Semiconductor Physics Division
Fachverband Halbleiterphysik (HL)

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Overview of Invited Talks and Sessions

(Lecture halls H31, H32, H33, H34, and H36; Poster P2 and P2)

Invited Talks

HL 2.1	Mon	9:30–10:00	H31	**Observation of quantum Zeno effects for localized spins** — •Alex Greilich, Nikita V. Leppenen, Vitalie Nedelea, Eiko Evers, Dmitry S. Smirnov, Manfred Bayer
HL 3.1	Mon	9:30–10:00	H32	**Pushing the limits in real-time meeasurements of quantum dynamics** — •Eric Kleinherbers, Philipp Stegmann, Annika Kurzmann, Martin Geller, Axel Lorke, Jürgen König
HL 6.1	Mon	9:30–10:00	H36	**g-factors in van der Waals heterostructures: revealing signatures of interlayer coupling** — •Paulo E. Faria Junior
HL 8.1	Mon	15:00–15:30	H32	**Crux of Using the Cascaded Emission of a Three-Level Quantum Ladder System to Generate Indistinguishable Photons** — •Eva Schöll, Lucas Schweickert, Lukas Hanschke, Katharina D. Zeuner, Friedrich Sbresny, Thomas Lettner, Rahul Trivedi, Marcus Reindl, Saimon Filipe Covre da Silva, Rinaldo Trotta, Jonathan Finley, Jelena Vučković, Kai Müller, Armando Rastelli, Val Zwiller, Klaus D. Jöns
HL 9.1	Mon	15:00–15:30	H33	**Exceptional points in optics: From bulk materials to one-dimensional confined systems** — •Chris Sturm
HL 9.2	Mon	15:30–16:00	H33	**Complex Skin Modes in Non-Hermitian Coupled Laser Arrays** — •Mercedeh Khajavikhan, Yuzhou Liu
HL 9.3	Mon	16:15–16:45	H33	**Non-Hermitian effects in exciton polaritons** — •Eliezer Estrecho
HL 9.4	Mon	16:45–17:15	H33	**Nonlinear dynamics and exceptional points in exciton-polariton condensates** — •Stefan Schumacher
HL 12.1	Tue	9:30–10:00	H32	**Wafer-Scale Epitaxial Modulation of Quantum Dot Densitiy** — •Nikolai Bart, Christian Dangel, Peter Zajac, Nikolai Spitzer, Marcel Schmidt, Kai Müller, Andreas D. Wieck, Jonathan Finley, Arne Ludwig
HL 14.1	Tue	9:30–10:00	H34	**Materials and Device Engineering for Gallium Oxide-based Electronics** — Nidhin Kurian Kalarickal, Sushovan Dhara, Ashok Dheenan, •Siddharth Rajan
HL 14.2	Tue	10:00–10:30	H34	**Ferroelectric two-dimensional electron gases for oxide spin-orbitronics** — •Julien Bréhin
HL 14.8	Tue	12:15–12:45	H34	**Strain-driven dissociation of water on (incipient) ferroelectrics** — Joshua L. Bates, •Chiara Gattinoni
HL 15.1	Tue	9:30–10:00	H36	**Ultrafast all-optical modulation and frequency conversion in 2D materials** — •Sebastian Klimmer, Artem Sinelnik, Isabelle Staude, Giancarlo Soavi
HL 19.1	Wed	9:30–10:00	H34	**Quantum Interference of Identical Photons from Remote GaAs Quantum Dots** — •Giang Nam Nguyen, Liang Zhai, Clemens Spinnler, Julian Ritzmann, Mattias C. Löbl, Andreas D. Wieck, Arne Ludwig, Alisa Javadi, Richard J. Warburton
HL 27.1	Thu	9:30–10:00	H33	**What limits state-of-the-art chalcopyrite solar cells?** — •Susanne Siebentritt
HL 27.2	Thu	10:00–10:30	H33	**Approaches to improve CIGS absorber quality and the CIGS/buffer interface to reach 24% efficiency and beyond** — •Wolfram Witte

HL 33.6	Thu	16:30–17:00	H32	**Ultrastrong light-matter coupling in materials** — •Niclas S. Mueller, Eduardo B. Barros, Florian Schulz, Holger Lange, Stephanie Reich
HL 34.1	Thu	15:00–15:30	H33	**Super-high efficiency CIGS devices: current status and pathways forward** — •Romain Carron
HL 34.2	Thu	15:30–16:00	H33	**Highlights from the development of the world record Cd-free CIGSSe 30x30cm2 solar module** — •Anastasia Zelenina
HL 34.5	Thu	17:00–17:30	H33	**Digital Twins - a simulation model for Cu(In,Ga)Se2 solar cells of high and moderate efficiency** — •Matthias Maiberg, Chang-Yun Song, Marcin Morawski, Felix Neduck, Joshua Damm, Heiko Kempa, Dimitrios Harisko, Wolfram Witte, Roland Scheer
HL 40.5	Fri	10:45–11:15	H33	**Ultrafast subcycle dynamics of deep-strong light-matter coupling** — •Joshua Mornhinweg, Maike Halbhuber, Laura Diebel, Viola Zeller, Josef Riepl, Cristiano Ciuti, Dominique Bougeard, Rupert Huber, Christoph Lange

Invited Talks of the joint Symposium Frontiers of Orbital Physics: Statics, Dynamics, and Transport of Orbital Angular Momentum (SYOP)

See SYOP for the full program of the symposium.

SYOP 1.1	Mon	9:30–10:00	H1	**Orbital degeneracy in transition metal compounds: Jahn-Teller effect, spin-orbit coupling and quantum effects** — •Daniel Khomskii
SYOP 1.2	Mon	10:00–10:30	H1	**Orbital magnetism out of equilibrium: driving orbital motion with fluctuations, fields and currents** — •Yuriy Mokrousov
SYOP 1.3	Mon	10:30–11:00	H1	**Orbitronics: new torques and magnetoresistance effects** — •Mathias Kläui
SYOP 1.4	Mon	11:15–11:45	H1	**Orbital and total angular momenta dichroism of the THz vortex beams at the antiferromagnetic resonances** — •Andrei Sirenko
SYOP 1.5	Mon	11:45–12:15	H1	**Observation of the orbital Hall effect in a light metal Ti** — •Gyung-Min Choi

Invited Talks of the joint Symposium SKM Dissertation Prize 2022 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	10:15–10:45	H2	**Charge localisation in halide perovskites from bulk to nano for efficient optoelectronic applications** — •Sascha Feldmann
SYSD 1.2	Mon	10:45–11:15	H2	**Nonequilibrium Transport and Dynamics in Conventional and Topological Superconducting Junctions** — •Raffael L. Klees
SYSD 1.3	Mon	11:15–11:45	H2	**Probing magnetostatic and magnetotransport properties of the antiferromagnetic iron oxide hematite** — •Andrew Ross
SYSD 1.4	Mon	11:45–12:15	H2	**Quantum dot optomechanics with surface acoustic waves** — •Matthias Weiss

Invited Talks of the joint Symposium From Physics and Big Data to the Design of Novel Materials (SYNM)

See SYNM for the full program of the symposium.

SYNM 1.1	Mon	15:00–15:30	H1	**How to tackle the "I" in FAIR?** — •Claudia Draxl
SYNM 1.2	Mon	15:30–16:00	H1	**Beyond the average error: machine learning for the discovery of novel materials** — •Mario Boley, Simon Teshuva, Felix Luong, Lucas Foppa, Matthias Scheffler
SYNM 1.3	Mon	16:00–16:30	H1	**The Phase Diagram of All Inorganic Materials** — •Chris Wolverton
SYNM 1.4	Mon	16:45–17:15	H1	**Automated data-driven upscaling of transport properties in materials** — •Danny Perez, Thomas Swinburne
SYNM 1.5	Mon	17:15–17:45	H1	**Data-driven understanding of concentrated electrolytes** — •Alpha Lee

Invited Talks of the joint Symposium High Yield Devices for Photonic Quantum Implementations (SYPQ)

See SYPQ for the full program of the symposium.

SYPQ 1.1	Tue	9:30–10:00	H1	**Designing driving protocols for high-fidelity quantum devices using numerically exact predictions** — •Moritz Cygorek, Erik M. Gauger
SYPQ 1.2	Tue	10:00–10:30	H1	**Challenges towards high efficiency quantum dot single photon sources** — •Arne Ludwig
SYPQ 1.3	Tue	10:30–11:00	H1	**Organic Molecules in photonic quantum technologies** — •Costanza Toninelli
SYPQ 1.4	Tue	11:15–11:45	H1	**Quantum-dot single-photon sources for quantum photonic networks** — •Peter Michler
SYPQ 1.5	Tue	11:45–12:15	H1	**Quantum light sources: entanglement generation in semiconductor nanostructures** — •Ana Predojevic

Invited Talks of the joint Symposium Entanglement Distribution in Quantum Networks (SYED)

See SYED for the full program of the symposium.

SYED 1.1	Wed	9:30–10:00	H1	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson
SYED 1.2	Wed	10:00–10:30	H1	**Quantum key distribution with highly entangled photons from GaAs quantum dots** — •Armando Rastelli, Santanu Manna, Saimon Covre da Silva, Gabriel Undeutsch, Christian Schimpf
SYED 1.3	Wed	10:30–11:00	H1	**Entanglement distribution with minimal memory requirements using time-bin photonic qudits** — •Johannes Borregaard
SYED 1.4	Wed	11:15–11:45	H1	**Quantum photonics: interference beyond HOM and quantum networks** — •Stefanie Barz
SYED 1.5	Wed	11:45–12:15	H1	**Photonic cluster-state generation for memory-free quantum repeaters** — •Tobias Huber

Invited Talks of the joint Symposium United Kingdom as Guest of Honor (SYUK)

See SYUK for the full program of the symposium.

SYUK 1.1	Wed	9:30–10:00	H2	**Structure and Dynamics of Interfacial Water** — •Angelos Michaelides
SYUK 1.2	Wed	10:00–10:30	H2	**A molecular view of the water interface** — •Mischa Bonn
SYUK 1.3	Wed	10:30–11:00	H2	**Motile cilia waves: creating and responding to flow** — •Pietro Cicuta
SYUK 1.4	Wed	11:00–11:30	H2	**Cilia and flagella: Building blocks of life and a physicist's playground** — •Oliver Bäumchen
SYUK 1.5	Wed	11:45–12:15	H2	**Computational modelling of the physics of rare earth - transition metal permanent magnets from $SmCo_5$ to $Nd_2Fe_{14}B$** — •Julie Staunton
SYUK 2.1	Wed	15:00–15:30	H2	**Hysteresis Design of Magnetic Materials for Efficient Energy Conversion** — •Oliver Gutfleisch
SYUK 2.2	Wed	15:30–16:00	H2	**Non-equilibrium dynamics of many-body quantum systems versus quantum technologies** — •Irene D'Amico
SYUK 2.3	Wed	16:00–16:30	H2	**Quantum computing with trapped ions** — •Ferdinand Schmidt-Kaler
SYUK 2.4	Wed	16:45–17:15	H2	**Breaking the millikelvin barrier in cooling nanoelectronic devices** — •Richard Haley
SYUK 2.5	Wed	17:15–17:45	H2	**Superconducting Quantum Interference Devices for applications at mK temperatures** — •Sebastian Kempf

Invited Talks of the joint Symposium Complexity and Topology in Quantum Matter (SYQM)

See SYQM for the full program of the symposium.

SYQM 1.1	Fri	9:30–10:00	H1	**The role of crystalline symmetries in topological materials: the topological materials database** — •Maia Vergniory
SYQM 1.2	Fri	10:00–10:30	H1	**Microwave Bulk and Edge Transport in HgTe-Based 2D Topological Insulators** — •Erwann Bocquillon, Matthieu C. Dartiailh, Alexandre Gourmelon, Hiroshi Kamata, Kalle Bendias, Simon Hartinger, Jean-Marc Berroir, Gwendal Fève, Bernard Plaçais, Lukas Lunczer, Raimund Schlereth, Hartmut Buhmann, Laurens Molenkamp
SYQM 1.3	Fri	10:30–11:00	H1	**Spectral Sensitivity of Non-Hermitian Topological Systems** — •Jan Carl Budich
SYQM 1.4	Fri	11:15–11:45	H1	**Topological photonics and topological lasers with coupled vertical resonators** — •Sebastian Klembt
SYQM 1.5	Fri	11:45–12:15	H1	**Spectroscopic Studies of the Topological Magnon Band Structure in a Skyrmion Lattice** — •Markus Garst

Sessions

HL 1.1–1.4	Sun	16:00–18:20	H2	**Tutorial: 2D Quantum Materials and Heterostructures: From Fabrication to Applications (joint session HL/TUT)**
HL 2.1–2.5	Mon	9:30–11:00	H31	**Spin Phenomena in Semiconductors**
HL 3.1–3.11	Mon	9:30–13:00	H32	**Quantum Dots and Wires 1: Transport and Electronic Properties**
HL 4.1–4.11	Mon	9:30–12:45	H33	**Semiconductor Lasers**
HL 5.1–5.11	Mon	9:30–12:45	H34	**Perovskite and Photovoltaics 1 (joint session HL/CPP/KFM)**
HL 6.1–6.10	Mon	9:30–12:45	H36	**2D Materials 1 (joint session HL/CPP/DS)**
HL 7.1–7.10	Mon	15:00–18:00	H31	**(Quantum) Transport Properties**
HL 8.1–8.10	Mon	15:00–18:15	H32	**Quantum Dots and Wires 2: Optics 1**
HL 9.1–9.5	Mon	15:00–17:30	H33	**Focus Session: Exceptional Points and Non-Hermitian Physics in Semiconductor Systems**
HL 10.1–10.13	Mon	15:00–18:30	H34	**Nitrides**
HL 11.1–11.12	Mon	15:00–18:30	H36	**2D Materials 2 (joint session HL/CPP/DS)**
HL 12.1–12.10	Tue	9:30–12:45	H32	**Quantum Dots and Wires 3: Growth**
HL 13.1–13.10	Tue	9:30–12:15	H33	**Ultra-Fast Phenomena**
HL 14.1–14.8	Tue	9:30–12:45	H34	**Focus Session: Quantum Properties at Functional Oxide Interfaces (joint session HL/DS)**
HL 15.1–15.8	Tue	9:30–12:00	H36	**2D Materials 3 (joint session HL/CPP/DS)**
HL 16.1–16.4	Wed	9:30–11:00	H17	**Focus Session: Quantum Properties at Functional Oxide Interfaces (joint session DS/HL)**
HL 17.1–17.10	Wed	9:30–12:30	H32	**Quantum Dots and Wires 4: Devices**
HL 18.1–18.11	Wed	9:30–12:30	H33	**Oxide Semiconductors (joint session HL/KFM)**
HL 19.1–19.11	Wed	9:30–13:00	H34	**Materials and Devices for Quantum Technology 1**
HL 20.1–20.9	Wed	9:30–12:00	H36	**2D Materials 4 (joint session HL/CPP/DS)**
HL 21.1–21.12	Wed	15:00–18:30	H32	**Optical Properties 1**
HL 22.1–22.10	Wed	15:00–18:00	H33	**Heterostructures, Interfaces and Surfaces**
HL 23.1–23.11	Wed	15:00–18:15	H34	**Perovskite and Photovoltaics 2 (joint session HL/CPP/KFM)**
HL 24.1–24.12	Wed	15:00–18:30	H36	**Functional Semiconductors for Renewable Energy Solutions (joint session HL/KFM)**
HL 25.1–25.98	Wed	18:00–20:00	P2	**Poster 1**
HL 26.1–26.11	Thu	9:30–12:45	H32	**Quantum Dots and Wires 5: Optics 2**
HL 27.1–27.4	Thu	9:30–11:00	H33	**Focus Session: Perspectives in Cu(In,Ga)Se 1**
HL 28.1–28.8	Thu	9:30–11:45	H34	**Organic Semiconductors 1**
HL 29.1–29.6	Thu	9:30–11:00	H36	**2D Materials: Graphene**
HL 30.1–30.51	Thu	11:00–13:00	P3	**Poster 2**
HL 31.1–31.4	Thu	11:15–12:15	H36	**2D Materials 5 (joint session HL/CPP/DS)**
HL 32.1–32.6	Thu	15:00–16:30	H31	**Perovskite and Photovoltaics 3 (joint session HL/CPP/KFM)**
HL 33.1–33.10	Thu	15:00–18:00	H32	**Optical Properties 2**
HL 34.1–34.7	Thu	15:00–18:00	H33	**Focus Session: Perspectives in Cu(In,Ga)Se 2**
HL 35.1–35.4	Thu	15:00–16:00	H34	**Acoustic Waves and Nanomechanics**
HL 36.1–36.10	Thu	15:00–17:45	H36	**Materials and Devices for Quantum Technology 2**
HL 37.1–37.3	Thu	16:30–17:15	H34	**Thermal Properties**

HL 38	Thu	18:00–19:00	H34	**Members' Assembly**
HL 39.1–39.5	Fri	9:30–10:45	H32	**Quantum Dots and Wires 6: II-VI and related**
HL 40.1–40.7	Fri	9:30–11:45	H33	**THz and MIR Physics in Semiconductors**
HL 41.1–41.5	Fri	9:30–10:45	H34	**Organic Semiconductors 2**
HL 42.1–42.9	Fri	9:30–12:00	H36	**2D Materials 6 (joint session HL/CPP/DS)**

Members' Assembly of the Semiconductor Physics Division

Donnerstag 18:00–19:00 H34

- Bericht
- Informationen zu Dresden 2023
- Verschiedenes

HL 1: Tutorial: 2D Quantum Materials and Heterostructures: From Fabrication to Applications (joint session HL/TUT)

Due to the atomic thickness of 2D materials, stacking of different monolayers has opened the door for artificial van der Waals heterostructures. By exploiting the strongly different nature of the individual layers (semiconducting, metallic, magnetic, superconducting, etc.) and rotating them from layer to layer, heterostructures with unique physical properties and functionalities can be envisioned for novel electronic or optical devices. The tutorial will cover the fabrication of these heterostructures and their potential use in applications ranging from electronic to optical devices, operating at the quantum level.

Time: Sunday 16:00–18:20 Location: H2

Tutorial HL 1.1 Sun 16:00 H2

Discovering, Creating, and Exploring Novel Atomically-Thin Materials and Heterostructures — •Joshua Robinson — The Pennsylvania State University, University Park, PA, USA

The last decade has seen an exponential growth in the science and technology of two-dimensional materials. Beyond graphene, there is a huge variety of layered materials that range in properties from insulating to superconducting. Furthermore, heterogeneous stacking of 2D materials also allows for additional dimensionality for band structure engineering. In this talk, I will discuss recent breakthroughs in two-dimensional atomic layer synthesis and properties, including novel 2D heterostructures and realization of unique 2D allotropes of 3D materials (e.g. 2D metals and oxides). Our recent works demonstrate that the properties and doping of 2D materials, especially synthetic 2D materials, are extremely sensitive to the substrate choice. I will discuss substrate impact on 2D layer growth and properties, doping of 2D materials, selective area synthesis of 2D materials, and creating 2D allotropes from traditionally 3D materials for photonic and quantum applications. Our work and the work of our collaborators has lead to a better understanding of how substrate not only impacts 2D crystal quality, but also doping efficiency in 2D materials, and stabilization of 3D materials at their quantum limit.

Tutorial HL 1.2 Sun 16:35 H2

Non-identical moire twins in bilayer graphene — •Rebeca Ribeiro-Palau[1], Everton Arrighi[1], Viet-Hung Nguyen[2], Mario Di Luca[1], Gaia Maffione[1], Kenji Watanabe[3], Takashi Taniguchi[3], Dominique Mailly[1], and Jean-Christophe Charlier[2] — [1]Universite Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies (C2N), 91120 Palaiseau, France — [2]Institute of Condensed Matter and Nanosciences, Universite catholique de Louvain (UCLouvain), 1348 Louvain-la-Neuve, Belgium — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba, Japan

I will present recent results which demonstrate that the moire superlattice formed by a bilayer graphene aligned with BN, is present every 60 deg, but the symmetry is broken between the 0 deg and 60 deg alignments, creating non-identical "moire twins" with different electronic properties. In particular, electron transport measurements display a fully developed valley Hall effect at 0 deg while on the contrary, it is completely absent at 60 deg. We explain this effect by performing numerical simulations, which highlight the central role of the atomic-scale structural relaxation of the second graphene layer. This in-plane atomic relaxation, different for the two alignments, impacts on the electronic band structure of our system. Our results demonstrate that in situ control of the rotational order provides a unique insight on the interplay between mechanical and electronic properties, and increases the posibilities for band-structure engineering on van der Waals heterostructures.

Tutorial HL 1.3 Sun 17:10 H2

Single-photon emitters in 2D materials — •Steffen Michaelis de Vasconcellos — University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Single-photon sources are key components for quantum technologies, such as communications, cryptography, computation, and metrology. Recently, the family of solid-state quantum light emitters was joined by single-photon sources in atomically thin materials [1]. Compared to 3D bulk materials, the 2D host crystals with their high structural flexibility allow for a high photon extraction efficiency, new methods for the deterministic creation, and convenient integration with photonic circuits.

In this tutorial, I will introduce the basic properties of single-photon emitters in different 2D van der Waals material systems and discuss present experimental methods for their creation, control, and coupling to photonic nanostructures.

[1] S. Michaelis de Vasconcellos et al., "Single-Photon Emitters in Layered Van der Waals Materials," Phys. Status Solidi B **2022**, 259, 2100566

Tutorial HL 1.4 Sun 17:45 H2

Introduction to 2D superconducting spintronics — •Elke Scheer — Department of Physics, University of Konstanz, Konstanz

The proximity effect between a conventional (s-wave) 3D superconductor (S) and a ferromagnet (F) can lead to the formation of Cooper pairs with parallel-spin (spin-triplet) alignment instead of the conventional antiparallel-spin (spin-singlet) state. The demonstration of spin-triplet generation in S/F systems [1,2] has inaugurated the field of superconducting spintronics aiming at developing energy-efficient spintronic devices [3]. Both superconductivity and ferromagnetism depend on the dimensionality of the system, but have been shown to exist in 2D or quasi-2D systems [4,5]. The possibility to exfoliate layered van der Waals (vdW) materials down to the few-layer limit [6] in combination with the existence of S and of F vdW materials makes this material basis in particular promising to explore triplet S in 2DS/2DF heterostructures. In this tutorial talk I will briefly recall the physics of SF spintronics in 3D, before I will describe the particular properties and challenges in the investigation of 2D-SF hybrid systems and give an overview over the so far best-studied material combinations and target devices.

