall, the free-running Sn droplets make phase separation of metastable GeSn layers particularly efficient at rather low temperatures. [1] S. Wirths *et al.*, Nat. Photonics **9**, 88-92 (2015). [2] H. Groiss *et al.*, Scientific Reports **7**, 16114 (2017).

HL 39.8 Thu 12:45 EW 015

High-resolution patterning of germanium for nanoelectronics applications — Anushka S. Gangnaik[1], Muhammad Bilal Khan[2], Shima J. Ghamsari[2], Lars Rebohle[2], Artur Erbe[2], Justin D. Holmes[1], and •Yordan M. Georgiev[2] — [1]Materials Chemistry and Analysis Group, School of Chemistry and Tyndall National Institute, University College Cork, Cork, Ireland and AMBER@CRANN, Trinity College Dublin, Dublin 2, Ireland — [2]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Bautzner Landstrasse 400, 01328 Dresden, Germany

Ge is among the most attractive alternative channel materials for the next-generation nanoelectronics. However, Ge patterning with electron beam lithography (EBL) using the negative resist HSQ is challenging. The complex native oxide GeOx is soluble in the HSQ aqueous developers. As a result, lift-off of sub-20 nm features written by EBL occurs during development. In the presentation, it will be shown that this issue can be solved by: (i) removal of GeOx and passivation of Ge surface prior to HSQ deposition or (ii) application of a buffer layer between GeOx and HSQ. Arrays of sub-20 nm HSQ lines were successfully fabricated on Ge with both approaches. Moreover, a significantly simplified process for removal of GeOx and passivation of Ge surface will also be presented, which allows patterning of 6-7 nm Ge NWs, the smallest Ge nanostructures reported to date.

Finally, different applications of the above mentioned patterning processes will be discussed.

HL 40: II-VI semiconductors

Time: Thursday 11:00–12:15 Location: EW 201

HL 40.1 Thu 11:00 EW 201

High Resolution Second Harmonic Spectroscopy with Femtosecond Laser Pulses — •Johannes Mund, Dietmar Fröhlich, Dmitri R. Yakovlev, and Manfred Bayer — Experimentelle Physik 2, Technische Universität Dortmund, Germany

We present a new method of high resolution second-harmonic spectroscopy (SHS) by use of broad band femtosecond laser pulses. We show, that in a system with inversion symmetry (Cu_2O, point group O_h) wherein second-harmonic generation (SHG) is forbidden in electric-dipole approximation one can detect resonances of even as well as odd parity exciton states. SHG is allowed if one of the odd parity dipole operators is replaced by the even parity quadrupole operator. We also investigate exciton transitions in crystals without a center of inversion (CuCl, ZnSe, point group T_d), where parity is not a good quantum number and thus even and odd parity excitons can be excited by dipole transitions. Detailed polarization diagrams for linearly as well as circularly polarized light are derived and show good agreement with the experimental results. We discuss the implications of exciton-polariton effects, which result in a spectral shift of resonances in SHG spectra in respect to the ones measured by one-photon absorption.

HL 40.2 Thu 11:15 EW 201

DFT assisted tailoring of fluorine-containing molecules for passivation of zinc oxide layers in thin film transistors — •Jonas Köhling[1], Nataliya Kalinovich[2], Gerd-Volker Röschenthaler[2], and Veit Wagner[1] — [1]Department of Physics & Earth Sciences, Jacobs University Bremen, 28759 Bremen, Germany — [2]Department of Life Sciences & Chemistry, Jacobs University Bremen, 28759 Bremen, Germany

In this work thin film transistors were fabricated by depositing ZnO thin films with a thickness of 12 nm by spray pyrolysis on substrates with predefined electrodes. Because of their instability against oxygen and moisture the thin film transistors were passivated using for this purpose tailor made β-diketones with trifluormethyl and benzene-derivatives as substituents. These molecules were characterized by DFT calculations in order to correlate their properties to electrical results. After passivation of the ZnO surface transistors exhibit reduced hysteresis, increased mobility and better stability against electrical bias stress. The improvement of ZnO thin film transistors depends on the used passivation molecule. UV-Vis, AFM, XPS and IV measurements were used to characterize optical, morphological and electrical properties, respectively. We conclude that functionalized β-diketones passivate surface traps on solution processed ZnO thin films achieving better stability against oxygen and moisture under electrical operation. Best electrical performance is found for thin film transistors passivated with molecules containing toluene and chlorobenzene side groups.

HL 40.3 Thu 11:30 EW 201

Electrical transport characteristics of implanted and epitaxially doped n-type ZnSe — •Johanna Janssen[1], Torsten Rieger[1], Arne Hollmann[2], Felix Hartz[2], Christian Kamphausen[2], Lars Schreiber[2], Detlev Grützmacher[1], and Alexander Pawlis[1] — [1]Peter Grünberg Institute 9 and JARA - FIT, Forschungszentrum Jülich GmbH, Germany — [2]JARA - Institute for Quantum Information, RWTH Aachen University, Germany

The reduced electron-nuclear interaction in isotopically purified ZnSe favorites this material towards the realization of electrostatically defined electron spin qubits with advanced coherence features. A prerequisite for such devices is the preparation of a 2D electron gas (2DEG) by fabricating ZnSe/(Zn,Mg)Se QW structures. To electrically contact the 2DEG, localized n-type doping of the (Zn,Mg)Se layer beneath the metal contacts is required. This is achieved either via ion implantation or by local epitaxial doping. While implantation causes defects, local epitaxial doping involves complex selective growth techniques. Consequently, fabrication of metal contacts on n-ZnSe with low contact resistance and ohmic behavior still remains a major challenge, especially at low temperatures. Here, we compare the transport characteristics of implanted and epitaxially doped ZnSe/(Zn,Mg)Se heterostructures. Different donor species and contact metals were investigated to identify the most promising device properties. Finally, we studied the gate-controlled transport characteristics at low temperatures. Our developed device structure represents a major step towards the realization of electrically controlled ZnSe based electron

spin qubits.

HL 40.4 Thu 11:45 EW 201

Second Harmonic Generation in ZnSe/BeTe Multiple Quantum Wells — •Andreas Farenbruch[1], Johannes Mund[1], Walter Warkentin[1], Dmitri Yakovlev[1], Manfred Bayer[1], and Andreas Waag[2] — [1]Experimentelle Physik 2a, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]Institute of Semiconductor Technology, University of Braunschweig, 38106 Braunschweig, Germany

ZnSe/BeTe multiple quantum wells with a type-II band alignment are studied by the nonlinear optical technique of second-harmonic generation (SHG). The sample has ten periods of 20 nm thick ZnSe well layers and 10 nm thick BeTe barriers grown on a GaAs substrate by molecular-beam epitaxy.

Resonances of quantum well exciton states are detected and identified. Application of a magnetic field in Voigt geometry up to 10 T reveals several resonances of magneto-excitons. These are identified by comparison with measurements on ZnSe bulk samples. The exciton signals show quadratic dependence of SHG intensity on magnetic field strength and the diamagnetic shift. Rotational diagrams of the SHG polarisation dependence are measured and compared to model calculations.

HL 40.5 Thu 12:00 EW 201

Full characterization of nuclear spin dynamics in CdTe quantum wells — •Eiko Evers[1], Tomasz Kazimierczuk[1,2], Alex Greilich[1], Dmitri Yakovlev[1,3], Grzegorz Karczewski[4], Tomasz Wojtowicz[4], Jacek Kossut[4], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]Institute of Experimental Physics, Faculty of Physics, University of Warsaw, 02-093 Warsaw, Poland — [3]Ioffe Institute, Russian Academy of Sciences, 194021 St. Petersburg, Russia — [4]Institute of Physics, Polish Academy of Sciences, 02668 Warsaw, Poland

In an n-doped CdTe quantum well structure, we studied the nuclear spin coherent and relaxation dynamics in the presence of coherently spin-polarized electrons by optically detected nuclear magnetic resonance (NMR). The pulsed, optical excitation leads to a partial transfer of the electron polarization to the nuclear spin bath. Thus, a considerable Overhauser field is induced which changes the electron spin precession frequency, detected by time-resolved Faraday rotation. We employed pulsed NMR techniques to selectively study the dynamics of all constituent nuclei separately, both the longitudinal and the transverse dynamics in an external magnetic field.

HL 41: Invited Talk: Michael Heuken (joint session HL/DS)

Time: Thursday 12:30–13:00 Location: EW 201

Invited Talk HL 41.1 Thu 12:30 EW 201

Industrial Aspects of 2D Nanomaterials — •Michael Heuken[1,2], Annika Grundmann[1], Matthias Marx[1], Holger Kalisch[1], and Andrei Vescan[1] — [1]Compound Semiconductor Technology, RWTH Aachen University, Sommerfeldstr. 18, 52074 Aachen, Germany — [2]AIXTRON SE, Dornkaulstr. 2, 52134 Herzogenrath, Germany

2D nanomaterials such as graphene and layered transition metal dichalcogenides (MoS2) have attracted a lot of attention. They are very promising for future (opto)electronic devices. For TMDC, the realization of industrial fabrication is still a major challenge. To deposit large-area 2D films, high-productivity MOCVD systems are attractive allowing uniform growth on large substrates. Defined precursor fluxes and advanced temperature control enable homogeneous, precise and reproducible deposition processes. We report on the optimization of MoS2 growth on sapphire with respect to crystal quality, i. e. large crystals, and homogeneous substrate coverage, using an AIXTRON MOCVD reactor. Molybdenum hexacarbonyl and di-tert-butyl sulfide are used as metal-organic precursors, N2/H2 as carrier gases. Samples are characterized via atomic force microscopy, scanning electron microscopy, photoluminescence and Raman spectroscopy. For the deposition of graphene, an established CVD technology has been developed. Roll-to-roll-deposition equipment or technology for semiconductor grade layers on 300 mm wafers are available. Details of industrial requirements, state of the art and predicted market opportunities for 2D nanomaterials will be discussed.

HL 42: Transport

Time: Thursday 15:00–16:45 Location: EW 015

HL 42.1 Thu 15:00 EW 015

Linear magnetoresistance in ultra-high mobility GaAs quantum wells with a parabolic dispersion — •Thomas Khouri[1], Uli Zeitler[1], Christian Reichl[2], Werner Wegscheider[2], Nigel Hussey[1], Steffen Wiedmann[1], and Jan Kees Maan[1] — [1]High Field Magnet Laboratory (HFML-EMFL), Radboud University, Nijmegen 6525 ED, NL — [2]Laboratory for Solid State Physics, ETH Zürich, 8093 Zürich, Switzerland

The observation of a linear magnetoresistance is often invoked as evidence for exotic quasiparticles in new materials such as topological semi-metals, though its origin remains controversial. Here we show that a strong non-saturating LMR is observable in GaAs quantum wells with a parabolic dispersion and ultra-high mobility (μ*25*106 cm2 V-1s-1). This LMR persists over a large magnetic field range up to 33 T and a wide temperature range between 0.3 K and 60 K. The simplicity of our system in combination with an almost defect-free environment allows us to exclude most exotic explanations that are known to give rise to a LMR. Instead our analysis suggests that small density fluctuations are the primary origin of the phenomenon. Interestingly, both the LMR and the quantum oscillations at low temperatures obey the empirical resistance rule with an α that remains unchanged over the entire temperature range. Only at low temperatures, small deviations from this resistance rule are observed beyond ν=1.

HL 42.2 Thu 15:15 EW 015

Interlayer Tunneling between Imbalanced Double Quantum Wells in the Quantum Hall Regime — •Gunnar Schneider[1], Rolf J. Haug[1], and Werner Dietsche[2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Max Planck Institut for Solid State Reasearch, 70569 Stuttgart, Germany

Bilayer phenomena such as 2D-2D Tunneling [1] or excitonic Bose-Einstein condensates (BEC) [2] are observable within double quantum wells in the quantum Hall regime. The BEC was found to arise at balanced layer densities with the filling factor combination of 1/2 and 1/2. In our work we are focusing on imbalanced layers, allowing not only the investigation of the filling factor combination 1/3 and 2/3 but also the systems behavior at various combinations of greater filling factors. All measurements were performed on a MBE grown GaAs double quantum well separated by a 10 nm AlAs/GaAs barrier. Gates allow tuning the charge carrier densities between 1E10 and 4E10. The interlayer tunneling for imbalanced charge carrier densities is measured and compared to balanced conditions existing in the samples leads. Measurements were performed at magnetic fields up to three Tesla and for varying density ratios. We were able to map the emergence of the excitonic condensate in the filling factor space. Furthermore regions of conductance and insulation were found at combination of higher filling factors referable to each layers individual Quanten Hall state.

[1]N. Turner et al., Phys. Rev. B 54(15), (1996).

[2]J.P. Eisenstein and A.H. MacDonald, Nature 432, 691-694 (2004)

HL 42.3 Thu 15:30 EW 015

Classical magnetoconductivity maximum in two-dimensional Lorentz gases — Jakob Schluck[1], Nima Siboni[2], Jürgen Horbach[2], and •Thomas Heinzel[1] — [1]Solid State Physics Laboratory, Heinrich-Heine-Universität Düsseldorf — [2]Institute for Theoretical Physics, Heinrich-Heine-Universität Düsseldorf

Two-dimensional Lorentz gases in the classical regime, formed by electrons moving in an array of identical but randomly placed obstacles, show a magnetoconductivity maximum that becomes visible only for high obstacle densities where the mean free path is comparable to the size of the obstacles.[1] It has been predicted by numerical simulations but its origin has remained obscure.[2,3] Here, we show that this maximum is a consequence of superdiffusive electron motion at intermediate time scales. The conductivity maximum turns out to be located at a magnetic field dependent obstacle density which equals the geometric mean of the two phase boundaries of the system.[1] The dependence of this effect on the size and shape of the obstacles is discussed as well. [1]N. H. Siboni et al., preprint arXiv:1708.01039 [cond-mat.dis-nn]. [2]A. Kuzmany and H. Spohn, Phys. Rev. E 57, 5544 (1998). [3]W. Schirmacher et al., Phys. Rev. Lett. 115, 240602 (2015).

HL 42.4 Thu 15:45 EW 015

Magnetotransport in narrow-gap semiconductor nanostructures — •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, 12489 Berlin, Germany — [2]High Field Magnet Laboratory, Radboud University Nijmegen, 6525ED Nijmegen, The Netherlands — [3]Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg, Germany

Electric transport measurements in magnetic fields are powerful tools to investigate the transport properties of low-dimensional electron systems. Our experimental work has been directed at the magnetotransport in semiconductor heterostructures and nanostructures with spin-orbit interaction (SOI), under the influence of in-plane and out-of-plane electric fields. We have combined quantum point contacts (QPCs) with in-plane gates, and Hall-bars with top- and back-gates in a narrow-gap semiconductor heterostructure with strong SOI. The Hall-bars and the constriction were fabricated 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 QPC and Hall-bar structures in magnetic fields. We observe the transition from reflection to transmission of the quantum Hall edge channels at the QPC.
[1] Chiatti *et al.*, Appl. Phys. Lett. **106**, 052102 (2015).

HL 42.5 Thu 16:00 EW 015

Investigation of an electrochemically operated metallic Pb single-atom transistor — •Fangqing Xie[1], Falco Hüser[2], Fabian Pauly[3], and Thomas Schimmel[1,4] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), D-76128 Karlsruhe, Germany — [2]Institut für Theoretische Festkörperphysik, KIT — [3]Department of Physics, University of Konstanz, D-78464 Konstanz, Germany — [4]Institute of Nanotechnology, KIT

The projected scaling limit of the gate lengths is 5 nm in silicon transistors. One focus of nanoelectronics research is to exploit the physical limits in size and energy efficiency. Here, we demonstrate a device in the form of a single-atom transistor based on a Pb quantum point contact. The atomic configuration of the point contact determines the conductance of the Pb single-atom transistor, which is confirmed with the charge transport calculations based on density functional theory for various ideal Pb contact geometries. The performance of the single-atom transistors indicates that both the signatures of atomic valence and conductance quantization play roles in electron transport and bistable reconfiguration. The bistable reconfiguration of the electrode tips is an underlying mechanism in the switching of the single-atom transistors. The operation voltage for the single-atom transistor is less than 30 mV. The dimension of the switching unit in the single-atom transistor is in the range of 1 nm, which is smaller than the projected scaling limit in silicon transistors. Therefore, the single-atom transistors may provide perspectives for electronic applications beyond silicon.

HL 42.6 Thu 16:15 EW 015

Semiclassical origin of quantum oscillations in high-mobility electrostatic superlattices — •Jakob Schluck[1], Juraj Feilhauer[2], Klaus Pierz[2], Hans Schumacher[2], and Thomas Heinzel[1] — [1]Universität Düsseldorf — [2]PTB Braunschweig

Semiconductor superlattices have long been a testground for the validity of semiclassical descriptions of electronic transport. Here we present experimental results of magnetotransport measurements on two-dimensional electrostatic superlattices prepared in high-mobility GaAlAs heterostructures. Superimposed on the classical commensurability resonances we find quantum oscillations, exhibiting an irregular behavior with respect to the quantum Hall transitions. Their semiclassical origin is discussed with the help of numerical simulations based on the Kwant package [1]. We propose an explanation based on the coexistence of skipping and hopping transport.
[1]: C.W. Groth et al., New Journal of Physics 16 063065 (2014)

HL 42.7 Thu 16:30 EW 015

Electron focusing at closed magnetic barriers — Bernd Schüler, •Mihai Cerchez, and Thomas Heinzel — Heinrich Heine University Düsseldorf, 40225, Düsseldorf

Ballistic electrons may pass through closed magnetic barriers [1] (high enough to turn the electrons around) in 2DEGs only by means of ExB drift at the edge [2]. We show that the exiting electron flow is restricted to a certain angular range. Experimentally, we probe this by using a second magnetic barrier placed at various distances from the first one, and measuring the magnetoresistance. The ballistic effects observed are oscillations of the magnetoresistance with a maximum amplitude of more than twice the magnetoresistance of a single magnetic barrier. [1] F. M. Peeters and A. Matulis, Phys. Rev. B 48, 15166, 1993. [2] M. Cerchez, S. Hugger, T. Heinzel, and N. Schulz, Phys. Rev. B 75, 035341, 2007.

HL 43: Spintronics (joint session HL/TT)

Time: Thursday 15:00–17:30 Location: EW 201

HL 43.1 Thu 15:00 EW 201

Anisotropic Spin Diffusion and Spin Helix Dynamics in a CdTe Quantum Well — •Felix Passmann[1], Sergiu Anghel[1], Alexander Valerievich Poshakinskiy[2], Sergey Anatolyevich Tarasenko[2], Alan Douglas Bristow[3], and Markus Betz[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, Otto-Hahn-Straße 4a, D-44227 Dortmund, Germany — [2]Ioffe Institute, St. Petersburg 194021, Russia — [3]Department of Physics and Astronomy, West Virginia University, Morgantown, WV 26506-6315, USA

In the recent past various experiments conducted on zinc-blende type III-V semiconductor quantum wells like GaAs have revealed the dynamics of persistent electron spin helices. However, similar investigations in a doped CdTe single quantum well remained unexplored. Here, we employ ultrafast two-color Kerr rotation spectroscopy to study the spatio-temporal evolution of a photo-excited spin distribution into a long living spin helix (SH). The evolution is governed by the spin-orbit interaction related to bulk and structural inversion asymmetries which manifests as an effective magnetic field. We directly extract the Dresselhaus and Rashba contributions via the coherent spin precession of the diffusing electrons. Further investigations of the SH evolution in the presence of in-plane magnetic fields reveal a so far unseen and theoretically unexpected behavior that we attribute to spatial and temporal gradients of the electron density. The experiments are well supported by corresponding theoretical simulations.

HL 43.2 Thu 15:15 EW 201

Magnetoconductance correction in zinc-blende semiconductor nanowires with spin-orbit coupling — •Michael Kammermeier[1], Paul Wenk[1], John Schliemann[1], Sebastian Heedt[2], Thomas Gerster[2], and Thomas Schäpers[2] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Peter Grünberg Institute (PGI-9) and JARA-Fundamentals of Future Information Technology, Forschungszentrum

Jülich, 52425 Jülich, Germany

We study the effects of spin-orbit coupling on the magnetoconductivity in diffusive cylindrical semiconductor nanowires [1]. Following up on our former study on tubular semiconductor nanowires [2], we focus now on nanowire systems where no surface accumulation layer is formed but instead the electron wave function extends over the entire cross-section.The derived model is fitted to the data of magnetoconductance measurements of a heavily-doped back-gated InAs nanowire [3] and transport parameters are extracted. At last, we compare our results to previous theoretical and experimental studies and discuss the occurring discrepancies.

* * *

[1] M. Kammermeier *et al.*, arXiv:1709.02621 (2017).
[2] M. Kammermeier *et al.*, PRB **93**, 205306 (2016).
[3] S. Heedt *et al.*, Nanoscale **7**, 18188 (2015).

HL 43.3 Thu 15:30 EW 201

Measuring Anisotropic Spin Relaxation in Graphene — Sebastian Ringer, Stefan Hartl, Matthias Rosenauer, Tobias Völkl, Maximilian Kadur, Franz Hopperdietzel, Dieter Weiss, and •Jonathan Eroms — Institute of Experimental and Applied Physics, University of Regensburg, Germany

To measure the anisotropy of the spin-lifetime in graphene, the most notable experiments are out-of-plane rotation of the ferromagnetic electrodes and oblique spin precession. We present a third method which is a Hanle experiment where the electron spins precess around either a magnetic field perpendicular to the graphene plane or around an in plane field. In the latter case, electrons are subject to both in-plane and out-of-plane spin relaxation.

To fit the data, we use a numerical simulation that can calculate precession with anisotropies in the spin-lifetimes under magnetic fields in any direction. Our data show a small, but distinct anisotropy that can be explained by the combined action of isotropic mechanisms, such as relaxation by the contacts and resonant scattering by magnetic impurities, and an anisotropic Rashba spin-orbit based mechanism.

We also perform oblique spin precession on our sample and compare it to our experiment of in-plane/out-of-plane Hanle in terms of reliability and precision. We find a non-trivial magnetization in our contacts that was only detected in the in-plane/out-of-plane Hanle experiment but is essential for a correct analysis of the oblique spin precession data. We conclude that the in-plane/out-of-plane Hanle experiment is the most reliable and precise method to measure the anisotropy.

HL 43.4 Thu 15:45 EW 201

Magneto-Raman spectroscopy and theoretical modelling of spin-density excitations in (001)-grown GaAs-AlGaAs quantum wells — •Sven Gelfert[1], Christian Frankerl[1], Christian Reichl[2], Dieter Schuh[1], Werner Wegscheider[2], Dominque Bougeard[1], Tobias Korn[1], and Christian Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Laboratory for Solid State Physics, ETH Zürich, 8093 Zürich, Schweiz

We performed inelastic light scattering experiments on 12-nm-wide (001)-oriented GaAs-AlGaAs single quantum well samples in the presence of an external applied magnetic field. The investigated systems are Si doped to obtain a balanced Rashba and Dresselhaus SOI contribution (α=β). The resulting effective spin-orbit field is either parallel or antiparallel to the relevant in-plane crystal directions which leads to a highly anisotropic spin splitting of intrasubband transitions in the conduction band.

In order to get deailed insights on the behavior of the spin splitting we perform magnetic field series in different crystal directions. The intrinsic spin-orbit field strength and the electron g-factor can be deducted from our observations. We also provide theoretical considerations which quantitatively predict the modified spin splitting under these experimental conditions.

HL 43.5 Thu 16:00 EW 201

Spin valley coherent transport in Graphene — •Saber Rostamzadeh — Sabanci University, Orta Mahalle, Universite Caddesi No:27, 34956 Orhanli/Tuzla/Istanbul

Due to the advent of Spintronics, which attempts to perform calculations and store information using the spin instead of charge, there is a gradual increase in investigating methods to manipulate the spin degree of freedom of electrons in quantum confined structures to propose a surrogate for conventional electronic devices.

It has been shown that spin orbit coupling in Graphene plays a major role in generating and manipulating of spin polarized currents which found useful in spintronics applications.

Extra degree of freedom such as valley index in Graphene always adds to the functionality of the system and in a sense enlarges the parameter space of the system and works as an additional control parameter without the effort to make one.

In this work we demonstrate the effect of Rashba spin orbit interaction in Graphene induced by adatoms and show that it produces spin-valley coupling. This feature is useful in manipulating spin degree of freedom via valley index and furthermore we illustrate and theoretically set up a formalism which suggest the extraction of spin current form a valley current.

15 min. break.

HL 43.6 Thu 16:30 EW 201

Calculation of Spin Diffusion Equations in Spin/Orbital Polarized Systems — •Vincent Sacksteder[1] and Yasufumi Araki[2] — [1]Royal Holloway University of London, UK — [2]Tohoku University, Japan

This talk is about how to derive coarse-grained spin diffusion equations suitable for modeling a spintronics device from realistic Hamiltonians describing spin and scattering at the atomic scale. The standard formalism for obtaining diffusion equations requires performing an average over the Fermi surface, weighted by the scattering time. In spin or orbital-polarized systems the scattering time depends on spin and/or the orbital index; we describe the consequences for spin diffusion. This is important for modeling new memory devices which combine spin-orbit interactions with magnetization.

HL 43.7 Thu 16:45 EW 201

Gate-controllable large magnetoresistance in a 2DES based spin valve device — •Franz Eberle, Martin Oltscher, Thomas Kuczmik, Andreas Bayer, Dieter Schuh, Dominique Bougeard, Mariusz Ciorga, and Dieter Weiss — Universität Regensburg, Regensburg, Germany

The realization of sFET like devices requires the presence of large local spin signals, which can be tuned by an electric field. In typical semiconductor structures, however, values of the magnetoresistance (MR) of only up to 1% have been observed. In this contribution we present the exceptionally large MR we observe in local two-terminal devices with the channel defined within a two-dimensional electron system (2DES) at an inverted GaAs/(Al,Ga)As interface.[1] Spin aligning source and drain contacts are based on a spin Esaki diode structure, consisting of ferromagnetic (Ga,Mn)As and n-doped GaAs. Depending on the applied bias, we observe MR ratios of up to 80%, which correspond to a signal height ΔR in the order of 1kΩ. We tune these large local signals by an electric gating scheme which, contrary to typical sFET proposals, is not based on the manipulation of spins due to the spin-orbit coupling. Instead, we use gates placed outside the current path to control confinement of spins in the region between the leads. With this method we can tune the MR in these devices by up to 14%.