[1] R. Keizer et al., Nature 95, 825 (2006)
[2] A. Buzdin, Rev. Mod. Phys. 77, 935 (2005)
[3] J. Linder & J. Robinson, Nature Phys. 11, 307 (2015)
[4] B. Huang et al., Nature 546, 270 (2017)
[5] M. Smidman et al., Rep. Prog. Phys. 80, 036501 (2017)
[6] A. K. Geim & I. V. Grigorieva, Nature 499, 419 (2013).

HL 2: Spin Phenomena in Semiconductors

Time: Monday 9:30–11:00 Location: H31

Invited Talk HL 2.1 Mon 9:30 H31

Observation of quantum Zeno effects for localized spins — •Alex Greilich[1], Nikita V. Leppenen[2], Vitalie Nedelea[1], Eiko Evers[1], Dmitry S. Smirnov[2], and Manfred Bayer[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany — [2]St. Petersburg, Russia

One of the main dephasing mechanisms for the localized carrier spins in semiconductors is the coupling to the fluctuating nuclear spin environment. Here we present an experimental observation on the effects of the quantum back action under pulsed optical measurements and demonstrate that the nuclei-induced spin relaxation can be influenced. We show that the fast measurements freeze the spin dynamics and increase the effective spin relaxation time, the so-called quantum Zeno effect. Furthermore, we demonstrate that if the measurement rate is comparable with the spin precession frequency in the effective magnetic field, the spin relaxation rate increases and becomes faster than in the absence of the measurements, an effect known as the quantum anti-Zeno effect.

HL 2.2 Mon 10:00 H31

Interplay of spin-orbit coupling and spin diffusion on spin helices lifetime in GaAs quantum wells — •Sergiu Anghel[1], Karl Schiller[1], Go Yusa[2,3], Takaaki Mano[4], Takeshi Noda[4], and Markus Betz[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, Otto-Hahn-Straße 4a, D-44227 Dortmund — [2]Department of Physics, Tohoku University, Sendai 980-8578, Japan — [3]Center for Spintronics Research Network, Tohoku University, Sendai 980-8578, Japan — [4]National Institute for Materials Science, Tsukuba, Ibaraki 305-0047, Japan

This work reveals the dependence of the persistent spin helix (PSH) lifetime on spin diffusion coefficient and the electron density, by employing time-resolved magneto-optical Kerr effect microscopy to study the spin polarization evolution in low-dimensional GaAs QWs. It is shown that for the achieving the longest PSH lifetime, the variation of scattering rate with the electron density is of higher importance than the fulfilling of the persistent spin helix condition when the Rashba α and Dresselhaus β parameters are balanced (suppression of D'yakanov-Perel spin dephasing mechanism). More specifically, the PSH relaxation rate is determined mostly by the spin diffusion coefficient that depends on electron density nonmonotonously. The longest experimentally observed PSH lifetime occurs at an electron density, corresponding to the transition from Boltzmann to Fermi-Dirac statistics - several times higher than that when the persistent spin helix is expected. These facts highlight the role the electron density may play when considering applications for spintronic devices.

HL 2.3 Mon 10:15 H31

Selective optical charging and spin preparation of a single quantum dot molecule — •C. Thalacker[1], F. Bopp[1], A. Ahmadi[1], N. Revenga[1], F. Vögl[1], C. Cullip[1], K. Boos[1], F. Sbresny[1], N. Bart[2], A. Wieck[2], A. Ludwig[2], D. Reuter[3], J. Schall[4], S. Reitzenstein[4], H. Riedl[1], K. Müller[1], and J. J. Finley[1] — [1]Walter Schottky Institut and Physik Department, TU München, Garching, Germany — [2]Ruhr-Universität Bochum, Bochum, Germany — [3]Universität Paderborn, Paderborn, Germany — [4]Technische Universität Berlin, Berlin, Germany

Coherence, ease of control and scalability lie at the heart of hardware for distributed quantum technologies. Spin-photon interfaces based on III-V semiconductor quantum dots (QDs) combine properties such as strong light-matter-interactions, robust spin-photon selection rules and ease of integration into opto-electronic devices. Two vertically stacked QDs, a so-called QD-molecule (QDM) are expected to exhibit enhanced coherence times (T_2^*) due to the formation of singlet-triplet (S-T) qubits. We embed a single QDM into an ultralow capacitance p-i-n diode that allows for ultrafast electrical tuning (>500 MHz). Photon extraction efficiencies are improved to >20% by deterministically placing a circular Bragg grating around the QDM. Using our device we demonstrate all optical control of the charge state, as well as optical spin pumping. Our results form the basis of an optically active S-T spin-qubit with enhanced coherence.

HL 2.4 Mon 10:30 H31

Resonant spin amplification in Faraday geometry — •Nedelea Vitalie[1], Philipp Schering[2], Dmitry Smirnov[3], Eiko Evers[2], Evgeny Zhukov[1,3], Dmitri Yakovlev[1,3], Manfred Bayer[1,3], Uhrig Götz[2], and Alex Greilich[1] — [1]Experimental Physics 2, TU Dortmund University, Dortmund, Germany — [2]Condensed Matter Theory, TU Dortmund University, Dortmund, Germany — [3]St. Petersburg, Russia

The possibility to use the spin degree of freedom for quantum information continues to drive research on semiconductors nanostructures. The main characteristic in this field is defined by the lifetime of the information or the spin coherence time. One of the most basic parameters of the spin dynamics is the g factor, which is often anisotropic in semiconductor nanostructures. Its transverse component can be measured very precisely when a magnetic field is applied in Voigt geometry by means of the resonant spin amplification effect (RSA).

Model consideration predict [1] that the realization of the RSA effect in Faraday geometry, where a magnetic field is applied parallel to the optically induced spin polarization, can be realized for a central spin interacting with a fluctuating spin environment. To confirm theory, we chose an ensemble of singly-charged (In,Ga)As/GaAs quantum dots, where the resident electron spin interact with the surrounding nuclear spins. The observation of RSA in Faraday geometry requires intense pump pulses with a high repetition rate and can be enhanced by means of the spin-inertia effect. Potentially, it provides the most direct and reliable tool to measure the longitudinal g factor of the charge carrier.

HL 2.5 Mon 10:45 H31

Cavity-enhanced single-shot readout of a quantum dot spin within 3 ns — •Nadia Olympia Antoniadis[1], Mark Richard Hogg[1], Willy Frederik Stehl[1], Alisa Javadi[1], Natasha Tomm[1], Rüdiger Schott[2], Sascha René Valentin[2], Andreas Dirk Wieck[2], Arne Ludwig[2], and Richard John Warburton[1] — [1]Department of Physics, University of Basel — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Rapid, high-fidelity single-shot readout of quantum states is a ubiquitous requirement in quantum information technologies. Readout of spin states in optically active emitters can be achieved by driving a spin-preserving optical transition and detecting the emitted photons. The speed and fidelity of this approach is typically limited by a combination of low photon collection rates and measurement back-action. Here, we demonstrate single-shot optical readout of a semiconductor quantum dot spin state, achieving a readout time of only a few nanoseconds. Our approach embeds a gated InAs quantum dot device into an open microcavity architecture. The Purcell enhancement generated by the microcavity selectively increases the readout transition emission rate, as well as efficiently channelling the emitted photons into a well-defined detection mode. We achieve single-shot readout of an electron spin state in 3 ns with a fidelity of (95.85±0.71)%, and observe quantum jumps using repeated single-shot measurements. Our work reduces the spin readout-time to values well below both the achievable spin T1 and T2* times in InAs quantum dots, opening up new possibilities for their use in quantum technologies.

HL 3: Quantum Dots and Wires 1: Transport and Electronic Properties

Time: Monday 9:30–13:00 Location: H32

Invited Talk HL 3.1 Mon 9:30 H32

Pushing the limits in real-time meeasurements of quantum dynamics — •Eric Kleinherbers[1], Philipp Stegmann[2], Annika Kurzmann[3], Martin Geller[1], Axel Lorke[1], and Jürgen König[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, 47057 Duisburg, Germany — [2]Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA — [3]2nd Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany

Time-resolved studies of quantum systems are the key to understand quantum dynamics at its core. The real-time measurement of individual quantum numbers as they switch between certain discrete values, well known as random telegraph signal, is expected to yield maximal physical insight. However, the signal suffers from both systematic errors, such as a limited time resolution and noise from the measurement apparatus, as well as statistical errors due to a limited amount of data. Here we demonstrate that an evaluation scheme based on factorial cumulants can reduce the influence of such errors by orders of magnitude [1]. The error resilience is supported by a general theory for the detection errors as well as experimental data of single-electron tunneling through a self-assembled quantum dot. Thus, factorial cumulants push the limits in the analysis of random telegraph data which represent a wide class of experiments in physics, chemistry, engineering and life sciences.

[1] E. Kleinherbers et al., Phys. Rev. Lett. 128, 087701 (2022)

HL 3.2 Mon 10:00 H32

Creating and detecting poor man's Majorana bound states in interacting quantum dots — •Athanasios Tsintzis[1], Rubén Seoane Souto[1,2], and Martin Leijnse[1,2] — [1]Division of Solid State Physics and NanoLund, Lund University, S-221 00 Lund, Sweden — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark

We theoretically study a system of two quantum dots (QDs) coupled via a third (coupler) QD which is additionally proximitized by an s-wave superconductor. For a wide parameter range, the system can be tuned to sweet spots with a doubly-degenerate ground state, as switches between even- and odd-parity ground states are found to be ubiquitous. The necessary ingredients are a) a finite magnetic field to break the spin degeneracy and b) spin-orbit interaction to mix the spin species. The sweet spots harbor poor man's Majorana bound states (Phys. Rev. B 86, 134528, 2012) whose quality is quantified by calculating the Majorana polarizations of the degenerate ground states (Phys. Rev. B 101, 125431, 2020). The QDs' electrochemical potentials are the control knobs utilized to reach the sweet spots and local and non-local conductance calculations provide a useful map for experimentalists navigating the parameter space. The above system can be realized in a semiconductor 2D electron gas or nanowire with gate- or epitaxially defined QDs coupled to a grounded superconductor. This work provides a path towards near-future demonstration of nonabelian and non-local Majorana properties, with possible (more long-term) applications in topologically protected quantum computing.

HL 3.3 Mon 10:15 H32

Interference and parity blockade in transport through a Majorana box — •Maximilian Nitsch[1], Rubén Seoane Souto[1,2], and Martin Leijnse[1,2] — [1]Division of Solid State Physics and NanoLund, Lund University, S-22100 Lund, Sweden — [2]Center for Quantum Devices, Niels Bohr Institute, University of Copenhagen, DK-2100 Copenhagen, Denmark

A Majorana box - two topological superconducting nanowires coupled via a trivial superconductor - is a building block in devices aiming to demonstrate nonabelian physics, as well as for topological quantum computer architectures. We theoretically investigate charge transport through a Majorana box and show that current can be blocked when two Majoranas couple to the same lead, fixing their parity. In direct analogy to Pauli spin blockade in spin qubits, this parity blockade can be used for fast and high-fidelity qubit initialization and readout, as well as for current-based measurements of decoherence times. Furthermore, we demonstrate that transport can distinguish between a clean Majorana box and a disordered box with additional unwanted Majorana or Andreev bound states.

HL 3.4 Mon 10:30 H32

Wave-function mapping of excited quantum dot states — •Daniel Hecker[1], Jens Kerski[1], Nelson Creutzburg[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, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Self-assembled quantum dots (QDs) are promising candidates for quantum information technologies, quantum sensing and various electro-optical applications. They are often approximated as two-dimensional harmonic oscillators. Although this approximation of electron states in a harmonic oscillator is very successful, the influence of the electron-electron interaction on the excited few-particle wave-functions and their dynamics into equilibrium has not been studied in detail.

We investigate an ensemble of InAs/GaAs QDs, embedded in a high-electron-mobility transistor with a two-dimensional electron gas (2DEG) as conductive channel. By applying a gate voltage to the transistor, the QDs can be selectively occupied with electrons tunneling from the 2DEG, and the time-resolved transconductance of the 2DEG can be measured. A rate equation based evaluation of the transconductance allows us to determine the tunneling rates of the QD states. In combination with a magnetic field that tunes the wave function-dependent tunneling probability, this enables us to investigate the shape and dynamics of the (excited) few-electron states.

HL 3.5 Mon 10:45 H32

Charge tuning of GaAs quantum dots using Schottky diode structure — •Nand Lal Sharma[1], Ghata Satish Bhayani[1], Oliver G. Schmidt[2], and Caspar Hopfmann[1] — [1]Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstrasse 20, 01069 Dresden, Germany — [2]Material Systems for Nanoelectronics, Technical University Chemnitz, 09107 Chemnitz, Germany

Semiconductor quantum dots (QDs) are promising candidates for high quality photon sources and the biexciton-exciton cascade in these structures is one of the most advanced techniques for generation of entangled photon pairs. In this work droplet etched GaAs/AlGaAs QDs [1] are embedded in Schottky diode structures within nanomembranes. The membranes are transferred to Au coated substrates via selective etching. The Au coated substrate facilitates the back while the Si-doped GaAs acts as the top contact. The QD photoluminescence from different charge states is controlled by application of an external bias. The effects of quantum dot charging, quantum confined Stark effect, exciton fine structure and photon coherence are investigated as a function of bias voltage.

[1] Keil et. al. Nat. comm. 8, 15501 (2017)

30 min. break

HL 3.6 Mon 11:30 H32

Modeling and simulation of the electric control of quantum dot photodiodes — •Dustin Siebert[1], Alex Widhalm[1,2], Sebastian Krehs[2], Nand Lal Sharma[2], Timo Langer[2], Björn Jonas[2], Dirk Reuter[2], Andreas Thiede[1], Artur Zrenner[2], and Jens Förstner[1] — [1]Paderborn University, Electrical Engineering Department, Warburger Straße 100, 33098 Paderborn, Germany — [2]Paderborn University, Physics Department, Warburger Straße 100, 33098 Paderborn, Germany

Optoelectronic devices like photodiodes based on single quantum dots are one of the new major fields of research for quantum computing, communication and sensing. In our work, we present our theoretical model and approaches using optoelectronic Bloch simulations to reproduce experimental results considering influences of a timing jitter between optical and electric pulses. Further, we use our model to validate quantum sensing methods and we show low frequency field simulations to estimate the electric properties of photodiodes, especially the RC-characteristics, to obtain a better understanding of the quantum dynamic and its electric control.

[1] Amlan Mukherjee, Alex Widhalm, Dustin Siebert, Sebastian Krehs, Nand Lal Sharma, Andreas Thiede, Jens Förstner, and Artur Zrenner, APL, Vol.116, 251103 (2020)

[2] Alex Widhalm, Sebastian Krehs, Dustin Siebert, Nand Lal Sharma, Timo Langer, Björn Jonas, Dirk Reuter, Andreas Thiede,

Jens Förstner, and Artur Zrenner, APL, Vol. 119, 181109 (2021)

HL 3.7 Mon 11:45 H32

Electrostatic coupling of double layer self-assembled quantum dots — •Lukas Berg[1], Laurin Schnorr[1], Thomas Heinzel[1], Arne Ludwig[2], and Andreas Dirk Wieck[2] — [1]Heinrich-Heine Universität, Düsseldorf, Germany — [2]Ruhr-Universität, Bochum, Germany

The electron capture- and emission dynamics of two layers of self-assembled quantum dots in large distance to each other as well as to their reservoirs is studied by time resolved capacitance spectroscopy. The occupation dynamics of the individual layers can be well separated at certain bias voltages. Additionally, an interaction of the electrostatic character is observed in terms of a shift of emission lifetimes and the extracted binding energies. To model this effect, the corresponding system of rate equations is solved.

HL 3.8 Mon 12:00 H32

Temperature-dependence of current peaks in InAs double quantum dots — •Olfa Dani[1], Robert Hussein[2], Johannes C. Bayer[1], Sigmund Kohler[3], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hanover, Germany — [2]Institut für Festkörpertheorie und -optik, Friedrich-Schiller-Universität Jena, Jena, Germany — [3]Instituto de Ciencia de Materiales de Madrid, CSIC, Madrid, Spain

We investigate electron transport through asymmetrically coupled InAs double quantum dots. Measurements of the resonances of single-electron tunneling shows a quite strong temperature dependence of those coherent current peaks. Their width and background increase with temperature in the range of 1.5-21 K, which indicates an influence of the substrate phonons. The broadening of such peaks can be modeled with rather good precision and can be fully explained with quantum dissipation [1] modeled by two baths, the one coupling to the dot occupation, the other to the inter-dot current. Application of magnetic fields helps us to identify the different quantum dot states.
[1] Olfa Dani, Robert Hussein, Johannes C. Bayer, Sigmund Kohler, Rolf J. Haug, Temperature-dependent broadening of coherent current peaks in InAs double quantum dots, arXiv:2204.06333 (2022)

HL 3.9 Mon 12:15 H32

Heterogeneous III-V nanowire quantum emitters on silicon photonic circuits — •Hyowon Jeong[1], Akhil Ajay[1], Nitin Mukhundhan[1], Marcus Döblinger[2], Jonathan J. Finley[1], and Gregor Koblmüller[1] — [1]Walter Schottky Institute & Physics Department, Technische Universität München, Garching, Germany — [2]Department of Chemistry, Ludwig-Maximilians-Universität München, Munich, Germany

III-V quantum dots (QDs) act as naturally bright and highly efficient quantum emitters that can generate deterministic single or entangled photons pairs. QDs embedded in a nanowire (NW) serve as a scalable platform for site-selective and geometry-controlled in-situ heterogeneous integration onto photonic waveguides (WG) - a crucial milestone for the realization of a Quantum Photonic Integrated Circuit.

In the first part, we show by numerical modelling how geometrical parameters of a NW and Si-WG design influence the spontaneous emission enhancement of the QD emitter and the in-coupling efficiencies at the NW-WG interface [1]. Preliminary experiments towards the development of an integrated III-V NW-QD system are then presented. Here, we demonstrate a droplet-free site-selective epitaxy of NWs, where first data of GaAsSb/InGaAs axial heterostructures and their distinct luminescence features will be shown. Furthermore, we discuss control of Indium incorporation into the InGaAs axial segment, in order to tune the emission wavelength before optimizing the axial size, progressing towards an axial QD.

[1] N. Mukhundhan, et al., Opt. Express 29, 43068 (2021).

HL 3.10 Mon 12:30 H32

Optoelectronic properties of GaAs(Sb)-AlGaAs core-shell NW diodes on silicon — •Tobias Schreitmüller, Patrick Jong, Daniel Ruhstorfer, Akhil Ajay, Andreas Thurn, Jonathan Finley, and Gregor Koblmüller — Walter Schottky Institute, Technical University of Munich, 85748 Garching, Germany

The ability to integrate III-V semiconductor nanowires (NW) on the silicon (Si) platform opens many perspectives for advanced nanoelectronic and optoelectronic device applications on-chip. However, for energy-efficient device performance, the design of axial or radial heterostructures, the control of accurate doping properties and the formation of low-resistance ohmic contacts are crucial. In this contribution, we present ongoing developments of radial n-i-p core-multishell NW heterostructures monolithically integrated on the n-Si (111) platform. The NW structure is designed to host n-type doped GaAs(Sb) cores, while the shell is composed of either GaAs homojunctions or (In,Al)GaAs(Sb)-based heterojunctions that define intrinsic and p-type doped regions. We show that n-type conduction is feasible in the Si-doped core by pioneering a novel catalyst-free, vapor-solid growth process of Si-doped GaAs NWs using molecular beam epitaxy (MBE). The n-doped NW cores were then implemented into radial n-i-p NW homo-junction devices to establish electrical contact formation and perform first electroluminescence (EL) experiments. The EL measurements illustrate successful diode characteristics, with luminescence features that are typical for the underlying material properties.

HL 3.11 Mon 12:45 H32

Band structure and end states in InAs/GaSb core-shell-shell nanowires — •Florinda Viñas Boström[1,2], Athanasios Tsintzis[2], Michael Hell[2], and Martin Leijnse[2] — [1]Institute for Mathematical Physics, TU Braunschweig, Braunschweig, Germany — [2]Division of Solid State Physics and NanoLund, Lund University, Lund, Sweden

Heterostructures made from the III-V semiconductors InAs and GaSb have been studied mainly for their bulk broken band gap alignment, meaning that the valence band of GaSb is higher in energy than the conduction band in InAs, in bulk. In addition, the materials are nearly lattice matched, leading to structures with almost no strain. In two dimensions, the InAs/GaSb quantum well is a topological insulator, exhibiting a hybridization gap in the topologically non-trivial regime where quantum spin Hall edge states are present. We have calculated the non-trivial band structures and wave functions of InAs/GaSb core-shell-shell nanowires, using $\mathbf{k}\cdot\mathbf{p}$ theory. For hollow core-shell-shell InAs/GaSb nanowires, we also calculate the wave functions for a finite system with wire ends, using a BHZ model with parameters taken from the resulting $\mathbf{k}\cdot\mathbf{p}$ calculations. We establish that there are localized end-states, with energies inside the bulk gap. However, in contrast to the topological edge states in two dimensions, these end states are fourfold degenerate, and split into two Kramers pairs under potential disorder along the nanowire growth direction. Nevertheless, the end states are robust against potential disorder applied in the angular direction, as long as the bulk band gap is not closed.

HL 4: Semiconductor Lasers

Time: Monday 9:30–12:45 Location: H33

HL 4.1 Mon 9:30 H33

Spin lasing in bimodal quantum dot micropillar cavities — •Niels Heeermeier[1], Tobias Heuser[1], Jan Grosse[1], Natalie Jung[2], Markus Lindemann[2], Nils Gerhard[2], Martin Hofmann[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universiät Berlin, D-10623 Berlin, Germany — [2]Lehrstuhl für Photonik und Terahertztechnologie, Fakulktät für Elektrotechik und Informationstechnik, Ruhr-Universität Bochum, D-44780 Bochum

Spin-controlled lasers have been shown to provide ultra-fast polarization dynamics in excess of 200 GHz. In contrast to conventional semiconductor lasers their temporal properties are not limited by the intensity dynamics, but are governed primarily by the birefringent mode splitting that determines the polarization oscillation frequency. Another class of modern semiconductor lasers are high-beta emitters which benefit from enhanced light-matter interaction due to strong mode confinement in low-mode-volume microcavities. In such structures, the emission properties can be tailored by the resonator geometry to realize for instance bimodal emission behavior in slightly elliptical micropillar cavities. We utilize this feature to demonstrate and explore spin-lasing effects in bimodal high-beta quantum dot micropillar lasers. The studied microlasers show spin laser effects with polarization oscillation frequencies up to 15 GHz controlled by the ellipticity of the resonator. Our results reveal appealing prospects for very compact and energy-efficient spin lasers and can pave the way for future purely electrically injected spin lasers enabled by short injection path lengths. Laser and Photonics Reviews 2022, 16, 2100585.

HL 4.2 Mon 9:45 H33

Temperature-dependent lasing operation of hybrid semiconductor nanowire - metal grating plasmonic nanolasers — •Francesco Vitale[1], Daniel Repp[2], Thomas Siefke[2], Uwe Zeitner[2], Thomas Pertsch[2], and Carsten Ronning[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, D-07743 Jena — [2]Institut für Angewandte Physik, Friedrich-Schiller-Universität Jena, Albert-Einstein-Straße 15, D-07745 Jena

Nanowire(NW)-based semiconductor-insulator-metal (SIM) plasmonic structures represent a benchmark platform for the next generation of hybrid nanolasers, capable of sustaining sub-wavelength hybrid lasing modes, which, in turn, lead to an overcoming of diffraction-limited mode footprints and an acceleration of the lasing dynamics, when compared to their photonic counterparts. In this work, we report on the realization and optical investigation of hybridized SIM platforms, in which single ZnO NWs are deterministically overlaid onto metal gratings (MGs), FIB-milled into a 70 nm Al layer with a nanometric Al_2O_3 spacer on top. By performing ns-excitation steady-state micro-PL, we study the spectral and temporal properties of such hybrid platforms, as a function of the cavity geometry (i.e. NW size, grating period and NW-trench orientation) and temperature. We report about room-temperature lasing in some of these hybrid NW-MG structures and lowering of the lasing threshold compared to the planar SIM plasmonic nanolasers.

HL 4.3 Mon 10:00 H33

Field-resolved high-order sub-cycle nonlinearities in a terahertz quantum cascade laser — •Josef Riepl[1], Jürgen Raab[1], Pavel Abajyan[2], Hanond Nong[2], Joshua Freeman[3], Lianhe H. Li[3], Edmund H. Linfield[3], A. Giles Davies[3], Andreas Wacker[4], Tim Albes[5], Christian Jirauschek[5], Christoph Lange[6], Sukheep S. Dhillon[2], and Rupert Huber[1] — [1]University of Regensburg, Germany — [2]Université de Paris, France — [3]University of Leeds, UK — [4]Lund University, Sweden — [5]Technical University of Munich, Germany — [6]TU Dortmund University, Germany

Employing ultrafast electron dynamics in quantum cascade lasers (QCLs) holds enormous potential for intense, compact mode-locked terahertz (THz) sources, squeezed THz light, frequency mixers, and comb-based metrology systems. Yet the important sub-cycle dynamics have been notoriously difficult to access in operational THz QCLs. Here, we perform the first ultrafast two-dimensional high-field spectroscopy of a free running THz QCL. The detected strong incoherent and coherent nonlinearities up to eight-wave mixing do not only reveal extremely short gain recovery times, but also reflect the nonlinear polarization dynamics of the QCL laser transition for the first time. A density-matrix approach reproducing all nonlinearities and their ultrafast evolution, allows us to map the coherently induced trajectory of the Bloch vector. The observed nonlinearities benefit from resonant enhancement in a regime of negative absorption and bear potential for various future applications, ranging from efficient intracavity frequency conversion and mode proliferation to passive mode locking.

HL 4.4 Mon 10:15 H33

Tuning nanowire lasers via hybridization with two-dimensional materials — •Edwin Eobaldt[1], Francesco Vitale[1], Maximilian Zapf[1], Margarita Lapteva[1], Christof Neumann[2], Andrey Turchanin[2,3], Giancarlo Soavi[1,3], and Carsten Ronning[1,3] — [1]Institute of Solid State Physics, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Institute of Physical Chemistry, Friedrich Schiller University Jena, 07743 Jena, Germany — [3]Abbe Center of Photonics, Friedrich Schiller University Jena, 07745 Jena, Germany

Semiconductor nanowires have attracted great scientific attention due to their remarkable waveguiding properties and their intrinsic capability to lase under sufficiently high excitation, thus, paving the way towards nanoscaled coherent light sources and the realization of all-optical circuits. After the spectral and temporal characteristic of single nanowire lasers have been extensively studied during the past decade, today's research focuses on their effective integration into functional and nanoscaled environments. In this regard, the hybridization of semiconductor nanowire lasers with two-dimensional materials could offer new capabilities for a dynamical emission tuning enabled by charge transfer processes at the heterointerface. As a proof of concept, hybrids systems containing ZnO nanowires on top of MoS_2 monolayers were investigated by micro-photoluminescence measurements. By further adopting a deterministic transfer approach, it was possible to study hybridization-related changes of the lasing emission on one and the same nanowire.

HL 4.5 Mon 10:30 H33

Generalization of the Siegert relation — •Monty Leon Drechsler[1,2], Frederik Lohof[1,2], and Christopher Gies[1,2] — [1]Institute for Theoretical Physics, University of Bremen, Bremen, Germany — [2]Bremen Center for Computational Materials Science, University of Bremen, Bremen, Germany

The Siegert relation connects the first- and second-order coherence properties of light. While it is valid for thermal light, this relation is routinely extended also to the partially coherent regime of high-β nanolasers, where it aids in the identification of the lasing threshold [1]. We test the validity of this extension by introducing a generalized Siegert relation. Based on the cluster expansion method we derive a full two-time quantum optical theory and combine it with our new approach, allowing us to revise the Siegert relation in different device regimes. We find that correlations lead to deviations from the Siegert relation and in particular highlight the influence correlations related to sub- and superradiance [2].

[1] Kreinberg et al., Laser & Photonics Reviews 14, 2000065 (2020)
[2] Drechsler et al., arXiv:2204.02747v2 (accepted for publication in Appl. Phys. Lett.)

HL 4.6 Mon 10:45 H33

Development of a 850 nm VCSEL array for real world QKD via the BB84 and decoy state protocol — •Moritz Birkhold, Michael Zimmer, Sergej Vollmer, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart

Quantum key distribution offers fundamental advantages over classical key distribution. If done correctly a perfectly private key (e.g. a one time pad) can be exchanged between two parties and any eavesdropping attack will be detected. This could be an intresting feature for e.g. worldwide financial applications but the technological hurdles to overcome are numerous.

Here we show the advances towards a complete eight VCSEL array with an integrated polarization grating in the light emission window, to create quantum states and transmit the quantum key. The basic structure is grown by metal-organic vapor-phase epitaxy (MOVPE).

Then this structure is processed to allow data transmission in the GHz regime. Varoius methodes including a co-planar contact geometry are used to achieve this. A vektor network analyzer is than used to measure the scattering parameter as well as the transmission bandwith. Finally a eye diagramm is recorded to determine the data rate. The polarization grating is defined by an electron beam lithography and etched with an ICP machine to allow light output in four different polarizations. The pulses of the eight different VCSEL are evaluated for indistinguishability.

30 min. break

HL 4.7 Mon 11:30 H33

Investigations on high-β silver-coated InP-based metallic nanolasers and their spectral line shape behavior — •Monty Leon Drechsler[1], J. Buchgeister[1], A. Koulas-Simos[2], K. Laiho[2], G. Sinatkas[2], T. Zhang[3], J. Xu[3], F. Lohof[1], F. Jahnke[1], C. Gies[1], W. W. Chow[4], C.-Z. Ning[3], and S. Reitzenstein[2] — [1]University of Bremen, Bremen, Germany — [2]Technical University of Berlin, Berlin, Germany — [3]Tsinghua University, 1303 Beijing 100084, China — [4]Sandia National Laboratories, Albuquerque, New Mexico, USA

We investigate a silver-coated InP-based metallic nanolasers with a diameter of several 100 nm and β-factor close to unity, pushing the device in the regime of quantum optics. We use a quantum optical semiconductor laser model utilizing an equation of motion approach together with the cluster expansion technique to analyze the device. Photon correlations quantified by $g^{(1)}(\tau)$ and $g^{(2)}(\tau)$ are an essential tool for this research. Information about the energy spectrum and the detection characteristics of photons is encoded in them. In this study, an unconventional behavior of the spectral line shape was found. We observe that the line shape takes a Gaussian profile above the laser threshold. The exciting question arises whether the Gaussian line shape can be used as an indicator of laser activity. In previous works, a similar behavior has been reported, but no explanation was given. We provide an explanation for this behavior of the line shape in the framework of an open-cavity multimode model.

HL 4.8 Mon 11:45 H33

Extraction of silver losses at cryogenic temperatures through optical characterization of Ag-coated plasmonic nanolasers — •Aris Koulas-Simos[1], Georgios Sinatkas[1,2], Taiping Zhang[3], Jia-Lu Xu[3], William E. Hayenga[4], Qiang Kan[5], Ruikang K. Zhang[5], Mercedeh Khajavikhan[4,6], Cun-Zheng Ning[3,7], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Institute of Integrated Photonics, RWTH Aachen University, Campus Blvd. 73, Aachen 20 52074, Germany — [3]Department of Electronic Engineering, Tsinghua University, Beijing, 100084, China — [4]CREOL, The College of Optics and Photonics, University of Central Florida, Orlando, FL, USA — [5]Institute of Semiconductors, Chinese Academy of Sciences, Beijing, 100083, China — [6]Ming Hsieh Department of Electrical and Computer Engineering, University of Southern California, Los Angeles, CA, USA — [7]School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, 85287, Arizona, USA

We present a rigorous method for the extraction of silver losses at temperatures T from 10 K to 180 K at NIR wavelengths through T-dependent μPL studies on silver-coated InP-based nanolasers in conjunction with cavity simulations. The numerical algorithm maps the changes of the Q-factor, estimated at transparency, into the imaginary part of silver permittivity. The results are in good agreement with theoretical predictions estimating a drop of one order from room to cryogenic temperatures. This data is long missing from the literature and sets a pathway for the optimization of plasmonic nanolasers.

HL 4.9 Mon 12:00 H33

Quantum-optical study of an InGaAsP metallic cavity nanolaser: A systematic approach to the identification of lasing — •J. Buchgeister[1], M. L. Drechsler[1], F. Lohof[1], C. Gies[1], A. Koulas-Simos[2], K. Laiho[2], G. Sinatkas[2], T. Zhang[4], J. Xu[4], Q. Kan[6], R. K. Zhang[6], C.-Z. Ning[4,5], S. Reitzenstein[2], W. W. Chow[3], and F. Jahnke[1] — [1]Universität Bremen, Germany — [2]Technische Universität Berlin, Germany — [3]Sandia National Laboratories, USA — [4]Tsinghua University, China — [5]Arizona State University, USA — [6]Institute of Semiconductors, China

Semiconductor nanolasers as small-scale sources of coherent light have become increasingly important for applications in the data industry for their size, power-efficiency, and modulation speed. Determining the presence of lasing, however, is challenging due to the near-thresholdless behaviour of ultra-efficient devices, which requires going beyond I/O characteristics. The research presented here focuses on a quantum-optical study of a silver-coated InGaAsP nanolaser by means of a full quantum-mechanical semiconductor laser theory. We calculate the time-resolved single- and two-photon correlation function, allowing us to identify the onset of coherent emission with confidence. Our theoretical model can match the experimentally obtained data using a single set of realistic parameters and hence presents a comprehensive strategy for the identification of lasing while being extensible to those gain materials requiring a more pronounced focus on quantum-material aspects, like TMDCs.

HL 4.10 Mon 12:15 H33

Random Lasing with Dye-doped Fluorescent Aerogels — •Matthias Kestler, Theobald Lohmüller, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Nano-Institute Munich and Department of Physics, Ludwig-Maximilians-Universität (LMU), Königinstr. 10, 80539 Munich, Germany

Aerogels are a translucent, amorphous network of colloidal particles, which scatter light at visible wavelengths. Doping an aerogel matrix with fluorescent dyes or nano-particles enables their wider use for optical applications, including random lasing. Here, we report on the synthesis of fluorescent silica aerogels by supercritical drying of dye-doped silica gels. By our refined process, we obtain large, porous samples, where scattering events lead to closed photon paths that act as optical oscillators in the micrometer range. We analyze the corresponding photo-luminescence, amplified stimulated emission and random lasing spectra that are obtained for different dye-loaded aerogel samples. Random lasing is confirmed by different characteristic features like a lasing threshold, bandwidth narrowing and strongly fluctuating Anderson localized modes. Furthermore, we find that the extraordinary thermal stability of aerogels enables the use of high laser pumping energies without visible sample degradation.

HL 4.11 Mon 12:30 H33

Towards a novel vertical external-cavity surface-emitting laser based on a grating waveguide structure — •Peter Gierss[1], Ana Ćutuk[1], Maxim Leyzner[2], Uwe Brauch[2], Marwan Abdou Ahmed[2], Michael Jetter[1], Thomas Graf[2], 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]Institut für Strahlwerkzeuge, University of Stuttgart, Pfaffenwaldring 43, 70569 Stuttgart

Vertical external-cavity surface-emitting lasers (VECSELs) provide favorable properties compared to other laser systems. The external cavity allows for incorporation of additional optical elements like birefringent filters or absorbers for passive mode-locking which makes it very attractive for various applications. While the possibility of band-gap engineering and a broad gain spectrum are also advantageous, the heat dissipation from the active region due to the thick distributed Bragg reflector (DBR) is a drawback.

A novel approach is a VECSEL based on a grating waveguide structure (GWS) paired with a low-refractive-index heat-spreader below the active region. The absence of a DBR improves the heat removal while the guided-mode resonances from the GWS should provide good coupling of the pump and laser field as well as the high reflectivity necessary for the laser operation. We present the progress towards the realization of an AlGaInP-based GWS-VECSEL for laser emission in the red spectral range.

HL 5: Perovskite and Photovoltaics 1 (joint session HL/CPP/KFM)

Time: Monday 9:30–12:45 Location: H34

HL 5.1 Mon 9:30 H34

The Electronic Structure of $Cs_2AgBiBr_6$ at Room Temperature — •Julian Gebhardt[1,2] and Christian Elsässer[1,2,3] — [1]Fraunhofer Institute for Mechanics of Materials IWM, 79108 Freiburg — [2]Cluster of Excellence livMatS at FIT - Freiburg Center for Interactive Materials and Bioinspired Technologies, Albert-Ludwigs-University Freiburg, 79104 Freiburg — [3]Freiburg Materials Research Center (FMF), Albert-Ludwigs-University Freiburg, 79104 Freiburg

$Cs_2AgBiBr_6$ is a stable halide double perovskite with a band gap of about 2.2 eV. Therefore, it is intensively studied as possible lead free alternative to hybrid perovskite solar cell absorber materials such as methylammonium-lead iodide. However, power conversion efficiencies of solar cells with this material have not yet exceeded 3%. A detailed understanding of the electronic structure of this material is difficult, due to the variance of reported data and experimental as well as theoretical difficulties that occur in going beyond a qualitative understanding of such an indirect semi-conductor at device operation temperature. Here we combine self-energy corrected electronic-structure theory including spin-orbit coupling and structural dynamics at room temperature to model and understand this compound in a quantitative manner, and we compare our theoretical findings with experimental ones. Based on an achieved good agreement, we propose that the observed low power conversion efficiencies can be attributed to the density of states in the conduction band region. From the relation between dimensionality and electron conductivity, we suggest a general design principle for absorber material search.

HL 5.2 Mon 9:45 H34

Photon-echo spectroscopy of a $CH_3NH_3PbI_3$ perovskite single crystal — •Stefan Grisard[1], Artur V. Trifonov[1,2], Aleksandr N. Kosarev[1,3], Ilya A. Akimov[1,3], Dmitrii R. Yakovlev[1,3], Julian Höcker[4], Vladimir Dyakonov[4], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, Technische Universität Dortmund — [2]Spin Optics Laboratory, St. Petersburg State University, Russia — [3]St. Petersburg, Russia — [4]Experimental Physics 6, Julius-Maximilian University of Würzburg

Lead halide perovskites such as $CH_3NH_3PbI_3$ ($MAPbI_3$) show outstanding characteristics important for photovoltaic and optoelectronic applications. However, the peculiarities of light-matter interactions in these materials are far from being fully explored. Here, we applied time-resolved photon echo spectroscopy to a high quality $MAPbI_3$ single crystal highlighting the importance of inhomogeneous broadening of excitonic transitions even at cryogenic temperatures. Furthermore, we developed an experimental photon-echo polarimetry method that unambiguously identifies contributions from exciton and biexciton to the coherent optical response. Most importantly, our method allows to accurately extract the biexciton binding energy of 2.4meV, even though the period of the observed quantum beats exceeds the coherence times of exciton and biexciton.

HL 5.3 Mon 10:00 H34

Structural properties of (hot-)pressed $MAPbI_3$ films revealed by detailed temperature-dependent optical analyses — •Christina Witt[1], Konstantin Schötz[1], Nico Leupold[2], Simon Biberger[1], Philipp Ramming[1], Ralf Moos[2], and Fabian Panzer[1] — [1]Soft Matter Optoelectronics, University of Bayreuth, Bayreuth 95440, Germany — [2]Department of Functional Materials, University of Bayreuth, Bayreuth 95440, Germany

Halide perovskites attracted much attention in recent years, due to the remarkable increase in corresponding solar cell efficiencies. More recently, hot-pressing has emerged as attractive method for manufacturing and post-treatment of perovskite films [1, 2]. However, a detailed understanding regarding the role of temperature during hot-pressing on resulting film properties is still missing. Thus, we use temperature-dependent PL and absorption measurements of $MAPbI_3$ thin films pressed with different temperatures and in detail analyze their optical properties. This allows us to draw conclusions about structural and optoelectronic properties, revealing that an increased temperature improves film morphology, structural and optoelectronic film properties.

[1] Witt, C. et al. Impact of Pressure and Temperature on the Compaction Dynamics and Layer Properties of Powder-Pressed Methylammonium Lead Halide Thick Films. ACS Appl. Electron. Mater. 2020, 2 (8), 2619-2628.

[2] Pourdavoud, N. et al. Room-Temperature Stimulated Emission and Lasing in Recrystallized Cesium Lead Bromide Perovskite Thin Films. Adv. Mater. 2019, 31, 1903717.

HL 5.4 Mon 10:15 H34

Application of atomic layer deposition and x-ray photoelectron spectroscopy in perovskite solar cells — •Małgorzata Kot[1], Chittaranjan Das[2], Lukas Kegelmann[3], Hans Koebler[3], Mikhailo Vorokhta[4], Carlos Escudero[5], Steve Albrecht[3], Antonio Abate[3], and Jan Ingo Flege[1] — [1]BTU Cottbus-Senfteberg, Cottbus, Germany — [2]KIT, Eggenstein-Leopoldshafen, Germany — [3]HZB, Berlin, Germany — [4]Charles University, Prague, Czech Republic — [5]ALBA Synchrotron, Cerdanyola del Vallès, Spain

In this work we have utilized near-ambient pressure and ultra-high vacuum X-ray photoelectron spectroscopy as well as atomic layer deposition to investigate perovskite solar cells (PSCs). We have demonstrated that ultrathin room temperature atomic layer-deposited aluminium oxide on the perovskite surface very effectively suppresses iodine migration[1] and improves the long term stability and efficiency of PSCs [2,3]. Furthermore, exposure to light proves more detrimental to the perovskite film than exposure to water vapor.[2] Absorbed photons create Frenkel defects in the perovskite crystal and their number strongly depends on the used illumination. The higher the photon flux, the higher the concentration of Frenkel defects, and thus the stronger the degradation of power conversion efficiency and the stronger the hysteresis in the J-V characteristics. [1] C. Das, M. Kot et al., Cell Reports Physical Science 2020, 1, 100112. [2] M. Kot et al., ChemSusChem 2020, 13, 5722. [3] M. Kot et al., ChemSusChem 2018, 11, 3640.

HL 5.5 Mon 10:30 H34

Chemical Engineering of Ferroelastic Twin Domains in MAPbI3 Thin Films — •Yenal Yalcinkaya[1], Ilka Hermes[1], Tobias Seewald[2], Katrin Amann-Winkel[1], Lothar Veith[1], Lukas Schmidt-Mende[2], and Stefan A.L. Weber[1] — [1]Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany — [2]Department of Physics, University of Konstanz, Universitätsstr. 10, 78464, Germany

In this study, we introduce a new chemical method for controlling the strain in methylammonium lead iodide (MAPbI3) perovskite crystals by varying the ratio of Pb(Ac)2 and PbCl2 in the precursor solution. We used a combination of piezoresponse force microscopy (PFM) and X-ray diffraction (XRD) to observe the effect on crystal strain. We observed larger ferroelastic twin domains upon increasing the PbCl2 content, indicating increased crystal strain via PFM images. We confirmed the increased crystal strain via the XRD patterns with strong crystal twinning features. We suggest that this behaviour is caused by different evaporation rates of methylammonium acetate and methylammonium chloride which led to a strain gradient during the crystallization as revealed by time-of-flight secondary ion mass spectroscopy (ToF-SIMS) and grazing incidence x-ray diffraction (GIXRD) measurements. We observed films with larger twin domain structures show an increased carrier via time-resolved photoluminescence (TRPL). The results demonstrate the potential of chemical strain engineering as an easy method for controlling strain-related e*ects in lead halide perovskites.

HL 5.6 Mon 10:45 H34

Inspecting the local structure of cubic phase halide perovskites from first-principles — •Xiangzhou Zhu, Sebastián Caicedo-Dávila, Christian Gehrmann, and David A. Egger — Department of Physics, Technical University of Munich, Garching, Germany

Halide perovskites (HaPs) have been identified as one of the most promising optoelectronic materials in recent years. Different from the conventional inorganic semiconductors, HaPs exhibit profound deviations from their average atomic structure at finite temperature, which have important consequences for their optoelectronic properties. However, a detailed understanding of these local structural fluctuations, the underlying physical mechanisms as well as their consequences is far from complete. Here, we perform molecular dynamics (MD) calcula-

tions based on density functional theory (DFT) to investigate the local structure and anharmonic dynamics of $CsPbBr_3$ in the cubic phase at T=425 K and 525K. We find that motions of neighboring Cs-Br atoms interlock within a nominal cubic unit cell. This manifests in the most likely Cs-Br distance being significantly shorter than what is inferred from an ideal cubic structure. Furthermore, we use the statistical information on the dynamic atomic distributions to quantify the effective potential associated with certain atomic motions at two temperatures. We find that Br motions occur in a dynamically disordered potential energy landscape and relate the Cs motion as well the Cs-Br coupling to $PbBr_6$ octahedral rotations.