The work was supported by the German Science Foundation through the project SFB 689.

[1] M. Oltscher et al., Nature Communications **8**, 1807 (2017)

HL 43.8 Thu 17:00 EW 201

Giant Bulk Rashba Splitting — •Louis Ponet and Sergey Artyukhin — Via Morega 30, 16163 Genova, Italy

Spintronics has been an exciting area in the last decades, due to a promise for devices that exploit the existence of spin-polarized states [1]. Important applications include storage media, where the use of spins to store data has been widespread since the earliest days of computing. An important challenge is the control of these states. Magnetic field control precludes further miniaturization. Possible solutions may include spin torques provided by spin-polarized currents. For use in electronic applications, there is a pressing need for electric control of the states, which was recently demonstrated in materials that showcase an anomalously large Rashba-effect [2]. Our research focused on quantitative description of the orbital Rashba-effect [3], an electrostatic effect that couples orbital angular momentum to the polarization. Due to its non-relativistic nature, the effect can be many orders of magnitude larger than would be expected from the spin Rashba-effect. We used model Hamiltonians and ab-initio calculations to examine the

effect and outline the design principles for promising compounds.

References [1] S. D. Bader and S. S. P. Parkin, Spintronics Ann. Rev. Cond. Matt. Phys. 1, 71 (2010). [2] D. Di Sante, P. Barone, R. Bertacco, S. Picozzi, Advanced Materials, 25, 509 (2013). [3] Park J. H., Kim C. H., Rhim J. W., Han J. H., Phys. Rev. B 85, 195401 (2012).

HL 43.9 Thu 17:15 EW 201

Spin-transfer torques generated by strained 3D HgTe TI — •Graciely Santos, Simon Hartinger, Christian Jünger, Erwann Bocquillon, Charles Gould, and Laurens Molenkamp — Julius-Maximilians-Universität Würzburg, Würzburg - Germany

Strained bulk HgTe is a well known topological insulator (3D TI) showing the coexistence of an insulating bulk with metallic Dirac surface states presenting intrinsic spin-momentum locking. By applying an electric current through the surface states of a 3D TI, a spin-polarized current can be generated allowing transfer of angular momentum to an adjacent ferromagnetic layer. Preliminary spin-pumping ferromagnetic resonance (FMR) measurements on the HgTe 3D TI coupled to a ferromagnet island showed a background contribution in the measured voltages. In this work we report on spin-transfer torque ferromagnetic resonance (STT-FMR) measurements in order to better understand the previous results in this system.

HL 44: Focussed Session: Frontiers in Laser Diode Physics II

Organizers: Tim Wernicke(TU Berlin), and André Strittmatter (OvGU Magdeburg)

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

Invited Talk HL 44.1 Thu 15:00 EW 202

Development of AlGaN based UV Laser Diodes — •Ronny Kirste[1,2], Biplab Sarkar[1], Seiji Mita[1,2], Will Mecouch[1,2], James Tweedie[1,2], Qiang Guo[1], Andrew Klump[1], Ramon Collazo[1], and Zlatko Sitar[1] — [1]North Carolina State University, Raleigh, NC, USA — [2]Adroit Materials, Cary, NC, USA

The AlGaN materials system offers unique opportunities to develop next generation UV lasers with emission ranging 210 to 350 nm. However, despite many efforts, no electrically injected laser diode with emission wavelength < 320 nm has been demonstrated yet. Among others, challenges for these devices include low doping efficiency, low carrier injection efficiency, absorbing layers and defects, and non-ohmic contacts. Here, we present recent advances in the growth and fabrication of UV laser diodes on single crystal AlN substrates. We will discuss all steps needed to achieve electrically injected UV lasing. First, it is shown that the MOCVD growth on AlN substrates results in high quality AlGaN layers with low defect concentration and excellent doping capabilities. Next, the design of the active region (MQW) is discussed and low threshold optically pumped lasing is demonstrated. Taking into account simulation results, the design and growth of a complete UV laser diode is shown and fabrication challenges are analyzed. Finally, we present electrical data and electroluminescence spectra from fabricated diodes and discuss the challenges that need to be addressed to realize the first electrically injected mid UV laser diode.

Invited Talk HL 44.2 Thu 15:30 EW 202

Semiconductor Nanolasers Based on 2D Monolayer of Transition Metal Dichalcogenides — •Cun-Zheng Ning — Department of Electronic Engineering, Tsinghua University, and School of Electrical, Computer & Energy Engineering, Arizona State University

This talk will begin with a brief review of the major progress in semiconductor nanolasers over the last decade and the potential applications of such nanolasers in the future integrated nanophotonic chips. The first part of the talk will be on semiconductor nanolasers with surface-plasmonic confinement mechanisms, including discussions of merits and major problems of plasmonics in metallic structures. The focus of the talk will be on the more recent progress in semiconductor nanolasers using a 2D monolayer of transition metal dichalcogenides as optical gain medium, potentially the thinnest gain medium possible. We will show some remarkable results of integrating a silicon nanobeam cavity structure with a monolayer of molybdenum ditelluride, demonstrating room temperature lasing in continuous wave mode for the first time. Concluding remarks and future perspectives will be provided towards the end of presentation.

HL 45: Organic photovoltaics and electronics

Time: Thursday 15:00–17:45 Location: EW 203

HL 45.1 Thu 15:00 EW 203

Excitons under the Microscope: Optical Observations in Organic Bulk Heterojunctions — •Martin Streiter, Alexander Wagenpfahl, and Carsten Deibel — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Most properties of organic bulk heterojunction photovoltaic devices are influenced by energetic disorder in the film. In order to investigate the effects of local morphology and different molecular conformations causing energetic disorder, we investigated organic donor–acceptor films by confocal microscopy with variable excitation photon energies. At higher photon energies we measured photoluminescence lifetimes of neat donor materials accessing the exciton diffusion lengths by varying the acceptor concentration. At lower photon energies, we observed local radiative recombination at the interface of such bulk heterojunctions in order to determine the charge transfer ground state energy by combining photoluminescence and excitation spectroscopy measurements. The combination of optical measurements with different ranges of excitation energies provides insights into bulk heterojunction films at the micron scale.

HL 45.2 Thu 15:15 EW 203

On the impact of capacity and transport on transient photovoltage measurements of organic solar cells — •Uli Würfel, Mathias List, and Moritz Unmüssig — Fraunhofer ISE, Heidenhofstr. 2, 79110 Freiburg, Germany

Transient photovoltage measurements (TPV) are applied to organic solar cells (OSC) to reveal recombination dynamics in these devices. From the recorded transients, charge carrier lifetimes are often derived by fitting an exponential function to the experimental data. In this contribution, numerical simulations of TPV experiments are presented which show that capacitive effects (due to very thin absorber layers) can have large impacts on the voltage transients which can lead - if not accounted for correctly - to questionable interpretations of TPV data. An analytical model describing generation, recombination and displacement current agrees very well with full numerical drift-diffusion simulations - but only for high charge carrier mobilities. In fact, the change in Voc can be dominated by the charge carrier mobilities, as the displacement current involves carrier transport in the absorber. Therefore we developed an expanded analytical model which takes explicitly into account the transport of charge carriers within the device. The results are in excellent agreement with full numerical drift-diffusion simulations for different absorber thicknesses and charge carrier mobilities and with experimental data. This shows that advancements in understanding recombination dynamics from photovoltage transients can only be achieved when properly considering carrier transport required for the displacement current.

HL 45.3 Thu 15:30 EW 203

Surface-tension driven assembly of a novel perylene diimide derivative leads to highly crystalline monolayers — Ilja Vladimirov[1,2], Matthias Kellermeier[1], Thomas Gessner[1],

Zahra Molla[3], Souren Grigorian[3], Ullrich Pietsch[3], Lilian Schaffroth[4], Michael Kühn[1], Falk May[1], and •R. Thomas Weitz[1,2,4] — [1]BASF SE Ludwigshafen — [2]InnovationLab GmbH Heidelberg — [3]Fakultät für Physik, Universität Siegen — [4]Physics of Nanosystems, NIM and CeNS, LMU Munich

The charge carrier mobility in thin films composed of organic semiconductors benefits from high crystalline order. An everlasting challenge with organic semiconductors when processed from solution is, that currently there is no general understanding of how to select solvents to yield a certain crystal morphology of the organic semiconductor. One approach is the crystallization of organic semiconductors at the liquid-air boundary of a drying droplet [1,2]. The systematics of why the used small molecules assemble preferably at the liquid-air interface have not been the focus of these studies. Here we show using a novel perylene diimide derivative that it is mainly the surface tension of a liquid, that drives the crystallization at the liquid-air interface of a drying droplet [3]. This confinement allows the growth of mm sized, few-nm thin crystals. We show that such crystals have excellent electrical performance. For example, electron field-effect mobilities of larger than 4 cm*/Vs were realized in only 3 nm thin films. [1] G. Giri et al. Nature Commun. 2014, 5, 3573 [2] H. Minemawari et al. Nature 2011, 475, 364 [3] I. Vladimirov et al. Nano Lett. 10.1021/acs.nanolett.7b03789

HL 45.4 Thu 15:45 EW 203

Circular Polarized Light Sensor based on Organic Photodiodes — •Manuela Schiek[1], Matthias Schulz[2], Dorothea Scheunemann[1], Oliver Kolloge[1], Arne Lützen[2], Oriol Arteaga[3], and Stefan C. J. Meskers[4] — [1]University of Oldenburg, D — [2]University of Bonn, D — [3]University of Barcelona, ES — [4]University of Eindhoven, NL

Enantiopure prolinol-functionalized squaraines with opposite handedness have been obtained via an ex-chiral pool strategy. Strong intrinsic circular dichroism within the green spectral range is probed in spin-casted thin films by Mueller matrix spectroscopy. Blended with a fullerene acceptor these small molecular squaraines function as active layer in a photodiode with reasonable frequency response in transient photocurrent recordings. Within the green spectral range circular polarized light is highly selectively converted into photocurrent outperforming the polymer-based devices by far [1]. Connecting such photodiodes of opposite handedness, we provide a fully integrated organic circular polarization light sensor that does not require any active manipulation of the polarization of the incoming light. [1] J. Gilot, R. Abbel, G. Lakhwani, E.W. Meijer, A.P.H.J. Schenning, S.C.J. Meskers, Adv. Mater. 22 (2010) E131-E134.

HL 45.5 Thu 16:00 EW 203

Flexible Vertical Organic Transistors for MHz Circuits — •Felix Dollinger, Markus P. Klinger, Axel Fischer, Hans Kleemann, and Karl Leo — Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP), Dresden, Germany

Organic large area electronics have the potential to enable fully flexible applications. This requires efficient transistors on flexible substrates as well as capacitors, inductors, and resistors to design an electrical circuit.

We operate Organic Permeable Base Transistors (OPBT) on polymer substrates to combine impressive transistor characteristics, facile manufacturing techniques and mechanical flexibility. Large current densities and on/off-ratios are achieved with simple shadow mask structuring. Currently our flexible devices reach on/off-ratios exceeding 10^6 and current densities above 1 A/cm^2.

Flexible transistors are presented and analyzed for their DC behavior and for frequencies up to the MHz regime. Information on the challenges and solutions connected to the transfer of our thin-film technology from rigid glass-substrates to flexible and bendable polymer substrates will be given. Thin-film capacitors and inductors are produced to fit the needs of a transmitter circuit that we aim to use for indoor wireless localization applications.

15 min. break.

HL 45.6 Thu 16:30 EW 203

Microscopic simulations of doped organic semiconductors and their layers — •Artem Fediai[1], Franz Symalla[2], and Wolfgang Wenzel[1] — [1]Karlsruhe Institute of Technology — [2]Nanomatch GmbH, Hermann-von-Helmholtz-Platz 1 76344 Eggenstein-Leopoldshafen

Thermally activated hopping transport in doped organic semiconductors has been studied using the efficient implementation of the kinetic Monte Carlo (KMC) method [1]. We present results for two types of simulation set-ups: (1) a bulk doped material and (2) a single doped layer sandwiched between two metallic electrodes.

For bulk systems, we have particularly investigated how the doping efficiency and the intrinsic energy disorder depend on dopant molar ratio for various energy disorders and offsets between IP of the host material and EA of the acceptor. Besides, the hole mobility in the same parameter space has been investigated.

For a single doped layer sandwiched between two electrodes, we have investigated the dopant molar ratio dependence of the chemical potential of the donated particles in the bulk of a material, and how the injection barrier at a metal/semiconductor interface evolves as the dopant molar ratio increases. Finally, the conductivity of a doped layer has been studied as a function of various parameters.

Our study allows a better understanding of microscopic mechanisms, which changes conductivity and other properties of doped organic semiconductor materials/layers in response to doping.

[1] F. Symalla et.al., Phys. Rev. Lett. 117, 276803.

HL 45.7 Thu 16:45 EW 203

Ideality and Charge Transfer State Characteristics of "Real" Organic Solar Cells — •Clemens Göhler and Carsten Deibel — Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Organic solar cells show promising progress by using the concept of a charge transfer (CT) state, but still trail their inorganic and hybrid counterparts in efficiency. One of the reasons might lie in the comparably high recombination of charge carriers, as numerous studies found links between recombination, CT state properties, and losses in the open circuit voltage of the solar cell.

In-depth analysis of the CT state is frequently performed with external quantum efficiency (EQE) measurements in the sub-gap region, focusing on small currents resulting from direct CT excitations; and by inducing electroluminescence (EL) emission from the solar cell using an applied driving current. Recombination effects can be quantified with the ideality factor n_{id} from the Shockley equation, usually acquired from the current–voltage (JV) characteristics of the solar cell.

Empirically, however, organic solar cells oftentimes do not represent an ideal Shockley diode, but should better be treated with regard to shunt and series resistances. Consequently, we find that even small driving currents applied during EL measurements cause significant heating of the solar cell that requires careful analysis; and that a resistance free method to obtain n_{id} is preferable to JV measurements.

HL 45.8 Thu 17:00 EW 203

Defect Patterns of Thin Film PV Devices: Imaging Experiments vs. Electric Circuit Simulations — •Daniel Fluhr[1], Marco Seeland[2], Burhan Muhsin[3], Stefan Krischok[1], and Harald Hoppe[3] — [1]Institute of Physics, Technische Universität Ilmenau, 98693 Ilmenau, Germany (D) — [2]Institute for Computer and Systems Engineering, Technische Universität Ilmenau, 98693 Ilmenau, D — [3]Center for Energy and Environmental Chemistry Jena (CEEC Jena), Friedrich Schiller University Jena, 07743 Jena, D

Defects and degradation are important issues for low cost photovoltaics. Laterally resolving imaging techniques have already proven their ability for resolving the location of performance decreasing problems. A one to one correlation between physical defect types and imaging measurement features cannot be established on a single imaging method alone. However, a combination of several measurement methods is suitable to distinguish different defect types. We classify defects by their electrical properties and correlate them with three different imaging techniques by simulation and experiment. The imaging techniques investigated are Electroluminescence Imaging, Light-Beam Induced Current mapping and Dark Lock-In Thermography. Our software is based on electrical simulations of a resistive network of diodes. The locally resolved current and voltage distributions are used for computing. We simulate a variety of defect types and correlate their electrical properties to fingerprints of the imaging methods. We confirm our findings by comparing with experiments with artificially induced defects and observe good agreement of the defect patterns.

HL 45.9 Thu 17:15 EW 203

Understanding the Capacitance Voltage Characteristics of Organic Light Emitting Diodes by Combining Photoelectron Spectroscopy, Impedance Spectroscopy and Cur-

rent Voltage Measurements — •Victoria Wissdorf[1,2], Paula Connor[2], Maybritt Kühn[2,3], Christof Pflumm[1], Wolfram Jaegermann[2,3], and Eric Mankel[2,3] — [1]Merck KGaA, Darmstadt — [2]Technische Universität Darmstadt, Darmstadt — [3]InnovationLab GmbH, Heidelberg

The determination of reliable material parameters, such as the mobility or injection barrier of charge carriers in organic semiconducting materials, is a crucial step towards an advanced understanding of the physical processes that determine the performance of Organic Light Emitting Diodes (OLEDs). This determination is by far means not trivial: It highly depends on the theoretical model assumed, the measurement technique used and the device that is evaluated. Within this study we present a drift-diffusion approach based on [1] that can be correlated with the photoelectron spectroscopy measurements of hole transport materials and their corresponding Hole-Only-Device (HOD) characteristics for current voltage and impedance spectroscopy (capacitance voltage) measurements. Based on the doping model presented in [2] we can explain how the Capacitance Voltage curves of HODs are influenced by the p-doping of the organic semiconductor.
[1] Kühn et al., Organic Electronics 37, 336-345, (2016)
[2] Mayer et al., Organic Electronics 13, 1356-1364, (2012)

HL 45.10 Thu 17:30 EW 203

Field-Assisted Charge Generation in PffBT4T-2OD:PC71BM Organic Solar Cells — •Andreas Weu[1], Tom Hopper[2], Artem Bakulin[2], and Yana Vaynzof[1] — [1]Centre for Advanced Materials, Universität Heidelberg — [2]Department of Chemistry, Imperial College London

Although remarkable progress has been made in both synthesis of new organic materials and optimisation of processing procedures for organic solar cells, the principle process of photo-induced charge generation in donor:acceptor systems with low driving energy remains unclear. Here, we present a photophysical study of the high performance material system PffBT4T-2OD:PC71BM, which shows efficiencies ~11% despite having only minimal energy offset. We demonstrate by steady-state and ultra-fast optical techniques that the built-in field within a device structure is required for long-range charge separation, while in neat blend films an energetic barrier prevents exciton dissociation and charge transfer to the fullerene acceptor.[1] Our observations are likely to be applicable to other material systems with low driving energy and highlight the importance of using complete devices for photophysical studies.

[1] Andreas Weu, Thomas R. Hopper, Vincent Lami, Joshua A. Kress, Artem A. Bakulin and Yana Vaynzof, "Field-Assisted Charge Generation in Highly Efficient PffBT4T-2OD:Fullerene Organic Solar Cells", submitted to J. Phys. Chem. Lett.

HL 46: Quantum dots and wires: Optical properties III

Time: Thursday 15:00–17:45 Location: A 151

HL 46.1 Thu 15:00 A 151

Ultrasensitive, high spectral resolution photocurrent spectroscopy of single QDs — •Sebastian Krehs[1], Alex Widhalm[1], Amlan Mukherjee[1,2], Björn Jonas[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 — [2]Department of Electrical Engineering, University of Paderborn, Paderborn 33098, Germany

Single InGaAs QDs embedded in electric field tunable structures allow for the realization of new coherent optoelectronic functionalities [1, 2]. In optical experiments on single QD photodiodes the exciton ground state transition appears as a two-level system with an almost lifetime limited linewidth of a few μeV. The measurement of the ground state occupancy can be performed quantitatively via photocurrent (PC) detection. Refinements of this method enabled us to improve its sensitivity down to the fA range. Resonant cw laser spectroscopy with high spectral resolution allows us to investigate the linewidth of QDs at very low excitation powers and at exceptionally low tunneling rates. Combined with PC detection we are able to demonstrate exciton linewidth down to 1.62 μeV. This result is close to the Fourier transform limit of the QD linewidth [3]. Ultrasensitive PC measurements at extremely low tunneling rates may be used in the future to perform the frequency stabilization of single photon emitters.
Ref:[1] A. Zrenner et al., Nature 418, 612 (2002). [2] S. de Vasconcellos et al., Nature Photonics 4, 545 (2010). [3] A.V. Kuhlmann et al. Nature Physics 9, 570-575 (2013).

HL 46.2 Thu 15:15 A 151

White light coherent 2D-spectroscopy on electrically pumped semiconductor nanostructures — Mirco Kolarczik, •Kevin Thommes, Bastian Herzog, Sophia Helmrich, Nina Owschimikow, and Ulrike Woggon — Institut für Optik und Atomare Physik, Technische Universität Berlin, Germany

InAs/GaAs nanostructures are an established material system for the fabrication of opto-electronic devices. Coherent and incoherent coupling mechanisms between the subsystems of different dimensionality (3D, 2D, and 0D) are the backbone of their functionality. We developed a setup for collinear two-dimensional coherent spectroscopy based on broadband laser pulses from a fiber laser system to address the complexity of such active media under operating conditions. We investigate Stranski-Krastanov grown InAs quantum dots in an InGaAs quantum well forming the active medium in the waveguide structure of a semiconductor optical amplifier. This device allows to control the inversion state of the optical transitions by electrical carrier injection. We observe the evolution of the homogeneous linewidth of the optical transitions in the inhomogeneously broadened quantum dot ensemble under variation of the initial inversion. Additionally, our broadband laser pulses allow us to observe coherent coupling of the quantum dot ground state and excited state separated by 70 meV.

HL 46.3 Thu 15:30 A 151

Exciton dynamics in InAs(Sb)/GaAs submonolayer stacks — •Bastian Herzog[1], Fuad Alhussein[1], Benjamin Lingnau[2], Mirco Kolarczik[1], Sophia Helmrich[1], David Quandt[3], Udo Pohl[3], André Strittmatter[4], Olaf Brox[5], Markus Weyers[5], Ulrike Woggon[1], Kathy Lüdge[2], and Nina Owschimikow[1] — [1]Institut für Optik und atomare Physik, Technische Universität Berlin — [2]Institut für theoretische Physik, Technische Universität Berlin — [3]Institut für Festkörperphysik, Technische Universität Berlin — [4]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg — [5]Ferdinand Braun Institut, Leibniz Institut für Höchstfrequenztechnik Berlin

The deposition of InAs as a submonolayer (SML) superlattice into a GaAs matrix creates an electronic potential landscape with heterodimensionally confined charge carriers. While holes are fully trapped inside the In-rich agglomerations, electrons are freely moving within an effective two-dimensional reservoir leading to ultrafast carrier relaxation time scales and a strong coupling of occupation and absorption dynamics. The emission lines of these structures are relatively narrow. Via the doping of antimony (Sb) atoms into these In-agglomerations the emission linewidth is strongly enhanced. In photoluminescence experiments, we show that while the recombination dynamics in the Sb-doped SML stacks is altogether slowed down compared to undoped SMLs, general SML-specific features like lateral mobility of carriers and large amplitude-phase coupling are maintained.

HL 46.4 Thu 15:45 A 151

Nonlinear modulation of PbS/CdS quantum dots observed by sideband pump-probe technique — •Mirco Kolarczik[1], Christian Ulbrich[1], Pieter Geiregat[2], Yunpeng Zhu[2], Laxmi Kishore Sagar[2], Akshay Singh[3], Bastian Herzog[1], Alexander W. Achtstein[1], Xiaoqin Li[3], Dries van Thourhout[2], Zeger Hens[2], Nina Owschimikow[1], and Ulrike Woggon[1] — [1]Technische Universität Berlin, Germany — [2]Ghent University, Belgium — [3]University of Texas, Austin, Texas, United States

Optimizing active materials for GBit/s and Tbit/s rates in optical telecommunications demands a characterization of the material on ultrafast timescales. Colloidal PbS/CdS quantum dots (QDs) are a promising system for nanophotonic applications in the near infrared. For characterization purposes, spin-coating of quantum dots onto silicon nitride waveguides is an easy way to integrate nanocrystals into optical fiber networks. However, the overlap of the QDs and the waveg-

uide mode is comparatively small, posing challenges to ultrafast spectroscopy. Douple-chop pump-probe setups provide high sensitivity, but usually lack the phase-sensitivity of heterodyne detection setups. Our hybrid setup provides both: Two parallel lock-in units detect the main heterodyne band and a pump-dependent sideband. Analog signal pre-conditioning allows for the detection of amplitude modulations in the range of 10^{-5} and corresponding phase-shifts of few arcseconds. While the ground state lifetime of PbS/CdS QDs is on the microsecond timescale, we observe fast sub-nanosecond modulation due to Auger effects and biexciton decay for high laser repetition rates (75 MHz).

HL 46.5 Thu 16:00 A 151

The Influence of the Individual Particles on the Ensemble Quantum Yield of Elongated CdSe/CdS Core/Shell Nanoparticles — •Alexandra Hinsch[1], Christian Strelow[1], Tobias Kipp[1], Christian Würth[2], Daniel Geissler[2], Ute Resch-Genger[2], and Alf Mews[1] — [1]Universität Hamburg, Grindelallee 117, 20146 Hamburg, Deutschland — [2]Bundesanstalt für Materialforschung und -prüfung, Richard-Willstätter-Straße 11, 12489 Berlin, Deutschland

Colloidal semiconductor nanoparticles with a spherical core and an elongated shell form bright emitters with a high absorption cross section. They show great potential for a multitude of opto-electronic applications such as LEDs or photovoltaic cells and can be used as gain material or as markers for bio imaging. For most of these applications high fluorescence quantum yields are a figure of merit for the emitter quality. Our previous work showed that the ensemble quantum yields depend strongly on the shell size and the excitation wavelength [1]. In this work we investigate how the ensemble quantum yield is affected by the properties of the individual particles. In particular, we prove the role of non-emitting particles as well as the role of blinking. Using a combination of AFM and spatially resolved photoluminescence spectroscopy we measured hundreds of individual CdSe/CdS dot/rod particles of different shell lengths exciting with two different excitation wavelengths for shell or core excitation, respectively.

[1] D. Geißler, C. Würth, C. Wolter, H. Weller, U. Resch-Genger, Physical Chemistry Chemical Physics 2017, 19, 12509-12516.

15 min. break.