30 min. break

HL 5.7 Mon 11:30 H34

Distinct Resonances in Absorption Spectra of Lead Halide-based Quantum Dots — •Anja Barfüsser, Quinten A. Akkerman, Sebastian Rieger, Amrita Dey, Ahmet Tosun, Tushar Debnath, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Nano-Institute Munich and Department of Physics, Ludwig-Maximilians-Universität (LMU), Königinstr. 10, 80539 Munich, Germany

In recent years, perovskite nanocrystals have attracted much attention for their unique optical properties. Here, we discuss sphere-like lead halide-based quantum dots with diameters in the range of 4.5-12 nm featuring a multitude of distinct resonances in their absorption spectra. We have investigated the nature of these resonances by comparing experimental data with model calculations based on weak and strong confinement. In transient absorption experiments, bleaching and induced absorption signals are observed, which we discuss in terms of confined excitons and biexcitonic contributions.

HL 5.8 Mon 11:45 H34

Revealing the doping density in perovskite solar cells and its impact on device performance — •Francisco Peña-Camargo and Martin Stolterfoht — Physik weicher Materie, Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24-25, 14776 Potsdam, Germany

Inorganic semiconductors can be electronically doped with high precision. Conversely, there is still conjecture regarding the assessment of the electronic doping density in metal-halide perovskites, not to mention of a control thereof. This study presents a multifaceted approach to determine the electronic doping density for a range of different lead-halide perovskite systems. Optical and electrical characterisation techniques comprising intensity-dependent and transient photoluminescence, AC Hall effect, transfer-length-methods, and charge extraction measurements were instrumental in quantifying an upper limit for the doping density. The obtained values are subsequently compared to the electrode charge per cell volume at short-circuit conditions (CU_{bi}/eV), which amounts to roughly 10^{16} cm^{-3}. This figure of merit represents the critical limit below which doping-induced charges do not influence the device performance. The experimental results demonstrate consistently that the doping density is below this critical threshold ($< 10^{12}$ cm^{-3} which means $\ll CU_{\mathrm{bi}}/eV$) for all common lead-based metal-halide perovskites. Nevertheless, although the density of doping-induced charges is too low to redistribute the built-in voltage in the perovskite active layer, mobile ions are present in sufficient quantities to create space-charge-regions in the active layer.

HL 5.9 Mon 12:00 H34

Ground-state structures, electronic structure, transport properties and optical properties of anion-ordered anti-Ruddlesden-Popper phase oxide perovskites — •Dan Han, Shizhe Wang, Thomas Bein, and Hubert Ebert — Department Chemie, Ludwig-Maximilians-Universität München, Germany

Anti-Ruddlesden-Popper (ARP) phase oxide perovskites Ca4OA2 (A = P, As, Sb, Bi) have recently attracted great interest in the field of ferroelectrics and thermoelectrics, while their optoelectronic application is dominantly limited by their indirect band gaps. In this work, we consider A-site anion ordering in Ca4OA2 (A = P, As, Sb, Bi), and find that it induces an indirect-to-direct band gap transition. Using first-principles calculations, we study the ground-state structures, electronic structure, transport properties and optical properties of anion-ordered ARP phase oxide perovskites Ca4OAA'. Based on an analysis of the lattice dynamics, the ground-state structures of Ca4OAsSb, Ca4OAsBi, Ca4OPSb and Ca4OPBi are identified. In contrast to the Ruddlesden-Popper (RP) phase oxide and halide counterparts, Ca4OAA' show larger band dispersion along the out-of-plane direction, smaller band gaps and highly enhanced out-of-plane mobilities, which is ascribed to the short interlayer distances and enhanced covalency of the pnictides. Although the out-of-plane mobilities of these n = 1 ARP phase perovskites highly increase, comparatively strong polar optical phonon (POP) scattering limits the further enhancement of their mobilities. This work shows that these anion-ordered Ca4OAA' exhibit the potential for optoelectronic applications.

HL 5.10 Mon 12:15 H34

Including light management concepts in performance prediction modelling of perovskite-silicon tandem solar cells by implementing transfer matrix method — Aminreza Mohandes[1,2], Peymaneh Rafieipour[1,2], Mohammad Moaddeli[1], and •Mansour Kanani[1] — [1]Department of Materials Science and Engineering, School of Engineering, Shiraz University, Shiraz, Iran — [2]Department of Physics, Shiraz University, Shiraz, Iran

The 2-T monolithic perovskite-silicon tandem design holds a record efficiency of 29.80%, recently. To perform more accurate, complete and experimentally reliable modelling of tandem solar cell, we adopt the transfer matrix method (TMM) which incorporates the interfacial reflections, light scattering and parasitic absorption losses in the calculation of the light transmitted from the top perovskite solar cell. The results reveal that the light scattering and interfacial reflection losses cannot be ignored and the previously used Beer-Lambert exponential relation is insufficient for studying tandem configuration. Including TMM method in the performance optimization of the tandem solar cells lets to consider light management concepts more extensively. Therefore, identifying and reducing optical losses in each layer/interface and designing appropriate anti-reflection coatings in a multilayer tandem simulation can be achieved. In this study, standalone and tandem devices have been analyzed and the effect of absorber layer thickness variation, J-V curves, external quantum efficiency (EQE), filtered spectra, current matching, and tandem performance parameters on the cell efficiency is considered.

HL 5.11 Mon 12:30 H34

Highly Efficient Perovskite-on-Silicon Tandem Solar Cells on Planar and Textured Silicon — •Christian M. Wolff[1], Xin Yu Chin[2], Kerem Artuk[1], Deniz Türkay[1], Daniel Jacobs[1], Quentin Jeangros[2], and Christophe Ballif[1,2] — [1]École polytechnique fédérale de Lausanne, STI IEM PVLAB, Rue de la Maladière 71b, 2000 Neuchâtel — [2]Centre Suisse d'Electronique et de Microtechnique, Rue Jaquet-Droz 1, 2002 Neuchâtel

Multi-junction devices offer the possibility to harness the sun's light beyond the limitations of single-junction solar cells. Among the different combinations perovskite-on-silicon (Pk/Si) tandems hold the great promise of high efficiencies >30%, while maintaining low cost. I will report on our latest progress in the development of Pk/Si tandems comparing our efforts on single-side and double-side textured Pk/Si tandems, reaching a V_{OC} up to 1.95V, summed short-circuit currents above $41\mathrm{mA/cm}^2$, and certified efficiencies >29%, on an active area of $1\mathrm{cm}^2$. We achieved these results by dedicated electrical and optical optimizations of all layers within the stack. Specifically, we reduced recombination and transport losses in the Pk absorbers through process and additive engineering for both solution-processed one-step and hybrid two-step deposited Pks, and improved the transparency of the front stack electrodes and contacts through simulation-guided optimizations of the front grid and layer thicknesses. Furthermore, we investigated the stability of single-junction Pk and tandem devices under reverse-bias and standardized accelerated aging conditions.

HL 6: 2D Materials 1 (joint session HL/CPP/DS)

Time: Monday 9:30–12:45 Location: H36

Invited Talk HL 6.1 Mon 9:30 H36

g-factors in van der Waals heterostructures: revealing signatures of interlayer coupling — •Paulo E. Faria Junior — University of Regensburg, Regensburg, Germany

The interplay of the spin and the orbital angular momenta of electrons in semiconductors governs the observed Zeeman splitting, often described by the effective g-factors. In the realm of 2D materials, transition metal dichalcogenides (TMDCs) are ideal candidates to explore the manifestation of coupled spin and orbital degrees of freedom under external magnetic fields. In this talk, I will cover the basic physics behind the Zeeman splitting and effective g-factors, emphasizing the recent first-principles developments in monolayer TMDCs that nicely reproduce the available experimental data. These new theoretical insights demystify the valley-Zeeman physics in TMDCs and finally establish a connection to the vast existing knowledge in the area of III-V materials. Beyond monolayers, I will discuss TMDC-based van der Waals heterostructures, particularly MoSe2/WSe2 and WS2/graphene systems, in which the spin-valley physics and g-factors encode valuable information about the interlayer coupling.

HL 6.2 Mon 10:00 H36

Optical Properties of Encapsulated Transition-Metal Dichalcogenide Monolayers, Bilayers, and Heterostructures — •Manan Shah[1], Philip Klement[1], Sangam Chatterjee[1], Kyungnam Kang[2], Eui-Hyeok Yang[2], and Arash Rahimi-Iman[1] — [1]I. Physikalisches Institut und Zentrum für Materialwissenschaften, Justus-Liebig Universität Gießen, D-35392, Germany — [2]Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, NJ, 07030, USA

Van-der-Waals heterostructures (vdW-HSs) based on 2D-layered materials have received unrivaled attention among nanomaterials due to their promising optoelectronic properties induced by moiré potential landscapes; secondly, their strong light-matter interactions; and third, the promise of bandgap engineering capabilities. The optical properties of transition-metal dichalcogenides (TMDs) depend considerably on the substrate, stacking configuration, interface quality, and encapsulation. As more and more layered materials have come into the focus, the demand for a comprehensive understanding of their optical, optoelectronic, and vibronic properties is increasing drastically.

We focus on the discussion of photoluminescence and the Raman response of tungsten-based TMD monolayers and stacks thereof [1, 2], as well as encapsulated configurations. We further aim at unraveling structural alterations and emission properties by monitoring the temporal behavior in their responses. [1] Semiconductors 2019, 53, 2140. [2] Sci. Rep. 2022, 12, 6939.

HL 6.3 Mon 10:15 H36

Electrically Tunable Photoluminescence in Monolayer MoS_2 and graphene/MoS_2 Heterostructures — •Tarlan Hamzayev and Giancarlo Soavi — Institute of Solid-State Physics, Friedrich Schiller University Jena, Germany

The optical response of monolayer (ML) transition metal dichalcogenides (TMDs) is dominated by the co-existence, even at room temperature, of excitons, bi-excitons, and trions.

The photoluminescence (PL) emission of these quasi-particles can be modulated via external knobs, such as doping, pressure and strain. In particular, the PL emission from the neutral exciton is greatly modulated during the crossover from the undoped to the highly doped regime [1]. In the latter case, PL emission is mainly suppressed due to the presence of trions, which have a fast non-radiative decay.

In this work, we study the gate dependence of the PL emission in encapsulated ML MoS_2 and ML graphene/MoS_2 heterostructures (HS). We show that in the HS region the PL emission mainly comes from neutral excitons even at large values of external gate voltage, thus confirming that graphene is an efficient filter for PL emission [2]. This work clarifies the interplay between charge transfer and PL filtering in graphene/TMD layered HS.

[1] Mak, K. F. et al. Nature materials 12, 207-211 (2013).

[2] Lorchat, E. et al. Nature Nanotechnology 15, 283-288 (2020).

15 min. break

HL 6.4 Mon 10:45 H36

Integration of Transferable Organic Semiconductor Nanosheets with 2D Materials for van der Waals Heterojunction Devices — •Sirri Batuhan Kalkan[1], Emad Najafidehaghani[2], Ziyang Gan[2], Fabian Alexander Christian Apfelbeck[1], Uwe Hübner[3], Antony George[2], Andrey Turchanin[2], and Bert Nickel[1] — [1]Faculty of Physics and CeNS, Ludwig-Maximilians-Universität, Geschwister-Scholl-Platz 1, 80539 Munich, Germany — [2]Institute of Physical Chemistry and Abbe Center of Photonics, Friedrich Schiller University Jena, Lessingstr. 10, 07743, Jena, Germany — [3]Leibniz Institute of Photonic Technology (IPHT), Albert-Einstein-Str. 9, 07745, Jena, Germany

Evaporation of organic semiconductors (OSC) on atomically thin transition metal dichalgonides (TMD) for van der Waals (vdW) heterojunctions is limited by obstructed growth of the organic small molecules on the TMD surface. For the realization of such vdW heterojunction devices, we have established a transfer technique that allows for wafer-scale fabrication of 50 nm OSC nanosheets on TMDs. A key feature of this transfer is the controlled release of the ultrathin OSC film from a water-soluble sacrificial film by a suited wetting geometry. We demonstrate functional and highly ordered OSC nanosheets on prefabricated electrodes and TMD monolayers. Devices fabricated this way include unipolar, ambipolar and anti-ambipolar field-effect transistors [1].

References: [1] Kalkan et al., Wafer scale synthesis of organic semiconductor nanosheets for van der Waals heterojunction devices, npj 2D Materials and Applications 5, 92 (2021)

HL 6.5 Mon 11:00 H36

Non-resonant and resonant low-frequency Raman scattering in twisted TMDC bilayers at millikelvin temperatures — •Hendrik Lambers[1], Nihit Saigal[1], Torsten Stiehm[1], Florian Sigger[2], Lukas Sigl[2], Mirco Troue[2], Johannes Figueiredo[2], Alexander Holleitner[2], and Ursula Wurstbauer[1] — [1]Institute of Physics, University of Münster, Münster, Germany — [2]Walter Schottky Institute and Physics Department, TU Munich, Garching, Germany

Twisted TMDC bilayers are subject of many current studies because they can host many body physics and correlated phases such as superconductors and Mott insulators.[1] The moiré potential evolving with a twist angle or lattice constant mismatch could also be exploited to simulate Mott-Hubbard physics. The interlayer coupling within the bilayer correlates with the interlayer breathing mode and the shear mode, which can be characterized by low frequency Raman spectroscopy.[2] We study TMDC heterobilayers of WSe2 and MoSe2 by resonant and non-resonant Raman spectroscopy at millikelvin temperatures. The shear mode is resonant with the exciton transitions in both monolayers and its lineshape and transition energy are modified due to coupling to the exciton continuum. In addition, several sharp and highly resonant modes are observed in the high frequency Raman spectrum. We acknowledge financial support via DFG WU 637/7-1 and SPP2244. [1] L. Sigl et al., Phys. Rev. Research 2, 042044(R) (2020) [2] J. Holler et al., Appl. Phys. Lett. 117, 013104 (2020)

HL 6.6 Mon 11:15 H36

Investigating Twist Angle Dependence of Exciton Resonances in WSe_2/$MoSe_2$ Heterostructures — •Chirag Palekar, Tobias Manthei, Bárbara Rosa, and Stephan Reitzenstein — Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany

Artificially produced TMDC heterostructures (HS) realized by stacking two different TMDC monolayers (ML) are a new class of promising semiconducting heterostructures. Due to their type-II band alignment, TMDC HSs tend to host the spatially indirect interlayer excitons (IX) where electrons and holes are located in conduction and valence bands, respectively, of the different layers. Here we study the twist angle dependence of IX resonances employing micro-photoluminescence excitation (PLE) measurements on twisted WSe_2/$MoSe_2$ heterobilayer. PLE measurements reveal anti-correlation between linewidth and emission energy of IX. Resonant excitation at intralayer exciton energies of constituent ML yields high emission intensity of the IX with linewidth narrowing above 10 meV. We measure a drastic reduction in PL emission from IX for twist angles in the range of 10°- 50° due to large inter-

layer separation. Moreover, we show a noticeable IX exciton resonance separation which increases as function of twist angle i.e. from 0° (67 meV) to 24° (96 meV) along with observable red shift in IX emission energy. This fundamental study of excitons resonances deepens the current understanding of physics of twisted TMDC heterostructures and paves the way for future experiments and theoretical work.

HL 6.7 Mon 11:30 H36

Counterintuitive electric-field dependence of weak antilocalization in a bilayer graphene/WSe_2 heterostructure — Julia Amann[1], Tobias Völkl[1], Tobias Rockinger[1], Denis Kochan[2], Kenji Watanabe[3], Takashi Taniguchi[3], Jaroslav Fabian[2], Dieter Weiss[1], and •Jonathan Eroms[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Regensburg, Germany — [2]Institute of Theoretical Physics, University of Regensburg, Regensburg, Germany — [3]National Institute for Materials Science, Tsukuba, Japan

Heterostructures of bilayer graphene (BLG) and transition metal dichalcogenides (TMDC) were recently proposed as a means of generating a gate-tunable, proximity-induced spin-orbit coupling (SOC) in graphene. Total SOC splitting of the band structure increases monotonically with the out-of-plane electric field, as confirmed by recent charge transport experiments. To elucidate the spin relaxation caused by SOC, weak antilocalization (WAL) experiments are frequently employed. Contrary to the naïve expectation of a monotonic increase of the WAL effect strength with electric field D, we observe a maximum of WAL visibility around $D = 0$. This counterintuitive behaviour originates in the intricate dependence of WAL in graphene on two different spin lifetimes τ_{sym} and τ_{asy}, which are due to spin relaxation caused by the valley-Zeeman and Rashba terms, respectively. Our calculations, based on modeling spin precession by an 8×8 Hamiltonian of BLG with one-sided TMDC show the same non-monotonic dependence on D as the experimental data.

15 min. break

HL 6.8 Mon 12:00 H36

Millikelvin Spectroscopy on Degenerate Exciton Ensembles in van der Waals Bilayers — •Nihit Saigal[1], Torsten Stiehm[1], Hendrik Lambers[1], Florian Sigger[2], Lukas Sigl[2], Mirco Troue[2], Johannes Figueiredo[2], Alexander Holleitner[2], and Ursula Wurstbauer[1] — [1]Institute of Physics, University of Münster, Münster, Germany — [2]Walter Schottky Institute and Physics Department, TU Munich, Garching, Germany

Homo- and hetero-bilayers of transition metal dichalcogenides host a rich variety of interlayer exciton (IX) species where the electrons and holes reside in different monolayers. [1] This leads to enhanced lifetimes of IXs and also imparts them with a permanent dipole moment. [1,2] Such IXs provide an ideal platform for exploring many body physics such as dipole-dipole interactions and Bose-Einstein condensation. [2] We have investigated IXs in a heterobilayer of MoSe2 and WSe2 encapsulated in hBN, using temperature, laser power and time dependent photoluminescence (PL) spectroscopy down to millikelvin temperatures. At lowest temperatures and exciton densities, we observe a single low energy peak in the IX PL spectrum which has been attributed to be a signature of degenerate exciton gas. [2] We observe an unexpected nearly excitation power-independent IX energies at lowest temperatures (10 mK to ~10K) that converts into the well-known dipolar blue-shift at elevated temperatures. We acknowledge financial support by DFG via WU 637/4-2 and No. HO 3324/9-2 and SPP2244.

[1] B. Miller et al., Nano Lett. 17, 5229 (2017). [2] L. Sigl et al., Phys. Rev. Research 2, 042044 (R) (2020).

HL 6.9 Mon 12:15 H36

Infrared photocurrent in transition-metal dichalcogenide heterostructures — Jeong Woo Han[1], Peize Han[2], Yijing Liu[2], Paola Barbara[2], Thomas E. Murphy[3], and •Martin Mittendorff[1] — [1]Universität Duisburg-Essen, Fakultät für Physik, 47057 Duisburg, Germany — [2]Georgetown University, Department of Physics, Washington, 20057 DC, USA — [3]University of Maryland, Institute for Research in Electronics and Applied Physics, College Park, 20740 MD, USA

Heterostructures of transition metal dichalcogenites (TMDCs) have characteristic optical properties like the interlayer excitons due to the band offset between two adjacent TMDC layers. Such heterostructures are promising candidates for photodetectors with higher efficiencies compared to a single TMDC layer, furthermore, the interlayer excitation enables photocurrents at photon energies below the direct bandgap of each of the layers. Here we present measurements on a MoS_2/WS_2 heterostructure at photon energies of around 800 meV, which is significantly below the interlayer exciton. The cross-shaped structure of our samples allows measurements of the heterostructure as well as each individual layer. While at high photon energies photocurrents are observed in each of the layers, the low photon energy only leads to a photocurrent when the heterostructure is illuminated. We interpret this effect to be caused by intraband absorption and subsequent interlayer tunneling.

HL 6.10 Mon 12:30 H36

Strong exciton-plasmon coupling in hybrids of 2D semiconductors and metal supercrystals — •Lara Greten, Robert Salzwedel, Malte Selig, and Andreas Knorr — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Monolayers of transition metal dichalcogenides (TMDC) are direct semiconductors that exhibit tightly bound excitons with uniquely large optical amplitudes. Thus, they are promising for optoelectronic applications and a prime example to investigate excitonic effects.

Complementary, plasmonic supercrystals, that are arrays of metal nanoparticles, support collective plasmon modes. They facilitate an impressive amplification of the electric near-field which allows to tailor electric fields on the nano-scale.

In the presented work, we theoretically consider exciton-plasmon coupling in a hybrid structure of a TMDC layer interacting with a single metal nano-particle or a two-dimensional supercrystal. For this purpose, we develop a Maxwell-Bloch theory where the excitons are described within the Heisenberg equation of motion framework and the metal nano-particles are treated as coupled dipoles in Mie theory.

Our studies reveal new "plexcitonic" eigenstates of the hybrid system. Furthermore, we are able to compute the scattered light in the near- and far-field explicitly and identify signatures of strong exciton-plasmon coupling featuring a Rabi splitting of tens of meV.

HL 7: (Quantum) Transport Properties

Time: Monday 15:00–18:00 Location: H31

HL 7.1 Mon 15:00 H31

A new Time-Domain Approach for Linear Responses and Electrical Conductivity — •Michel Panhans[1,2] and Frank Ortmann[1,2] — [1]Department of Chemistry, TU München — [2]Center for Advancing Electronics Dresden, TU Dresden

Linear-response theory is a powerful theoretical framework to investigate, e.g., electrical and magnetic transport and to compare theory with experiments. Many intriguing quantum-transport phenomena such as quantum Hall effects, spin Hall effects, and quantum spin Hall effects have been derived within this framework. Beyond the general theory, strong efforts have been spent in the last decade to develop efficient and accurate computational methods to calculate charge transport in condensed matter. [1] In our recent work, we present a new time-domain approach to calculate arbitrary linear responses, which is based on a decomposition of the general Kubo formula into time-symmetric and time-antisymmetric parts. [2] The new algorithm is at least 1000 times faster compared to former time evolution schemes. [3] As a showcase, we have investigated the quantum anomalous Hall effect of the disordered Haldane model, where the quantum dynamics of the topological state have been analyzed. The proposed theory and the computational method provide a promising route to access transport phemomena in complpex and topological systems.

[1] Z. Fan et al., Physics Reports, 903, 1-69 (2021)

[2] M. Panhans and F. Ortmann, Phys. Rev. Lett. 127, 016601 (2021)

[3] F. Ortmann et al., Phys. Rev. B 91, 165117 (2015)

HL 7.2 Mon 15:15 H31

Anomalous photo-Nernst currents in $HfTe_5$ — •Waldemar Schmunk, Maanwinder Singh, Alexander Holleitner, and Christoph Kastl — Walter Schottky Institut

Recently, strong evidence of a quasi-quantized 3D quantum Hall effect in non-magnetic semimetals $HfTe_5$ and $ZrTe_5$ has been reported by various groups. Plateau-like features in the Hall conductivity of $HfTe_5$ and $ZrTe_5$ point towards unconventional Hall physics in these 3D semimetals. Additionally, in high-density $HfTe_5$ crystals, an anomalous, but non-hysteretic, Hall conductivity has been reported as well, which points to a non-zero Berry curvature. Here, we present photocurrent measurements of thin $HfTe_5$ films in an external magnetic field. We find a localized edge photo response with opposite polarity at opposite edges. We interpret these edge photocurrents in terms of an anomalous Nernst current arising from the local excitation, the symmetry breaking at the edges, and the anomalous Hall conductivity. Such local photocurrents open the possibility to image anomalous Hall responses and possible related edge state physics in layered quantum materials.

HL 7.3 Mon 15:30 H31

Aharonov-Bohm oscillations and phase-coherence analysis in selectivly grown topological-insulator rings — •Gerrit Behner, Dennis Heffels, Jonas Kölzer, Kristoff Moors, Abdur Rehman Jalil, Erik Zimmermann, Gregor Mussler, Detlev Grützmacher, Hans Lüth, and Thomas Schäpers — Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany

The study of quantum-interference effects in 3D topological insulators is crucial for understanding their transport properties. We present low-temperature magneto-transport measurements on selectively-grown Sb_2Te_3 ring structures. Pronounced Aharonov-Bohm oscillations in the conductance are observed with a major contribution of surface-state transport. The surface contributions are determined from magnetotransport under the application of an in-plane magnetic field. Furthermore we determine the phase-coherence length by analysing universal conductance fluctuations. Finally, we perform quantum transport simulations based on tight-binding calculations using KWANT. The simulations allow us to reproduce the predominant features of the experimental data and further deepen the understanding of the underlying physical effects.

HL 7.4 Mon 15:45 H31

Tunneling spectroscopy simulations of topological insulator (TI) nanoribbons — •Dennis Heffels[1], Declan Burke[2], Malcolm R. Connolly[2], Peter Schüffelgen[1], Kristof Moors[1], and Detlev Grützmacher[1] — [1]PGI-9, FZ Jülich — [2]IC London

TI nanoribbons with proximity-induced superconductivity have been proposed as a possible platform for the realization of Majorana bound states (MBS). Attempts to detect these MBS have received much attention in solid-state physics in recent years. A major goal is to exploit their unusual non-Abelian statistics for topologically protected quantum computing. A very common method for the detection of MBS is tunneling spectroscopy. Implementing this experimental scheme with TI nanoribbons is very challenging, due to stringent requirements on the interfaces of the required heterostructure. Similar experiments on semiconductor nanowires have shown that careful interpretation of the measured data is of prime importance. Here, we present simulations that are tailored to support such tunneling spectroscopy experiments on TI nanoribbons that are proximitized via the top surface with a superconductor. We show that a 3D simulation of the TI-based tunnel junction device is essential to properly describe the proximity effect and disorder, which plays a crucial role. Interestingly, the absence or presence of a zero-bias conductance peak does not always reveal whether the system is in the trivial or the topological regime. We obtain a phase diagram of subgap features in the tunneling conductance as a function of magnetic field and Fermi level.

HL 7.5 Mon 16:00 H31

Transport in high mobility HgTe heterostructures — •Michael Kick, Lena Fürst, Johannes Kleinlein, Saquib Shamim, Hartmut Buhmann, and Laurens W. Mohlenkamp — Experimentelle Physik III, Physikalisches Institut, Universität Würzburg, Am Hubland, 97074

The Fractional Quantum Hall Effect (FQHE) has not yet been observed in the material system of HgTe. Due to recent progress in MBE growth, routinely charge carrier mobilities of HgTe heterostructures of over $\mu > 1 \cdot 10^6\,\mathrm{cm}^2/\mathrm{Vs}$ are obtained which is in the same order of magnitude as in the first reported experimental observation of the FQHE in GaAs/GaAlAs heterostructures. This opens up new prospects for transport investigations into the long time still open question of fractional states in this material system.

In 2-dimensional HgTe quantum wells, transport measurements show well pronounced quantum Hall plateaus for all filling factors, but no indication of any fractional state. High magnetic field measurements show a prolonged $\nu = 1$ plateau and a transition to an insulating state. Intriguingly, the $\nu = 1$ plateau exhibits a transition to an insulating state for filling factor $\nu = 1/2$.

Another possibility to observe the FQHE in HgTe is provided by the 2D surface states of a 3D topological insulator. High mobility layers, $\mu > 2 \cdot 10^6\,\mathrm{cm}^2/\mathrm{Vs}$, of tensil strained HgTe are subject of extensive magneto-transport investigations. First results reveal so far unresolved features predicted by recent band structure calculations, while the search for FQHE states is still on.

30 min. break

HL 7.6 Mon 16:45 H31

Structure-imposed electronic topology in cove-edged graphene nanoribbons — •Florian Arnold[1], Tsai-Jung Liu[1], Agnieszka Kuc[2], and Thomas Heine[1,2,3] — [1]Technische Universität Dresden, Dresden, Germany — [2]HZDR, Leipzig, Germany — [3]Yonsei University, Seoul, Republic of Korea

Cove-edged zigzag graphene nanoribbons (ZGNR-C) take their name from a regular pattern of coves which is formed by removing one terminal CH group per length unit on each zigzag edge. Based on three structural parameters that unambiguously characterize the atomistic structure of ZGNR-C, we present a scheme that classifies their electronic state, i.e., if they are metallic, topological insulators or trivial semiconductors, for all possible widths N, unit lengths a and cove position offsets at both edges b, thus showing the direct structure-electronic structure relation. We further present an empirical formula to estimate the band gap of the semiconducting ribbons from N, a, and b. Finally, we show possible ribbon terminations, which should give guidance for future synthetic efforts to realize new topological ZGNR-C with large band gap and to realize topologically protected edge states in these systems.

HL 7.7 Mon 17:00 H31

Temperature and magnetic field-dependent noise measurements in GaAs/AlGaAs quantum rings — •Birkan Düzel[1], Olivio Chiatti[1], Sven S. Buchholz[1], Andreas D. Wieck[2], Dirk Reuter[3], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44780 Bochum, Germany — [3]Optoelektronische Materialien und Bauelemente, Universität Paderborn, 33098 Paderborn, Germany

Nanostructured materials offer a way to investigate phase-coherent transport of electrons and the resulting interference effects in systems. Measurements of the white noise have been used to determine system properties such as the elctron temperature T_e. Recently noise measurements in quantum ring structures have revealed white noise exceeding the expected thermal noise [1].

This work investigates the dependence of the excess noise in quantum rings on the bath temperature and applied magnetic field. Noise measurements in Al_xGa_xAs/GaAs-based etched quantum rings are performed in equlibrium with bath temperatures ranging from 15 mK to 4.2 K and magnetic fields ranging from -50 mT to 50 mT. Additionally, magnetotransport measurements are performed at 1 K with magnetic fields ranging from 0 T to 12 T.

[1] C. Riha *et al.*, Appl. Phys. Lett. **117**, 063102 (2020).

HL 7.8 Mon 17:15 H31

Coplanar waveguides for electronic measurements at terahertz frequencies — •Sergey Lavrentyev[1], Johannes Gröbmeyer[1], Gerhard Huber[2], and Alexander Holleitner[1] — [1]Walter Schottky Institut and Physics Department, TU Munich — [2]Walther-Meißner-Institut and Physics Department, TU Munich

We explore the usability of gold coplanar waveguides on a sapphire substrate as contacts for electronic transport measurements on 2D and topological materials in the terahertz regime. Our simulations reveal different modes with low attenuation. For the coplanar waveguide,

we find the lowest attenuation in even modes compared to the predominance of odd modes in coplanar strip geometries. Moreover, our results show a frequency dependent behavior of the complex refractive index of the modes at sub-millimeter wavelengths. We find that gold coplanar waveguides are well suited for electronic measurements at terahertz frequencies.

HL 7.9 Mon 17:30 H31

Influence of fixed scatterers of various sizes and densities on the giant negative magnetoresistance in two dimensional electron gases. — •Janus Lammert[1], Beate Horn-Cosfeld[1], Jakob Schluck[1], Mihai Cerchez[1], Thomas Heinzel[1], Klaus Pierz[2], Hans Werner Schumacher[2], and Dominique Mailly[3] — [1]Institut für Experimentelle Physik der kondensierten Materie, Heinrich-Heine-Universität, Universitätsstraße 1, 40225 Düsseldorf, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [3]CNRS, Univ. Paris-Sud, Université Paris-Saclay, C2N Marcoussis, 91460 Marcoussis, France

The giant negative magnetoresistance (GNMR) in a 2DEG is studied through the effects produced by artificial scatterers (Lorentz arrays [1]) with varying scatterer density. The influence of the different types and ratios of scattering mechanisms shed light on both the temperature independent and the temperature dependent parts of the GNMR [2]. The effect of scattering on the shape and amplitude of the GNMR will be discussed. [1] H. A. Lorentz, Proc. R. Acad. Sci. Amsterdam 7, 438, 1905, [2] B. Horn-Cosfeld et al. Phys. Rev. B 104, 045306, 2021

HL 7.10 Mon 17:45 H31

First-principles calculations of temperature-dependent transport in semiconductors — Dan Han, Andreas Held, •Masako Ogura, and Hubert Ebert — Ludwig-Maximilians-University Munich, Munich, Germany

The carrier mobility is one of the central properties of semiconductors. So far, most first-principles calculations of carrier mobilities for bulk semiconductors are based on the Boltzmann transport equation. In this contribution, we present an alternative scheme to evaluate temperature dependent carrier mobilities.

As a starting point, we calculate the electronic structures using the Korringa-Kohn-Rostoker (KKR) Green's function method in combination with the coherent potential approximation (CPA) alloy theory allowing for chemical as well as temperature induced disorder in the material. Dealing with undoped elemental or compound systems, we account this way for lattice vibrations, i.e. atom displacements depending on temperature, which affect the electronic structure and also cause a finite electric resistivity. The corresponding electric conductivity is calculated by means of the Kubo-Greenwood formula implemented on the basis of the KKR-CPA. The carrier mobility is evaluated from the resulting temperature-dependent conductivity and carrier concentration. Results for the intrinsic transport properties of undoped elemental and compound semiconductors will be presented.

HL 8: Quantum Dots and Wires 2: Optics 1

Time: Monday 15:00–18:15 Location: H32

Invited Talk HL 8.1 Mon 15:00 H32

Crux of Using the Cascaded Emission of a Three-Level Quantum Ladder System to Generate Indistinguishable Photons — •Eva Schöll[1,2], Lucas Schweickert[2], Lukas Hanschke[1,3], Katharina D. Zeuner[2], Friedrich Sbresny[3], Thomas Lettner[2], Rahul Trivedi[4], Marcus Reindl[5], Saimon Filipe Covre da Silva[5], Rinaldo Trotta[6], Jonathan Finley[3], Jelena Vučković[4], Kai Müller[3], Armando Rastelli[5], Val Zwiller[2], and Klaus D. Jöns[1,2] — [1]PhoQS, CeOPP, and Department of Physics, Paderborn University, Germany — [2]KTH Stockholm, Sweden — [3]WSI, MCQST and TUM Munich, Germany — [4]Stanford University, California, USA — [5]JKU Linz, Austria — [6]Sapienza University Rome, Italy

Single and indistinguishable photons are basic building blocks for many quantum technology applications. Here (PRL, **125**, 233605 (2020)), we investigate the degree of indistinguishability of cascaded photons emitted from a three-level quantum ladder system; in our case the biexciton-exciton cascade of semiconductor quantum dots. Despite unprecedented single-photon purity, we theoretically show that the indistinguishability for both emitted photons is inherently limited by the ratio of the lifetimes of the excited and intermediate states. We confirm this finding both experimentally and with quantum optical simulations by comparing the quantum interference visibility of cascaded and non-cascaded exciton emission of the same quantum dot. Based on our model, we propose photonic structures or stimulated emission (PRL, **128**, 093603, (2022)) from the excited to the intermediate state to increase the lifetime ratio and overcome the limited indistinguishability.

HL 8.2 Mon 15:30 H32

Carrier dynamics in quantum-dot tunnel- injection structures: microscopic theory and experiment — •Michael Lorke[1], Igor Khanonkin[2], Stephan Michael[1], Johann Peter Reithmaier[3], Gadi Eisenstein[2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Otto-Hahn-Allee 1, Bremen, 28359, Germany — [2]Electrical Engineering Department and Russel Berrie Nanotechnology Institute, Technion, Haifa, 32000, Israel — [3]Technische Physik, Institute of Nanostructure Technologies and Analytics, Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Kassel, 34132, Germany

Among the challenges for the next generation of semiconductor lasers is the enhancement of their modulation speed to satisfy the need for higher data transfer rates. For this purpose, tunnel injection lasers are an appealing concept, as they promise improved modulation rates and better temperature stability. Moreover, they eliminate a major detrimental effect of quantum dot lasers, which is the gain nonlinearity caused by hot carriers. It is shown in this work how the aforementioned improvements depend on the design of tunnel-injection devices. We perform a theory-experiment comparison on scattering times in tunnel injection devices to highlight the importance of alignment between the injector well and the quantum dot ensemble. It is shown how differences in the coupling to the injector quantum well caused by the alignment lead to scattering times into the quantum dot ensemble that vary by an order of magnitude.

HL 8.3 Mon 15:45 H32

Statistical limits for entanglement swapping with independent semiconductor quantum dots — •Jingzhong Yang[1], Michael Zopf[1], Pengji Li[1], Nand Lal Sharma[2], Weijie Nie[2], Frederik Benthin[1], Tom Fandrich[1], Eddy Patric Rugeramigabo[1], Caspar Hopfmann[2], Robert Keil[2], Oliver. G. Schmidt[2,3,4], and Fei Ding[1,5] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Schneiderberg 39, 30167 Hannover, Germany

Semiconductor quantum dots are promising constituents for future quantum communication. Here we explore the limits for sources of polarization-entangled photons from biexciton-exciton cascade of the quantum dots. We stress the necessity of tuning the exciton fine structure, and explain why the time evolution of photonic entanglement in quantum dots is not applicable for large quantum networks. We identify the critical device parameters and present a numerical model for benchmarking the device scalability in order to bring the realization of distributed semiconductor-based quantum networks one step closer to reality.

HL 8.4 Mon 16:00 H32

Maximally entangled and GHz-clocked on-demand photon pair source — •Caspar Hopfmann[1], Weijie Nie[1], Nand Lal Sharma[1], Carmen Weigelt[1], Fei Ding[2], and Oliver G. Schmidt[1,3,4] — [1]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany — [3]Material Systems for Nanoelectron-

ics, Technische Universität Chemnitz, 09107 Chemnitz, Germany — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, 01062 Dresden, Germany

We present a 1 GHz-clocked, maximally entangled and on-demand photon pair source based on droplet etched GaAs quantum dots using two-photon excitation. By employing these GaP microlens-enhanced devices in conjunction with their substantial brightness, raw entanglement fidelities of up to 0.95 and post-selected photon indistinguishabilities of up to 0.93, the suitability for quantum repeater based long range quantum entanglement distribution schemes is shown. Comprehensive investigations of a complete set of polarization selective two-photon correlations facilitate an innovative method to determine the extraction and excitation efficiencies directly - opposed to commonly employed indirect techniques. Additionally, time-resolved analysis of Hong-Ou-Mandel interference traces reveal an alternative approach to the investigation of pure photon dephasing.

HL 8.5 Mon 16:15 H32

Photoneutralization of charges in GaAs quantum dot based entangled photon emitters — Jingzhong Yang[1], Tom Fandrich[1], •Frederik Benthin[1], Robert Keil[2], Nand Lal Sharma[2], Weijie Nie[2], Caspar Hopfmann[2], Oliver G. Schmidt[2,3,4], Michael Zopf[1], and Fei Ding[1,5] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Germany — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz, Germany — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden, Germany — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Germany

Semiconductor-based quantum dot emitters are an attractive source for generating pairwise photonic entanglement and a promising constituent of photonic quantum technologies. However, quantum dots typically suffer from luminescence blinking, lowering the efficiency of the source and hampering their scalable application in quantum networks. We investigate the spectral and quantum optical response of the quantum dot emission by introducing an additional wavelength tunable gate laser. Under two-photon resonant excitation of the neutral biexciton in a GaAs/AlGaAs quantum dot, the blinking of the neutral exciton emission was observed. Our finding demonstrates that the emission blinking can be actively suppressed by controlling the balance of free electrons and holes in the vicinity of the quantum dot thereby significantly increasing the quantum efficiency by 30%.

30 min. break

HL 8.6 Mon 17:00 H32

Franson interference on a resonantly driven biexciton cascade — •Marcel Hohn[1], Kisa Barkemeyer[2], Matthias Kunz[1], Arsenty Kaganskiy[1], Samir Bounouar[1], Alexander Carmele[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörper Physik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Theoretische Physik, Technische Unviersität Berlin, 10623 Berlin, Germany

The deterministic generation of entangled photon pairs is of special interest for applications in quantum communication and computation. As many experiments focus on entanglement in the polarization base, energy-time entangled photons used for Franson interference offer the advantage of high robustness in long-distance fiber transmission. We report on Franson measurements performed in cw mode on the resonantly driven biexciton cascade of a deterministically fabricated quantum dot device. The two-photon visibility of such a three-level system crucially dependents on the decay rates of the ideally long upper- and short living intermediate state [1]. A relation hard to achieve for the biexciton cascade, where the lifetime of the biexciton state is usually short compared to the exciton state. Nevertheless, our measurements yield a high two-photon visibility up to (73 ± 2)%, surpassing the CHSH inequality of 70.7% [2]. This result demonstrates the high potential of generating energy time entangled photons in a resonantly driven biexciton cascade.

[1] K. Barkemeyer, et al., Phys. Rev. A, 103, 62423 (2021)
[2] J. F. Clauser, et al., Phys. Rev. Lett. 23, 880 (1969)

HL 8.7 Mon 17:15 H32

Red Detuned Excitation of a Quantum Dot — •Yusuf Karli[1], Florian Kappe[1], Thomas Bracht[2], Julian Münzberg[1], Tim Seidelmann[3], Vollrath Martin Axt[3], Saimon Covre da Silva[4], Armando Rastelli[4], Vikas Remesh[1], Doris Reiter[5], and Gregor Weihs[1] — [1]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [2]Institut für Festkörpertheorie, Universität Münster, Münster, Germany — [3]Theoretische Physik III, Universität Bayreuth, Bayreuth, Germany — [4]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Linz, Austria — [5]Condensed Matter Theory, Department of Physics, TU Dortmund, Dortmund, Germany

Semiconductor quantum dots have emerged as promising sources of highly indistinguishable single photons. To operate as an on-demand photon source, a quantum dot must be prepared in its exciton state, for which, several protocols exist. A recent remarkable theoretical discovery, also presented at this conference, showed that the exciton state in a quantum dot can be efficiently populated by two red-detuned pulses in a swing-up mechanism. We demonstrate the experimental implementation of this mechanism relying on amplitude-shaping of a broadband laser pulse in a 4f shaper including a spatial light modulator. The decisive advantage of our scheme is that both pulses are red-detuned and therefore, no higher-lying states of the quantum dot will be directly addressed. Our results contribute towards an effortless method for generating high-purity single photons, yet most importantly, removing the need for stringent polarization filtering.

HL 8.8 Mon 17:30 H32

Dephasing mechanisms revealed by two-photon coincidence measurements — •Julian Wiercinski, Moritz Cygorek, and Erik M. Gauger — SUPA, Institute of Photonics and Quantum Sciences, Heriot-Watt University, Edinburgh, UK

Cooperative effects of entangled quantum emitters play a key role in quantum technologies like, e.g., quantum computing and are known to influence their light emission as well as absorption - a key ingredient for highly efficient quantum batteries and light harvesting complexes. Only recently, cooperative emission of two quantum dots has been observed experimentally.

Inspired by these results we use numerically complete methods to theoretically investigate the impact of different dephasing mechanisms on the cooperative emission of two quantum dots. We show that different dephasing mechanisms lead to severe qualitative differences in the two-photon coincidence signals. These can be explained by the influence of dephasing on the dynamics of the inter-emitter entanglement. Therefore, we argue, two-photon coincidence measurements make dephasing visible in the experiment acting as a probe for underlying dephasing mechanisms.

HL 8.9 Mon 17:45 H32

Bandwidth Limit in Optically Detected Single Electron Tunneling Events — •Jens Kerski[1], Hendrik Mannel[1], Pia Lochner[1], Eric Kleinherbers[1], Annika Kurzmann[2], Arne Ludwig[3], Andreas D. Wieck[3], Jürgen König[1], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]2nd Institute of Physics, RWTH Aachen University, Germany — [3]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Measurements of single quantum processes have recently attracted increasing attention. One example is the counting of single electron tunnel events in quantum dots. These individual quantum jumps are usually measured electrostatically. However, new optical detection methods have been developed that promise higher time resolution, although their potential has not yet been fully investigated. Here, we study the resonance fluorescence of the excitonic transition from a self-assembled quantum dot embedded in a tailored diode structure.

We detect the optical signal with single photon resolution and use a post-processing procedure to identify the optimal bandwidth for the analysis of our data. We demonstrate that we can evaluate our data with up to 175 kHz bandwidth and show how the chosen bandwidth affects the determined tunneling rates and the evaluation by full counting statistics. Using a simple model, we discuss how the Poisson distribution of the photons limits the time resolution even in ideal measurements and propose how a time resolution of more than 1 MHz could be achieved.