HL 46.6 Thu 16:30 A 151

Frequency Feedback for Two-photon Interference from Separate Quantum Dots — •Michael Zopf[1], Tobias Macha[2], Robert Keil[1], Eduardo Uruñuela[2], Yan Chen[1], Wolfgang Alt[2], Lothar Ratschbacher[2], Fei Ding[1,3], Dieter Meschede[2], and Oliver G. Schmidt[1,4] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany — [2]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany — [3]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [4]Merge Technologies for Multifunctional Lightweight Structures, Technische Universität Chemnitz, 09107 Chemnitz, Germany

We employ frequency feedback to stabilize the single-photon emission of two separate, strain-tunable quantum dots to an atomic standard. Their transmission through a single rubidium-based Faraday filter serves as an error signal for frequency stabilization to less than 1.5 % of the emission linewidth. The long-term stability is demonstrated by two-photon interference between two quantum dots. The observed visibility of $V_{\mathrm{lock}} = (41 \pm 5)$ % agrees with theoretical predictions. Our approach facilitates the way towards quantum networks with indistinguishable photons from different emitters.

HL 46.7 Thu 16:45 A 151

Quantum dots for silicon photonics: A new approach of telecom light for sensing applications — •Norbert Witz, Fabian Olbrich, Sascha Kolatschek, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und funktionelle Grenzflächen (IHFG), Research Centers SCoPE and IQST, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany

Almost 100 years after the formulation of quantum mechanics, physicists face the challenge of finding possible utilizations of the theory. Beside the most prominent applications, quantum-cryptography and quantum-computing, a different class has emerged in the recent years, which employs quantum mechanical states for sensing. As shown in theory and first experiments, quantum sensing can beat the classical counterpart in terms of sensitivity and facilitate precise measurements of various physical quantities beyond the shot noise limit. The highly developed silicon platform, which has been utilised extensively for classical sensing on biological and chemical systems is also a promising candidate for quantum sensing. Therefore, non-classical light from semiconductor quantum dots grown by metal organic vapour phase epitaxy (MOVPE) with emission wavelength in the telecom bands will be sent by direct fiber-chip coupling to a photonic integrated circuit, implemented on the silicon platform. Single photons from a quantum dot will be funneled into different waveguide-based structures, with the perspective of realizing quantum sensing on chip.

HL 46.8 Thu 17:00 A 151

Pure single-photon emission from InGaAs QDs in a tunable fiber-based external mirror microcavity — •Thomas Herzog[1], Marc Sartison[1], Sascha Kolatschek[1], Stefan Hepp[1], Alexander Bommer[2], Christoph Pauly[3], Frank Mücklich[3], Christoph Becher[2], Simone Luca Portalupi[1], 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]Universität des Saarlandes, Fachrichtung 7.2 (Experimentalphysik), Campus E2.6, 66123 Saarbrücken, Germany — [3]Lehrstuhl für Funktionswerkstoffe, Materialwissenschaft und Werkstofftechnik, 66123 Saarbrücken Germany

Cavity QED is extensively used in many solid-state systems in order to improve the quantum-emitter performances and accessing interesting physical regimes. It is essential that the cavity mode matches the emitter wavelength perfectly. In this work, we present an open fiber-based Fabry-Pérot cavity with a finesse of 140 coupled to single-photon emission by In(Ga)As quantum dots. We are able to match every emitter inside the cavity spatially and spectrally by precisely tuning the cavity in subnanometric resolution. Additionally, by using state-of-the-art photolithography we are able to deterministically relocate selected emitters. This allows comparing their behavior in resonance to the cavity and without any cavity effects. We find Purcell enhancement up to a factor of 4.5, while still having single-photon emission with a second-order correlation function limited only by the detector noise.

HL 46.9 Thu 17:15 A 151

Back-Focal-Plane Imaging on ZnO-Nanowires — •Christian Zietlow[1], Robert Röder[1], Maximilian Zapf[1], Robert Buschlinger[2], Ulf Peschel[2], and Carsten Ronning[1] — [1]Institute of Solid State Physics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Institute for Solid State Theory and -Optics, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany

Semiconductor nanowires (NW) are one of the smallest lasing sources and thus gained a lot of attention in order to achieve the required future miniaturization of optoelectronic devices. Light-matter interaction in NWs and their angular emission distribution are determined by the operating transverse laser mode and thus to the polarization of the propagating light. Since single ZnO NWs provide gain material combined with a Fabry-Pérot-Cavity, coherent laser emission can be achieved by optical pumping. The laser emission is most pronounced at the end-facets such that both interfere similar to Young*s double-slit experiment. The emerging pattern is used to characterize the transverse NW lasing modes via Fourier optics in angular-resolved Microphotoluminescence. In addition to this back-focal-plane imaging, the Stokes parameters for individual modes can be determined giving an insight into the field distribution in the NW. These results are compared to measurements performed in head-on geometry [NanoLett.2016, 16, 2878-2884] that measure the field distribution of the emission emerging out of one end-facet in direction of the NW axis. Combining both techniques provides a broader understanding of transversal mode properties

HL 46.10 Thu 17:30 A 151

Deterministic implementation of a bright, on-demand single-photon source with near-unity indistinguishability via quantum dot imaging — •Stefan Gerhardt[1], Yu-Ming He[2], Jin Liu[3,4,5], Sebastian Maier[1], Monika Emmerling[1], Marcelo Davanço[3], Kartik Srinivasan[3], Christian Schneider[1], and Sven Höfling[1,2,6] — [1]Technische Physik, Physikalisches Institut and Wilhelm Conrad Röntgen-Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]University of Science and Technology of China, Hefei, Anhui 230026, China — [3]Center for Nanoscale Science and Technology, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA —

[4]Maryland NanoCenter, University of Maryland, College Park, Maryland 20742, USA — [5]School of Physics, Sun-Yat Sen University, Guangzhou 510275, China — [6]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, KY16 9SS, United Kingdom

We report on the observation of bright emission of single photons generated via pulsed, resonance fluorescence conditions from a quantum dot deterministically centered in a micropillar cavity device via nanoscale quantum dot imaging. The brightness of the QD fluorescence is greatly enhanced on resonance with the fundamental mode of the pillar, leading to an extraction efficiency of $\nu = (49 \pm 4)\,\%$ for a single photon emission as pure as $g^(2)(0) = 0.015 \pm 0.009$ with a two-photon wave packet overlap up to $\nu = (94 \pm 3)\,\%$.

HL 47: Theory of electronic structure

Time: Thursday 16:15–17:30 Location: EW 202

HL 47.1 Thu 16:15 EW 202

Calculation of the bulk photovoltaic effect using maximally localized Wannier functions — •Julen Ibañez-Azpiroz[1] and Ivo Souza[1,2] — [1]Centro de Física de Materiales, Universidad del País Vasco, 20018 San Sebastián, Spain — [2]Ikerbasque Foundation, 48013 Bilbao, Spain

The bulk photovoltaic effect (BPVE), also known as the shift-current effect, is a nonlinear optical response that yields a net photocurrent in noncentrosymmetric crystals. Although the theory of the BPVE is well established, its practical implementation is challenging because it involves a subtle Berry-phase-like quantity [1]. Here we calculate the BPVE using a Wannier-interpolation scheme, which provides two main advantages over previous numerical schemes. First, it avoids summing over a complete set of virtual states, and hence it is free from truncation errors. Second, it allows for an efficient interpolation of the Brillouin-zone integrand onto a fine **k**-point mesh, providing high accuracy and convergence. We test the Wannier interpolation of the BPVE in well studied systems including GaAs [1], $BaTiO_3$ [2] and several single-layer monochalcogenides [3]. Finally, we briefly discuss how our formalism relates to the tight-binding-based approach to the BPVE [4].

Funding provided by the CFM Postdoc Programme.

[1] J. E. Sipe and A. I. Shkrebtii, PRB **61**, 5337 (2000) [2] S. M. Young and A. M. Rappe, PRL **109**, 116601 (2012) [3] T. Rangel *et al.*, PRL **119**, 067402 (2017) [4] A. M. Cook *et al.*, Nat. Comm. **8**, 14176 (2017)

HL 47.2 Thu 16:30 EW 202

Dielectric response function in colloidal quantum dots: combining microscopic and macroscopic screening — •Anastasia Karpulevich[1,2], Hanh Bui[1,2], Zhi Wang[1,2], and Gabriel Bester[1,2] — [1]Institute of Physical Chemistry, Hamburg University, Grindelallee 117, D-20146 — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761

Dielectric environment profoundly affects the optical properties of colloidal quantum dots (QDs), and modelling of the screening effects remains a challenging task. The recently developed Atomic Effective Pseudopotential (AEP) method provides single-particle energies and wave functions with close to ab-initio quality for colloidal QDs with atomistic passivation [1]. Configuration Interaction (CI) approach was implemented on top of ground-state wave functions to investigate excitonic properties of QDs [2]. We have developed the norm-dependent screening using masking function [3] applied to the individual wave functions. The method offers the opportunity to treat electron-electron interactions fully in reciprocal space, which considerably speeds up calculations, and considers both macroscopic (long-range) and microscopic (short-range) screening effects. The high-level transferability on different semiconductor materials and the influence of the non-polar solvents on the exciton binding energy were demonstrated. The obtained results were compared to the low-temperature experiments as well as to other CI-based models. [1] Karpulevich A. et al. (2016) Phys.Rev.B, 94 [2] Franceschetti A. and Zunger, A. (2000) Phys.Rev.B, 62 [3] Cartoixa X. and Wang L.W. (2005) Phys.Rev.Lett., 94

HL 47.3 Thu 16:45 EW 202

Empirical Band Gap Correction for DFT based Calculations — •Jens Hühnert[1,2], Anastasia Karpulevich[1,2], and Gabriel Bester[1,2] — [1]Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, D-20146 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, Germany

An empirical correction scheme is used on DFT-based effective pseudopotential calculations to reproduce the experimental bulk band structure of II-VI (CdTe, ZnTe) and III-V (InAs, GaAs, GaP) semiconductors. The local potential as well as the non-local potentials can be corrected with a maximum of 4 parameters. The main focus of the correction is the band gap and the effective electron mass. It will be shown on the example of InAs that the bulk correction is transferrable to quantum dots to reach a good agreement with experimental results.

HL 47.4 Thu 17:00 EW 202

Optical properties of NV centres using combined DFT/configuration interaction — •Walter. Pfäffle[1,3], Denis Antonov[2], Jörg Wachtrup[2], and Gabriel Bester[1,3] — [1]Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, D-20146 Hamburg, Germany — [2]Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg, Germany

Configuration Interaction (CI) is a well established and widely used approach for solving the electronic Schrödinger equation including many-body correlations. Using wave functions obtained from density functional theory leads to an intricate double counting (DC) problem. We investigate the DC issue and derive an appropriate restricted CI Hamiltonian. The developed calculation scheme is applied to predict the many-body energy levels of the neutral, negatively and positively charged nitrogen vacancy centres in diamond.

HL 47.5 Thu 17:15 EW 202

Excitonic optical spectra from a *GW*-free Bethe-Salpeter Equation — •Joshua Elliott[1,2], Nicola Colonna[3], Margherita Marsili[1], Nicola Marzari[3], and Paolo Umari[1] — [1]Dipartimento di Fisica e Astronomia, Università degli studi di Padova, Padova Italy — [2]CNR-IOM DEMOCRITOS, Consiglio Nazionale delle Ricerche–Istituto Officina dei Materiali, c/o SISSA, Trieste, Italy — [3]Theory and Simulation of Materials (THEOS) and National Centre for Computational Design and Discovery of Novel Materials (MARVEL), École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

We present our recent implementation that combines Koopman's compliant (KC) Density Functionals with the Bethe-Salpeter Equation (BSE). Our method may be used to compute the optical properties of materials including excitonic effects, avoiding the costly *GW*-approximation. In this proof-of-concept work, quasiparticle eigenvalues are obtained perturbatively from the KC functional. Thus we use as input for the BSE: Kohn-Sham wavefunctions with quasiparticle-corrected energies, roughly equivalent to one-shot G_0W_0+BSE calculations. In addition, within the BSE calculation, we introduce a new method for obtaining the exact screened Coulomb interaction directly. This new approach has multiple advantages: it removes the need to compute the screened Coulomb interaction matrix, $W(\mathbf{r}, \mathbf{r}')$, further driving down the overall computation time and reducing the number of user-defined parameters. We evaluate the performance of our current implementation in the context of Thiel's set, a collection of 28 organic molecules.

HL 48: Thermoelectricity

Time: Thursday 17:00–18:00 Location: EW 015

HL 48.1 Thu 17:00 EW 015

Ab-initio calculations of the thermoelectric properties of MXenes — •Udo Schwingenschlögl, Appala Naidu Gandi, and Sonu Kumar — King Abdullah University of Science and Technology (KAUST), Physical Science and Engineering Division (PSE), Thuwal 23955-6900, Saudi Arabia

Ab-initio calculations are used to study the MXenes Ti_2CO_2, Zr_2CO_2, and Hf_2CO_2 in order to evaluate the role of the metal atom for the thermoelectric properties. The lattice thermal conductivity is demonstrated to grow along the series Ti-Zr-Hf in the temperature range 300-700 K, resulting in the highest figure of merit in the case of Ti_2CO_2. Flat conduction bands promote the thermopower in the case of n-doping. Functionalization effects are studied for Sc_2C, which is semiconducting for various functional groups, including O, F, and OH. The lowest lattice thermal conductivity is found for OH functionalization. Despite a relatively low thermopower, $Sc_2C(OH)_2$ therefore and due to a high electrical conductivity can be interesting for intermediate-temperature thermoelectric applications. We also discuss results on heterostructures built of MXenes and transition metal dichalcogenide monolayers. Low frequency optical phonons are found to occur as a consequence of the van der Waals bonding. They contribute significantly to the thermal transport and compensate for reduced contributions of the acoustic phonons (strong scattering in heterostructures), such that the thermal conductivities become similar to those of the constituent MXenes. References: Chem. Mater. **28**, 1647 (2016); Phys. Rev. B **94**, 035405 (2016); J. Phys.: Condens. Matter **29**, 035504 (2017).

HL 48.2 Thu 17:15 EW 015

Half-Heusler materials : predictions from density functional theory and many-body perturbation theory — •Maedeh Zahedifar and Peter Kratzer — University Duisburg-Essen

For harvesting waste heat at elevated temperature (T > 400 K), ternary materials with crystal structure $C1_b$, so-called half-Heusler alloys, have attracted much attention due their high thermal stability and their environmental friendliness. Different exchange correlation functionals (GGA-PBE, HSE06) and the GW approach are used to investigate the effects of these approaches on the band structures and effective masses of six half-Heusler materials with chemical formula ANiSn and ACoSb (A = Zr, Hf and Ti). The GW approach is recommended for Sb compounds in particular, because not only does the position of the valence band maximum change from $\Gamma \rightarrow L$, but also it strongly affects in thermoelectric properties. In Sn compounds, the conduction band effective mass is underestimated by the HSE06 functional (compared with the GW calculation), but for Sb materials, HSE06 calculations are closer to GW results. Of the six investigated materials, ZrCoSb is determined to be the best thermoelectric material due to its high ZT. After comparing results from different methods for the considered materials, it can be concluded that the simplest method, PBE, is not enough to give conclusive results about thermoelectric properties of investigated materials.

HL 48.3 Thu 17:30 EW 015

performance simulation of micro thermoelectric coolers — •david alberto lara ramos — Leibniz-Institut für Festkörper- und Werkstoffforschung. Dresden. Germany

Micro thermoelectric coolers are increasingly considered as an attractive technology to meet the heat management requirements in electronic and solid state devices due to their simplicity, compact size, robustness, noise free operation, high long term reliability (due to their lack of mechanical moving parts or working fluids) and subsequently maintenance free capability and fast control response. However, due to nature of thermoelectricity, a comprehensive device performance simulation process is needed in order to fully make use of the available material properties; and this device optimization turns to be challenging due to the thermoelectricity Multiphysics environment which involves coupled electrical and heat fluxes. Furthermore, despite optimization strategies for macro thermoelectric coolers are well known, new challenges take place when designing thermoelectric coolers at the micro scale. In the present work, finite element analysis were performed in order to study the parasitic effect of the geometrical definition of a single leg pair micro thermoelectric module manufactured by available state of the art lithography and electrochemical deposition techniques. The obtained results show how the observed maximum temperature suppression and heat dissipation power, are affected by parasitic effects, such as Joule heating and heat flux across the thermoelectric leg pair.

HL 48.4 Thu 17:45 EW 015

Understanding chemical ordering in intermetallic clathrates from atomic scale simulations — •Mattias Ångqvist and Paul Erhart — Chalmers, Sweden

Intermetallic clathrates exhibit great variability with respect to elemental composition and distribution. While this provides a lot of flexibility for tuning properties it also poses a challenge with regard to developing a comprehensive understanding of these systems. In this study we employ a combination of alloy cluster expansions and density functional theory calculations to exhaustively sample the compositional space with *ab-initio* accuracy. Using this methodology we study chemical ordering and associated properties in the clathrate systems $Ba_8Al_xSi_{46-x}$, $Ba_8Al_xGe_{46-x}$, $Ba_8Ga_xGe_{46-x}$, and $Ba_8Ga_xSi_{46-x}$ as a function of composition and temperature. We achieve very good agreement with the available experimental data for the site occupancy factors (SOFs) even for stoichiometries beyond the composition range considered during construction of the cluster expansions. This validation enables us to resolve trends in the experimental data and explain non-monotonic variations of the SOFs. In particular, we provide a rationale for the pronounced composition dependence of the SOFs in Al based clathrates. Furthermore, we quantify the effect of chemical ordering on both heat capacity and lattice expansion. Finally, we determine the effect of chemical disorder on the displacements of the guest species (Ba), which enables us to at least partially explain experimental observations of the nuclear density of Ba in different clathrates.

HL 49: Annual General Meeting of theSemiconductor Physics division

Time: Thursday 18:00–19:00 Location: EW 201

Duration 60 min.

HL 50: HL Poster IV

Time: Thursday 19:00–21:00 Location: Poster B

HL 50.1 Thu 19:00 Poster B

Geometry-induced effect on magnetoresistance in open superconductor microtubes — Roman Rezaev[1,2], Ekaterina Smirnova[1], Evgeniy Posenitskiy[1], Evgeniy Levchenko[1], and •Vladimir Fomin[3] — [1]Tomsk Polytechnic University, Tomsk, 634050, Russia — [2]Moscow Engineering Physics Institute, Moscow, 115409, Russia — [3]Insitute for Integrative Nanosciences, IFW Dresden, Dresden, D-01069, Germany

Superconductor order parameter is analyzed numerically in an open superconductor Nb microtube in an applied magnetic field orthogonal to the tube axis in the presence of a transport current flowing from one to the other bank of the cut. An open microtube manifests significantly different behavior of magnetoresistance due to the vortex motion as compared to the planar membrane of the same dimensions. The magnetoresistance in an open tube as a function of the magnetic field reveals an expressed geometry-induced peak. A three-fold increase of the magnetoresistance in its peak value at 7.5 mT is revealed numerically in an ultrathin Nb tube of radius 500 nm and length 5 μm. This non-monotonic behavior is presumably due to the occurrence of a phase slip line in the area with small absolute values of the normal-to-the-surface magnetic field component, when the quasi-stationary pattern of vortices changes from single to double chains in each half-turn. The effect is promising for design of novel superconductor switching based detectors. The work was partially supported by the Federal Targeted Program of the Russian Federation (agreement no. 14.578.21.0198) and by the COST Action MP1201 Nanoscale Superconductivity.

HL 50.2 Thu 19:00 Poster B

Soft Microrobots with Adaptive Geometry — •Mariana Medina Sánchez — Leibniz Institute for Solid State and Materials Research , Helmholtzstrasse 20, Dresden, Germany

The creation of soft microrobots able to adapt and move in complex environments has attracted the attention of scientists over the world. These microrobots with adaptive geometry could potentially move in complex environments, through small cavities, and in viscoelastic fluids in a very efficient way as many microorganisms and cells do. Here an overview of the existing materials and technologies that can be used to create such smart microrobots will be given, as well as the strategies to perform novel soft microrobots with dynamic geometry and collective behaviour will be highlighted.

HL 50.3 Thu 19:00 Poster B

Functional renormalization group approach to interacting three-dimensional Weyl semimetals — Anand Sharma, •Arthur Scammell, Jan Krieg, and Peter Kopietz — ITP Goethe Universität, Frankfurt am Main, Deutschland

We study quasiparticle properties due to long-range Coulomb interaction in clean threedimensional Weyl semimetals using a functional renormalization group (FRG) approach. The Coulomb interaction is represented via a bosonic Hubbard-Stratonovich field which couples to the fermionic density. We derive truncated FRG flow equations for the fermionic and bosonic self-energies and for the three-legged vertex with two fermionic and one bosonic external leg. We consider two different cutoff schemes - cutoff in fermionic or bosonic propagators - in order to calculate the renormalized quasiparticle velocity and the dielectric function for varying number of Weyl nodes, charge neutrality points with nondegenerate chiralities, and the bare effective dimensionless interaction strength. If we approximate the dielectric function by its static limit, our results for the velocity and dielectric function are in good agreement with the nonperturbative method of Abrikosov and Beneslavskii [Sov. Phys. JETP 32, 699 (1971)] which exhibits slowly varying logarithmic divergence for small momenta. Moreover, we extend their result for any given number of nodes and finite frequency by evaluating the renormalized velocity in the presence of dynamic screening and calculate the wavefunction renormalization factor.

HL 50.4 Thu 19:00 Poster B

Spectral imaging for deterministic positioning of quantum dots in photonic devices — •Magdalena Moczala-Dusanowska, Lukasz Dusanowski, Christian Schneider, and Sven Höfling — Technische Physik, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany

In this contribution a method for deterministic fabrication of micropillar cavities with centered bright quantum dots will be presented. By combining a low-temperature micro-photoluminescence with a wide-field sample illumination a full position resolved emission spectral maps have been recorded. It allowed for registering positions of quantum dots in respect to the alignment marks, making feasible deterministic fabrication of the different kinds of photonic structures including micropillar cavities by utilizing the high-yield e-beam lithography.

HL 50.5 Thu 19:00 Poster B

Towards ultra broadband photon pairs using PZT material — •Stephane Clemmen — Université Libre de Bruxelles, Bruxelles, Belgium

PZT materials have a strong second order nonlinear response. This allows using short crystal and relaxes the phase matching condition therefore allowing broadband spontaneous down conversion.

HL 50.6 Thu 19:00 Poster B

Investigation of 3D-printed phase waveplates for THz beam shaping — •Jan Gospodaric[1], Stefan Rotter[2], Christian Huber[3], Dieter Suess[3], and Andrei Pimenov[1] — [1]Institute of Solid State Physics, Vienna University of Technology, 1040 Vienna, Austria — [2]Institute for Theoretical Physics, Vienna University of Technology, 1040 Vienna, Austria — [3]Faculty of Physics, University of Vienna, 1090 Wien, Austria

Additive manufacturing with 3D-printers has gained significant attention in the recent years due to its versatility, accessibility and generally because it presents a quick, easy-to-use and affordable technique to produce complex and high-precision structures. The layer height resolution of 3D-printers (up to 0.1 mm) and high transparency of the polymers used in 3D-printers are suitable for printing devices that manipulate electromagnetic radiation in the THz region — a frequency range that recently gained a lot of attention. Here we present a way of calculating, designing and fabricating a THz waveplate that phase modulates an incident THz beam (λ=2.14 mm) in order to create a predefined intensity profile of the optical wavefront on the distant image plane. The calculation was performed for two distinct target intensities with the use of the Gerchberg-Saxton algorithm. Resulting phase modulating profiles were used to model two elements, which were printed out of polyactide (PLA) with a commercially available 3D-printer and then tested in an optical experimental setup, which showed good agreement with the preliminary theoretical predictions.

HL 50.7 Thu 19:00 Poster B

Receiver Module for Free-Space Single-Photon QKD using Solid-State Quantum-Light Sources — •Timm Kupko, Stephan Reitzenstein, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

High modulation bandwidth and high purity of single-photon states make InAs/GaAs based quantum dots an ideal light source for free space quantum-key-distribution (QKD) [1]. For such systems, we developed a receiver module with passive basis choice for polarization-encoded QKD via the BB84 protocol. The module consists of off-the-shelf optics, four APD detectors and time-tagging electronics.
Many attacks are known for trusted-device QKD systems. With this knowledge, we investigate the susceptibility of our receiver for spatial-side-mode channel attacks [2][3], a subgroup of faked state attacks exploiting detection efficiency mismatches.
We conduct experiments to estimtate the influence of the angle of incidence on the detection efficiencies and how countermeasures like spatial filtering can prevent such attacks.
[1] T. Heindel et al., New J. Phys. 14, 083001 (2012)
[2] M. Rau et al., IEEE J. Quantum Electron. 21, 660905 (2015)
[3] S. Sajeed el al., Phys. Rev. A 91, 062301 (2015)

HL 50.8 Thu 19:00 Poster B

Droplet epitaxy growth and characterization of InAs QDs — •David Fricker[1,3], Zheng Zeng[1,3], Detlev Grützmacher[1,2,3], Mihail Ion Lepsa[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

Self-assembled InAs quantum dots have been successfully applied in a number of devices for quantum information processing and communication, starting from single photon emitters and detectors to spin-photon interfaces. Droplet epitaxy represents an interesting alternative to the well -known Stranski-Krastanow growth mode of QDs permitting a high degree of control over the shape, size and density and avoiding the wetting layer which can be detrimental for spin-photon interfaces. Here, we report on the MBE growth of InAs QDs using droplet epitaxy method. The InAs QDs have been grown on GaAs (100) substrates. We have investigated the growth conditions for optimum size and density of the QDs. Their morphological and structural characteristics have been obtained using different microscopy methods. Preliminary results regarding optical characterization will be presented as well.

HL 50.9 Thu 19:00 Poster B

Effects of crystal annealing on the spin coherence time in silicon carbide — •Daniel Klenkert[1], Christian Kasper[1], Georgy V. Astakhov[1], Ingo Lederer[2], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

The silicon vaccancy defect (V_{Si}) in silicon carbide (SiC) has recently emerged as a topic of research interest because of its coherent properties. The V_{Si} center forms a $S = 3/2$ system, which can be extensivly controlled by infrared and microwave radiation. Additonally, the V_{Si} defect shows spin coherence times on the order of several hundred microseconds at room temperature. Therefore the use of this defect in quantum sensing and quantum computing applications seems realistic. The defects are usually created by irradiation, which in turn impairs the coherent properties.
In this study, we examine the effects of crystal annealing on the spin-lattice relaxation time T_1 and the spin-spin relaxation time T_2 of the V_{Si} defect. The silicon vaccancy is stable and, in contrast to some other crystal defects, can only be anneald at high temperatures. This gives rise to the hope, that annealing at lower temperatures yields a better orderd crystal with longer coherence times.