HL 8.10 Mon 18:00 H32

The Origin of Antibunching in Resonance Fluorescence — •Lukas Hanschke[1,2], Lucas Schweickert[3], Juan Camilo López Carreño[4], Eva Schöll[1,3], Katharina D. Zeuner[3], Thomas Lettner[3], Eduardo Zubizarreta Casalengua[4], Mar-

cus Reindl[5], Saimon Filipe Covre da Silva[5], Rinaldo Trotta[6], Jonathan J. Finley[2], Armando Rastelli[5], Elena del Valle[4,7], Fabrice P. Laussy[4,8], Val Zwiller[3], Kai Müller[2], and Klaus D. Jöns[1] — [1]PhoQS, CeOPP, and Department of Physics, Paderborn University, Germany — [2]WSI, MCQST and TU Munich, Germany — [3]KTH Stockholm, Sweden — [4]University of Wolverhampton, UK — [5]JKU Linz, Austria — [6]Sapienza University Rome, Italy — [7]Universidad Autónoma de Madrid, Spain — [8]Moscow, Russia

We present measurements that prove that the simultaneous observation of sub-natural linewidth and antibunching of resonance fluorescence is not possible. High-resolution spectroscopy reveals the sharp spectral feature of the weak driving regime with a vanishing component of incoherently scattered light. Filtering the emission in the order of the Fourier limited linewidth leads to the loss of antibunching in the correlation measurement. Our theoretical model identifies two-photon interference between the coherent and incoherently scattered light as the origin of antibunching. This prefigures schemes to achieve a source of single photons with sub-natural linewidth [PRL 123, 170402 (2020)].

HL 9: Focus Session: Exceptional Points and Non-Hermitian Physics in Semiconductor Systems

The strong recent interest into nonconservative/non-Hermitian systems and their exotic degeneracies - so-called exceptional points - is driven by the occurrence of rather unconventional and fascinating physics and by potential applications such as ultrasensitive sensing, orbital angular momentum lasers, and topological energy transfer for mode and polarization conversion. This Focus Session aims at discussing the latest experimental and theoretical results in the rapidly developing field with special focus on semiconductor systems, where engineering the interplay of coupling, dissipation and amplification mechanisms offers novel opportunities. Moreover, we give an overview to young scientists of the exciting possibilities of interdisciplinary research in this field.

Organized by Sebastian Klembt and Jan Wiersig

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

Invited Talk HL 9.1 Mon 15:00 H33

Exceptional points in optics: From bulk materials to one-dimensional confined systems — •Chris Sturm — Felix Bloch Institute for Solid State Physics, Universität Leipzig, Leipzig, Germany

The research of exceptional points (EP) was initiated by W. Voigt in 1902 when he discovered that for certain directions in orthorhombic crystals only one circular polarized eigenstate exists, as soon as absorption sets in [1]. These directions corresponds to EPs in the momentum space. The presence of such EP is not limited to orthorhombic crystals only and appears in many optical systems. Here we present an overview of the appearance and the properties of these EPs in bulk crystal and optically one-dimensional confined systems. We show that the properties of the EPs in bulk crystals are determined by the dielectric function and the symmetry of the crystal, which allows to distinguish between optically biaxial materials having triclinic, monoclinic or orthorhombic crystal symmetry. In the presence of an optical confinement, like in thin films or microresonators, EPs can even appear in systems consisting of optically uniaxial materials, which was recently observed experimentally (e.g. Ref. [2]). Furthermore, in contrast to bulk crystals, the properties of the EPs are determined not only by the dielectric function of the materials but depends also on the design of the system, e.g., film thickness and confinement properties.

[1] W. Voigt, Ann. Phys. **314**, 367 (1902).
[2] S. Richter, Phys. Rev. Lett. **123**, 227401 (2019).

Invited Talk HL 9.2 Mon 15:30 H33

Complex Skin Modes in Non-Hermitian Coupled Laser Arrays — •Mercedeh Khajavikhan and Yuzhou Liu — 1002 Childs Way, Los Angeles, CA 90089

In the realm of non-Hermitian physics, the possibility of complex and asymmetric exchange interactions between a network of oscillators has been theoretically shown to lead to novel behaviors like delocalization, skin effect, and bulk-boundary correspondence. While the ramifications of these theoretical works in optics have been recently pursued in synthetic dimensions, the Hatano-Nelson model has yet to be realized in real space. In this work, by using active optical oscillators featuring non-Hermiticity and nonlinearity, we introduce an anisotropic exchange between the resonant elements in a lattice, an aspect that enables us to observe the non-Hermitian skin effect, phase locking, and near-field beam steering in a Hatano-Nelson laser array. This work can open up new regimes of phase-locking in lasers while shedding light on the fundamental physics of non-Hermitian systems.

15 min. break

Invited Talk HL 9.3 Mon 16:15 H33

Non-Hermitian effects in exciton polaritons — •Eliezer Estrecho — ARC Centre of Excellence in Future Low-Energy Electronics Technologies and Department of Quantum Science and Technology, Research School of Physics, The Australian National University, Canberra, ACT 2601, Australia

I will present our experimental results highlighting non-Hermitian effects in exciton-polariton systems—quasiparticles arising from the strong coupling of excitons in semiconductors and photons in a cavity. This hybrid system is naturally non-Hermitian due to inherent loss and gain. The former arises from photon leakage through the cavity mirrors and the short lifetime of excitons, while the latter arises from an external pump used to maintain the density, for example, in the creation of Bose-Einstein condensates.

Using exciton-polariton condensates, we demonstrate exceptional points in the deformation parameter space of a quantum billiard. In particular, we are able to trace the energy levels close to the exceptional point, observe the topological Berry phase, and demonstrate the chirality of the state.

We also observe exceptional points in momentum space. By studying the energy and pseudospin structure, we directly measured a novel non-Hermitian topological invariant and differentiated it from its Hermitian counterparts. Furthermore, we also observe an anomalous dispersion resulting from the dissipative coupling of excitons and photons. The resulting inverted dispersion leads to a negative-mass propagation where the particles move in the opposite direction to their momentum.

Invited Talk HL 9.4 Mon 16:45 H33

Nonlinear dynamics and exceptional points in exciton-polariton condensates — •Stefan Schumacher — Physics Department & CeOPP, Paderborn University, Germany

Non-Hermitian physics and exceptional points have attracted significant attention in the past two decades. Enormous progress has been made for example in non-Hermitian optics. Non-Hermitian degeneracies and exceptional points have also been demonstrated for exciton polaritons in semiconductor microcavities [1]. For non-resonant excitation, polaritons can spontaneously exhibit macroscopic coherence, known as polariton condensation. The non-equilibrium nature of polariton condensates makes them perfect for studies of non-Hermitian physics. The gain can be tailored by varying the spatial optical pump profile, for example allowing realization of PT-symmetric lattices [2]. The polariton-polariton interaction gives rise to inherently nonlinear phenomena such as vortex formation [3]. Recently, we reported the observation of an exceptional point in a double-well potential [4]. There, the polariton condensate can be localized in one well and switched off by an additional optical excitation in the other well that surprisingly induces additional loss [4]. The nonlinearity and related energy

blueshift also allows to approach the exceptional point. This work paves the way to explore non-Hermitian physics in a system with strong nonlinearity and in tailored potential energy landscapes. [1] T. Gao et al., Nature 526, 554-558 (2015). [2] X. Ma et al., New Journal of Physics 21, 123008 (2019). [3] X. Ma et al., Nature Communications 11, 897 (2020). [4] Y. Li et al., arXiv:2101.09478 (2021).

HL 9.5 Mon 17:15 H33

Exceptional points in anisotropic ZnO thin films — •Sebastian Henn, Evgeny Krüger, Chris Sturm, and Marius Grundmann — 1 Universität Leipzig, Faculty of Physics and Earth Sciences, Felix Bloch Institute for Solid State Physics, Linnéstr. 5, 04103 Leipzig, Germany

In this talk we present findings regarding the existence of exceptional points in anisotropic thin films. Analogous to degeneracies of optic axes in absorptive biaxial materials, so-called singular optic axes [1], anisotropic transparent structures contain exceptional points in momentum space, where two orientation- and polarization-dependent modes are equal in resonance energy and lifetime. The latter is determined by dissipative photon loss at the interfaces, which renders the system non-Hermitian. This phenomenon has been observed in dielectric optical microcavities [2] and principally exists also in anisotropic thin films, where resonances correspond to well-known Fabry-Pérot modes. We show results of rigorous calculations for m-ZnO thin films, based on scattering matrices whose complex poles correspond to the resonance energies. This allows to find exceptional points in two-dimensional momentum space and we confirm important characteristics, such as a square-root topology and circularity.

[1] Grundmann et al., Phys. Status Solidi RRL 11.1 1600295 (2017)
[2] S. Richter et al., Phys. Rev. Lett. 123 227401 (2019)

HL 10: Nitrides

Time: Monday 15:00–18:30 Location: H34

HL 10.1 Mon 15:00 H34

Degradation of the electrooptical properties of UVB LEDs observed by temperature dependent electroluminescence spectroscopy — •Jakob Höpfner[1], Priti Gupta[1], Martin Guttmann[1], Jan Ruschel[2], Johannes Glaab[2], Tim Kolbe[2], Arne Knauer[2], Tim Wernicke[1], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

The operation of UVB-LEDs induces changes in their electrooptical characteristics, especially a gradual reduction in the emission power. As the lifetime of a device is a key property for its application, it is important to understand the microscopic processes governing their degradation behavior. We report an investigation on UVB-LEDs emitting at 310 nm before and after aging for 1000 h at 100 mA (67 Acm^{-2}) and a heatsink temperature of 70 °C using temperature(T)-dependent electroluminescence spectroscopy from 20 K - 340 K. Before aging, the external quantum efficiency (EQE) at 10 mA gradually increases with decreasing temperature from 0.8 % at 340 K to 1.8 % at 150 K and stays at that level for lower temperatures, indicating that EQE(T) is dominated by the radiative recombination efficiency. After 1,000 h of operation, the EQE has reduced to 0.45 % at 340 K and it shows a maximum of 1.4 % at 80 K. Also below 80 K, the EQE again decreases. These findings suggest a stress-induced reduction of both the radiative recombination efficiency and the carrier injection efficiency.

HL 10.2 Mon 15:15 H34

Short pulse operation of (Al,In)GaN laser diodes to increased linewidth and decreased coherence for laser displays — •Jannina J. Tepass[1], Lukas Uhlig[1], Dominic Kunzmann[1], Georg Brüderl[2], and Ulrich T. Schwarz[1] — [1]Institute of Physics, Chemnitz University of Technology, 09126 Chemnitz, Germany — [2]ams OSRAM Group, 93055 Regensburg, Germany

Red, green, and blue (RGB) laser diodes are used as the light source in laser displays in particular laser glasses for augmented, virtual, and mixed reality (AR/VR/MR). A narrow linewidth and corresponding high coherence will lead to speckles and non-uniform scattering at the gratings used for the projection into the eye box. Therefore, it is necessary to enhance the spectral linewidth of each laser diode to about 10 nm.

Mode competition causes a dynamic broadening of the laser spectrum already to about 1 nm. Here, we explore short pulse modulation to further increase the linewidth. A wavelength chirp at the beginning of each pulse is generating additional broadening at a pulse length of the order of a few nanoseconds. This chirp is the consequence of overshooting the carrier density above the threshold carrier density, resulting in a blue-shifted gain spectrum.

We investigate these broadening effects in blue and green (Al,In)GaN and red (Al,Ga)InP laser diodes with the help of a streak camera experiment. We took measurements for varying pulse length to analyse the spectral changes of those laser diodes and the behaviour with different pulse length.

HL 10.3 Mon 15:30 H34

Investigation of lateral charge carrier diffusion via micro-photoluminescence in InGaN MQWs and SQWs — •Conny Becht[1], Ulrich T. Schwarz[1], Michael Binder[2], Bastian Galler[2], Jürgen Off[2], Maximilian Tauer[2], Alvaro Gomez Iglesias[2], Heng Wang[2], and Martin Strassburg[2] — [1]Institute of Physics, Chemnitz University of Technology, 09126, Chemnitz, Germany — [2]ams-OSRAM International GmbH, Leibnizstr. 4, 93053 Regensburg, Germany

InGaN multi-quantum well (MQW) structures are used to obtain highly efficient blue light emitting diodes (LED). After the injection of carriers into the active layer of blue LEDs, a part of the carriers diffuses laterally before recombining (non-)radiatively. The diffusion behaviour in InGaN MQWs is up to now poorly understood.

In this study InGaN MQWs and single QWs (SQW) are investigated by micro-photoluminescence at room temperature. To study the diffusion behaviour, the excitation spot is decoupled from the detection area, which we call a pinhole scan. With the size of the excitation spot known, conclusions about the diffusion length of the charge carriers after optical pumping can be drawn. For deeper analysis of the diffusion behaviour the excitation density is varied and an external bias can be applied in addition.

The results show a long-range diffusion up to several 10 μm's. The energy shows a increasing blue shift with higher excitation power at the center (i.e. excitation spot).

HL 10.4 Mon 15:45 H34

Threshold and gain measurements of AlGaN-based UVC lasers — •Markus Blonski[1], Giulia Cardinali[1], Bernd Witzigmann[2], Norman Susilo[1], Daniel Hauer Vidal[1], Martin Guttmann[1], Tim Wernicke[1], and Michael Kneissl[1] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Department Elektrotechnik-Elektronik-Informationstechnik (EEI), University Erlangen-Nürnberg (FAU), Erlangen, Germany

Recently, first UVC laser diodes were demonstrated, with relatively high threshold current densities and pulsed operation. Critical parameters affecting the threshold are the electron and hole wavefunctions overlap and the optical confinement factor. While thicker quantum wells (QWs) yield higher confinement factors, the wavefunctions overlap in AlGaN QWs thicker than 3 nm is reduced due to the quantum-confined Stark effect (QCSE). In this work, the influence of QW thickness on lasing threshold and optical gain in AlGaN-based optically pumped lasers with SQWs between 3 nm and 12 nm emitting at 275 nm is studied. The lasing peak shifts to shorter wavelengths with respect to the spontaneous emission in thin wells, while the widest wells ex- hibit a red-shift. Similar lasing threshold power density was observed for all samples at around 1.4MW cm^{-2}. Variable stripe length method measurements showed positive net gain in all the samples with compa- rable values of differential net gain. Simulations of the material gain show that higher energy states contribute to the gain in wider wells, whereas in the 3 nm AlGaN QW the ground state provides the gain.

HL 10.5 Mon 16:00 H34

Drift-diffusion simulation of UVC-LEDs with varied emission

wavelength — •F. Bilchenko[1], A. Muhin[1], M. Guttman[1,2], T. Wernicke[1], F. Römer[3], B. Witzigmann[3], 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 — [3]Friedrich-Alexander-Universität Erlangen-Nürnberg, Lehrstuhl für Optoelektronik, Erlangen, Germany

The external quantum efficiency (EQE) of AlGaN-based deep ultraviolet (UVC) light emitting diodes (LEDs) decreases strongly for emission wavelengths (λ) below 240 nm by two orders of magnitude from 1% (240 nm) to 0.01% (217 nm). We showed that the light extraction efficiency (LEE) on wafer level decreases only by a factor of less than 3 from 4% (240 nm) to 1.5% (217 nm), leaving current injection efficiency (CIE) and radiative recombination efficiency (RRE) as possible major causes for the EQE decrease. In order to estimate the contribution of the CIE and RRE to the EQE we analyse measured electroluminescence characteristics by simulating an LED-series with nominally identical heterostructure but varying AlGaN composition in the active region in order to achieve λ ranging from 217 nm to 263 nm. Our results suggest that, in this wavelength range, the change in CIE contributes greatly to the decrease in EQE. For devices emitting at 263 nm and 249 nm the CIE stays roughly constant at around ∼50%, showing a significant decrease towards shorter λ, i.e. 48% at 240 nm and 2% at 217 nm. Based on these results, it appears that improvement of the CIE is paramount for achieving high-power UVC-devices.

HL 10.6 Mon 16:15 H34

Realizing tunnel junctions in AlGaN-based UVC light emitting diodes emitting at 232 nm — •Verena Montag[1], Frank Mehnke[1], Martin Guttmann[2], Luca Sulmoni[1], Christian Kuhn[1], Johannes Glaab[2], Tim Wernicke[1], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

An ultraviolet C (UVC) -transparent p-AlGaN layer is needed to overcome the strong absorption of p-layers in deep UV light emitting diodes (LEDs). However, transparent p-AlGaN layers exhibit high sheet and contact resistances resulting in very large operating voltages. A promising alternative to standard p-contacts is the injection of holes into the AlGaN quantum well by tunnel heterojunctions (TJs). This allows for low resistivity n-layers and n-contacts on both sides of the device. We have successfully demonstrated fully transparent AlGaN-based TJ-LEDs emitting at 232 nm grown entirely by metal-organic vapor phase epitaxy. A thin GaN interlayer was implemented to enhance carrier tunneling at the TJ interface. Typically, the operating voltages, the output powers and the external quantum efficiencies of a 0.15 mm^2 TJ-LED featuring a 8 nm thick GaN interlayer are 24 V, 77 μW and 0.29%, respectively, measured on wafer at 5 mA in cw operation. This is the first reported TJ-LED in the wavelength range below 240 nm.

15 min. break

HL 10.7 Mon 16:45 H34

Influence of the AlGaN MQW growth temperature on the performance characteristics of DUV-LEDs with emission at 235 nm — •Marcel Schilling, Norman Susilo, Giulia Cardinali, Anton Muhin, Frank Mehnke, Tim Wernicke, and Michael Kneissl — Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany

The realization of efficient deep ultraviolet light emitting diodes (DUV-LEDs) with emission wavelength near 235 nm is very challenging as the photon energy is very close to the band gap of AlN. For AlGaN layers with high Al mole fractions point defects like vacancies and impurities are easily incorporated during metal organic vapor phase epitaxy (MOVPE). Deep levels in the energy band gap associated with these point defects play a decisive role in non-radiative carrier recombination and consequently low internal quantum efficiency (IQE) of DUV-LEDs. Therefore, the understanding of the generation of point defects during the growth of high Al containing AlGaN layers is crucial for the development of efficient DUV-LEDs. In this study the influence of the AlGaN MQW growth temperature on the point defect density in 235 nm DUV-LEDs is investigated. DUV-LEDs were grown by MOVPE with MQW growth temperatures between 850 °C and 1100 °C. Temperature dependent PL measurements show that the point defect incorporation might be controlled with the MOVPE growth temperature. Electroluminescence measurements showed an increase in optical output power from 5 μW up to 300 μW at 20 mA for 235 nm DUV-LEDs for increasing MQW growth temperatures from 850°C up to 1020 °C.

HL 10.8 Mon 17:00 H34

Temperature dependent electroluminescence spectroscopy on AlGaN-based 235nm far-UVC LEDs with different active region growth temperature — •Paula Vierck, Jakob Höpfner, Martin Guttmann, Marcel Schilling, Luca Sulmoni, Anton Muhin, Tim Wernicke, and Michael Kneissl — Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany

Light emitting diodes (LEDs) emitting in the far ultraviolet-C (far-UVC) spectral range are promising for applications such as sensing and monitoring of gases, and skin safe disinfection. To improve their external quantum efficiency (EQE), it is crucial to understand the influence of growth parameters on their performance. In this paper, AlGaN-based LEDs emitting around 235 nm were investigated, while their active region growth temperature (T_{growth}) was varied between 900 °C and 1100 °C. Temperature dependent light output power-current-voltage characteristics (LIV) and spectra were measured on-wafer for temperatures between 100 K and 340 K. An increasing EQE was observed for increasing T_{growth} up to 1060 °C with a maximum value of 0.25 % at room temperature. This increase in EQE is attributed to a reduced point defect incorporation at higher active region growth temperatures. This finding is supported by a shift of the EQE vs. temperature maximum from a sample stage temperature of 220 K for an active region growth temperature of 900 °C to 260 K for an active region growth temperature of 1060 °C indicating an increased radiative recombination efficiency as a consequence of reduced point defect incorporation.

HL 10.9 Mon 17:15 H34

UVC-LEDs grown on HTA-AlN templates with low dislocation densities and high Si doping for strain management — •Sarina Graupeter[1], Michael Gail[1], Giulia Cardinali[1], Massimo Grigoletto[1,2], Sylvia Hagedorn[2], Tim Wernicke[1], Markus Weyers[2], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut (FBH),Gustav-Kirchhoff-Straße 4, 12489 Berlin, Germany

High temperature annealing (HTA) of AlN layers reduces the threading dislocation densitiy of such layers on sapphire substrates below 10^9cm^{-2} enabling UVC-LEDs with improved efficiencies. However, the HTA AlN-layers are under high compressive strain after cooling down, which leads to strain relaxation and defect formation during further LED heterostructure growth. Growing Si-doped AlN layers on HTA-AlN can reduce the strain. In this work we investigate the influence of such an AlN:Si-interlayer on the growth of UVC-LEDs emitting at 265nm on HTA AlN/sapphire templates, with different thicknesses and offcut angles. XRD measurements show a reduction of the compressive strain from 0.5% to 0.1% depending on layer thickness. Optical characterization with Photoluminescence and Cathodoluminescence shows, that depending on the layer thickness, defect formation in the form of Ga-rich plateus occurs. Electroluminescence measurements of full UVC-LED structures shows emission powers around 0.75mW at 20mA for the templates with 350nm layer thickness, which is comparable to LEDs grown on more expensive standard templates.

HL 10.10 Mon 17:30 H34

Distributed polarization doping for 265 nm UVC LEDs — •Massimo Grigoletto[1,2], Sarina Graupeter[1], Anton Muhin[1], Fedir Bilchenko[1], Eviathar Ziffer[1], Norman Susilo[1], Tim Wernicke[1], and Michael Kneissl[1,2] — [1]Technische Universität Berlin, Institute of Solid State Physics, 10623 Berlin, Germany — [2]Ferdinand-Braun-Institut, 12489 Berlin, Germany

Distributed polarization doping (DPD) for optoelectronic devices with high aluminium mole fractions in AlGaN alloys is a promising concept for achieving high hole densities and simultaneously minimize the light absorption on the p-side.

A continuous grading downward from an higher to a lower aluminium mole fraction in the alloy composition of the AlGaN layer, leads to a steady piezoelectric polarization change creating a negative net charge that is compensated by free holes. In this way, dopant-free without thermal activation is possible, which can exhibit orders of magnitude higher hole densities than comparable magnesium impurity doped AlGaN layers.

In this study we investigate the influence of the DPD graded layer de-

sign on the electro optical properties and material properties of 265 nm AlGaN-based LEDs by varying the thickness and aluminium gradient. The LED heterostructures with and without the different DPD-layers are grown by metal organic vapor phase epitaxy and analyzed by electroluminescence measurements, transmission spectroscopy, high resolution X-ray diffraction, atomic force microscopy, capacitance voltage spectroscopy and determination of sheet and contact resistance.

HL 10.11 Mon 17:45 H34

Temperature dependent photoluminescence spectroscopy of self-assembled InGaN superlattices embedded in GaN Nanowires — •Rudolfo Hötzel[1], Manuel Alonso Orts[1], Tim Grieb[2], Jörg Schörmann[1], Stephan Figge[1], and Martin Eickhoff[1] — [1]University of Bremen, Institute of Solid State Physics, 28359 Bremen, Germany — [2]I. Physikalisches Institut, Justus-Liebig-Universität, Heinrich-Buff-Ring 16, 35392 Giessen, Germany

In this work, the structure and optical properties of single InGaN/GaN Nanowires grown by plasma assisted molecular beam epitaxy have been analyzed by micro photoluminescence (PL), scanning transmisssion electron microscopy (STEM) and energy dispersive X-rayspectroscopy (EDX). These nanowires consist of an indium rich core that contains a self assembled InGaN superlattice within a GaN shell. In order to understand the origin of their optical properties, PL was combined with STEM analysis to idendify single nanowire structures. Temeperature-dependent as well as polarized PL were conducted on isolated nanowires and revealed an emission consisting of broader bands at room temperature and multiple narrow peak superpositions at low temperatures. The overall emission ranges from 1,8 eV to up to 2,9 eV. One contributing factor to their emission is the indium distribution within the superlattice, which was determined by EDX. A polarization dependence of the PL signal with respect to the growth direction was observed at 4K and room temperature and ascribed to the indium rich core (parallel contributions) and self assembled superlattice (perpendicular contributions).

HL 10.12 Mon 18:00 H34

Luminescence Characteristics of GaInN/GaN Multi Quantum Wells with Ga and N Polarity — •Samar Hagag, Malte Schrader, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut f. Angewandte,TU Braunschweig,Germany

The optical properties of Ga- and N-polar GaInN/GaN Multi Quantum Wells (MQW) grown on sapphire and bulk N-polar GaN substrates, respectively, using metal-organic chemical vapor deposition were investigated using photoluminescence (PL) and time-resolved photoluminescence (TRPL) spectroscopy. The low temperature PL spectrum of N-polar GaInN/GaN MQW showed a reduced PL intensity and broad emission peak compared to their Ga-polar counterparts and shorter PL decay times of N-polar GaInN/GaN MQW were observed in low temperature TRPL measurements. Using non-resonant excitation, N-polar GaN PL spectra at low temperature have shown the presence of luminescence lines associated with structural defects of the type I1 basal-plane stacking faults. The low PL intensity and short PL decay time at low temperature of N-polar GaInN/GaN MQW indicate the existence of non-radiative recombination at low temperature likely caused by partial dislocations associated with the stacking faults. For the fabrication of pyramidal nanostructures serving as nanooptical light emitters, wet etching of N-polar GaInN/GaN MQW in KOH solution has been used. The etched N-polar samples have shown an improved luminescence and the absence of stacking fault-related luminescence lines. Optimization of the growth procedure for N-polar GaInN/GaN MQW is required in order to reduce structural defects.

HL 10.13 Mon 18:15 H34

Pump-probe studies with varying excitation wavelengths applied for GaInN/GaN single quantum wells — •Malte Schrader, Rodrigo De Vasconcellos Lourenco, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik & Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Germany

The goal of this study is to characterize the ultra-fast carrier dynamics in c-plane GaInN/GaN single quantum wells (SQWs). To make transmission experiments possible the samples were grown on double-side polished sapphire by MOVPE. Furthermore we use time-resolved photoluminescence (TRPL) to measure the radiative and non-radiative carrier lifetimes of the samples from 5 K up to 300 K. By using a transmission-mode degenerate pump-probe technique at 300 K the generated state occupation in the SQW can be observed directly. Different excitation wavelengths produced using an optical parametric amplifier provided pulses of nominal 35 fs duration.

We observe carrier lifetimes at room temperature in the low ns range by TRPL, which are strongly impacted by nonradiative processes. Pump-probe at 300 K gives a fast characteristic relaxation time in the low ps range and a slower component associated with the decay observed in TRPL. This indicates that a fast initial non-equilibrium relaxation is followed by a component representing recombination of a quasi-equilibrium carrier ensemble. A surprising observation is the relatively slow relaxation time of a few ps, which one would rather expect to be in the femtosecond range.

HL 11: 2D Materials 2 (joint session HL/CPP/DS)

Time: Monday 15:00–18:30 Location: H36

HL 11.1 Mon 15:00 H36

On-demand light emission from helium ion induced defects in atomically thin WS_2 — •Nina Pettinger, Ana Micevic, Alexander Hötger, Christoph Kastl, and Alexander Holleitner — TU Munich, Germany

Optically active defects created with a helium ion microscope (HIM) propose the possibility for structuring and tailoring quantum emitters on an atomistic scale [1]. We introduce the generation of positioned defects in encapsulated monolayer WS_2 with a HIM. The HIM induced defects exhibit sharp photoluminescence emission in the energy range of 1.55 to 1.79 eV.

[1] J. Klein and L. Sigl et al., ACS Photonics 8, 669 (2021).

HL 11.2 Mon 15:15 H36

Concept of an all-optical THz near-field microscope for flakes of 2D materials — •Ahmad-Reza Etemadi, Sebastian Matschy, Ahana Bhattacharya, and Martin Mittendorff — Department of physics, University of Duisburg-Essen, 47057 Duisburg, Germany

While THz spectroscopy is an excellent tool to investigate the free charge carriers in many semiconducting materials, the long-wavelength is an inherent feature linked to a large spot size in the millimeter range, and thus large samples are required. Small flakes of two-dimensional materials exfoliated from bulk crystals are usually much smaller than the spot size of a conventional THz spectrometer. The direct detection of the THz signal in the vicinity of the flake gains the phase and amplitude information with a higher spatial resolution. This is accessible by placing the sample directly on top of an electro-optic crystal. Sampling the THz field at the flake position gives access to the complex conductivity and thus the carrier density as well as the carrier mobility. A frequency-doubled fiber laser with a pulse duration of about 80 fs at 780 nm is exploited to generate and sample the THz field. GaSe, and ZnTe are employed as electro-optic crystals. Here we present the current state of the near-field microscope and the first measurements of the spatial resolution. The experimental results are accompanied by rigorous modeling of the THz propagation within the electro-optic crystal.

HL 11.3 Mon 15:30 H36

Ab initio description of valley-selective circular dichroism — •Maximilian Schebek[1], Yiming Pan[2], Cecilia Vona[1], Claudia Draxl[1], and Fabio Caruso[2] — [1]Institut für Physik and IRIS Adlershof, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, Kiel, Germany

By enabling control of valley degrees of freedom, valley-selective circular dichroism (VSCD) has become a key concept in valleytronics. In this work, we present an *ab initio* many-body theory of VSCD based on the Bethe-Salpeter equation. Our approach provides a new route to accurately predict the degree of valley polarization upon absorption of circularly polarized light. With the example of monolayer transition-metal dichalcogenides, we further show that valley excitons - bound

electron-hole pairs formed at either the K or $\overline{\text{K}}$ valley upon absorption of circularly-polarized light - are chiral quasiparticles characterized by a finite orbital angular momentum (OAM). Beside governing the interaction with circularly polarized light, the OAM results in a finite magnetization of excitons, which in turn provides a route for the interaction of excitons with external magnetic fields and other spin-orbital degrees of freedom.

HL 11.4 Mon 15:45 H36

Dark and bright exciton dynamics probed by time-resolved photoluminescence in hBN-encapsulated $MoWSe_2$ monolayers — •Julian Schröer[1,3], Joanna Kutrowska-Girzycka[2], Leszek Bryja[2], Joanna Jadczak[2], and Jörg Debus[1] — [1]TU Dortmund, Experimentelle Physik 2, AG Debus — [2]Wroclaw University of Science and Technology, Department of Experimental Physics — [3]Universität Rostock, Institut für Physik, AG Korn: Zweidimensionale Kristalle und Heterostrukturen

Semiconducting monolayers of ternary $MoWSe_2$ alloys combine the unique properties of the binary transition metal dichalcogenide (TMDC) materials $MoSe_2$ and WSe_2. The alloying leads to, for example, brightening of the momentum- and spin-forbidden dark exciton states. Detailed studies on the dynamics of these brightened dark states are missing. We report on the exciton and trion formation lying in the 1-3 ps range, while the decay time approaches hundreds picoseconds. Additionally, strong dependences on the temperature and exciting laser light polarization are observed. In time-resolved and stationary photoluminescence measurements, we reveal the impact of the crystal disorder potential on the exciton properties. The polarization dynamics of the exciton and trion photoluminescence indicate possible contributions from chiral phonons as well as electrons and holes from different valleys of the Brillouin zone. Our work is a further step towards a deeper understanding of the dynamics of dark excitons in TMDC materials.

15 min. break

HL 11.5 Mon 16:15 H36

Signatures of a degenerate many-body state of interlayer excitons in a van der Waals heterostack — •Johannes Figueiredo[1], Lukas Sigl[1], Florian Sigger[1], Jonas Kiemle[1], Mirco Troue[1], Ursula Wurstbauer[2], and Alexander Holleitner[1] — [1]Walter-Schottky-Institut, Technical University of Munich — [2]Institute of Physics, Westfälische Wilhelms-Universität Münster

In atomistic van der Waals heterostacks of transition metal dichalcogenides, the reduced dimensionality and changing dielectric environement leads to the formation of stronlgy bound excitons. Optically generated interlayer excitons exhibit an additional spatial separation of the electron-hole pair with a reduced overlap of the electrons' and holes' wave-functions, evidenced through their long lifetimes. These long-lived, photogenerated composite bosons yield several signatures of a quantum degenerate many-body system at cryogenic temperatures. The emergence of this state is in accordance with theoretical predictions of a critical condensation temperature above 10K. We present new insights into the phase-diagram of such interlayer exciton ensembles. [1]

[1] L. Sigl *et al.*, Phys. Rev. Research 2, 042044(R) (2020)

HL 11.6 Mon 16:30 H36

exciton species in highly doped WS_2 monolayers — david tiede, •hossein ostovar, hendrik lambers, nihit saigal, and ursula wurstbauer — Institute of Physics, University of Münster, Münster, Germany

Semiconducting two-dimensional transition metal dichalcogenides such as WS_2 excel due to their exciton dominated light-matter interaction even at room temperature (RT) that is highly tunable by external stimuli such as doping, light excitation, dielectric environment, or strain [1]. In this work, an optimized field effect structure utilizing a polymer electrolyte top gate electrode is employed to study the evolution of the optical response in monolayer WS_2 at RT in dependence of doping by means of photoluminescence and spectroscopic imaging ellipsometry measurements. The huge geometrical gate capacitance enables capacitance spectroscopy of the conduction band as well as valence band edge yielding a gap energy of 2.6eV in agreement with the determination from the exciton Rydberg series. The gate allows the injection of large electron and hole densities exceeding $10^{14} cm^{-2}$, sufficient to enable the exciton Mott transition. The obtained doping dependent emission and absorption spectra also facilitate the identification of phonon activated, neutral and charged exciton species as well as dressed excitons in a fermi sea. We acknowledge financial support via DFG WU 637/7-1 and SPP2244. [1] U. Wurstbauer et al. J. Phys. D: Appl. Phys. 50, 173001 (2017).

HL 11.7 Mon 16:45 H36

Pump probe signatures of interlayer excitons in TMDC heterostructures — •Henry Mittenzwey, Manuel Katzer, Andreas Knorr, and Malte Selig — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

TMDC heterobilayers are promising candidates for novel optoelectronic applications, since they exhibit long-lived excitonic states with spatially separated electrons and holes located in different layers. The relaxation dynamics of these interlayer excitons and their interplay with intralayer excitons are still under investigation.

Here, we present a microscopic description for the phonon and tunneling induced formation and relaxation of intra- and interlayer excitons in a $MoSe_2/WSe_2$ stack. Based on the microscopic dynamics we calculate the pump probe signal for intra- and interlayer transition and their population dynamics including hot exciton bottleneck effects.

HL 11.8 Mon 17:00 H36

Angle- and polarization-resolved luminescence from suspended and hBN encapsulated $MoSe_2$ monolayers — •Bo Han[1], Sven Stephan[1], Joshua J.P. Thompson[2], Martin Esmann[1], Carlos Antón-Solanas[1], Hangyong Shan[1], Samuel Brem[3], Christoph lienau[1], Kenji Watanabe[4], Takashi Taniguchi[4], Martin Silies[1], Ermin Malic[2,3], and Christian Schneider[1] — [1]Carl von Ossietzky Universität, Oldenburg, Germany. — [2]Philipps Universität, Marburg, Germany. — [3]Chalmers University of Technology, Gothenburg, Sweden. — [4]National Institute for Materials Science, Tsukuba, Japan.

We apply combined angle- and polarization-resolved spectroscopy to explore the interplay of excitonic physics and phenomena arising from the commonly utilized encapsulation on the optical properties of atomically thin transition metal dichalcogenides. In our study, we probe $MoSe_2$ monolayers which are prepared in both a suspended and an encapsulated manner. We show that the hBN encapsulation significantly enhances the linear polarization of exciton PL at large emission angles. This degree of linear polarization of excitons can increase up to 17 % in the hBN encapsulated samples. As confirmed by finite-difference time-domain simulations, it can be directly connected to the optical anisotropy of the hBN layers. In comparison, the linear polarization at finite exciton momenta is significantly reduced in suspended $MoSe_2$ monolayer, and only becomes notable at cryogenic conditions. This phenomenon strongly suggest that the effect is rooted in the k-dependent anisotropic exchange coupling inherent in 2D excitons.

15 min. break

HL 11.9 Mon 17:30 H36

Photonic and Phononic Couplings in Hybrid High-Q Nanocavities with Encapsulated MoS2 Monolayer — •Chenjiang Qian[1], Viviana Villafañe[1], Pedro Soubelet[1], Alexander Hötger[1], Takashi Taniguchi[2], Kenji Watanabe[2], Nathan Wilson[1], Andreas Stier[1], Alexander Holleitner[1], and Jonathan Finley[1] — [1]Walter Schottky Institut and Physik Department, Am Coulombwall 4, 85748 Garching, Germany — [2]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

Monolayer TMDs are ideal active materials for solid-state cQED. However, the direct cou-pling of TMDs to 0D nanocavities whilst preserving pristine excitonic properties and large cavi-ty-TMD overlap remains a challenge. Most commonly, non-encapsulated TMDs are stacked on top of prefabricated photonic structures using pick-and-place assembly. In this case, environ-mental disorders strongly perturb the excitonic properties. Whilst disorder can be mitigated by full hBN encapsulation, this approach moves the TMD away from the cavity field, thereby, trad-ing spatial coupling for homogeneous linewidth. Here, we integrate hBN/MoS2/hBN heterostruc-tures to Si3N4 nanobeams as hybrid nanocavities. Our approach solves the trade-off problem by making the unpatterned heterostructure a functional part of the cavity field. Therefore, the pris-tine excitonic quality, high cavity mode Q-factor > 10000, and the strong cavity-MoS2 overlap are achieved simultaneously. We study the coupling of MoS2 excitons to the cavity

optical and vibrational modes using PL and Raman spectroscopy, and novel coupling phenomena are ob-served based.

HL 11.10 Mon 17:45 H36

Terahertz free carrier absorption to modulate the optical properties of nanometer-thick van der Waals semiconductors — •Tommaso Venanzi[1,2], Malte Selig[3], Alexej Pashkin[2], Stephan Winnerl[2], Manuel Katzer[3], Himani Arora[2], Artur Erbe[2], Amalia Patane[4], Zakhar R. Kudrynskyi[4], Zakhar D. Kovalyuk[5], Leonetta Baldassarre[1], Andreas Knorr[3], Manfred Helm[2], and Harald Schneider[2] — [1]Sapienza University of Rome, 00185 Rome, Italy — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [3]Technical University Berlin, 10623 Berlin, Germany — [4]University of Nottingham, Nottingham NG7 2RD, UK — [5]The National Academy of Sciences of Ukraine, 58001 Chernivtsi, Ukraine

Free carriers in doped semiconductors absorb terahertz radiation when the frequency of the electromagnetic field is lower or comparable to the plasma frequency of the system. This phenomenon can be used to manipulate the optical response of the material. We present here the results of two different experiments performed at the infrared free-electron laser FELBE on atomically-thin van der Waals semiconductors. In MoSe2 monolayers, we observe a terahertz-induced redshift of the trion resonance. Terahertz absorption induces an average high momentum to the carriers and this momentum gets transferred during the trion formation, resulting in a net redshift in the absorption. In few-layer InSe, the terahertz pulses induce a transient quenching of the photoluminescence emission. In both cases, a microscopic study of the hot carrier distribution cooling is also presented.

HL 11.11 Mon 18:00 H36

Theory of Exciton-Phonon Interaction for Stationary State Experiments in Atomically Thin Semiconductors — •Manuel Katzer, Andreas Knorr, and Malte Selig — Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

Atomically thin semiconductors exhibit tightly bound electron hole pairs which stimulated exciton research in recent years [1]. While typical experimental techniques include the cw excitation of the material, only few is known theoretically about the related exciton dynamics and the formation of non-equilibrium steady states. Based on excitonic Boltzmann scattering equations, we demonstrate that the formation of such stationary states is also accompanied with the formation of phonon replica in the photoluminescence excitation spectrum [2], in agreement with available experiments [3]. So far, many studies focused on the understanding of exciton dynamics in the limit of weak excitation. Above this limit, we find both bosonic but also fermionic contributions to the thermalization, due to the co-bosonic nature of excitons. Based on a Heisenberg equation of motion ansatz [4], we discuss the first order of non-linear exciton-phonon interaction exceeding the classical Boltzmann scattering limit, in order to analyze the exciton thermalization at elevated excitation densities.

[1] Wang et al. RMP, 90, 021001 (2018). [2] Selig et al. arXiv:2201.03362 (2022). [3] Chow et al., Nano lett. 17, 1194 (2017); Shree et al. PRB 98, 035302 (2018). [4] Selig et al. PRR, 1, 022007 (2019); Katsch et al., PRL 124 25 257402 (2020).

HL 11.12 Mon 18:15 H36

Ultrafast control of spins in transition metal dichalcogenides — •Abhijeet Kumar[1], Denis Yagodkin[1], Douglas J. Bock[1], Nele Stetzuhn[1,2], Sviatoslav Kovalchuk[1], Alexey Melnikov[3], Peter Elliott[2], Sangeeta Sharma[2], Cornelius Gahl[1], and Kirill I. Bolotin[1] — [1]Department of Physics, Freie Universität Berlin, 14195 Berlin, Germany — [2]Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie, Max-Born Straße 2a, 12489 Berlin, Germany — [3]Institute for Physics, Martin Luther University Halle, 06120 Halle, Germany

Control and manipulation of the coupled spin/valley degrees of freedom in transition metal dichalcogenides (TMDs) are essential for their applications in spin/valleytronics. Here, we achieve ultrafast control of spins in TMDs via two distinct approaches, namely, proximity-coupling to another TMD and strain. First, we use a type-II heterostructure $MoS_2 - MoSe_2$ to enable directional optical pumping of spin-polarized carriers. We find that the photoexcited carriers conserve their spin for both tunneling directions across the interface. We observe dramatic differences in the spin/valley depolarization rates for electrons and holes, 30 and $<1\ ns^{-1}$, respectively, which relates to the disparity in the spin-orbit splitting in conduction and valence bands of TMDs. Second, by applying biaxial strain (exceeding 2%) in monolayer WSe_2, we evidence the hybridization of the conduction bands with the in-gap localized defects that brightens the lowest-lying dark excitons. This novel hybrid state exhibits unique spin/valley signatures which are strongly manipulated on picosecond-timescale by strain and doping.

HL 12: Quantum Dots and Wires 3: Growth

Time: Tuesday 9:30–12:45 Location: H32

Invited Talk HL 12.1 Tue 9:30 H32

Wafer-Scale Epitaxial Modulation of Quantum Dot Densitiy — •Nikolai Bart[1], Christian Dangel[2], Peter Zajac[1], Nikolai Spitzer[1], Marcel Schmidt[1], Kai Müller[2,3], Andreas D. Wieck[1], Jonathan Finley[2], and Arne Ludwig[1] — [1]Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44801 Bochum, Germany — [2]Walter Schottky Institut and Physik Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany — [3]Walter Schottky Institut and Department of Electrical and Computer Engineering, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

The effect of nanoscale surface roughness on the nucleation of self-assembled InAs quantum dots (QD) is investigated with photoluminescence (PL) spectroscopy and atomic force microscopy. We show in-situ control of the roughness modulation by common epitaxial layer-by-layer growth, leaving alternating atomically smooth (rough) surfaces for integer (fractional) completion of a monolayer. We report significant differences in both PL intensity and QD surface density at the critical threshold of nucleation. By varying the underlying GaAs thickness gradients, we create and control 1- and 2-dimensional density modulation patterns on entire 3-inch wafers with modulation periods between a few mm and down to hundreds of μm and densities between 1 and 10 QDs/μm^2.

Bart, N., Dangel, C. et al. Wafer-scale epitaxial modulation of quantum dot density. *Nat Commun* **13**, 1633 (2022).

HL 12.2 Tue 10:00 H32

Full Wafer Property Control of Local Droplet Etched GaAs Quantum Dots — •Hans-Georg Babin, Nikolai Bart, Marcel Schmidt, Nikolai Spitzer, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Deutschland

Local droplet etched GaAs quantum dots (LDE-QDs) are a promising candidate for excellent single and entangled photon sources [1]. It is important that the carefully developed and highly complex structures are matched perfectly with the embedded QDs [2]. In this submission, we show a way to control QD properties during molecular beam epitaxy on a single wafer, which opens the opportunity to find optimally fitting QDs for the desired experiments by just changing the position on the wafer.