HL 50.10 Thu 19:00 Poster B

Defect-affected Current in Silicon Carbide: Towards Photoelectric Spin Readout — •Michael Hollenbach[1], Christian Kasper[1], Dimitrij Poprygin[1], Andreas Sperlich[1], Makino Takahiro[2], Takeshi Ohshima[2], Georgy V. Astakhov[1], and Vladimir Dyakonov[1,3] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]National Institutes for Quantum and Radiological Science and Technology (QST, formerly Japan Atomic Energy Agency), Takasaki, Japan — [3]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Silicon carbide (SiC) is a extremely versatile wide bandgap semiconductor for high-power and high-temperature electronics and is envisioned to be employed in solid-state quantum information systems. At present, the optical readout of the atomic-scale defects, localized within the bandgap, is typically based on confocal mircroscopy. In this study, we intend to introduce an alternative detection method, allowing the direct light induced photoelectric readout of the silicon defects (V_{Si}) in SiC.
Furthermore, of key intertest is the electrical characterization of 4H-SiC diodes with varying spatial distribution of Si-vacancies, introduced by electron and neutron irradiation. By analyzing current-voltage-characteristics as well as optically and electrically detected magnetic resonance (ODMR, EDMR) of active V_{Si} centers, we determine an irradiation/voltage threshold to optimize diodes with suitable quantity of V_{Si} for magnetic field sensing applications.

HL 50.11 Thu 19:00 Poster B

Towards an Optical Interface to Spin Qubits in GaAs — •Zheng Zeng[1], Arne Ludwig[2], Eva Gross[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 would enable quantum networks and more complex quantum computing architectures. 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. We pursue an approach where an InAs self-assembled quantum dot (SAQD) facilitates a coherent transfer of a energy encoded photon qubit into a singlet-triplet spin qubit. We briefly analyse the device operation principle and conditions necessary to achieve high fidelity transfer. We will report on our progress on device fabrication with an emphasis on the alignment between the quantum dots and incorporation of back gates for tuning the electric field in the device.

HL 50.12 Thu 19:00 Poster B

Accurate Optical Alignment of Self-assembled Quantum Dots with Gate-defined Quantum Dots — •Eva Gross[1], Arne Ludwig[2], Zheng Zeng[1], Detlev Grützmacher[1], and Beata Kardynał[1,3] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [3]JARA - Fundamentals of Future Information Technology, RWTH Aachen University, Germany

InAs self-assembled quantum dots (SAQDs) are widely used in various quantum devices for quantum information processing with photons. In many of these applications an alignment of the SAQDs with other elements of the device is crucial to the device operation. Here we explore optical methods to locate SAQDs which can be used as pre-processing steps in device fabrication. The method should be compatible with processing of hybrid devices in which SAQDs and gate defined quantum dots in GaAs/AlGaAs are tunnel coupled. In this presentation we will compare two different photoluminescence based approaches. In both cases, alignment features are used to determine the position of the QDs. In the first method, the imaging process is realized directly by an EMCCD camera. SAQDs and alignment markers are selectively illuminated with light sources of different wavelengths. In the second approach, photoluminescence spectra at different positions of the sample are recorded while a focused spot of laser light is scanned across it.

HL 50.13 Thu 19:00 Poster B

Spin Lifetime and Magnetoconductance in Wurtzite Semiconductor Nanowires — •Paul Wenk[1], Michael Kammermeier[1], John Schliemann[1], Florian Dirnberger[2], and Dominique Bougeard[2] — [1]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Deutschland — [2]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, D-93040 Regensburg, Deutschland

This study is motivated by our experiments on catalytically grown wurtzite semiconductor nanowires, where spin densities are optically excited homogeneously along the nanowire axis [1]. Recently, we carried out these measurements by systematically changing the wire width. Here, a theoretical analysis of the width dependent D'yakonov-Perel' spin relaxation in these wires is presented, which is due to spin-orbit coupling in the diffusive regime. It is shown that the motional narrowing differs significantly from the case in zincblende wires [2,3]. Moreover, by taking into account an external electric and magnetic field magnetoconductivity corrections (*weak (anti-)localization*) are calculated, going also beyond the diffusive regime by following Ref. [4].

* * *

[1] S. Furthmeier *et al.*, Nat. Commun. **7**, 12413 (2016)
[2] S. Kettemann, PRL **98** 176808 (2007)
[3] M. Kammermeier *et al.*, arXiv:1709.02621 (2017)
[4] P. Wenk *et al.*, PRB **83** 115301 (2011)

HL 50.14 Thu 19:00 Poster B

Topological spintronic devices based on $BiSbTeSe_2$ flakes — •Patrick Janoschka, Fan Yang, Zhiwei Wang, Alexey Taskin, and Yoichi Ando — Institute of Physics II, University of Cologne

Topological insulators belong to a new class of quantum materials in which a strong spin-orbit coupling leads to a band inversion and therefore, to gapless surface states with helical spin texture. Due to the spin-momentum locking, the topological surface states are promising for spintronic applications.

A big obstacle in spintronic-device fabrication is to reach a high spin-polarization detection efficiency. Because of the conductivity mismatch between the topological insulator and the ferromagnetic (FM)

spin detector, the detection efficiency is usually low.

In this poster we present the approach of solving the conductivity mismatch with an Al_2O_3 tunnel barrier grown by atomic layer deposition (ALD) between the $BiSbTeSe_2$ flake and the FM spin detector. With this technique we are able to reach a spin-polarization detection efficiency of up to 36% and the current-induced spin polarization was reproducibly observed in many devices.

HL 50.15 Thu 19:00 Poster B

Effect of Exchange-correlation functional on spin-admixture parameter calculated from first principles — •Uday Chopra[1,2], Shambhawi Pandey[2,3], Sergei Egorov[4], Jairo Sinova[1], and Erik R. McNellis[1] — [1]Institute for Physics, Johannes Gutenberg University, Mainz, Germany — [2]Graduate School Materials Science in Mainz, Germany — [3]Department of Chemical Engineering, Indian Institute of Technology Roorkee, India — [4]Department of Chemistry, University of Virginia, USA

Organic semiconductors (OSC) are known to have a small spin-orbit coupling (SOC) and this has strong implications in their spintronic properties. It has been shown that SOC can be characterised by mixing of up- and down-spin states and is expressed by the spin-admixture parameter, γ^2[1]. This parameter governs the probability of a spin-flipping as the polaron hops between different sites in the OSC. Since for most OSC, transport is described by hopping mechanism, the spin-relaxation time is very sensitive to γ^2 therefore it becomes important to determine the parameter with high accuracy. We present a method for calculation of spin-admixture in organic semiconductors from first-principles on the level of Density Functional Theory. In this work, we use a methodical procedure to obtain precise values of γ^2 and demonstrate the effect of exchange-correlation functional on the parameter. Moreover, we generalise this approach under the Unrestricted DFT. We also find that γ^2, strongly depends on the delocalization error of the functional and tends to decrease as the functional becomes more localized. [1] Z. G. Yu, Phys. Rev. B. 85, 115201, 2012.

HL 50.16 Thu 19:00 Poster B

Structural and spin transport studies of Co_2FeSi/MgO/GaAs heterostructures — •Georg Hoffmann, Manfred Ramsteiner, and Jens Herfort — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

Lateral spin valve (SV) structures allow the investigation of spin generation in semiconductors (SC) as well as spin transport and detection within one device. Regarding the spin-polarized contacts, Heusler alloys, such as Co_2FeSi (CFS), are of particular interest because of their possible half-metallic behavior. However, the properties of CFS/SC hybrid structures are often deteriorated by the diffusion of Fe and Co into the SC material. MgO interlayers at the CFS/SC interface have the potential to prevent the Fe and Co diffusion and to act as spin-filtering barriers. We studied CFS/MgO/GaAs hybrid structures with different MgO layer thicknesses (0 to 2.1 nm) grown by molecular beam epitaxy (MBE). The structural and magnetic properties of the CFS contact layers (20 nm thickness) were characterized by x-ray diffraction and superconducting-quantum-interference-device magnetometry. For the evaluation of the spin generation and transport, SV devices were processed and investigated by using a nonlocal SV arrangement. The SV measurements reveal an enhanced spin generation efficiency and an increased spin diffusion length in the GaAs transport channel with respect to CFS/GaAs reference structures. These results demonstrate the benefit of MgO interlayers for the performance of lateral SV structures with CFS contacts.

HL 50.17 Thu 19:00 Poster B

Simulation of Spin Transport with Spatially Varying Transport Parameters — •Daniel Schiermeier, Stefan Hartl, Tobias Völkl, Dieter Weiss, and Jonathan Eroms — Institute of Experimental and Applied Physics, University of Regensburg, Regensburg, Germany

Spin transport properties of graphene devices are typically determined from Hanle spin precession measurements by using an analytical solution of the Bloch equation, which assumes infinitely long transport channels and uniform parameters. We investigate the influence of spatially varying parameters on the measured Hanle curves by finite element simulations using Comsol Multiphysics. To this end, we developed a model considering electric currents and spin transport properties, e.g., spin lifetime anisotropy. Thus we are able to simulate spin transport in suspended graphene, to investigate background signals originating from Hall effect due to pinholes within tunnel barriers and to explore the influence of a finite flake size and non-magnetic reference electrodes. We demonstrate that in case of uniform spin transport parameters one can overestimate the extracted spin lifetimes from Hanle measurements. In contrast, if one graphene region in a non-local spin valve device exhibits a comparatively short spin lifetime, by, e.g., contact-induced spin dephasing or lower mobility graphene parts directly connected to a suspended region, this will also affect the spin lifetime extracted in any other region, which becomes underestimated. Furthermore, we simulate normal and inverse spin Hall effect in WSe_2 graphene heterostructures to optimize our sample fabrication.

HL 50.18 Thu 19:00 Poster B

Higher order noise spectra of continuous quantum measurements — •Daniel Hägele and Fabian Schefczik — Fakultät für Physik und Astronomie, Ruhr-Universität Bochum, Bochum, Germany

Quantum physics does not allow for a perturbation free measurement. Nevertheless, experimental methods like spin noise spectroscopy gain important information about a quantum system by weakly probing the system with a laser beam yielding a detector output $z(t)$. The noise spectrum $S_z(\omega)$ of z consists of a constant laser shot noise background and an additional contribution that reveals some dynamical properties of the quantum system. We show that additional information can be obtained from $z(t)$ if also higher order spectra are evaluated. Treating continuous quantum measurements within a stochastic master equation approach, we recently derived the all-order continuous quantum noise formula (CQNF) which expresses $z(t)$ without approximations in terms of multiple convolutions of white Gaussian noise, the system propagator $\mathcal{G}(t)$, and the observable A in dependence on the measurement strength β [1]. Quantum mechanical expressions for the third order bispectrum and the fourth order trispectum follow. The power of higher order noise spectroscopy is demonstrated by calculating fourth order spectra for the indium electron donor in the semiconductor ZnO. The strong coupling of the electron spin to the 9/2 indium nuclear spin leads to a rich dynamics that leaves characteristic fingerprints in higher order quantum noise spectra.
[1] D. Hägele, https://arxiv.org/abs/1611.02077

HL 50.19 Thu 19:00 Poster B

Fabrication of bulk-insulating topological insulator nanowires — •Matthias Rössler, Dingxun Fan, Andrea Bliesener, Zhiwei Wang, Alexey Taskin, and Yoichi Ando — Institute of Physics II - University of Cologne

With proximity-induced superconductivity, bulk-insulating topological insulator nanowires 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, finite bulk transport contribution yet showed potential for improvements. To tackle this issue, we have been performing fabrication and optimization of bulk-insulating nanowires through two different approaches:

1) Naturally grown $(Bi_{1-x}Sb_x)_2Te_3$ and Bi_2Te_2Se nano-wires prepared by a vapor-solid method.

2) Nanowires etched from bulk-insulating exfoliated $Bi_{2-x}Sb_xTe_{3-y}Se_y$ nanoribbons or MBE-grown $(Bi_{1-x}Sb_x)_2Te_3$ thin films.

By using chemical wet etching, nano-ribbons with a diameter of down to 100 nm have been prepared. Magneto-transport measurements have been carried out to characterize their properties such as carrier density and mobility. Once bulk-insulating topological insulator nanowires have been obtained, they will be utilized for studying proximity-induced superconductivity.

HL 50.20 Thu 19:00 Poster B

Topological Weyl semimetals of $Bi_{1-x}Sb_x$ alloys — •Yu-Hsin Su, Wujun Shi, Claudia Felser, and Yan Sun — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

Investigation on variety atomic composition and arrangement of bismuth antimony $Bi_{1-x}Sb_x$ alloys by making use of first-principle calculation has been accomplished and analysed. Firstly, the bulk of pure Bi and Sb have also been individually identified their topological invariant Z_2 which shows Bi is topological trivial while Sb is topological non-trivial. As increasing the concentration of Sb (increase x), the topological phase will be anticipated more significantly. When x is larger than 0.5 in $Bi_{1-x}Sb_x$ alloys, it shows strong 3D topological insulator phase confirmed in previous research. Surprisingly, in our investigation, at particular concentrations x=0.5 and x=0.83 with specific inversion symmetry broken elemental arrangement, topologi-

cal properties of weyl semimetal have been manifestly demonstrated from the emergence of Fermi arc. The Weyl semimetal phase provides a reasonable explanation for the current transport study of BiSb alloy with the violation of Ohm's law [Nature Materials 16, 1096 (2017)]. This work shows that the plenty of topological phases in BiSb alloys depend on the collaboration of the elemental composition and their specific arrangement.

HL 50.21 Thu 19:00 Poster B

MBE grown ultrathin and magnetically doped topological insulator films — •Andrea Bliesener[1], Gertjan Lippertz[1,2], Fan Yang[1], Alexey Taskin[1], and Yoichi Ando[1] — [1]Institute of Physics II, University of Cologne, Germany — [2]Instituut voor Kern- en 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 and, as a consequence, to a symmetry-protected gapless metallic state on the surface. Time-reversal symmetry breaking by magnetic doping opens a energy gap at the Dirac point. This kind of gapped topological insulator has been reported to show new quantum phenomena, including the quantum anomalous Hall effect (QAHE).

To observe these kind of novel quantum phenomena, fabrications of thin-film devices are required which allows for tuning the Fermi level across the Dirac point. It is necessary to improve growth conditions for the ternary compound $(Bi_{1-x}Sb_x)_2Te_3$ such that the composition between n-type Bi_2Te_3 and p-type Sb_2Te_3 can be almost perfectly compensated. Decreasing the thickness of the MBE grown films, reduces the bulk-to-surface ratio and leads to TI samples where the surface transport is dominating. Doping ultrathin films with V or Cr allows to obtain the ferromagnetic state, which opens a gap in the surface states, leading to the QAHE at low temperatures.

In this contribution we report our efforts to grow ultrathin $(Bi_{1-x}Sb_x)_2Te_3$ films and to increase the T_c of V-doped samples.

HL 50.22 Thu 19:00 Poster B

Chemical and structural defects in magnetically doped topological insulators — •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 basic way to change physical properties of TI consists in doping the compound by magnetic atoms, which disturbs by magnetic field the time-reversal symmetry guaranteed uncommon surface properties. Besides, the non negligible influence on conductive surface states rests in the presence of defects of crystal structure, e.g. point defects, stacking faults, twinning planes which appear in real conditions [1]. The aim of the work is studying physical properties of TI under the influence of the above mentioned structural defects and magnetic atoms in well known bismuth chalcogenides as Bi_2Se_3 or Bi_2Te_3 [2], using electronic structure calculation and the simulations of the magnetization dynamic. Ab-initio calculations based on layered TB-LMTO+CPA method have been employed to obtain the dependence of surface states, energetic gap or magnitudes of exchange interactions on presented defects. Furthermore we used the results from ab-initio calculation to simulate the magnetic behavior of magnetic atoms in non-zero temperatures, where we calculated ordering temperatures of magnetically doped compounds. The obtained results are compared with experimental results as well.

[1] D. Kriegner et al.,J.Appl.Cryst. 50 (2017), 369-377.
[2] K. Carva et al., Phys.Rev.B 93 (2016), 214409.

HL 50.23 Thu 19:00 Poster B

Geometry and electronic structure of the antimonene/Bi2Se3 interface — •Conor Hogan[1], Kris Holtgrewe[2], Simone Sanna[2], Roberto Flammini[1], Stefano Colonna[1], Fabio Ronci[1], Sanjoy Mahatha[3,4], Paolo Moras[3], Polina Sheverdyaeva[3], Alessandro Barla[3], Marco Papagno[5], Z. S. Aliev[6], E. V. Chulkov[7], and Carlo Carbone[3] — [1]CNR-ISM, Rome, Italy — [2]University of Giessen, Germany — [3]CNR-ISM, Trieste, Italy — [4]University of Aarhus, Denmark — [5]University of Calabria, Italy — [6]Azerbaijan National Academy of Science, Baku, Azerbaijan — [7]DIPC, San Sebastian, Spain

The interface between the 2D trivial semiconductor antimonene (Sb-ene) and the 3D topological insulator Bi2Se3 has attracted much interest due to its potential for exploiting the proximity effect. We report a joint theoretical-experimental study of the growth and electronic properties of single/multilayered Sb-enes on Bi2Se3. STM measurements show the presence of ordered domains displaying a perfect lattice match with bismuth selenide. Ab initio DFT calculations of the most stable atomic configurations demonstrate that the ordered domains can be attributed to stacks of single or double bilayers of buckled antimonene sheets. ARPES of the clean Bi2Se3 surface and Sb-ene interfaces, coupled with spin polarization analyses of the computed band structures, yield clear interpretations of the measured spectra in terms of topological surface states, confirming that Sb/Bi2Se3 is an ideal model system for investigating the unique physical topological and emergent phenomena at such heterostructures.

HL 50.24 Thu 19:00 Poster B

Selective area grown ZnTe nanowires as the basis for a quasi-one-dimensional realization of the Topological Insulator HgTe — •Jan Hajer, Willi Mantei, Maximilian Kessel, Christoph Brüne, Hartmut Buhmann, and Laurens W. Molenkamp — Physikalisches Institut (EP3), Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

In this work, we present a successful approach to selective area molecular beam epitaxy of ZnTe nanowires. The wires obtained serve as a substrate for radial overgrowth with different II-VI materials, allowing for the realization of quasi-one-dimensional CdTe-HgTe nanowire shells. The full position control due to patterning of the growth seed not only guarantees a homogeneous environment for overgrowth, but also opens up the possibility for designing high quality bottom-up grown Topological Insulator networks.

HL 50.25 Thu 19:00 Poster B

Growth and Electrical Characterization of $(Bi_{1-x}Sb_x)_2Te_3$ Topological Insulator Nanoribbons — •Dingxun Fan, Matthias Rössler, Zhiwei Wang, Oliver Breunig, Fan Yang, Alexey Taskin, and Yoichi Ando — II. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, D-50937 Köln, Germany

Surface states of topological insulator (TI) nanoribbons, when proximitized by s-wave superconductors, are expected to realize topological superconducting phases harbouring Majorana bound states (MBS) at the ends. MBS platform based on TI nanoribbons has the advantage of a wide parameter range in terms of the chemical potential and magnetic field, resulting from the inherent property of spin-momentum locking. However, the experimental progress is largely hindered by bulk conduction. As a first step, it is desired to grow bulk-insulating TI nanoribbons where the bulk contribution is minimized while preserving circumferential quantization from quasi-1D band structure.

Here we study the growth of ternary $(Bi_{1-x}Sb_x)_2Te_3$ nanoribbons by a Au-catalysed VLS method in a tube furnace. High quality Bi_2Te_3 and Sb_2Te_3 powders prepared by crushing lab-grown single crystals are placed at different temperatures in an Ar gas flow. By tuning the growth temperature and flow rate, very thin $(Bi_{1-x}Sb_x)_2Te_3$ nanoribbons down to ∼20 nm in width and thickness and up to ∼10 um in length can be achieved. The composition of the nanoribbons is determined by electron diffraction spectroscopy. Subsequent nanofabrication is also carried out to characterize the electrical properties of these nanoribbons.

HL 50.26 Thu 19:00 Poster B

Measuring Quantum Spin Networks with NV Centers in Diamond — •Domenico Paone[1,2], Dinesh Pinto[1,2], Lukas Schlipf[1], Bastian Kern[1], Amit Finkler[3], Jörg Wrachtrup[1,2], and Klasu Kern[1,4] — [1]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]3rd Institute of Physics and Research Center SCoPE, University Stuttgart, 70569 Stuttgart, Germany — [3]Department of Chemical and Biological Physics, Weizmann Institute of Science, Rehovot, Israel — [4]Institut de Physique, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

The coherent control and communication between distant qubits is essential for quantum information processing. A sensor scheme based on an atomic sized quantum sensor, the nitrogen vacancy (NV) center in diamond, pushes the sensitivity to the local read out of single spins. Due to its access to various transitions in the optical and microwave frequency domain the coupling between single NV centers and electron spin networks can be observed in a reliable way [1]. Here, we present electron spin resonance studies on doubly spin labeled polypeptides and endohedral $N@C_{60}$ controlled by shallow NV centers. For this, we employ an UHV cryo-microscopy setup [2]. By locally coupling our atomic-sized sensor to interacting spins we are able to investigate transfer mechanisms through spin networks.

[1] L. Schlipf et al., Sci. Adv. 2017; 3, e1701116 (2017)

[2] E. Schaefer-Nolte et al., Rev. Sci. Inst. 85, 013701 (2014)

HL 50.27 Thu 19:00 Poster B

Tight-Binding Simulation of Multilayer Graphene Quantum Dots — •Christian Wimmenauer, Stefan Fasbender, and Thomas Heinzel — Solid State Physics Laboratory (IPkM), Heinrich-Heine-Universität-Düsseldorf

Multilayer Graphene Quantum Dots (ML-GQDs) are simulated using an tight binding approach implemented with the KWANT Software Package. The emphasis lies on the investigation of the size, shape and edge structure interplay in regards to the energetic structure of these multilayer systems. Thus armchair type and zigzag type ML-GQDs, as well as mixed edge type ML-GQDs are examined for different lateral sizes and numbers of layers. The calculations suggest, that the systems will undergo a redshift with a growing number of layers, the magnitude depends on the edge type and the lateral size of the ML-GQDs. The results are supposed to help preparing superior nanoparticles for biomedical applications and to understand the impact of clustering on their optical properties.

HL 50.28 Thu 19:00 Poster B

Precise frequency estimation using a quantum sensor — •Simon Schmitt[1], Daniel Louzon[1,2], Tuvia Gefen[2], Liam McGuinness[1], Alex Retzker[2], and Fedor Jelezko[1] — [1]Institute of Quantum Optics, University of Ulm, Germany — [2]Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

Precise frequency measurements are important for a range of applications in science, medicine and technology. Using a quantum sensor to measure frequency has particular advantages of sensitivity and spatial resolution to measure at the single molecule level. For quantum sensors, the best possible parameter estimation is limited by the sensor decoherence time. While for static components of a given Hamiltonian the uncertainty scales linear with the sensor coherence time, it was recently theoretically shown that for frequency estimation an optimal quadratic scaling is possible. We use single nitrogen vacancy centres in diamond to experimentally verify this enhanced scaling and discuss possible applications in nanoscale metrology, where frequency measurements are important in spectroscopy, imaging and analysis.

HL 50.29 Thu 19:00 Poster B

Coherent control of solid state nuclear spin nano-ensembles — •Nikolas Tomek[1], Thomas Unden[1], Timo Weggler[1], Florian Frank[1], Paz London[2], Hideyuki Watanabe[3], Kohei M. Itoh[4], Martin B. Plenio[5], Boris Naydenov[1], and Fedor Jelezko[1] — [1]Institute for Quantum Optics and IQST, Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany — [2]Department of Physics, Technion, Israel Institute of Technology, Haifa 32000, Israel — [3]Correlated Electronics Group, Electronics and Photonics Research Institute, AIST, Tsukuba, Japan — [4]Department of Applied Physics and Physico-Informatics, Faculty of Science and Technology, Keio University, Yokohama, Japan — [5]Institute for Theoretical Physics and IQST, Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany

Detecting and controlling nuclear spin nano-ensembles is crucial for the further development of nuclear magnetic resonance (NMR) spectroscopy and an important step towards a nuclear spin based quantum simulator. Here we demonstrate a method for coherent control of few tens of nuclear spins by using radio frequency pulses. A single nitrogen-vacancy center in diamond (NV) is used for polarization of the nuclear spins and the readout of their magnetization. The experiments are performed on a nanometer thick layer of 13C enriched single crystal diamond doped with NV centers embedded in a nuclear spin free 12C diamond matrix. We demonstrate the basic coherent control experiments - Rabi oscillations, Ramsey spectroscopy and Hahn echo, though any NMR pulse sequence can be implemented.

HL 50.30 Thu 19:00 Poster B

CVD grown nitrogen-vacancy centers in isotopically controlled <111> diamond — •Christian Osterkamp, Martin Mangold, Priyadharshini Balasubramanian, Boris Naydenov, and Fedor Jelezko — Institut für Quantenoptik, Ulm University, Albert Einstein Allee 11, Ulm 89081, Germany

The negatively charged nitrogen-vacancy center (NV) in diamond is one of the most promising candidates for realizing a quantum sensor. The fluorescence of single NVs can be detected and its electron spin can be polarized, read-out and manipulated at ambient conditions. The creation of NVs on demand is an important step towards quantum magnetic- and electric field sensors [1]. We engineer ^{15}NVs by delta doping during a plasma enhanced chemical vapor deposition (PECVD) process [2] and we are able to produce isotopically pure diamond by changing the ratio of ^{12}C/^{13}C atoms in the growth chamber. A high nitrogen incorporation rate combinded with the controllability of the NV axis alignment makes <111> oriented diamond an interesting material for the creation of ensembles. Shallow ensembles can be used for NV magnetometry and the detection of very small electric and magnetic fields [3].

HL 50.31 Thu 19:00 Poster B

Structural and electronic properties of natural graphite — •Ana Champi and Henrique Ferreira — Centro de Ciências Naturais e Humanas, Universidade Federal do ABC, 09210-170, Santo André, SP, Brazil

In this work, we have studied natural graphite flakes extracted from Brazil mines with high content of rhombohedral phase than artificial graphites like HOPG. We have performed measurements of Raman spectroscopy in many samples and different points on the surface in order to obtain a good statistical characterization. We verified the electrical behavior of the samples through electrical resistance measurements as a function of the temperature, initially the flakes shows extrinsic semiconductor like behavior, followed by persistent metallic behavior in the studied temperature ranges (300K to 500K). We have also studied the effect of the temperature on the Raman spectra, showing a broadening of the characteristic bands of graphite. According to the obtained results, we interpret that the extrinsic semiconductor-like behavior is due to oxygen adsorption at the graphite defects.

HL 50.32 Thu 19:00 Poster B

XPS Study on the Doping of Single-walled Carbon Nanotubes by Covalent Functionalization — •Daniel Przyrembel[1,2], Mareen Gläske[1,2], Antonio Setaro[1,2], Mohsen Adeli[1,3,4], Rainer Haag[1,3], Stephanie Reich[1,2], and Martin Weinelt[1,2] — [1]Sonderforschungsbereich 658 — [2]Freie Universität Berlin, Dept. of Physics, Berlin, Germany — [3]Freie Universität Berlin, Dept. of Chemistry and Biochemistry, Berlin, Germany — [4]Lorestan University, Dept. of Chemistry, Khorramābād, Iran

We have investigated functionalized carbon nanotubes (CNTs) by means of X-ray photoelectron spectroscopy (XPS). Covalent functionalization normally trades added functionalities for the electronic and optical properties of the CNTs. These rely on the conjugated sp^2 hybridized carbon backbone that locally breaks upon the addition of functional groups. The functionalization used for this study aims to preserve the π-conjugation.**[1]** XPS measurements prove that after formation of aziridine rings by cycloaddition and subsequent ring opening the conjugated sp^2 hybridized carbon backbone of single-walled semiconducting CNTs is restored. Moreover, the electron lone pair of the additional nitrogen atom is pushed into the π-electron system of the nanotube thereby doping it and leading to XPS peak shifts. By the amount of functionalization the doping level of the CNTs is tunable. The introduced side groups can also serve as attachment points for further functionalization, e.g., with molecular switches, to ultimately make the properties of the CNTs variable by external stimuli. See **[1]**: A. Setaro, M. Adeli, M. Glaeske et al. *Nat. Commun.* **2017**, *8*, 14281.

HL 50.33 Thu 19:00 Poster B

Mid- to far-infrared localized surface plasmon resonance in chalcogen-hyperdoped Si — •Mao Wang[1,2], Slawomir Prucnal[1], Yonder Berencén[1], Lars Rebohle[1], Tommy Schönherr[1], Ye Yuan[1,2], Chi Xu[1,2], Muhammad Bilal Khan[1], Roman Böttger[1], Wolfgang Skorupa[1], Manfred Helm[1,2], and Shengqiang Zhou[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstr. 400, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany

Mid-infrared plasmonic sensing allows the direct targeting of molecules relevance in the so-called *vibrational fingerprint region*. Presently, heavily doped semiconductors exhibiting the potential to replace and outperform metals in the mid- infrared frequency range to revolutionize plasmonic devices. In this work, we demonstrate the occurrence of localized surface plasmon resonances (LSPR) in Te heavily-doped Si layers developed by ion implantation combined with flash lamp annealing. We fabricate micrometer-sized antennas out of the Te-hyperdoped Si layers by electron-beam lithography and reactive ion etching processes. The optical response characterized by Fourier-transform infrared (FTIR) spectroscopy demonstrates the enhancement of localized

plasmon resonances in antennas, from mid- to far- infrared frequency range. Our results set a new path toward integration of plasmonic sensors with the one-chip CMOS platform.

HL 50.34 Thu 19:00 Poster B

Stimulated Microwave Emission from Vacancy Defects in 4H Silicon Carbide for Maser Applications — •Andreas Gottscholl[1], Georgy V. Astakhov[1], Andreas Sperlich[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

It is hard to imagine everyday life without lasers and their applications. Nevertheless the maser, which operates with electromagnetic waves in a lower energy regime, is only finding its use in some niche applications such as microwave amplification for radio astronomy or satellites. One main reason are the operating conditions, requiring cryogenic temperatures and vacuum techniques. Here, we investigate a concept for microwave emission which is promising masing even at room-temperature based on vacancy defects in 4H silicon carbide [1]. These spin defects form a quadruplet ground-state which can be spin-polarized by near infrared light. By applying an external magnetic field we tune the microwave transition into the range of 10GHz and by means of high optical pumping a population inversion can by far exceed the Boltzmann equilibrium at room-temperature.

[1] Kraus et al., Nat. Phys. **10**, 152 (2014)

HL 50.35 Thu 19:00 Poster B

Liquide phase crystallized silicon for tandem cell application — •Martina Trahms[1], Natalie Preissler[2], Cham Thi Trinh[1], Bernd Rech[1], and Daniel Amkreutz[1] — [1]Institute for Silicon Photovoltaics, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany — [2]PVcomB, Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany

Silicon Photovoltaic has been approaching the theoretical Shockley-Queisser limit of energy conversion efficiency over the last decades. For that reason, the reduction of material usage and production cost becomes more important. An approach to that challenge consists in thin film technologies, among which Liquid Phase Crystallized Silicon (LPC-Si) is a promising candidate with relatively high efficiencies and the potential of low cost production. The idea to boost the efficiencies in tandem devices became especially important as Perovskites emerged for top cell application.

In this contribution we present tandem-concepts for two and four terminal devices. Optical simulations show that theoretically efficiencies up to 23 % are possible on thin-film LPC-Si/Perovskite tandem devices. First experiments involving Perovskite filters show that there is much room for improvement on both the Silicon and Perovskite side.

Investigations of the interface at the pn-junction in the LPC-Si cells show that especially Carbon and Nitrogen impurities can be responsible for defects and high recombination at that interface. Furthermore stacking faults and grain boundaries serve as recombination centers in this polycrystalline material.

HL 50.36 Thu 19:00 Poster B

Structure and chemistry of crystalline silicon-aluminum oxide interfaces — •Arne Ahrens and Michael Seibt — Georg-August University Göttingen, 4th Physical Institute, Göttingen, Germany

Aluminum oxide deposited on crystalline silicon by atomic layer deposition (ALD) is known for its high surface passivation capabilities. This surface passivation is attributed to a high negative fixed charge density of about -4×10^{12} cm^{-2}[1] in the aluminum oxide layer close to the silicon-aluminum oxide interface [2]. This makes aluminum oxide an interesting material to increase the efficiency of solar cells by passivation of surface states. The high surface passivation capability of aluminum oxide on silicon changes and can even be improved due to UV irradiation depending on the temperature treatment [3], which is used to activate the surface passivation.

In this work, we apply transmission electron microscopy (TEM) and electron energy loss spectroscopy (EELS) to study the structure and chemistry of the interface of aluminum oxide deposited by atomic layer deposition (ALD) and crystalline silicon subjected to different processing schemes. Here, we focus on the effect of post-deposition heat treatments and the effect of the UV irradiation.

[1] F. Werner and J. Schmidt, Appl. Phys.Lett Vol.104, 091604 (2014). [2] B. Hoex et al., J. Appl. Phy. Vol.104, 113703 (2008). [3] B. Veith-Wolf et al., Photovoltaic Specialists Conference (PVSC), 2016 IEEE 43rd, 16483697

HL 50.37 Thu 19:00 Poster B

Controlled Nickel Silicidation of Silicon Nanowires for Fabrication of Reconfigurable Field Effect Transistors — •Muhammad Bilal Khan[1], Dipjyoti Deb[1], Slawomir Prucnal[1], Mathias Voelskow[1], Artur Erbe[1], and Yordan M. Georgiev[1,2] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]On leave of absence from the Institute of Electronics at the Bulgarian Academy of Sciences, 72, Tsarigradskochausseeblvd., Sofia 1784, Bulgaria

Physical scaling down of field effect transistors (FET) is reaching its end. To meet the consistent demand for faster, smaller and energy efficient transistors, new concepts which include new materials, new architectures, new computation principles and enhanced functionality are under research. The aim of this work is to fabricate devices with enhanced functionality, the so called reconfigurable FET (RFET) which can be configured as *p*- or *n*-channel FET. The RFETs are realised by fabricating silicon nanowires (SiNWs) on Si on insulator (SOI) substrates. These NWs are subsequently nickel silicided at both ends to form Si-$NiSi_2$-Si Schottky junctions. Control over silicide length is important to scale down the Si channel and to have symmetric contacts on both sides of the nanowires. The focus of our recent work is to achieve this control by using flash lamp annealing (FLA). Comparison between silicidation with flash lamp annealing (FLA) and rapid thermal annealing (RTA) along with the resulting electrical characteristics of these devices will be presented at the conference.

HL 50.38 Thu 19:00 Poster B

Top-down fabrication of sub-20 nm germanium nanowires for nanoelectronics and photonics applications — •Shim Jazavandi Ghamsari[1], Muhammad Bilal Khan[1], Lars Rebohle[1], Arthur Erbe[1], and Yordan M. Georgiev[1,2] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]Institute of Electronics at the Bulgarian Academy of Sciences, 72, Tsarigradsko chaussee blvd., Sofia 1784, Bulgaria

High-mobility channel materials are one of the recent performance boosters in the roadmap of semiconductor industry. Germanium(Ge) is among the materials that are nominated for future nanoelectronic devices beside silicon (Si).However, the chemical characteristics of Ge native oxide are a matter of concern in fabrication processes, especially at nanoscale. To produce Ge nanostructures of sub-20 nm size using electron beam lithography (EBL) with hydrogen silsesquioxane (HSQ) as a negative tone EBL resist, it is imperative to remove the Ge native oxide and passivate the Ge surface. In this poster we will present a fast and simple method to clean and passivate the Ge surface, which uses only non-hazardous household acids such as citric and acetic acids.The method improves the adhesion of HSQ to the substrate and allows to effectively avoid lifting off the HSQ nanostructures. With this method, sub-20 nm Ge nanowires can be fabricated, which will be used to develop a technology for doping Ge nanostructures by ion implantation and flash lamp annealing with outlook to possible nanoelectronics and photonics applications.

HL 50.39 Thu 19:00 Poster B

Magneto-conductivity experiments and simulation on two dimensional Lorentz gas systems — •Beate Horn[1], Jakob Schluck[1], Klaus Pierz[2], Hans Werner Schumacher[2], and Thomas Heinzel[1] — [1]Institut für Experimentelle Physik der kondensierten Materie, Heinrich-Heine-Universität, Universitätsstraße 1, 40225 Düsseldorf, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesalle 100, 38116 Braunschweig, Germany

The Lorentz gas system (LGS) is of fundamental scientific interest predicting omnipresent phenomena like the motion of pathogens in blood stream or the electron motion in porous media. In the present contribution two dimensional LGSs are realized by patterning Poission distributed obstacles of equal size and shape by electron beam lithography and reactive ion etching on a high electron mobility $GaAs/Ga_xAl_{1-x}As$ heterostructure [1]. Magneto-conductivity measurements are performed on samples with different obstacle densities. The as described system is implemented in numerical simulations using the Python package Kwant [2]. Experimental and simulated data are compared.

[1] N. Siboni, J. Schluck, K. Pierz, H.W. Schumacher, D. Kazazis, J. Horbach and T. Heinzel, arXiv:1708.01039 (2017) (manuscript sub-

mitted for publication)

[2] Groth, M. Wimmer, A. R. Akhmerov, X. Waintal, *Kwant: a software package for quantum transport*, *New J. Phys.* 16, 063065, (2014)

HL 50.40 Thu 19:00 Poster B

Simulation of morphology and electric behavior of a printed vertical field effect transistor — •Manuel Rommel, Pascal Friederich, and Wolfgang Wenzel — Institute of Nanotechnology, Karlsruhe Institute of Technology, Germany

Decreasing device dimensions is a common strategy to increase field effect transistor performance. In printed electronics, device dimensions are linked to the printing resolution, thus limiting its properties. Therefore, a vertical field effect transistor has been experimentally demonstrated (doi:10.1002/adma.201603858), where channel length is defined by the thickness of the printed layers instead. However, neither the local charge distribution nor the influence of parameter changes on the transistor are easily accessible in experiment.

Therefore, we will show simulation results of domain formation using a Monte Carlo method as well as 3D drift diffusion simulations of the electric behavior of this device architecture. The drift diffusion simulations yield the local charge carrier distribution and electric potential, which show the conduction channel doesn't penetrate the whole system, resulting in ohmic stray currents. A domain formation model was used to generate morphologies exhibiting smaller and larger domain sizes, as they would occur in a slower or faster annealing step in experiment. The simulated transfer curves of these virtual devices show an increased on/off-ratio for smaller domain sizes. A doping concentration sweep yields a dependence of the off-current on doping concentration. These results promise increased performance on smaller domain sizes and the tunability via doping concentration.

HL 50.41 Thu 19:00 Poster B

Quantum mechanical simulations of the magneto-conductivity of two dimensional Lorentz-gases — •Christopher Kraus, Jakob Schluck, and Thomas Heinzel — Heinrich-Heine Universität

An electron gas with poisson-distributed obstacles is known as Lorentz-gas. Even though it has been studied for more than 20 years some properties of the magneto-conductivity of such systems are not fully understood. Since previous simulations in the classical regime deviated from the experiments, especially for high scatterer densities, it seems natural to look into quantum mechanics for further insight. By using Kwant [1], a Python package with focus on quantum transport, we simulate the magneto-cunductivity in the quantum regime and compare our results with data of experiments and classical simulations. Reproducing aspects of the experimental data in our simulation that were absent in classical simulations shows that they are of quantum mechanical origin.

[1] Groth, M. Wimmer, A. R. Akhmerov, X. Waintal, Kwant: a software package for quantum transport, New J. Phys. 16, 063065, (2014)

HL 50.42 Thu 19:00 Poster B

Optical and structural properties of PLD-grown TiN single layers and TiN/MgO superlattices on MgO(100) substrates — •Florian Jung[1], Santana Ellis[1], Chris Sturm[1], Rüdiger Schmidt-Grund[1], Michael Lorenz[1], Marius Grundmann[1], Christian Patzig[2], Susanne Selle[2], and Thomas Höche[2] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Leipzig, Germany — [2]Fraunhofer IMWS, CAM, Halle, Germany

For TiN/MgO-superlattices with single layer thickness of some nanometers, a hyperbolic dispersion in the NIR and visible spectral range is predicted[1]. These structures are promosing for a variety of applications, such as hyperlenses[2]. However, the growth of high-quality superlattices is challenging due to the combined *in situ* growth of an oxide and a nitride material. We investigate the optical properties of the TiN/MgO-superlattices by ellipsometry. We found that the miscut of the substrate has a strong impact on the dielectric function of the first layer pair and is negligible for subsequent layers. As expected, the plasma frequency of TiN was found to be in the visible spectral range. Structural properties were determined using RHEED, x-ray- and TEM-techniques. The analysis shows that smooth TiN/MgO-interfaces, a homogeneous layer density, as well as a low strain gradient and low mosaicity of the films were achieved[3].

[1] Naik, G.V., *et al.*, Opt. Mater. Express 2, pp. 478-489 (2012)
[2] Liu, Z., *et al.*, Science, Vol. 315, 1686 (2007)
[3] Lorenz, M., *et al.*, J. Mater. Res. 32, pp. 3936-3946 (2017)

HL 50.43 Thu 19:00 Poster B

Investigation of Silicon Nanocrystals in Silicon-Rich Silicon Oxide using Electron Nanodiffraction in STEM — •Hendrik Voigt, Tobias Meyer, and Michael Seibt — IV. Physikalisches Institut der Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen

Silicon as the most prominent element in semiconductor physics shows interesting behaviour in low-dimensional systems. Nanocrystalline Silicon (nc-Si) particles exhibit photoluminescence at room temperature which is of great interest for future applications in light-emission techniques. Different methods have been utilized to achieve the temperature driven phase transition of silicon rich silicon oxide into stable silicon dioxide and nc-Si, one of which is laser irradiation allowing for spatially confined formation of nc-Si [1].

Lamellas of such laser irradiated samples are prepared by focused ion beam and subsequently, to investigate the properties of the nc-Si after phase transition, Electron Nanodiffraction in a Scanning Transmission Electron Microscope (STEM) is used. A diffraction map is recorded and Fluctuation Electron Microscopy is utilized to further characterize the distribution and size of the nanoparticles.

[1] Nan Wang, et al., Journal of Alloys and Compounds 707 (2017) 227-232

HL 50.44 Thu 19:00 Poster B

Optical properties of carbon nanodots as active material in planar microcavities — •Lukas Trefflich[1], Frank Dissinger[2], Mizuki Kakei[1], 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 present electronic and optical properties as well as temporal dynamics of carbon nanodots (C-dots) in different solvents and transparent matrices. We found bright light emission in the visible spectral range and decay time constants in the order of 10 nanoseconds. Both properties depend on the dilution of the solvents or the material of the host matrix, leading to differing emission wavelengths and decay times. This enables to tune the optical properties of carbon nanodots. We explore their application as active material in planar microcavities for possible laser and white LED application. White light LEDs usually contain rare-earth elements [1], which are rare 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 50.45 Thu 19:00 Poster B

New approaches for hybrid passivation layers — •Till Welzel[1], Markus Wiesinger[1], Rui N. Pereira[1,2], and Martin Stutzmann[1] — [1]Walter Schottky Institut and Physik-Department, Technische Universität München, Garching bei München, Germany — [2]Department of Physics and Institute for Nanostructures, Nanomodelling and Nanofabrication, University of Aveiro, Aveiro, Portugal

The application of new hybrid materials for devices such as neuromorphic field effect transistors or high power devices is motivated by novel properties of hybrid dielectric passivation layers such as tunable dielectric constants or the ability to screen high electric fields effectively. In this study, we explore different scalable approaches to produce hybrid (semiconducting-insulating) passivation layers composed of semiconducting nanocrystals embedded in insulating organic or inorganic matrices. We investigate the morphology and optical properties of these layers by means of AFM and ellipsometry. The dielectric and electric behavior of the most promising layer structures have been investigated using impedance spectroscopy and CV-measurements. The observed properties are discussed in terms of the corresponding layer morphology and structure.

HL 50.46 Thu 19:00 Poster B

Metallurgical grade Silicon-Air Battery in alkaline solution — •Benjamin Griesche[1], Richard Schalinski[1], Stefan L. Schweizer[1], and Ralf B. Wehrspohn[1,2] — [1]Institute of Physics, Martin-Luther-University Halle-Wittenberg, Germany — [2]Fraunhofer

Institute for Microstructure of Materials and Systems IMWS, Halle (Saale), Germany

The demand of energy storage technologies is one of the most discussed, regarding the transition from fossil fuels towards renewable energy systems. Therefore, lots of research was done. Some of them are highly promising, e.g. Lithium-ion battery, which achieved extreme progress over the last 25 years, and which is widely spread in portable devices. However, concerning the huge ever-increasing request, it is necessary to develop alternative battery systems. Metal-air batteries represent a category of these alternatives, from which the zinc-air battery (820 Ah/kg) is used in small applications. We are investigating another promising system, the silicon-air battery, since its components are abundant with a high theoretical specific capacity of 3.817 Ah/kg.

We introduce a new route of electrode preparation by using inexpensive metallurgical grade silicon as starting material and ball mill it to obtain small Si-nanoparticles. These were mixed with different binders to form slurries and were then coated on a substrate. The dried electrodes were analyzed by electrochemical methods in alkaline electrolyte solution and were investigated by optical methods. In order to optimize the battery performance a variation of chemical contents and treatments were performed.

HL 50.47 Thu 19:00 Poster B

Dispersion-engineered AlGaAsOI waveguides for on-chip SPDC — •Marlon Placke and Sven Ramelow — Humboldt-Universität zu Berlin, Germany

We present AlGaAs-on-insulator as a promising nonlinear optics platform with C-band compatibility. Combination of the semiconductor's ultra-high material nonlinearity with submicron waveguiding renders possible an efficient interface with great potential for full on-chip integration - provided phasematching can be achieved. Our simulations elucidate the capabilities of dispersion engineering on this platform and predict that modal phasematching is feasible for SHG and SPDC at telecom wavelengths.

HL 50.48 Thu 19:00 Poster B

MAD-grown $NdNiO_3$ thin films for PEEM study of electronic phase separation — •Henrike Probst, Marius Keunecke, David Schmitt, Vitaly Bruchmann-Bamberg, Sabine Steil, Daniel Steil, Stefan Mathias, and Vasily Moshnyaga — I. Physikalisches Institut Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Rare earth nickelates ($RENi0_3$, RE=La, Pr, Nd, Sm) are strongly correlated electron systems in which the structure and electronic properties are interconnected. They exhibit a metal-insulator transition at T_{MI} ∼100-400 K, coupled to a charge/orbital ordering and structural phase transition.
Epitaxial $NdNiO_3$ thin films have been prepared by metalorganic aerosol deposition technique (MAD) on perovskite substrates, i.e. $NdGaO_3$, $SrTiO_3$ und $LaAlO_3$, to achieve different strain states of the films. Previously [Mattoni, Nature Comm. 7, 13141 (2016)], a coexistence of metallic and insulating regions at the scale of 100-200 nanometers in the vicinity of the T_{MI} in $NdNiO_3$ epitaxial thin films was suggested. Electrical resistivity measurements reveal a pronounced R(T) hysteresis, ΔT∼10-20 K, close to T_{MI}, thus, indicating a first-order MI transition with metastable coexistence of such regions.
To study electronic phase separation across a first-order MI transition of $NdNiO_3$ we will use photoemission electron microscopy (PEEM) to visualize metallic and insulating domains.

HL 50.49 Thu 19:00 Poster B

Spin dependent giant junction resistance in Fe/*p*-Si Schottky heterojunction — •Anirban Sarkar[1,2], Amal Kumar Das[2], and Thomas Brückel[1] — [1]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Sciences JCNS and Peter Grünberg Institute PGI, JARA-FIT, 52425 Jülich, Germany. — [2]Department of Physics, Indian Institute of Technology Kharagpur, West Bengal 721302, India.

We report on the giant positive magnetoresistive behavior of a simple Fe/*p*-Si Schottky heterojunction diode at low temperatures. The device shows good rectifying characteristics at room temperature and a dual - Schottky as well as magnetic diode - characteristics at low temperature (<50 K). Large change in the junction magnetoresistance value of 10^4% at 10 K is observed which saturates at a relatively low magnetic field (∼0.5 kOe). Quantitative analysis of the field dependence of the diode forward characteristic, reveal a spin diffusion length of 100 nm with a spin life-time of 300 ps.

Formation of a magnetic field dependent potential barrier at the interface, due to electrical injection of spin-polarized carriers from the ferromagnetic electrode into the semiconductor template is often referred to result in such large junction resistance. However, there lacks a proper experimental evidence to such models and therefore we propose that probing the depth profile of magnetization with polarized neutron reflectrometry (PNR) can reveal more information about the magnetic properties near the interface of such ferromagnetic/semiconductor heterostructures.

HL 50.50 Thu 19:00 Poster B

Charge Carrier Dynamic and Disorder in (Ga,In)As/GaAs/Ga(As,Sb) heterostructures — •Luise Rost, Sarah Karrenberg, Sebastian Gies, Christian Fuchs, Wolfgang Stolz, and Wolfram Heimbrodt — Department of Physics and Materials Science Center, Philipps- Universität Marburg, Renthof 5, 35032 Marburg, Germany

The (Ga,In)As/GaAs/Ga(As,Sb) material system is used for lasers operating over a wide spectral range in the infrared. To further optimize the design of such heterostructures, it is important to have deep understanding of the influence of the interface morphology and the charge carrier dynamic through the interface. Here we present a thorough analysis of the optical properties of (Ga,In)As/GaAs/Ga(As,Sb) type-II heterostructures by means of temperature-dependent and time resolved photoluminescence spectroscopy. We were able to determine die influence of growth interruption on the disorder in our samples to further optimize growth condition. Additionally, we introduced monolayers of GaP on different positions in our heterostructure to vary the quantum confinement and the electronic structure. Furthermore, we analyzed the decay dynamics of charge-transfer excitons in the different samples to specify correlation between interface morphology and charge carrier dynamics.

HL 50.51 Thu 19:00 Poster B

atomic-scale observations of microstructure and local chemistry at the SrMnO3-SrTiO3 heterointerface — •Hongguang Wang, Vesna Srot, Yi Wang, Hans Boschker, Jochen Mannhart, and Peter A van Aken — Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Oxide heterointerfaces show unprecedented physical properties such as electro-magnetic coupling, 2-dimensional electron gas and high-Tc superconductivity which cannot be found in their bulk analogies. It is the interfacial lattice reconstruction that induces these unexpected electronic states dominating the macroscopic characteristics. Therefore, atomic-scale observations of the oxide heterointerfaces are important for appropriate interpretation of these phenomena. Here, by using an aberration-corrected scanning transmission electron microscope (STEM) equipped with an electron energy-loss spectrometer (EELS), we performed atomic-scale investigations at the heterointerface between SrTiO3 (STO) and SrMnO3 (SMO). Atomic-resolved high-angle annular dark-field and annular bright-field images were used to evaluate the local lattice and oxygen distortions. The lattice structure analysis shows a remarkable variation near the heterointerface. Using STEM-EELS line scan, we observe an asymmetric cationic intermixing at the interface between STO and SMO. A simulation of STEM-EELS spectrum image was performed at the interface. This demonstrates that the beam-spreading effect is weak and confirms the intermixing data. The EELS fine structure of Mn-L2,3 edges unveils a variation of Mn oxidation states at the heterointerface.

HL 50.52 Thu 19:00 Poster B

Development of industrially compatible patterning processes for the fabrication of IBC-SHJ solar cells — •Philipp Wagner[1,2], Johann-Christoph Stang[2], Lars Korte[2], Christof Schultz[1,3], Bernd Stannowski[3], Bert Stegemann[1], and Bernd Rech[2] — [1]HTW Berlin, Wilhelminenhofstraße 75a, D-12459 Berlin — [2]HZB, Institut für Silizium-Photovoltaik, Kekuléstraße 5, D-12489 Berlin — [3]PVcomB/HZB, Schwarzschildstraße 3, D-12489 Berlin

The interdigitated back contacted silicon hetero-junction (IBC-SHJ) solar cell is the ultimate Si wafer-based high efficiency approach with record power conversion efficiencies of 26.6 % [1]. It combines the advantages of IBC cells (i. e. high jsc and FF by small optical and resistive losses, respectively) and SHJ cells (i. e. high Voc by excellent interface passivation). Contact preparation of such solar cells with lab-based photolithographic processes yields high cell efficiencies [2], but is complex and costly and therefore not applicable in industrial fabrication. Hence it is the main objective of our work to develop simplified and damage-free, industrially compatible fabrication processes, while

maintaining exceptional cell properties. Here we demonstrate the successful development of a photolithography-free patterning technique using shadow masks and compare the challenges and advantages with screen printing and laser ablation. First solar cell results are presented and discussed with respect to further improvement of the passivation and minimisation of the contact resistance.

[1] K. Yoshikawa et al. (2017). Nature Energy, 2, 17032.
[2] J.-C. Stang et al. (2017). JJAP, 56(8S2), 08MB22

HL 50.53 Thu 19:00 Poster B

Shubnikov-de Haas studies on Gallium Nitride / Aluminum Gallium Nitride Heterostructures for High-electron-mobility transistors — •Raphael Müller[1], Sebastian Bauer[1], Manfred Madel[2], Hervé Blanck[2], and Klaus Thonke[1] — [1]Institute of Quantum Matter / Semiconductor Physics Group, Ulm University — [2]United Monolithic Semiconductors GmbH/ Ulm

Key parameters for High-electron-mobility transistors (HEMTs) are the electron mobility and sheet carrier density in the 2-dimensional electron gas forming at the n-type heterointerface. On GaN/AlGaN heterostructures with and w/o an additional AlN interlayer, these properties were analyzed in detail by low-temperature Shubnikov-de Haas and Hall measurements in magnetic fields up to 15 T.
With the presented results it is shown, that the AlN interlayer has a positive influence on several key parameters of the Heterostructure, due to the additional polarization field and the enlarged effective conduction band offset. We show that the carrier concentration, mobility, classical scattering time and quantum mechanical scattering time can be increased by adding this AlN interlayer, with positive influence on the performance of HEMTs.

HL 50.54 Thu 19:00 Poster B

KPFM under local illumination - direct observation of local band bending in contacted nanostructures — •Jan Siebels, Andreas Kolditz, Dino Behn, Tobias Kipp, and Alf Mews — Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg

The understanding and control of charge transfer processes within semiconductor materials and at interfaces is crucial for the design of semiconductor devices such as, e.g., solar cells, photodetectors, and gas sensors. Here, we demonstrate the power of Kelvin probe force microscopy with simultaneous, localized illumination of a nanostructure device by focused laser light. A combination of this technique with scanning photocurrent measurements allows the exploration of the mutual interaction between local charge carrier generation and band profiles. The nanostructure devices under investigation are Pt contacted (i) CdS nanowires and (ii) SnS nanosheets. For (i), the combined measurements show that local photocurrents can be explained by a strong dependence of the surface potential on the position of illumination while, for (ii), the occurrence of zero-bias photocurrent can directly be attributed to changes of the band bending due to the optically generated charge carriers.

HL 50.55 Thu 19:00 Poster B

Growth of Na-doped SnSe single crystals — •Yannik Bartlock, Marius Peters, Kristin Kliemt, and Cornelius Krellner — Physikalisches Insitut, Goethe-Universität Frankfurt am Main, D-60438 Frankfurt

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.

[1] L.-D. Zhao et al., Science 351, 141 (2016)

HL 50.56 Thu 19:00 Poster B

Organic-Inorganic Hybrid Thermoelectrics based on Mesoporous Silicon and PEDOT:PSS — •Haider Haseeb, Tommy Hofmann, Danny Kojda, and Klaus Habicht — Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Berlin, Germany

This contribution presents mesoporous silicon and derived hybrid systems that incorporate conducting PEDOT:PSS into the vacant pore space as thermoelectric materials of interest. First, the synthesis of mesoporous silicon by means of electrochemical etching is explained. Grown samples are characterized in microscopic SEM studies as well as with gas adsorption isotherms to reveal morphological features that are pore size distributions, specific surfaces and porosities. Second, the impact of porousification on the thermoelectric properties is revealed and discussed. Macroscopic transport measurements that probe electrical and thermal conductivity, Hall mobility, charge carrier concentration and Seebeck coefficients allow to compare the thermoelectric performance of mesoporous silicon with the properties of the corresponding bulk system. In the third and final part of the poster, we show the infiltration of PEDOT:PSS into porous silicon as a way to form organic-inorganic hybrids. Their preliminary thermoelectric characterization and microscopic analysis conclude our presentation and allow an outlook on future material improvements.

HL 50.57 Thu 19:00 Poster B

Submonlayers as novel gain medium in opto-electronic devices — •Fuad Alhussein[1], Bastian Herzog[1], Benjamin Lingnau[2], Mirco Kolarczik[1], Sophia Helmrich[1], David Quandt[3], Udo Pohl[3], André Strittmatter[4], Olaf Brox[5], Markus Weyers[5], Ulrike Woggon[1], Kathy Lüdge[2], and Nina Owschimikow[1] — [1]Institut für Optik und atomare Physik, Technische Universität Berlin — [2]Institut für theoretische Physik, Technische Universität Berlin — [3]Institut für Festkörperphysik, Technische Universität Berlin — [4]Institut für Experimentelle Physik, Otto-von-Guericke-Universität Magdeburg — [5]Ferdinand Braun Institut, Leibniz Institut für Hüchstfrequenztechnik Berlin

For lasers and optical amplifiers the gain provided by the active region along with the line width and energy of the emitted light are important features. For many applications a broad emission spectrum is desired, such as it is produced by self-assembled quantum dots. The submonolayer growth method produces dense In-rich islands within a GaAs matrix, with a density of localization centers exceeding the density of quantum dots by an order of magnitude. We compare the properties of optical amplifiers and lasers with quantum dots, submonolayers and single quantum wells emitting at the optical band of 1060 nm. Our devices reach a peak net modal gain of 9, 25 and 28 $cm^{(-1)}$ per layer on a 3 dB bandwidth of 60, 38 and 7 meV and a lasing threshold of 1.5, 0.75 and 0.23 kA $cm^{(-2)}$, respectively.

HL 51: 2D Materials: Session III (joint session DS/CPP/HL)

Time: Friday 9:30–12:30 Location: H 2032

Invited Talk HL 51.1 Fri 9:30 H 2032

Tunable Electronic Structures, Magnetism, and Axis-Dependent Conduction Polarity in Ge and Sn-based 2D Materials — •Joshua Goldberger — The Ohio State University, Columbus, OH USA

Here, we will discuss recent developments in the synthesis, properties, and applications of two classes of Ge- and Sn-based 2D materials; the ligand-functionalized Ge/Sn graphane analogues, and the exfoliatable van der Waals Zintl phases. First, the Ge/Sn graphane analogues have generated much excitement as their electronic structures are predicted to range from trivial insulators, to semiconductors with tunable gaps, to semimetallic, to topological insulators, depending on the substrate, chemical functionalization and strain. Through the synthesis and characterization of a large family of ligand-functionalized germananes, we will show how the electronic structure can be manipulated via surface chemistry. Second, we will highlight a new family of chemically and thermally robust exfoliatable 2D materials having a stoichiometry of ASn2Pn2, where A is a cation, and Pn is a pnictogen. This class of materials can be designed to exhibit a broad range of phenomena including the topological insulating compound, SrSn2As2, as well as the magnetic compound, EuSn2As2. Also, we will show that NaSn2As2 simultaneously exhibits opposite sign conduction polarities along its in-plane and cross-plane axes. Using a variety of advanced transport measurements we establish the band structure origins of this behavior. Together, these materials show how the inherent anisotropy in 2D materials can be rationally tailored to give rise to new phenomena.

HL 51.2 Fri 10:00 H 2032

Chemical and optical properties of transition metal dichalcogenide monolayers at the nanometer and subnanometer scale — •Luiz Tizei[1], Alberto Zobelli[1], Ching-Hwa Ho[2], Kazu Suenaga[3], Alexandre Gloter[1], Mathieu Kociak[1], and Odile Stéphan[1] — [1]Laboratoire de Physique des Solides, University of Paris-Sud, CNRS, Orsay, France — [2]National Taiwan University of Science and Technology, Taipei, Taiwan — [3]AIST, Tsukuba, Ibaraki, Japan

Defects and interface play an important role in material properties. Therefore, their characterization at the nanometer scale is crucial. Here, core-loss EELS and high angle annular dark field imaging have been used to identify single Cr atoms in WSe_2 monolayers. These atoms are always located at the metal site (W) with a 3+ formal valence, as deduced from EELS fine structure comparison with known references and X-ray photoelectron spectroscopy (XPS). Furthermore, Cr atoms are observed systematically close to single our double Se vacancies, indicating a possible electron doping of the system. Moreover, semiconducting 2H phase TMD monolayers present spin-split valence and conduction bands due to spin-orbit coupling. These two near band edge states are separated by from a few tens to a few hundred meV and can be measured by EELS with high spatial resolution. As an example, we will show measurements of the near band edge losses as a function of position across an interface between two TMDs. Results will be compared to calculated loss functions, tacking into account the materials' dielectric function.

HL 51.3 Fri 10:15 H 2032

Excitonic Phonon Sidebands in Monolayer Transition Metal Dichalcogenides — •Dominik Christiansen[1], Malte Selig[1], Gunnar Berghäuser[2], Robert Schmidt[3], Iris Niehues[3], Robert Schneider[3], Ashish Arora[3], Steffen Michaelis de Vasconcellos[3], Rudolf Bratschitsch[3], Ermin Malic[2], and Andreas Knorr[1] — [1]Technische Universität Berlin, Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Berlin, Germany — [2]Chalmers University of Technology, Department of Physics, Gothenburg, Sweden — [3]Physikalisches Institut und Zentrum für Nanotechnologie, Universität Münster, 48149 Münster, Germany

Monolayers of transition metal dichalcogenides (TMDs) show an extraordinarily strong Coulomb interaction, leading to the formation of tightly bound excitons. Because of a complex quasi-particle band structure, TMDs possess a variety of bright sates (addressable by light) and dark states (addressable by phonons). Here, we present a joint experiment-theory study on the influence of exciton-radiative and exciton-phonon interaction on the absorption line shape of different monolayer TMD materials. Solving the TMD Bloch equations in the quantum kinetic limit, we predict the appearance of spectrally asymmetric phonon-induced sidebands that are accompanied by a pronounced polaron-red shift. We analyze the influence of the interplay of phonon emission/absorption processes and dark intra- and intervalley excitonic states on the asymmetry of the absorption line shape.

D. Christiansen, et. al, Phys. Rev. Lett. 119, 187402 (2017)

HL 51.4 Fri 10:30 H 2032

Lifetime of Valley Excitons in Monolayer Transition Metal Dichalcogenides — •Malte Selig[1], Samuel Brem[2], Florian Katsch[1], Gunnar Berghäuser[2], Ermin Malic[2], and Andreas Knorr[1] — [1]Nichtlineare Optik und Quantenelektronik von Halbleitern, Institut für Theoretische Physik, Technische Universität Berlin, Berlin, Germany — [2]Chalmers University of Technology, Department of Physics, Gothenburg, Sweden

In monolayers of transition metal dichalcogenides, weak screening leads to the formation tightly bound excitons which dominate the optical properties of these ultrathin materials. A pronounced circular dichroism leads to a spin and valley selective excitation of excitons at the corners of the hexagonal Brillouin zone. A microscopic understanding of the lifetime of such optically injected spins is of crucial interest for future technological applications. Here, based on a Heisenberg of motion formalism for excitons, we perform microscopic momentum and spin resolved computations to investigate the impact of exciton phonon coupling and intervalley exchange coupling on the valley lifetime of excitons. In our analysis, we also include recently discussed indirect dark excitons [1,2]. In the absence of low lying dark states we find valley lifetimes below 1 ps, which increases by orders of magnitude if the material is indirect.

[1] M. Selig et al., Nat. Commun. 7, 13279 (2016)
[2] M. Selig et al., arXiv:1703.03317 (2017)

HL 51.5 Fri 10:45 H 2032

Interface sensitive structure determination of silicon nanoribbons on Gold surfaces — •Peter Roese[1,2], Philipp Espeter[1,2], Karim Shamout[1,2], Ulf Berges[1,2], and Carsten Westphal[1,2] — [1]Experimentelle Physik 1, Technische Universität Dortmund, Germany — [2]DELTA, Technische Universität Dortmund, Germany

In the last years there has been much progress in the growth and analysis of 2D-materials beyond graphene on metallic surfaces. Especially, silicon based two-dimensional silicene and one-dimensional silicon nano-ribbons came into scientific focus due to their promising electronic properties. Beside the exact knowledge of the fascinating electronic and chemical properties of such systems, the structural information is of great interest for precise DFT calculations. In this context the interaction between the silicon nano-ribbons and the substrate plays an important role. Techniques like STM or LEED provide information about the electronic structure of such systems but neither chemical information about the atomic bonds nor information about the interface. Photoelectron spectroscopy and diffraction easily provide information about atomic bonds and the interface between silicon nano-ribbons and the substrate, recently shown by Espeter et al [8]. The structure of silicon nano-ribbons on Ag(110) has recently been resolved whereas their exact structure on Au(110) and the effect of the interface needs to be analyzed in detail. Based on previous works, we present first photoelectron diffraction results of silicon nano-ribbons on Au(110).

15 min. break.

HL 51.6 Fri 11:15 H 2032

Disclosing the nature of excitons in van der Waals materials: The role of layer stacking in hexagonal boron nitride — •Wahib Aggoune[1,2], Caterina Cocchi[2,3], Dmitrii Nabok[2,3], Karim Rezouali[1], Mohamed Akli Belkhir[1], and Claudia Draxl[2,3] — [1]Laboratoire de Physique Théorique, Faculté des Sciences Exactes, Université de Bejaia, 06000 Bejaia, Algeria — [2]Institut fur Physik and IRIS Adlershof, Humboldt-Universitat zu Berlin, Berlin, Germany — [3]European Theoretical Spectroscopic Facility (ETSF)

With the example of bulk hexagonal boron-nitride, a prototypical van der Waals (vdW) crystal, we demonstrate that the electronic and optical properties of these materials can be tuned by layer patterning. By modifying the stacking, energy, intensity, and character of the electron-hole (e-h) pairs can be selectively modulated. Depending on the specific layer arrangement, lowest-energy excitons are localized within a single layer or delocalized in the three-dimensional space. Only in specific stackings charge-transfer e-h pairs appear above the absorption onset, triggered by the spatial distribution of the electronic states involved. Our results, obtained within a first-principles many-body framework, provide all the ingredients to identify, predict, and tailor the character of the e-h pairs in vdW materials.

HL 51.7 Fri 11:30 H 2032

Evidence for low-dimensional charge transport in carbon nitride polymers — •Christoph Merschjann — Helmholtz-Zentrum-Berlin für Materialien und Energie GmbH, Hahn-Meitner-Platz 1, 14109 Berlin — Freie Universität Berlin, Fachbereich Physik, Arnimallee 14, 14195 Berlin

Carbon nitride (CN) polymers have gained much interest in recent years due to their potential application as both dark- and photocatalysts for various renewable-energy tasks, including water-splitting and CO_2 reduction, and others. Given their layered, van-der-Waals bound structure, these materials resemble graphite, and are hence often called "graphitic carbon nitrides" (g-C_3N_4). The main technical advantage of CNs is the abundance of their constituents (C, N, and H) and the absence of precious metals. However, compared to metal-based catalysts, the activity of CN materials is still rather low, a fact that has been largely attributed to their low conductivity. Recently, we found evidence that this low conductivity is due to polaronic hopping motions of photoexcited electrons and holes, which predominantly move vertical to the graphitic planes of the material. Backed-up by very recent transient-spectroscopy studies, we will discuss the validity of such a low-dimensional transport scenario, and its consequences for applications in catalysis as well as in organic electronics in general.

HL 51.8 Fri 11:45 H 2032

Deterministic Positioning of Single-Photon Emitters in Monolayer WSe_2 on the Nanoscale — •Johannes Kern[1], Iris Niehues[1], Philipp Tonndorf[1], Robert Schmidt[1], Daniel Wigger[2], Robert Schneider[1], Torsten Stiehm[1], Steffen Michaelis de Vasconcellos[1], Doris E. Reiter[2], Tilman Kuhn[2], and Rudolf Bratschitsch[1] — [1]Institute of Physics and Center for Nanotechnology, University of Münster, Germany — [2]Institute of Solid State Theory, University of Münster, Germany

Single-photon emitters are an important building block for photonic quantum technology. Here, we deterministically position single-photon emitters in monolayer WSe_2 on the nanoscale [1]. The atomically thin semiconductor is placed on top of a gapped single-crystalline gold rod which results in a folding of the monolayer around the metal nanostructure. At the gap position, local strain is induced in the atomically thin semiconductor. Excitons localize there and radiatively decay via single-photon emission.

[1] J. Kern et al., "Nanoscale positioning of single-photon emitters in atomically thin WSe2", Adv. Mater. 28, 7101-7105, (2016).

HL 51.9 Fri 12:00 H 2032

Pulsed Laser Deposition of Monolayer WSe_2 — •Avaise Mohammed[1], Hiroyuki Nakamura[1], Peter Wochner[1], Shyjumon Ibrahimkutty[1], Armin Schulz[1], Kathrin Müller[1], Krystian Nowakowski[2], Keita Matsuda[3], Johannes Geurs[1], Yijin Zhang[1], Mona Stadler[4], Kenji Watanabe[5], Takashi Taniguchi[5], Benjamin Stuhlhofer[1], Georg Cristiani[1], Gennady Logvenov[1], Michael Jetter[4], Peter Michler[4], Jurgen Smet[1], Ulrich Starke[1], and Hidenori Takagi[1,6] — [1]MPI-FKF — [2]University of Twente — [3]Nagoya University — [4]IHFG, University of Stuttgart — [5]NIMS — [6]IFMQ, University of Stuttgart

Ultrathin WSe_2 films were deposited using a custom built hybrid-Pulsed Laser Deposition (PLD) system on different substrates. Raman spectroscopy and atomic force microscopy were used to identify the monolayer (ML) WSe_2. Synchrotron based grazing incidence X-ray diffraction revealed WSe_2 films to have a compressive strain on Al_2O_3 r-cut substrates. Angle resolved photoelectron spectroscopy confirmed the valance band structure of ML WSe_2 on epitaxial graphene with a clear spin splitting of 480 meV. Photoluminescence signal was identified from ML WSe_2 deposited on hexagonal BN. The results give evidence for PLD to be an excellent approach for the growth of monolayer transition metal chalcogenides.

HL 51.10 Fri 12:15 H 2032

Gate-dependent spin dynamics of dark trion states in monolayer WSe_2 — •Manfred Ersfeld, Frank Volmer, Maximilian Heithoff, Christopher Franzen, Christoph Stampfer, and Bernd Beschoten — 2nd Institute of Physics and JARA-FIT, RWTH Aachen University, 52074 Aachen, Germany

We explore the spin dynamics in WSe_2 monolayers by time-resolved Kerr rotation measurements. The longest spin lifetimes of up to 150 ns are observed at 5 K when resonantly pumping into charged exciton states (trions). We explain these long spin lifetimes by the formation of dark trion states which exhibit equal recombination lifetimes independently measured by time-resolved reflectivity [1]. We show that the spin lifetimes of the dark trion states strongly depend on the chemical potential which we tune by applying a gate voltage to the WSe_2 flake through a SiO_2/Si^{++} substrate. The formation of the dark trion states require intervalley scattering driven by short range scattering centres. Additional photoluminescence measurements indicate that this short range scattering is caused by localized states and gets strongly diminished with increasing temperature which may also be relevant for the overall strong decrease of both the spin amplitude and the spin lifetime of the dark trion states with increasing temperature.

[1] F. Volmer et al., Phys. Rev. B 95, 235408 (2017)

HL 52: Optical properties & Photonic crystals

Time: Friday 9:30–12:45 Location: EW 201

HL 52.1 Fri 9:30 EW 201

Gyrotropic effects in trigonal tellurium studied from first principles — •Stepan S. Tsirkin[1,2], Pablo Aguado Puente[1,2], and Ivo Souza[1,3] — [1]Centro de Física de Materiales, Universidad del País Vasco, 20018 San Sebastián, Spain — [2]Donostia International Physics Centre, 20018 San Sebastián, Spain — [3]Ikerbasque Foundation, 48013 Bilbao, Spain

We present a combined *ab initio* study of several gyrotropic effects in *p*-doped trigonal tellurium (effects that reverse direction with the handedness of the spiral chains in the atomic structure). The key ingredients in our study are the Berry curvature and the orbital magnetic moment induced in the Bloch states by the broken spatial inversion symmetry of the crystal structure.

We show that the observed sign reversal of the circular photogalvanic effect with temperature can be explained by the presence of Weyl points near the bottom of the conduction band acting as sources and sinks of Berry curvature. The passage of a current along the trigonal axis induces a parallel magnetization, leading to the occurence of Faraday rotation alongside natural optical rotation. In agreement with experiment, we find that when infrared light propagates antiparallel to the current at low doping, the induced Faraday effect enhances the natural optical rotation. The plane of polarization rotates in the opposite sense to the bonded atoms in the spiral chains, in agreement with a recent experimental determination of the handedness of a Te crystal that contradicts earlier reports.

The work is published as arXiv:1710.03204.

HL 52.2 Fri 9:45 EW 201

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, Duisburg 47057, Germany — [2]Division of Material Science, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan

Organic semiconductor Borondipyrromethene (BODIPY) derived samples have drawn much attention in recent years in the field of bioimaging due to their good photo-physical properties such as high ex-

tinction coefficient and quantum yield. BODIPY molecules, under certain conditions, can be grown into rods. Different growth methods result in BODIPY rods with different photo-emission wavelengths.

In this contribution we show photo-luminescence (PL) spectra from different rods under 405nm laser excitation. Emitted light from the rods can travel through the rod due to total internal reflection, combining their excellent PL properties with waveguide physics. The light intensity emitted at the end of the rod shows an exponential decrease as the distance between end of the rod and the excitation spot is increased. This is attributed to reabsorption and scattering. We quantify the extinction parameter for different rods and compare them. Interestingly, the PL spectrum from the green emitting rod, shows, besides a broad luminescence, a set of peaks with energies that follows a $1/n^2$ rule. Such behavior, known from Rydberg atoms comes unexpected. The spectra will be discussed using different models such as Rydberg excitons or charge accumulation in the crystal.

HL 52.3 Fri 10:00 EW 201

Sorting exciton polariton vortices by their orbital angular momentum — •Bernd Berger[1], Marius Kahlert[1], Daniel Schmidt[1], Marc Assmann[1], Martin Kamp[2], Christian Schneider[2], Sven Höfling[2], and Manfred Bayer[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, D-44221 Dortmund, Germany — [2]Technische Physik, Physikalisches Institut, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, D-97074 Würzburg, Germany

Vortices are elementary excitations in exciton polariton condensates that consist of a low-density core and a phase rotation of a multiple of 2π around it. In our experiment a light beam carrying orbital angular momentum (OAM) is utilized to excite exciton polariton vortices in a GaAs microcavity at cryogenic temperatures. Thereby the topological charge of the vortex directly corresponds to the quantized OAM of the incident light beam. In a sophisticated approach, the sample signal is sorted by the vortex topological charge and resolved in time without the need of a phase reference. Thus the dynamics of vortices with different topological charges are investigated.

HL 52.4 Fri 10:15 EW 201

Microscopic theory of two-photon absorption and stimulated emission in direct-gap semiconductors — •Wolf-Rüdiger Hannes and Torsten Meier — Department of Physics and CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany

Two-photon absorption (TPA) rates in semiconductors are analyzed within a simple two-band model. The light-matter interaction is treated non-perturbatively using the semiconductor Bloch-equations extended by the intraband accelaration [1], which is shown to cause a significant enhancement of the $\chi^{(3)}$ nonlinear response as compared to the two-photon transition rate from second-order perturbation theory. [2] The enhancement is particularly strong for widely-nondegenerate signal and idler photons. Our results are in agreement with experimental spectra for both TPA [3] and stimulated two-photon emission. [4]

[1] H. T. Duc, T. Meier, and S. W. Koch, Phys. Rev. Lett. **95**, 086606 (2005); E. Sternemann, T. Jostmeier, C. Ruppert, H. T. Duc, T. Meier, and M. Betz, Phys. Rev. B **88**, 165204 (2013)
[2] M. Sheik-Bahae, D. C. Hutchings, D. J. Hagan, and E. W. Van Stryland, IEEE Journal of Quantum Electronics **27**, 1296 (1991).
[3] C. M. Cirloganu, L. A. Padilha, D. A. Fishman, S. Webster, D. J. Hagan, and E. W. Van Stryland, Opt. Express **19**, 22951 (2011).
[4] M. Reichert, A. L. Smirl, G. Salamo, D. J. Hagan, and E. W. Van Stryland, Phys. Rev. Lett. **117**, 073602 (2016)

HL 52.5 Fri 10:30 EW 201

Functionalized Nanoporous Au Particles for Enhanced Optical Nonlinearities — •Jue-min Yi[1], Dong Wang[2], Felix Schwarz[3], Germann Hergert[1], Jan Vogelsang[1], Petra Gross[1], Peter Schaaf[2], Erich Runge[3], and Christoph Lienau[1] — [1]Carl von Ossietzky Universität, Oldenburg — [2]TU Ilmenau, Ilmenau — [3]TU Ilmenau, Ilmenau

Nanoporous Au particles (nanosponges) have promising optical properties due to their percolated nanoporous structure with disorder and nanometers-sized pores where coherent multiple scattering of light can form a series of localized hot spots with large field enhancement. Here we have systematically studied the nonlinear optical effects from nanosponges and their functionalization with ZnO materials. In particular, we have performed time-resolved photoemission measurements on single nanosponges using ultrashort laser pulse excitation. The long-lived electron emission with high excitation efficiency proves the existence of localized plasmon states on the surface of the nanoporous particles with lifetimes of more than 20 fs [1]. We have further investigated their potential as disordered nanoantennas by depositing ZnO into nanometers-sized pores. Strong second harmonic emissions from ZnO in the vicinity of nanosponges have been observed. Our results indicate that individual nanosponges are robust disordered nanoantennas with strong local resonances, and shed new light on tailoring disorder with functional materials for specific applications.[1] G. Hergert, et al., Light: Science &Applications 6, e17075 (2017).

HL 52.6 Fri 10:45 EW 201

Routing of exciton-polaritons in microcavity waveguides — •Johannes Beierlein[1], Sebastian Klembt[1], Martin Klaas[1], Monika Emmerling[1], Holger Suchomel[1], Karol Winkler[1], Sebastian Brodbeck[1], Hugo Flayac[2], Christian Schneider[1], and Sven Höfling[1,3] — [1]Technische Physik, Universität Würzburg, Germany — [2]Institute of Theoretical Physics, EPFL, CH-1015 Lausanne, Switzerland — [3]School of Physics and Astronomy, University of St. Andrews, KY 16 9SS, United Kingdom

Exciton-polaritons have been in the centre of scientific investigation due to their hybrid light-matter nature. It allows for large propagation distances while maintaining a strong non-linearity. This work sheds light on the functionality of two passive exciton-polariton routing devices. First, two microcavity waveguides (WGs), which are realized by etching the top and bottom DBRs, are evanescently coupled. Due to the evanescent coupling, a Josephson oscillation manifests itself. This oscillation is clearly displayed in real-space due to the propagating nature of the condensate. Depending on the device parameters a different phase at the end of the coupling area can be achieved, resulting in different routing ratios. Further, we discuss two WGs which are coupled by a microcavity disc. A propagating condensate along one WG can be transmitted into the disc where it circulates and eventually exits into the other wire. Both of those tunneling events are energy dependent. The size parameters of the disc as well as the WGs influences the energy transmission pattern and therefore allows for energy controlled reshaping of the condensate.

HL 52.7 Fri 11:00 EW 201

Time-resolved spectroscopic ellipsometry with sub-ps resolution — •Steffen Richter[1], Oliver Herrfurth[1], Shirly Espinoza[2], Mateusz Rębarz[2], Miroslav Kloz[2], Jakob Andreasson[2,3], Marius Grundmann[1], and Rüdiger Schmidt-Grund[1] — [1]Universität Leipzig, Felix-Bloch-Instiut für Festkörperphysik, Linnéstr. 5, 04103 Leipzig, Germany — [2]ELI beamlines, Za Radnicí 835, Dolní Břežany, Czech Republic — [3]Chalmers tekniska högskola, Institutionen för fysik, Kemigården 1, 41296 Göteborg, Sweden

Knowledge of the temporal evolution of the complex optical properties in response to optical excitation is crucial for understanding of fundamental physical processes inherent in semiconductors. We demonstrate time-resolved ellipsometry in a pump-probe scheme employing continuum white-light probe and UV pump pulses. The ellipsometric approach allows to obtain the dynamics of the dielectric function in a broad spectral range with an estimated time resolution of 170fs. We will stress on essential experimental requirements and show data obtained from ZnO samples. We will also give an outlook on the pump-probe VUV ellipsometer being built up at ELI beamlines.

15 min. break.

HL 52.8 Fri 11:30 EW 201

Invisible excitons in hexagonal Boron Nitride — •Claudio Attaccalite[1,4], Lorenzo Sponza[2], Myrta Gruning[3], Hakim Amara[1], and François Ducastelle[1] — [1]CINaM UMR 7325, Aix-Marseille University - CNRS, Marseille, France — [2]LEM UMR 104, ONERA - CNRS, Chatillon, France — [3]Queen's University, Belfast, UK — [4]Universita Tor Vergata, Roma, Italy

In this work we study excitations in hexagonal Boron Nitride that are invisible in linear optical response. We show that these dark states can be measured with other spectroscopic techniques and they play an important roles in the response of h-NB. Our results clarify the indirect nature of h-BN and its excitation spectra.

HL 52.9 Fri 11:45 EW 201

Radiative versus non-radiative color conversion in an InGaN/polymer hybrid material system — •Niklas Mutz, Emil J. W. List-Kratochvil, and Sylke Blumstengel — Hybrid Devices Group, Institut für Physik, Institut für Chemie und IRIS Adlershof, Humboldt-Universität zu Berlin

White light generation in InGaN/GaN based light-emitting diodes (LEDs) is commonly achieved by so called external color conversion, where blue light emitted from an InGaN quantum well (QW) is subsequently partially absorbed by an inorganic phosphor material and reemitted in the yellow-orange spectral region to yield white light. In this process, the overall yield of converted photons is limited by the product of the quantum yield of the involved constituents. As an alternative, more efficient process, non-radiative Förster-like energy transfer from the inorganic QW to an organic acceptor can be used for the color conversion.

Here we investigate energy transfer from an InGaN/GaN single QW to a thin top layer of a light-emitting polymer, a cyano-ether-poly(p-phenylen-vinylen) (Cn-ether-PPV). We experimentally find that Cn-ether-PPV can be efficiently excited through the InGaN/GaN single QW when the organic polymer layer is in close proximity to the InGaN/GaN single QW. By means of time-resolved and -integrated photoluminescence spectroscopy at various temperatures we quantify the contribution of radiative and non-radiative energy transfer to the color conversion observed in this hybrid material system.

HL 52.10 Fri 12:00 EW 201

Trapping potentials for Rydberg excitons in cuprous oxide (Cu_2O) — •Sjard Ole Krüger and Stefan Scheel — Institut für Physik, Universität Ro- stock, D-18059 Rostock, Germany

The trapping of neutral atoms by optical dipole potentials is an established experimental technique. For semiconductor excitons, similar traps can be created by a spatially inhomogeneous strain field and have been applied in the pursuit of BEC of the excitonic ground state in Cu_2O. These strain traps offer a great variety achievable geometries, depending on the stressor, its orientation relative to the crystal axes, the stress and the excitonic state in question. In this talk, calculations of a strain-induced waveguide potential [1] for the Rydberg excitons of the yellow series in Cu_2O [2] will be presented and conditions for the formation of such traps will be evaluated. Additionally, the possibility of using optical dipole potentials to trap excitons will be discussed.

[1] S. O. Krüger and S. Scheel, http://arxiv.org/abs/1711.06639

[2] T. Kazimierczuk et al. , Nature 514, 343 (2014)

HL 52.11 Fri 12:15 EW 201

Wafer-scale metallic two-dimensional superlattice photonic crystals for light trapping — •Rui Xu, Huaping Zhao, and Yong Lei — Am Ehrenberg 2, 98693 ilmenau

Two-dimensional (2D) superlattice PhCs of alumina are found to be formed when preparing perfectly-ordered porous alumina membranes by anodizing surface-nanopatterned aluminium foils. Through a two-step replication process, we successfully replace alumina with metals (e.g., nickel, gold, silver, cobalt) to obtain wafer-scale metallic 2D superlattice PhCs. The geometrical and structural parameters of metallic 2D superlattice PhCs can be precisely tuned based on those of alumina counterparts, and finally leading to tailorable light trapping properties. As an example, nickel 2D superlattice PhCs can achieve stably strong (over 90%) light absorption below the steep cut-off wavelength which is controlled in the wavelength range of 600 - 1500 nm. Numerical simulations and systematic experiments reveal that the surface plasmon resonance and cavity resonance stemming from both nanopores and nanoconcaves are fundamentally responsible for light trapping.

HL 52.12 Fri 12:30 EW 201

Resonant state expansion for disordered claddings in photonic crystal fibers — •Swaathi Upendar[1], Izzatjon Allayarov[1], Guangrui Li[2], Markus Schmidt[2,3], and Thomas Weiss[1] — [1]4th Physics Institute and Research center SCoPE, University of Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology, Jena, Germany — [3]Otto Schott Institute of Material Research, Friedrich Schiller University, Jena, Germany

Photonic crystal fibers guide light in a central defect core surrounded by a periodic cladding using a bandgap effect. We would like to study how disorder in the cladding affects the properties of an all solid photonic crystal fiber. As effects originating from disorder need to be averaged over many realizations, fast simulation techniques are required.

In this contribution we show how to adapt the so-called resonant state expansion [1] to such fiber geometries. Resonant states are solutions of Maxwell's equations with outgoing boundary conditions in the absence of source terms. For resonant state expansion, the resonant states need to be normalized correctly. The difficulty is that modes in hollow-core photonic crystal fibers radiate in the direction normal to the fiber axis, so that the electromagnetic fields of the modes grow exponentially with distance to the core and cladding. We demonstrate the correct normalization of the modes in such fibers and use the normalized modes to derive the propagation constants of modes in perturbed and thus, disordered systems.

[1] M. B. Doost, W. Langbein, and E. A. Muljarov, Phys. Rev. A **87**, 043827 (2013).

HL 53: Energy materials (other than photovoltaics)

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

HL 53.1 Fri 9:30 EW 202

Oxygen vacancies: effective strategy to boost sodium storage performance — •Yang Xu, Min Zhou, Chenglin Zhang, Liying Liang, and Yong Lei — Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, Germany

Utilization of oxygen vacancies (OVs) is an effective strategy to boost electrochemical performance in sodium-ion batteries. We demonstrated that OVs could benefit oxide anodes regardless of their crystallinity, by taking amorphous SnO2 nanoarrays and crystalline MoO3-x nanosheets as examples. The OV-containing SnO2 nanoarrays delivered reversible capacities of 376 mAh g-1 after 100 cycles (0.05 A g-1) and 220 mAh g-1 after 800 cycles (1 A g-1) as well as great rate capability by retaining 200 mAh g-1 at 20 A g-1. Moreover, by coating the MoO3-x electrode with an ultrathin Al2O3 layer, the long-term cycling capacity and rate capability of MoO3-x were increased by four and ten times, respectively, comparing with the MoO3 electrode. Electrochemical kinetic study revealed that OVs could greatly enhance charge transfer/transport properties at the electrode/electrolyte interface and within the electrodes. Our work opens up new possibilities of designing strategies in energy storage systems.

[1] Y. Xu, M. Zhou, C. Zhang, C. Wang, L. Liang, Y. Fang, M. Wu, L. Cheng, Y. Lei, Nano Energy 2017, 38, 304. [2] Y. Xu, M. Zhou, X. Wang, C. Wang, L. Liang, F. Grote, M. Wu, Y. Mi, Y. Lei, Angew. Chem. Int. Ed. 2015, 54, 8768.

HL 53.2 Fri 9:45 EW 202

Evaluate the Role of Nanostructure Current Collector in Supercapacitor Electrode when the Elctroactive Material is in the Form of Thick Layer — •Long Liu, Huaping Zhao, Yang Xu, Shipu Xu, Chenglin Zhang, and Yong Lei — Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, German

Electroactive materials (especially pseudocapacitive materials) are generally in the form of ultrathin conformal coating in supercapacitor electrodes based on nanostructured current collectors, thus the resultant low mass loading of electroactive materials largely limits the applications of nanostructured current collectors. Here, supercapacitor electrodes with nickel nanorod arrays as nanostructured current collectors and MnO2 as electroactive materials are fabricated to study the role of nanostructured current collectors in determining the energy storage capability when electroactive materials are in thick layer rather than ultrathin conformal coating. Electrochemical analysis revealed that Ni nanorods could create numerous electrical conductive tunnels in the thick-layer electrodes to dramatically alleviate the contact resistance at the electroactive-materials/current-collectors interface. These results open up new opportunities for nanostructured current collectors to construct supercapacitors with superior energy storage capability.

[1]. Liu L., Zhao H.P.*, Wang Y., Fang Y.G., Xie J.L., Lei Y.*, Adv. Funct. Mater., 2017, DOI: 10.1002/adfm.201705107.

HL 53.3 Fri 10:00 EW 202

Structure function correlation of $Co_2Mn_{1-x}Fe_xO_4$ regarding the OER — •Maike Uptmoor and Kathrin M. Lange — Bielefeld University, Germany

A promising approach for a clean energy future is to store solar energy in a chemical fuel like hydrogen by photoelectrochemical (PEC) water splitting. Because the production of oxygen at the anode is sluggish compared to the one of hydrogen it is of high relevance to develop new catalytic materials to accelerate the oxygen evolution reaction (OER) thus enhance the overall efficiency of this process. First row transition metal oxide catalysts are very promising candidates because they are abundant have low costs and are stable in several oxidation states.

Thin films of the transition metals oxides $Co_2Mn_{1-x}Fe_xO_4$ are investigated in detail. They are synthesized by co-sputtering and subsequently post annealed to obtain a crystalline structure. Several measurements are performed to correlate the structure to the catalytic activity. The crystal structure and morphology are analyzed in detail by X-ray-diffraction (XRD) and secondary electron microscopy (SEM). Electrochemical methods are performed in a three electrode configuration with an alkaline electrolyte while the metal oxides sputtered on gold layers act as working electrode in the electrochemical-setup. Different methods are performed to measure the activity and the stability of the sample, among others cyclic voltammetry and chronopotentiometry. First results of the structure characterization and electrochemical measurements of the material will be presented.

Schwanke, C., et al. (2017). Sci Rep 7: 44192.

HL 53.4 Fri 10:15 EW 202

Template-based nanoengineering strategies for photoelectrodes design toward enhancing photoelectrochemical water splitting — •Huaping Zhao, Rui Xu, Yan Mi, Long Liu, Yaoguo Fang, and Yong Lei — Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, Germany

Solar-driven hydrogen production through photoelectrochemical (PEC) water splitting is considered as one of the most highly-efficient approaches to utilize the unlimited solar energy economically and environmentally. The architecture of photoelectrode plays an important role in determining the overall PEC performance. As known that nanostructures have the significant capability of decoupling light absorption and charge carrier collection, and shortening minority carrier diffusion distance compared to bulk structures, various nanoengineering strategies therefore have been developed for the rational photoelectrode design aiming at improving the PEC energy conversion efficiency. Remarkably, template-based nanoengineering strategies provide the opportunities to rationally design nanoarchitectured photoelectrodes. Studies have shown the fact that template-realized highly-ordered nanostructure arrays can spatially redistribute the light intensity and efficiently scatter light in the device resulting in enhanced light absorption, and thus will enable high quantum efficiencies for solar energy conversion. Moreover, such nanostructure arrays could facilitate carrier collection via orthogonalizing the direction of light propagation and carrier collection, resulting in significantly improved PEC performance.

HL 53.5 Fri 10:30 EW 202

Photolytic water splitting by surface-conditioned n-GaP(100) photoanodes — •waqas saddique, gerhard lilienkamp, and winfried daum — Institute of Energy Research and Physical Technologies, Technical University Clausthal, Clausthal-Zellerfeld, Germany

III-V semiconductors are candidates for photoelectrochemical (PEC) water splitting but they are prone to corrosion and suffer from corrosion-related decrease of efficiency. Gallium phosphide (GaP) has an indirect band gap of 2.26 eV which covers both the hydrogen evolution potential (HEP) and the oxygen evolution potential (OEP). Thus, in principle, GaP can be used as photocathode and photoanode. We have studied the structural and chemical surface modifications of n-GaP(100) photoanodes before and after extended PEC treatment by scanning electron microscopy (SEM), atomic force microscopy (AFM), Auger electron spectroscopy (AES) and X-ray photoelectron spectroscopy (XPS). An approximately 2 nm thin stable oxide film is produced at the surface of n-GaP(100) photoanode via oxidizing the surface at 0.8 V vs RHE (reversible hydrogen electrode) and subsequent hydrogenation to passivate the electrically active defects in the oxide film. After appropriate surface-conditioning, PEC water splitting was observed at potentials between 0 and 0.3 V. After extended PEC treatment, AFM revealed a very flat surface, and no sign of corrosion were observed. XPS results indicate that the surface oxide consists mainly of Ga2O3, while small amounts of GaPO4, P2O5 and metal-like Ga are also present in the topmost layers.

HL 53.6 Fri 10:45 EW 202

Activating CO_2 for photocatalytic reduction at the semiconductor surface — •Veronika König, Peter Budweiser, Jacek Stolarczyk, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Department of Physics, Ludwig-Maximilians-Universität, Munich, Germany

In modern photocatalysis sunlight is used to convert water or carbon dioxide into solar fuels like molecular hydrogen or methane. Semiconductor materials thereby serve as the catalyst and reaction site. They absorb the sunlight, separate electron-hole pairs and transfer the charges to the respective molecules triggering electrochemical reactions that ultimately lead to the formation of the desired solar fuels.

Compared to water splitting CO_2 reduction is even more challenging due to the high stability of the CO_2 molecule. The reduction potential for the initial placement of an electron on the CO_2 is much more negative than the potential of the conduction band edges of most known semiconductor materials, making appropriate catalysts rare.

Copper (I) compounds such as Cu_2S have been found to be promising candidates for CO_2 reduction[1] and were shown by our group to produce CH_4 and CO[2]. Here, we use Cu_2O nanocrystals ranging from 10 to 100 nm in size in combination with ZnO for better charge separation. We investigate ways to increase the efficiency of photocatalytic CO_2 reduction by activation of the CO_2 molecule at the nanocrystal surface to lower the barrier for the initial one-electron reduction.

[1] Habisreutinger, S., et al. Angew. Chem. Int. Ed. 2013, 52, 7372
[2] Manzi, A., et al. J. Am. Chem. Soc. 2015, 137, 14007

HL 54: Organic semiconductors

Time: Friday 9:30–12:15 Location: EW 203

HL 54.1 Fri 9:30 EW 203

Molecular origin of the anisotropic orientation of molecules in organic light emitting diodes — •Pascal Friederich[1], Vadim Rodin[2], Florian von Wrochem[2], Reinder Coehoorn[3], and Wolfgang Wenzel[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Deutschland — [2]Sony, Stuttgart, Deutschland — [3]Technische Universität Eindhoven, Eindhoven, Niederlande

Molecular orientation anisotropy of the emitter molecules used in organic light emitting diodes (OLEDs) can give rise to an enhanced light-outcoupling efficiency, when their transition dipole moments are oriented preferentially parallel to the substrate. A similar effect is observed when the anisotropic orientation of molecules with electrostatic dipole moments leads to the spontaneous buildup of an electrostatic potential perpendicular to the substrate. This so-called giant surface potential (GSP) effect can as well be exploited in organic electronics applications. Here, the orientation anisotropy of widely used organic semiconductors is investigated using a simulation approach which mimics the physical vapor deposition process of amorphous thin films [1]. Our simulations reveal for all studied systems significant orientation anisotropy which is in agreement with experimental results for the emitter orientation as well as the GSP effect. We find that the electrostatic interaction between the dipole moments of the molecules limits the orientation strength while short range van der Waals interactions between molecules and the surface during deposition act as driving force for the anisotropic orientation. [1] P. Friederich, R. Coehoorn, W. Wenzel, Chem. Mater., 2017, 29 (21)

HL 54.2 Fri 9:45 EW 203

Investigation of charge transport in solution processed and vacuum-deposited organic semiconductors — •Deepthi K. Mangalore, Paul W. M. Blom, and Gert-Jan A.H. Wetzelaer — Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany

Organic light emitting diodes based on pi-conjugated polymers have been instrumental in revolutionizing the area of displays and lighting in the last decade. The immense opportunity presented by this technology has driven the research to find cheaper alternatives to the traditional deposition method of thermal evaporation. At the same time, the solubility of organic semiconductors in organic solvents enables film deposition from the solutions and the charge transport in these films has not been fully investigated. This work examines the transport in solution processed organic small molecule films and presents a comparison to the charge transport in vacuum-deposited films. Temperature-dependent space-charge-limited currents in single carrier devices of two hole transporting materials α-NPD and Spiro-TAD are used to investigate the transport properties in pristine and doped devices (dopants- F4TCNQ , F6TCNNQ). After optimizing the deposition conditions, comparable hole mobilities (4*10-8 m2V-1s-1 for Spiro-TAD and 0.8*10-8 m2V-1s-1 for α-NPD) were obtained in pristine solution-processed and vacuum-deposited films. In addition, the J-V characteristics were also analyzed with the extended Gaussian disorder model.

HL 54.3 Fri 10:00 EW 203

Core-Level Excitations in Oligothiophene Crystals from *Ab-Initio* Many-Body Theory — •Konstantin Lion, Caterina Cocchi, and Claudia Draxl — Physics Department and IRIS Adlershof, Humboldt-Universität zu Berlin D-12489 Berlin

We study core-level excitations in a series of linear crystalline oligothiophenes, i.e., bithiophene, quaterthiophene, and sexithiophene. Employing the full-potential all-electron `exciting` code [1], we compute X-ray absorption spectra from first principles through the solution of the Bethe-Salpeter equation, with a fully relativistic treatment of core states [2]. We investigate transitions from the carbon K, the sulfur K, and the sulfur $L_{2,3}$ edges. Our results, in very good agreement with available experimental data [3, 4], reveal the excitonic character of the near-edge resonances and allow us to resolve the individual contributions from inequivalent atoms. Core-level excitations in these systems exhibit strong excitonic effects, with electron-hole binding energies ranging from 3 to 2 eV, going from bithiophene to sexithiophene. Only in the spectrum from the carbon K edge, the individual contributions from inequivalent atoms show distinct features. Peaks in this spectrum are attributed to transitions from two types of carbon atoms, either sharing a covalent bond to a sulfur atom or not.

[1] A. Gulans *et al.*, J. Phys.: Condens. Matter **26**, 363202 (2014).
[2] C. Vorwerk *et al.*, Phys. Rev. B **26**, 155121 (2017).
[3] P. Väterlein *et al.*, Surf. Sci. **452**, 20 (2000).
[4] U. Hörmann *et al.*, J. Phys. Chem. C **118**, 26462 (2014).

HL 54.4 Fri 10:15 EW 203

Design of high mobility molecular organic semiconductors — Pascal Friederich[1], Franz Symalla[1], Velimir Meded[1], Vadim Rodin[2], Christian Sprau[1], Florian von Wrochem[2], Alexander Colsmann[1], Mario Ruben[1], and •Wolfgang Wenzel[1] — [1]Karlsruher Insitut für Technologie , Karlsruhe, Germany — [2]Sony Europe Ltd, Stuttgart, Germany

Small-molecule organic semiconductors are used in a wide spectrum of applications, ranging from organic light emitting diodes to organic photovoltaics. A number of factors determine mobility, such as molecular packing, electronic structure, dipole moment and polarizability. Presently, quantitative ab-initio models to assess the influence of these molecule-dependent properties, including the influence of dopants, are lacking. Here, we present a multi-scale model, which provides an accurate prediction of experimental data over ten orders of magnitude in mobility and demonstrate the de novo designg of a novel organic semicoduntor with improved mobility. The availability of first-principles based models to compute key performance characteristics of organic semiconductors may enable in-silico screening of numerous chemical compounds for the development of highly efficient opto-electronic devices.

HL 54.5 Fri 10:30 EW 203

High current density vertical electrolyte gated organic transistors — •Jakob Lenz[1] and Ralf Thomas Weitz[1,2] — [1]Physics of Nanosystems, Physics Department, Ludwig Maximilians Universität München — [2]NanoSystems Initiative Munich (NIM), Center for NanoScience (CeNS), Solar Technologies go Hybrid(SolTech)

In some areas of renewable energy high currents must be handled. For example, in the case of charging an electrical vehicle, currents of multiple Ampere need to be switched. Using conventional transistors for such a switching purpose is not an option since here typical current levels are in the muA to mA range. However, when utilizing a comparably novel concept, the so called vertical organic transistors (VOFETs), allows to reach current densities in the 1 A/cm^2 regime [1] where typically small molecules as semiconductor and conventional gating is utilized. Here, we show that using organic semiconducting polymers in combination with an ionic liquid even higher current densities up to 100 A/cm^2 can be realized.

[1] A. Fischer et al. Appl. Phys. Lett. 2012, 101, 213303

15 min. break.

HL 54.6 Fri 11:00 EW 203

Doping-induced Optimization of Organic Field Effect Transistors — •Marc-Michael Barf[1,2], Christian Willig[1,2,3], Robert Lovrincic[1,2], and Wolfgang Kowalsky[1,2,3] — [1]IHF, TU Braunschweig — [2]InnovationLab, Heidelberg — [3]KIP, Heidelberg University

Doping of organic semiconductors has become a common method to improve the efficiency of devices like organic light emitting diodes, organic solar cells and more recently also organic field effect transistors (OFETs). By increasing conductivity or creating space charge regions charge transport within such can be enhanced. Here, metal oxides are used to optimize charge carrier injection in p-type OFETs. Through the implementation of molybdenum oxide layers, it was possible to fabricate OFETs consisting of the polymer Poly[[(2,4-dimethylphenyl)imino]-1,4-phenylene(6,12-dihydro-6,6,12,12-tetraoctylindeno[1,2-b]fluorene-2,8-diyl)-1,4-phenylene] (PIF8-TAA) which are, to the best of our knowledge, the first of their kind that can be operated with silver contacts. This paves the way towards all-solution-processed devices. n-type OFETs were optimized using small molecules as dopants. The performance of OFETs consisting of the polymer Poly([N,N*-bis(2-octyldodecyl)-1,4,5,8-naphthalenedicarboximide-2,6-diyl]-alt-5,5*-(2,2*-bithiophene)) (N2200) could be improved significantly through a contact treatment with derivatives of 1,3-Dimethyl-2-phenyl-2,3-dihydro-1H-benzoimidazole (DMBI).

HL 54.7 Fri 11:15 EW 203

Three-dimensional photonic confinement in imprinted liquid crystalline pillar microcavities — •Marco Dusel[1], Simon Betzold[1], Sebastian Brodbeck[1], Stefanie Herbst[2], Frank Würthner[2], Daniel Friedrich[3], Bert Hecht[3], Christof P. Dietrich[1], and Sven Höfling[1,4] — [1]Technische Physik, Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institut für Organische Chemie and Center for Nanosystems Chemistry, Universität Würzburg — [3]Nano-Optics and Biophotonics Group, Universität Würzburg — [4]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Organic semiconductors are used as an active material in laser cavities for more than 50 years where they have shown great versatility and flexibility and furthermore enable measurements to be conducted at room temperature. The most common organic cavity design is given by sandwiching an organic material between two highly reflective mirrors. However, those planar microcavities suffer from photonic losses within the layer plane.

Alternatively, we demonstrate three-dimensional photonic confinement in a planar organic microcavity by using thermal imprint technology to structure pillars in an organic liquid crystal (LC) on top of a mirror. After structuring, we evaporate Au on top to form the cavity. The so-fabricated pillar microcavities achieve three-dimensional photonic confinement. Our developed process brings the investigation of optical phenomena in much more complicated photonic potentials such as coupled pillars, chains or lattices, into reach.

HL 54.8 Fri 11:30 EW 203

Tuneable Light-Matter Hybridization in Open Organic Microcavities — •Simon Betzold[1], Marco Dusel[1], Stefanie Herbst[2], Jürgen Ohmer[3], Utz Fischer[3], Aurelien A. P. Trichet[4], Jason M. Smith[4], Frank Würthner[2], Sven Höfling[1,5], and Christof P. Dietrich[1] — [1]Technische Physik, University of Würzburg, Germany — [2]Institut für Organische Chemie and Center for Nanosystems Chemistry, University of Würzburg, Germany — [3]Institut für Biochemie, University of Würzburg, Germany — [4]Department of Materials, University of Oxford, United Kingdom — [5]SUPA, School of Physics and Astronomy, University of St Andrews, United Kingdom

Strong interaction between excitons and photons, e.g. in a semiconductor microcavity, lead to the formation of hybrid light-matter quasiparticles called exciton-polaritons. Frenkel excitons, characteristic of organic semiconductors, possess large binding energies, making polariton experiments at ambient conditions possible. Organic materials further exhibit large oscillator strenghts and thus strongly interact with a cavity field. Open cavities are tunable systems rendering non-invasive investigation possible and allow independent control of the excitonic and the photonic part (e.g. mode detuning). Here, we demonstrate the versatility of open cavities and examine the strong exciton-photon coupling between different organic systems (J-aggregates, proteins) and the dielectric cavity for 2D (planar) and 0D (hemispherical) cavities. We further analyzed the transversal mode patterns of the emission of hemispherical cavities.

HL 54.9 Fri 11:45 EW 203

Fano resonance in hybrid nanostructures - result of exciton-surface plasmon polaritons coupling — •Xuan Trung Nguyen[1], Antonietta De Sio[1], James Lim[2], Alexandra Markovic[3], Julia Witt[3], Moritz Gittinger[1], Martin Silies[1], Gunther Wittstock[3], Susana Huelga[2], Martin Plenio[2], and Christoph Lienau[1] — [1]Institut für Physik, Universität Oldenburg, Germany — [2]Institut für Theoretische Physik and IQST, Universität Ulm, Germany — [3]Institut für Chemie, Universität Oldenburg, Germany

The coupling between excitons and surface plasmon polaritons in organic-metal hybrid nanostructures has been subject of many studies. Using broadband spectral interferometry, we observe that the linear optical spectrum of a J-aggregate cyanine dye transforms from a symmetric Lorentzian into an asymmetric Fano line shape in the presence of an ultrathin gold layer. Reconstruction of both amplitude and phase of the linear optical response function in the time domain allows us to determine the Fano asymmetry parameter q as a phase shift with respect to the Lorentzian response function. We show that, in the frequency domain, q results in a rotation of the optical response in the complex plane . We explain the formation of the Fano resonance as the result of coupling between the J-aggregate excitons and surface plasmon supported by the dielectric-metal interface and quantitatively extract the coupling strength. This introduces a new and straightforward technique for probing the interaction between plasmons and quantum emitters, also at the single nanoparticle level.

HL 54.10 Fri 12:00 EW 203

Ultrafast dynamics through a conical intersection in a donor-acceptor oligomer thin film — Ephraim Sommer[1], •Antonietta De Sio[1], Johannes Krantz[2], Elena Mena-Osteritz[2], Peter Bäuerle[2], and Christoph Lienau[1] — [1]Institut für Physik, Universität Oldenburg, Germany — [2]Institut für organische Chemie II und neue Materialien, Universität Ulm, Germany

Conical intersections (CoIns) arising from strong multimode vibronic coupling are a universal feature of molecular systems. They are predicted to play a key role for the ultrafast dynamics of ubiquitous processes such as charge transfer in donor-acceptor (D-A) systems. However, clear experimental signatures of nonadiabatic dynamics at CoIns are challenging to obtain. Here we use ultrafast two-dimensional electronic spectroscopy to track the initial dynamics in an A-D-A oligomer thin film used in efficient organic photovoltaics (OPV). Upon impulsive excitation, we observe a clear grid-like peak pattern suggesting coherent wavepacket motion in the excited state. After only 40 fs, this peak structure transforms into a broad, nearly featureless peak. The data show an increase of oscillation period and concurrent, abrupt amplitude drop of the optically excited wavepacket within 40 fs, followed by the appearance of a new wavepacket with different oscillation. These results cannot be described in a single mode vibronic coupling scenario, as recently reported for some polymers [1,2]. They instead show that the initial intramolecular charge separation in this OPV material is governed by strong multimode vibronic coupling via a CoIn. [1] Nature Commun. 7,13742(2016), [2] PCCP 19,18813(2017)

HL 55: Quantum dots and wires: Preparation and characterization

Time: Friday 9:30–12:45 Location: A 151

HL 55.1 Fri 9:30 A 151

MOVPE grown InGaAs Metamorphic Buffers for InAs Quantum Dots in the Telecom C-Band — •Robert Sittig, Matthias Paul, Fabian Olbrich, Susanne Schreier, Jonatan Höschele, Jan Kettler, 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, Allmandring 3, 70569 Stuttgart

For the application of semiconductor quantum dots (QDs) as non-classical light sources in communication networks, single-photon emission at 1.55 μm, corresponding to the glass fiber and atmospheric transmission window known as the telecom C-band, is vital. While the desired QD emission is achievable in the InAs/InP-system, the InP substrate quality and cost as well as the absence of an efficient binary distributed Bragg reflector structure prevents an application in the industrial scale. The starting point is our success in showing single-photon emission at 1.55 μm with resolution-limited linewidths and low fine-structure splitting from InAs QDs grown on an InGaAs metamorphic buffer (MMB). Nevertheless, the MMB quality can still be improved for the integration of the QDs in photonic nanostructures. With the goal to decrease the layer thickness and increase the interface/surface quality, different MMB-designs are studied via AFM, photoluminescence spectroscopy and X-ray diffractometry. The influence of varied grading profiles, annealing steps and total thickness on the formation of dislocations, lattice relaxation and surface texture is discussed.

HL 55.2 Fri 9:45 A 151

Transport Measurements on Single CdSe Nanowires during Cation Exchange — •Maximilian Schwarz, Christian Strelow, August Dorn, and Alf Mews — Institut für Physikalische Chemie, Universität Hamburg, Grindelallee 117, 20146 Hamburg, Germany

Cation Exchange proved to be a powerful tool for designing the composition of nanoparticles with a given shape. By using the anionic framework of a crystalline nanocrystal, cations can be exchanged topotaxial. Simple reaction routes can establish systems, which are unattainable by standard wet chemical synthesis. Here, we used CdSe Nanowires grown via the solution-liquid-solid (SLS) technique [1] directly on a substrate. The purpose was to get an insight into the reaction dynamics by monitoring the transport characteristics of single CdSe Nanowires during cation exchange to Ag2Se. Throughout the exchange reaction, the change in properties was traced non-invasive via spectroscopic and microscopic methods. We gratefully acknowledge financial support by the DFG via U-4-6-02-DFG-17-08.

[1] A. Dorn et al., Advanced Materials, 2009, 21 (34), pp 3479-3482

HL 55.3 Fri 10:00 A 151

Structural characterization of InGaAs/GaP quantum dots grown by MOVPE with varying growth interruptions — •Christopher Prohl[1], Andrea Lenz[1], Gernot Stracke[1], Udo W. Pohl[1], André Strittmatter[1,2], Dieter Bimberg[1], Mario Dähne[1], and Holger Eisele[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, 10623 Berlin — [2]Otto-von-Guericke Universität Magdeburg, Institut für Exp. Physik, 39106 Magdeburg

The monolithic integration of III-V based nanostructures onto Si is enabled by using GaP, with its particularly low lattice mismatch to Si. InGaAs/GaP quantum dots (QDs) are very promising for novel nanoflash memories. Furthermore, a first light emitting diode grown on a monolithic GaP/Si substrate was already demonstrated.

In this contribution, cross-sectional scanning tunneling microscopy (XSTM) was used to structurally analyze InGaAs/GaP QD layers on the atomic scale, grown by metalorganic vapor-phase epitaxy (MOVPE). As shown previously, the introduction of a GaAs interlayer prior to the InGaAs deposition favors the local concentration of indium and thereby the formation of indium-rich QDs. The growth interruption (GRI) after the $In_{0.5}Ga_{0.5}As$ deposition was varied, influencing the photoluminescence intensity. The XSTM analysis shows that depending on the duration of the GRI a structural redistribution of the QD layer occurs. This is characterized by a strong intermixing of the locally concentrated indium within the layer and leads to the

formation of a laterally more homogeneous quaternary InGaAsP layer. This work was supported by the DFG, SFB 787, TP A2 and A4.

HL 55.4 Fri 10:15 A 151

Axial Ga(As,Bi) insertions in GaAs nanowires grown by molecular beam epitaxy — •Miriam Oliva, Ryan B. Lewis, Guanhui Gao, Esperanza Luna, Manfred Ramsteiner, Chiara Sinito, Oliver Brandt, Uwe Jahn, and Lutz Geelhaar — Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5–7, 10117 Berlin

The Ga(As,Bi) semiconductor alloy is promising for infrared optoelectronics, allowing all bandgaps below that of GaAs to be reached in principle. Growth of Ga(As,Bi) by molecular beam epitaxy requires very low growth temperatures (220–330°C) and Ga-rich environments [R. B. Lewis et al.; Appl. Phys. Lett. **101**, 082112 (2012)]. These requirements often result in Ga droplets on the Ga(As,Bi) surface, which are detrimental for optoelectronic applications. Here we show that the Ga droplets atop Ga-assisted GaAs nanowires provide an ideal environment for the growth of Ga(As,Bi), and we develop a novel growth procedure to realize axial Ga(As,Bi) insertions in GaAs nanowires. First, we enrich the Ga droplets with Bi, resulting in a Bi/Ga-volume ratio of around 8. We then expose these droplets to an As_2 flux, precipitating a Ga(As,Bi) segment from the liquid droplet. Finally, excess Bi that did not incorporate into Ga(As,Bi) can be desorbed. We explore the dependence of the Bi content on the substrate temperature during growth. Transmission electron microscopy reveals uniform Ga(As,Bi) segments, with a Bi content of about 17% for segments formed at 300°C. These results open the door to infrared optoelectronic devices based on GaAs/Ga(As,Bi) axial nanowire heterostructures.

HL 55.5 Fri 10:30 A 151

Self-catalysed MBE-grown III-V nanowire arrays on Si(111) substrates — •Pujitha Perla[1,3], Dinesh Arumugam[1,3], Lidia Kibkalo[1,3], Patrick Zellekens[1,3], Torsten Rieger[1,3], Thomas Schäpers[1,3], Detlev Grützmacher[1,2,3], and Mihail Ion Lepsa[2,3] — [1]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich GmbH, 52425 Jülich, — [2]Peter Grünberg Institute (PGI-10), Forschungszentrum Jülich GmbH, 52425 Jülich — [3]JARA - Fundamentals of Future Information Technology

III-V semiconductor nanowires (NWs) are interesting for studying new quantum transport phenomena. The selective growth in arrays on Silicon (Si) substrates offer the advantages of growth parameter optimization and easier integration of the processed NW devices. Here we report on the self-catalysed growth of InAs and GaAs NW arrays by molecular beam epitaxy (MBE) on Si(111) substrates.

For the growth of the NW arrays,hole patterns have been processed by e-beam lithography,dry and wet chemical etching on SiO2 on Si(111) substrates. We have observed that the substrate preparation is critical, especially for the growth GaAs NWs. For the growth of InAs and GaAs NW arrays, vapour-solid and vapour-liquid-solid growth modes have been used respectively. The influence of Te-doping on the morphology of InAs NWs was studied as well. The growth results have been analysed for the yield and morphology of vertical NWs using scanning electron microscopy. These results further increase the scope for evaluation of the Te-doping of the InAs NWs and the growth of advanced core-shell NW arrays with Sb based shell materials.

HL 55.6 Fri 10:45 A 151

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). By modifying the growth conditions, it is possible to control the density. 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 $10^{10}\,cm^{-2}$. 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 achieve emission energies around 1.3 eV. The QDs have been analyzed by photoluminescence spectroscopy, atomic force microscopy and capacitance-voltage-spectroscopy. We will also discuss an alternative approach to realize low QD densities employing a subcritical InAs deposition and subsequent annealing.

15 min. break.

HL 55.7 Fri 11:15 A 151

Wet chemical etching of optical microstructures in gallium arsenide to enhance the extraction efficiency of InAs quantum dots — •Lena Engel, Marc Sartison, Sascha Kolatschek, Stefan Hepp, Simone 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

Semiconductor quantum dots (QDs) have proven to be well-defined, pure and efficient single-photon sources. They have shown to be promising candidates for various applications such as quantum communication or quantum computing. One prerequisite for these applications in free-space or fiber-based quantum information is high brightness. As the emitters are embedded in a semiconductor environment, the extraction efficiency is strongly limited. In contrast to narrow band cavity quantum electrodynamic systems like micro pillars or photonic crystal cavities, we investigate a broadband approach, introducing wet chemically etched hemispheric and Gaussian micro lenses precisely aligned on a single emitter. The QDs are optically pre-selected, marked via in-situ lithography and formed by a following wet chemical etching step. This wet chemical approach results in a superior surface quality, which enables us to perform quantum optical experiments on optically resonant excited QDs with enhanced extraction efficiency. According to FDTD simulations, hemispheric and Gaussian micro lens geometries also show promising enhancement factors.

HL 55.8 Fri 11:30 A 151

Epitaxial Growth and Characterization of low-density InGaAs Quantum Dots for Single-Photon Emission at 1300 nm — •Jan Grosse, Nicole Srocka, Tobias Heindel, and Stephan Reitzenstein — Technische Universität Berlin, Institute for Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany

Quantum dots are widely known as promising sources for single photons, which in turn enables a large variety of photonic applications from quantum cryptography to quantum computing. In(Ga)As/GaAs quantum dots grown by metal organic chemical vapour deposition (MOCVD) have been proven to emit single photons over a widely tuneable spectral range. Moreover they allow for a relatively easy monolithic integration in photonic cavities using lattice matched AlGaAs/GaAs DBR mirrors. Here we tackle the challenge to grow InGaAs quantum dots for single-photon emission at the telecom O-Band around 1300 nm. The spectral shift of the quantum dot emission wavelength is achieved by introducing a strain reducing InGaAs layer [1] with an indium content of approximately 25 % immediately after the growth of the quantum dot layer, tailored to yield a dot density of about $5 \times 10^7\ cm^{-2}$. We present micro-photoluminescence and atomic force measurements for the characterization of the quantum dots. Moreover, we show deterministic device integration and discuss preliminary results of optical characterization measurements.

[1] Bloch, J. et al. Appl. Phys. Lett. 75, 2199 (1999).

HL 55.9 Fri 11:45 A 151

Investigation of Bi induced three-dimensional InAs nanostructures on GaAs(110) by cross-sectional scanning tunnelling microscopy. — •Wjatscheslav Martyanov[1], Ryan B. Lewis[2], Hendrik Janssen[1], Celina S. Schulze[1], Pascal Farin[1], Andrea Lenz[1], Mario Dähne[1], Lutz Geelhaar[2], and Holger Eisele[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

While on GaAs(100) three-dimensional (3D) growth is preferred, on other low-index GaAs surfaces such as (110) and (111) the deposition always results in a two-dimensional growth. On the other hand, the growth of 3D nanostructures like quantum dots on these surfaces is of interest for high efficiency single photon sources. Latest investigations show that the presence of Bi as a surfactant induces the 3D growth on GaAs(110) by modifying the surface energy. In this contribution the Bi induced InAs-3D-island within InAs monolayers grown on GaAs(110) are investigated by cross-sectional scanning tunnelling microscopy (XSTM). The XSTM images allow the characterisation of these structures in terms of size, density, and atomic structure depending on Bi exposure time. In order to explore the influence of Bi, we

compare XSTM images of monolayers deposited without Bi, monolayers grown with simultaneous Bi flux and monolayers exposed Bi flux for different times after deposition. This work was supported by the CRC 787, Project A4.

HL 55.10 Fri 12:00 A 151

Quantum dot-microlenses for single-photon sources operating at telecom wavelength — •Nicole Srocka[1], Pawel Mrowinski[2], Lukasz Duanowski[2], Anna Musial[2], Grzegorz Sek[2], David Quandt[1], Andrei Strittmatter[1,3], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universiät 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 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 $900-950\,\mathrm{nm}$ [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].

References:

[1] M. Gschrey, A.Thoma *et al*, Nat. Commun., 6, 7662 (2015).
[2] L. Dusanowski, *et al*, Opt. Express., 25(25), 31122-31129 (2017).

HL 55.11 Fri 12:15 A 151

Macro-mechanics Controls Quantum Mechanics: Mechanically Controllable Quantum Conductance Switching of an Electrochemically Fabricated Atomic-scale Transistor — •Torben Staiger[1,2], Florian Wertz[1], Fangqing Xie[1], Marcel Heinze[1], Philipp Schmieder[1], Christian Lutzweiler[1], and Thomas Schimmel[1,2] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany

We present a silver atomic-scale device fabricated and operated by a combined technique of electrochemical control (EC) and mechanically controllable break junction (MCBJ). With this EC-MCBJ technique, we can perform mechanically controllable bistable quantum conductance switching of a silver quantum point contact (QPC) in an electrochemical environment at room temperature. In this way, the silver QPC of the atomic quantum transistor can be controlled both mechanically and electrochemically, and the operating modes can be changed from electrochemical to mechanical, which expands the possibilities for controlling QPCs.

HL 55.12 Fri 12:30 A 151

Investigation of Bi induced three-dimensional InAs nanostructures on GaAs(110) by cross-sectional scanning tunnelling microscopy. — •Wjatscheslav Martyanov[1], Ryan B. Lewis[2], Hendrik Janssen[1], Celina S. Schulze[1], Pascal Farin[1], Andrea Lenz[1], Mario Dähne[1], Lutz Geelhaar[2], and Holger Eisele[1] — [1]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Hausvogteiplatz 5-7, 10117 Berlin, Germany

While on GaAs(100) three-dimensional (3D) growth of InAs is preferred, on other low-index GaAs surfaces such as (110) and (111) the deposition always results in a two-dimensional growth. On the other hand, the growth of 3D nanostructures like quantum dots on these surfaces is of interest for high efficiency single photon sources. Recent investigations show that the presence of Bi as a surfactant induces 3D growth on GaAs(110) by modifying the surface energy. In this contribution Bi induced InAs 3D islands formed within InAs monolayers on GaAs(110) are investigated by cross-sectional scanning tunneling microscopy (XSTM). The XSTM images allow the characterization of these structures in terms of size, density, and atomic structure depending on Bi exposure time. In order to explore the influence of Bi, we compare XSTM images of InAs monolayers deposited both with and without the presence of a Bi flux, and InAs monolayers subsequently exposed to Bi for different durations. This work was supported by the DFG, SFB 787, Project A4.

HL 56: New materials and concepts

Time: Friday 11:15–12:30 Location: EW 202

HL 56.1 Fri 11:15 EW 202

Characterization of dip coated tungsten sulfide flakes — •Talha Nisar, Torsten Balster, and Veit Wagner — Jacobs University Bremen gGmbH, Campus Ring 1, 28759 Bremen, Germany

WS_2 is a promising material for future electronics due to its 2 dimensional nature. In our approach we use growth on liquid surface as an alternative deposition method to atomic layer deposition and chemical vapor deposition to grow tungsten sulfide flakes. For this purpose, ammonium tetrathiotungstate (ATTW) is used as precursor material in a 5 mM aqueous solution. No flakes are formed while at room temperature, formation of flakes at the liquid-air interface is observed after heating the solution at $80°C$ for an hour. Flakes with sizes up to 50 μm are transferred onto a silicon substrate by dip-coating. A post annealing step is done at $800°C$ in a quartz tube applying a constant flow of forming gas (95% Ar/5% H_2) with additional sulfur source. Chemical characterization of the flakes by mean of x-ray photoelectron spectroscopy (XPS) reveal that the flakes initially consist out of WO_2 and ATTW. Post growth annealing converted this layer to WS_2. High crystallinity of the flakes is proved by Raman measurements.

HL 56.2 Fri 11:30 EW 202

Nanoporous Alumina Membranes as Promising Platforms for Rationally Designing Supercapacitor Electrodes — •Huaping Zhao, Long Liu, Yaoguo Fang, and Yong Lei — Institut für Physik & IMN MacroNano (ZIK), Technische Universität Ilmenau, 98693, Ilmenau, Germany

Supercapacitors present growing significance as the advanced energy storage devices to bridge the gap between batteries and conventional capacitors owing to the high power density, the fast charge-discharge rate, and the excellent cycle stability. In addition to the electroactive materials themselves, the design of electrode architectures also plays an important role in determining the charge storage capability and rate capability of supercapacitors. A promising supercapacitor electrode therefore should have larger specific area to realize high charge storage capability meanwhile should provide shorter ion diffusion path and lower electron transfer resistance to enable the achievement of high rate capability. Here, we demonstrate nanoporous alumina membranes as promising platforms for rationally designing supercapacitor nanoelectrodes. By employing nanoporous alumina membranes as nanostructuring templates, supercapacitor electrodes in the forms of arrayed nanorod, nanotube, and nanopore have been designed and fabricated. These as-prepared supercapacitor electrodes have large specific surface area ensuring high capacitance and highly-oriented structure facilitating ion transport, thus high charge storage capability and high rate capability of supercapacitor were achieved simultaneously.

HL 56.3 Fri 11:45 EW 202

Properties of a novel cubic phase in the monochalcogenides — Elad Segev, Ran Eitan Abutbul, Uri Argaman, Yuval Golan, and •Guy Makov — Materials Dept, Ben-Gurion University of the Negev, Beer Sheva, Israel

A new nanometric cubic binary phase has been synthesised in the tin mono-selenide and monosulfide systems, π-SnSe, π-SnS, as cube shaped nanoparticles. This new phase has promising optical properties due to the larger bandgap and non-centrosymmetric structure of the crystal. The structure, atomic positions and band gaps of these phases were determined by ab-initio density functional calculations and found to be in very good agreement with experimental measurements. The phases were determined to be mechanically stable and energetically

close to competing structures such as rocksalt and orthorhombic. Density functional calculations have been extended to study the stability of the new phase in other monochalcogenides systems and new phases are predicted. This talk will focus on the results of our calculations and comparison with experimental studies available. [1] E. Segev et al., A new cubic prototype structure in the IV-VI monochalcogenide system: a DFT study, CrystEngComm. 19 (2017) 1751. [2] R.E. Abutbul et al., Synthesis and Properties of Nanocrystalline π-SnS * A New Cubic Phase of Tin Sulphide, RSC Adv. 6 (2016) 5848. [3] R.E. Abutbul et al., A new nanocrystalline binary phase: Synthesis and properties of cubic tin monoselenide, CrystEngComm. 18 (2016). [4] U. Argaman et al., Prediction of the stability of the rhombohedral phase in IV-VI monochalcogenides and its origin, CrystEngComm. 19 (2017) 6107.

HL 56.4 Fri 12:00 EW 202

Strong Anharmonic and Quantum-Nuclear Effects in the Low Temperature Dyamics of CsCl — •Hagen-Henrik Kowalski, Matthias Scheffler, and Christian Carbogno — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin

In solid-state theory, the *quasi-harmonic* approximation is generally expected to hold for the description of the nuclear dynamics in crystals at temperatures $\ll$ 300 K. However, a recent experimental study [1] of single crystalline CsCl reveals that its thermal conductivity is comparable to those of amorphous materials ($\sim$ 1 W/mK). Strong anharmonic effects hence appear to be active even at 50 K, a temperature at which the quantum-statistics for the nuclei is not negligible ($C_V < 65\%$ of the Dulong-Petit value). Using first-principles calculations, we investigate the nature of these effects by performing fully anharmonic molecular dynamics with *classical* nuclei (MD) and path-integral MD simulations with *quantum* nuclei. The comparison with respective *quasi-harmonic* calculations confirms that pronounced quantum-nuclear and anharmonic effects are active in this material and reveals how the respective mechanisms couple. Eventually, we discuss how these effects can affect simulations of the thermal conductivity [2] and the resulting implications for simulations across material space.

[1] M. Sist, *et al.*, *Ang. Chemie* **56**, 3625 (2017).
[2] C. Carbogno, R. Ramprasad, and M. Scheffler, *Phys. Rev. Lett.* **118**, 175901, (2017).

HL 56.5 Fri 12:15 EW 202

Scanning tunneling microscopy study of an excitonic insulator candidate — •Xinglu Que[1,2], Lihui Zhou[1], Qingyu He[1,2], Tomohiro Takayama[1,2], Andreas Rost[1,2], and Hidenori Takagi[1,2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany

An excitonic insulator is resulted from strong electron-hole coupling as compared to the single electron energy gap of a semiconductor or semimetal, where new exotic electronic phases have theoretically been predicted to emerge. I present our study of an excitonic insulator candidate by scanning tunneling microscopy. The surface topography as well as the electronic structure was investigated at different temperatures in ultrahigh vacuum. Our atomic resolution studies revealed a strong correlation of its electronic properties with the structure, laying the ground out for further study on physics of excitonic insulators.