We induce flux gradients by stopping sample rotation and using the parallax of the effusion-cells, resulting in a gradual change of deposited material and cell flux. By this we can vary properties of the QDs like density and emission wavelength on a single wafer. In this work, the widest achieved wavelength shift of the ground state emission energy at 100 K extends over the range of 795 nm to 737 nm [3]. The induced surface roughness modulation additionally induces a stripe-patterned modulation, which was shown before only with Stranski-Krastanov QDs [4].

[1] Huber, D. et al., Nat. Commun. 8 (1), S. 15506 (2017).
[2] Zhai, L. et al., Nat. Commun. 11 (1), S. 4745 (2020).
[3] Babin, H.G. et al., J. Cryst. Growth 591, S. 126713 (2022).
[4] Bart, N.; Dangel, C.; et al., Nat. Commun. 13, 1663 (2022).

HL 12.3 Tue 10:15 H32

Towards MOVPE-grown c-band emitting InAs quantum dots

on a Si (001) substrate based on heterogeneous integration of membrane and epitaxial regrowth — •Ponraj Vijayan, Robert Sittig, Simone Luca Portalupi, Michael Jetter, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, Universität Stuttgart, Germany

Silicon photonics for telecommunications applications has garnered much attention in recent decades. The optical transparency and the large refractive index contrast of silicon in the telecommunication wavelengths allow the implementation of high-density photonic integrated circuit. The drawback of silicon photonics is that there is no native light source due to the indirect band-gap nature of silicon. Integration of III-V material, which offers outstanding optical emission properties, on silicon provides a potential solution. The monolithic integration i.e. the direct growth of III-V materials on silicon is the most desired approach. However, it is very challenging because of large lattice mismatch and material polarity difference between the III-V materials and silicon. An alternate monolithic approach is through heterogeneous integration of thin III-V membrane using direct bonding techniques followed by epitaxial regrowth. Our group has previously developed InAs QD/InGaAs MMB/GaAs substrate structures for long-distance optical fiber applications. Here, we report on the route to monolithically integrate the telecom C-band emitting InAs QD on a wafer bonded GaAs/Si substrate using MOVPE.

HL 12.4 Tue 10:30 H32

Non-vapor-liquid-solid selective area epitaxy of GaAs1-xSbx nanowires on silicon — Akhil Ajay[1], Hyowon Jeong[1], •Haiting Yu[1], Nitin Mukhundhan[1], Tobias Schreitmüller[1], Markus Döblinger[2], and Gregor Koblmüller[1] — [1]Walter Schottky Institute & Physics Department Technical University of Munich, Garching, Germany — [2]Ludwig-Maximilians-University, Munich, Germany

Epitaxial growth of semiconductor nanowires(NWs)is generally known to proceed via a vapor-liquid-solid(VLS). However,an absence of the liquid droplet would be ideal for III-V NW integration on Si and the exploration of atomically abrupt NW heterostructures.In this work,we report a novel non-VLS growth mechanism for the selective area growth of GaAs1-xSbx NWs on Si(111)substrates using molecular beam epitaxy.Non-VLS NWs are known to have many structural defects and poor aspect ratios.Surprisingly,we observe an increased axial growth and aspect ratio in these NWs by adding low concentrations of Sb.This also contrasts the commonly believed enhancement in radial growth for VLS growth claimed to be due to the surfactant effect of Sb.We report on realizing control over aspect ratio and yield by optimizing SiO2 mask hole diameter,growth time and growth temperature.In this process we observe a hitherto unreported dynamic growth rate that increases with time.We also investigate the initial growth of such non-VLS NWs forming inside the SiO2 mask opening,describing the facets and morphology.We also explore n-doping in these NWs with Si which also helps in realizing nearly unity yield and homogeneity.

HL 12.5 Tue 10:45 H32

Epitaxial growth and characterization of multilayer site-controlled InGaAs quantum dots based on the buried stressor method — •Imad Limame, Ching-Wen Shih, Alexej Koltchanov, Moritz Plattner, Johannes Shall, Sven Rodt, and Stephan Reitzenstein — Institute for Solid State Physics, Technical University of Berlin, Germany

The buried-stressor epitaxial growth concept is a prim approach for the realization of site- and number- controlled quantum dots (QDs) with optical high quality. This advanced technique has a wide application spectrum including nanophotonics devices such as single-photon sources (SPSs), microlasers, and emitter-arrays for neuromorphic photonic computing. Here, we report on the development of multi-layer site-controlled QDs (ML-SCQDs) integrated in micropillar laser arrays with low threshold pump power. The buried-stressor technique utilizes a partially oxidized buried AlAs aperture to engineer the strain profile in the following GaAs capping layer and control the position and number of the QDs at the GaAs surface. Thanks to the unetched GaAs surface, the buried-stressor SCQDs exhibits excellent optical properties in comparison to other SCQDs growth approaches, using for instance nano-hole arrays as nucleation centers. Additionally, after integration into micropillar cavities the partially oxidized aperture results in additional confinement of the optical mode in lateral direction, leading to lower mode volume and higher Q-factor for a given micropillar geometry. The grown ML-SCQDs are investigated using atomic force microscopy , micro-photo- and cathodoluminescence spectroscopy.

30 min. break

HL 12.6 Tue 11:30 H32

Growth of shallow GaAs quantum dots and investigation of their optical properties — •Moritz Langer[1], Nand Lal Sharma[1], Ghata Satish Bhayani[1], Ankita Choudhary[1], Oliver G. Schmidt[2], and Caspar Hopfmann[1] — [1]Institute for Integrative Nanoscience - IFW Dresden, Dresden, Germany — [2]Center for Materials, Architectures, and Integration of Nanomembranes (MAIN), TU Chemnitz, Chemnitz, Germany

In recent years local droplet etching developed into an attractive growth process for strain-free semiconductor quantum dots. Typically, conical nanoholes etched into Al0.15Ga0.85As buffer layer by the droplet etching process using molecular beam epitaxy machine [1], have a width of about 50 nm and a depth of 15 nm. By using migration enhanced epitaxy, these nanoholes filled with GaAs and capped with an Al0.15Ga0.85As layer, buried around 6 nm high quantum dot structures of high optical quality are obtained. For enhanced interaction of quantum dots with external stimuli e.g. magnetic fields of thin films -, it is desirable to produce quantum dots close to the surface. Consequentially, the nature of the sample surface and the electronic and optical properties the quantum dot cannot be considered independently. For this purpose, the influence of capping layer thickness on the optical properties of GaAs/Al0.15Ga0.85As quantum dots are investigated using photoluminescence spectroscopy.

[1] Xiaoying Huang et al, 2020 Nanotechnology 31 495701 (2020)

HL 12.7 Tue 11:45 H32

Local droplet etching on InAlAs/InP surfaces with InAl droplets — •Yiteng Zhang[1], Xin Cao[1], Chenxi Ma[1], Yinan Wang[1], Benedikt Brechtken[2], Rolf J. Haug[2], Eddy P. Rugeramigabo[1], Michael Zopf[1], and Fei Ding[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany — [2]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

GaAs quantum dots (QDs) grown by local droplet etching (LDE) have been studied extensively in recent years. The LDE method allows for high crystallinity, as well as precise control of the density, morphology, and size of QDs. These properties make GaAs QDs an ideal candidate as single photon and entangled photon sources at short wavelengths (<800 nm). For technologically important telecom wavelengths, however, it is still unclear whether LDE grown QDs can be realized. In this work, we study Indium-Aluminum (InAl) droplet etching on ultrasmooth In0.55Al0.45As surfaces on InP substrates, with a goal to lay the foundation for growing symmetrical and strain-free telecom QDs using the LDE method. We report that both droplets start to etch nanoholes at a substrate temperature above 415 °C, showing varying nanohole morphology and rapidly changing density (by more than one order of magnitude) at different temperatures. Al and In droplets are found to not intermix during etching, and instead etch nanoholes individually. The obtained nanoholes show a symmetric profile and very low densities, enabling infilling of lattice-matched InGaAs QDs on InAlAs/InP surfaces in further works.

HL 12.8 Tue 12:00 H32

Influence of miscut angle on the exciton fine structure in GaAs/AlAs(111) and InAs/GaAs(111) quantum dots — •Geoffrey Pirard[1] and Gabriel Bester[1,2] — [1]Physical Chemistry and Physics Departments, University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee, 149, D-22761 Hamburg, Germany

Self-assembled quantum dots (QDs) grown on (111) surfaces constitute, in principle, excellent solid-state quantum emitters of polarized-entangled photon pairs making them promising candidates for quantum information processing applications. However, in practice, the growth on such substrates introduces limitations on the growth rate hindering the generation of sufficiently intense signal for such applications. One potential solution to address this problem is to grow these systems on misoriented substrates.

Using atomistic, million-atom screened pseudopotential theory together with configuration interaction, we perform numerical calculations and analyze the influence of the miscut on the exciton fine structure (FS) of GaAs/AlAs(111) and InAs/GaAs(111) QDs. We show that the presence the miscut modifies the spatial distribution of the electron and hole wave functions, which elongate along the $[1\bar{1}0]$ crystal axis. In turn, the polarization of the excitonic states acquires a clear

preferential orientation and this effect is strongly enhanced in strained systems. Finally, the FS splitting increases with the miscut within a range depending on the material and the amplitude of the miscut.

HL 12.9 Tue 12:15 H32

Controlled MOF growth on functionalized carbon nanotubes — •Marvin J. Dzinnik[1], Necmettin E. Akmaz[1], Adrian Hannebauer[2], Peter Behrens[2], and Rolf J. Haug[1] — [1]Leibniz Universität Hannover, Institut für Festkörperphysik, 30167 Hannover — [2]Leibniz Universität Hannover, Institut für Anorganische Chemie, 30167 Hannover

The class of metal organic frameworks (MOFs) is continuously growing. These materials consist of inorganic building blocks, held together by organic linker molecules. Schulze *et al.* [1] showed that adding functionalized multi-walled carbon nanotubes (MWCNTs) to a UiO-66 synthesis drastically decreased the nucleation time. The MOFs preferably grow on the MWCNT until they fully encapsulate it. We demonstrate a mechanism to spacially control the UiO-66 MOF growth on individual carbon nanotubes and deplete the encapsulation. The MWCNTs are drop-casted on a silicon dioxide surface and then locally modified. The samples are then submerged in the synthesis solution. This process leads to a growth of MOF crystals on the MWCNT surface leaving the modified areas depleted. With this method we are able to define lines free of MOF on the length of a single MWCNT down to several hundred nanometres for example to electrically contact the tubes ends.

[1] Schulze, H. A., et al. Electrically Conducting Nanocomposites of Carbon Nanotubes and Metal-Organic Frameworks with Strong Interactions between the two Components. ChemNanoMat, 5(9), (2019), 1159-1169.

HL 12.10 Tue 12:30 H32

Surface quantum dots with pure, coherent, and blinking-free single photon emission — •Michael Zopf[1], Xin Cao[1], Jingzhong Yang[1], Pengji Li[1], Tom Fandrich[1], Eddy P. Rugeramigabo[1], Chenxi Ma[1], Robert Keil[2], Frederik Benthin[1], Benedikt Brechtken[1], Rolf J. Haug[1,4], Yiteng Zhang[1], Susanne Woche[3], Zhao An[1], Constantin Schmidt[1], and Fei Ding[1,4] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Fraunhofer-institut für Angewandte Festkörperphysik IAF, Freiburg, Germany — [3]Institut für Bodenkunde, Leibniz Universität Hannover, Germany — [4]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Germany

The surface of semiconductor micro- and nanostructure-based devices has a major impact on their performance. Disorder and defects in the crystal typically lead to electronic states in the bandgap, degrading charge carrier transport and radiative recombination. In next generation semiconductor devices such as single or entangled photon sources, surface effects lead to low efficiency, photon dephasing, blinking or spectral jittering. Here we show unprecedented optical quality of GaAs quantum dots that are grown directly on an AlGaAs surface and passivated with 1-Octadecanethiol. Single photons are generated with 98.8 % purity, 78 % indistinguishability and narrow linewidths down to 7 μeV, close to the radiative limit. The emission is unaffected by the surface and shows no blinking over more than 12 orders of magnitude in time, yielding an on-fraction of 99.7 %. These results are likely to stimulate new fundamental studies and quantum applications.

HL 13: Ultra-Fast Phenomena

Time: Tuesday 9:30–12:15 Location: H33

HL 13.1 Tue 9:30 H33

Ultrafast hot charge carrier transport across graphene nano-gaps — •Johannes Gröbmeyer, Philipp Zimmermann, and Alexander Holleitner — Walter Schottky Institute and Physics Department, Technical University of Munich, Germany

We study the hot charge carrier transport across nanoscale junctions for ultrafast electric pulse generation on the nanometer scale. To avoid laser ablation problems common to metal based photoemission devices, we investigate the possibility of graphene nanojunctions positioned on a sapphire substrate. We create the emitter-collector structure by bisecting a graphene strip utilizing a helium ion beam to create a ˜30 nm wide nano-gap. Due to substrate interaction with the helium ion beam this gap is filled by a bulge of highly defected sapphire. Measuring the ultrafast and time-integrated charge carrier transport, we find evidence of an ultrafast photoemission across this gap. Our work demonstrates that graphene based nano-gaps have the potential of replacing photoconductive switches at low temperatures.

HL 13.2 Tue 9:45 H33

Studying hot electron transport in bismuth with transient all optical pump-probe spectrocopy — •Fabian Thiemann[1], Germán Sciaini[2], Alexander Kassen[1], and Michael Horn-von Hoegen[1] — [1]University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany — [2]University of Waterloo, 200 University Avenue West, Waterloo, ON N2L 3G1, Canada

Bismuth as a Peierls-Jones distorted semimetal is famous for its photoexcited coherent optical phonon modes and its delicate interplay with the electron dynamics. Especially the A_{1g} phonon mode at ≈ 3 THz and its characteristic softening upon photoexcitation is easily accessible and can be studied with all optical pump-probe spectroscopy, solely by monitoring the change in reflectivity $\Delta R/R_0$. The number of excited carriers in bismuth influences the atomic potential energy surface and thus the mode's softening. Therefore, in turn, we employed the redshift of the A_{1g} mode as a robust quantity to determine the spatial distribution of excited carriers and the absorbed energy density in the carrier system. A homogenous distribution due to ultrafast transport of hot carriers was observed, limited by an effective carrier penetration depth that is way beyond the optical skin depth.

HL 13.3 Tue 10:00 H33

Ultrafast Dynamics of Inter- and Intraband Transitions in GaP Investigated by fs-Time Resolved Ellipsometry — •Rüdiger Schmidt-Grund[1], Noah Stiehm[1], Erich Runge[1], Martin Zahradník[2], Shirly Espinoza[2], Mateusz Rebarz[2], Jakob Andreasson[2], and Stefan Krischok[1] — [1]TU Ilmenau, Technische Physik I and Theoretische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany — [2]ELI Beamlines, Fyzikální ústav AV ČR, Za Radnicí 835, 25241 Dolní Břežany, Czech Republic

We discuss the ultrafast dynamics of the dielectric function after excitation with a high-power laser pulse of the semiconductor GaP in the spectral range around the fundamental absorption edge, measured by pump-probe fs-time resolved spectroscopic ellipsometry [1,2]. The excited hot carriers cause several effects: we observe in different regions of the Brillouin zone both, Pauli-blocking of valence-to-conduction-band transitions and arising of new intra-conduction and -valence-band transitions, enabled by carrier scattering within the Brillouin zone and in particular tunnelling to the indirect minimum. We understand our observations with the help of density functional theory from which we derived band structure, transition matrix elements and the joint density of states between bands energetically relevant in our study. Our results show long lasting non-equilibrium phenomena (> ns), probably due to carrier trapping processes.

[1] S. Richter *et al.*, Rev. Sci. Instrum. **92**, 033104 (2021).
[2] S. Richter *et al.*, New J. Phys. **22**, 083066 (2020).

HL 13.4 Tue 10:15 H33

Multiparameter determination of time-resolved photoluminescence measurements — •Sebastian Bohm[1], Max Grossmann[1], Stefan Heyder[1], Klaus Schwarzburg[2], Peter Kleinschmidt[1], Erich Runge[1], and Thomas Hannappel[1] — [1]Fakultät für Mathematik und Naturwissenschaften, Technische Universität Ilmenau, Ehrenbergstraße 29, 98693 Ilmenau — [2]Institut Solare Brennstoffe, Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin

Accurate knowledge of radiative, non-radiative, and trapping photoluminescence lifetimes is crucial for the understanding and improvement of semiconductor devices. In principle, these parameters can be obtained from time-resolved photoluminescence spectroscopy (TRPL) measured at different excitation level, see, e.g., M. W. Gerber and R. N. Kleiman, J. Appl. Phys. 122, 095705 (2017), DOI 10.1063/1.5001128. We show that a full multi-parameter estimation based on a suitable maximum likelihood estimator and state-of-the-art non-linear multi-

parameter optimization yields superior results compared to conventional data analysis.

HL 13.5 Tue 10:30 H33

Strategies for Automating Femtosecond Time-Resolved Ellipsometry Data Analysis — •Noah Stiehm[1], Yixuan Zhang[2], Erich Runge[3], Stefan Krischok[1], Hongbin Zhang[2], and Rüdiger Schmidt-Grund[1] — [1]Technische Universität Ilmenau, Fachgebiet Technische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany — [2]Technische Universität Darmstadt, Research Group Theory of Magnetic Materials, Otto-Berndt-Straße 3, 64287 Darmstadt — [3]Technische Universität Ilmenau, Fachgebiet Theoretische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany

With the recently developed experimental method of femtosecond time-resolved spectroscopic ellipsometry [1], it is possible to obtain the transient dielectric function of a sample after excitation in a pump-probe scheme. However, modeling the experimental data manually with established ellipsometry modeling workflows is cumbersome and significantly reduces the throughput of the experiment. Here we present strategies I) to formalize the experience and physical intuition usually entering modeling strategies, II) to reduce computational costs by application of dimensionality reduction techniques, especially in the additionally required ab-initio theory calculations, and III) to improve stability, to enable an automated modeling pipeline with minimal human intervention.

[1] S. Richter *et al.*, Rev. Sci. Instrum. 92, 033104 (2021).

15 min. break

HL 13.6 Tue 11:00 H33

Coherent Dynamics of Charge-Transfer Excitons — •Markus Stein[1], Melanie Fey[1], Christian Fuchs[2], Wolfgang Stolz[2], Kerstin Volz[2], and Sangam Chatterjee[1] — [1]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany — [2]Department of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg, Germany

Charge carrier transport phenomena through internal interfaces in semiconductor heterostructures are currently in the spotlight of scientific research due to the advancing miniaturization of devices. However, how internal interfaces in semiconductor heterostructures affect the coherent dynamics, i.e., the transition from a coherent polarization to a population, is largely unexplored. To shed some light on the subject, we use a GaInAs/GaAs/GaAsSb type-II like double quantum well structure which, due to its design, exhibits a charge-transfer exciton resonance in the linear absorption. This allows us to study the coherent dynamics of charge-transfer excitons and excitons that can relax across the internal interface into a charge-transfer state by means of degenerate four-wave-mixing. Furthermore, adding an optical prepulse, the phase relaxation of charge-transfer excitons subjected to collisions with either free carriers or incoherent excitons is investigated.

HL 13.7 Tue 11:15 H33

Intense terahertz radiation via the transverse thermoelectric effect — •Tim Priessnitz[1,2], Petar Yordanov[1], Min-Jae Kim[1,2,3], Georg Cristiani[1], Gennady Logvenov[1], Bernhard Keimer[1], and Stefan Kaiser[1,2,3] — [1]Max-Planck Institute for Solid State Research, 70569 Stuttgart, Germany — [2]4th Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany — [3]Institute of Solid State and Materials Physics, Technical University Dresden, 01069 Dresden, Germany

Terahertz (THz) radiation became a powerful tool with widespread applications ranging from imaging and spectroscopy to nonlinear optical control of materials. However, efficient and scalable THz sources remain rare. Here, we present a novel approach to generate powerful THz radiation making use of an ultrafast current induced via the transverse thermoelectric effect (TTE). We realize this in off-cut grown thin films of the delafossite $PdCoO_2$ and the cuprate $La_{1.84}Sr_{0.16}CuO_4$ driven by femtosecond laser pulses resulting in an ultrafast transient diffusion of charge carriers. Characterizing the resulting THz radiation, we find it comparable in power and spectral bandwidth to standard emitters based on nonlinear crystals. A first basic model including the Seebeck anisotropy, electrical and thermal conductivities and the transient diffusivity allows materials based predictions. Due to its simplicity and potential for scalability in terms of multiple tunable material parameters, THz generation based on the TTE opens a new avenue for high-field THz generation and novel cost-efficient emitters.

HL 13.8 Tue 11:30 H33

Clocking the dynamics of correlated Bloch electrons on an attosecond time scale — •Josef Freudenstein[1], Markus Borsch[2], Manuel Meierhofer[1], Dmytro Afanasiev[1], Christoph Peter Schmid[1], Fabian Sandner[1], Marlene Liebich[1], Anna Girnghuber[1], Matthias Knorr[1], Mackillo Kira[2], and Rupert Huber[1] — [1]University of Regensburg, 93051 Regensburg, Germany — [2]University of Michigan, Ann Arbor, Michigan 48109, USA

Delocalized Bloch electrons and the low-energy correlations between them determine key properties of solids. To directly capture how many-body correlations affect the actual motion of Bloch electrons, sub-femtosecond temporal precision is desirable. Here, we study attosecond shifts in the dynamics of charge carriers at the Fermi level, combining sub-fs resolution with meV energy selectivity. Coherent excitons are injected in bulk and monolayer tungsten diselenide and subsequently accelerated by multi-terahertz light fields. Quasiparticle collisions lead to the emission of high-order sidebands, which contain key information about the ballistic dynamics of the charge carriers. We show how the excitonic binding energy, the strength of the driving field, the valley polarization and Pauli blocking influence these dynamics on an attosecond time scale and faithfully reproduce these results with quantum-dynamic many-body computations in a Wigner-function representation. This opens a new pathway to understanding emergent quantum dynamics and phases and sets a corner stone for future optoelectronics and quantum-information processing.

HL 13.9 Tue 11:45 H33

Time-resolved ellipsometry on CuI thin films — •Carola Emminger[1,2], Evgeny Krüger[1], Michael Bar[1], Shirly Espinoza[3], Martin Zahradnik[3], Mateusz Rebarz[3], Felix-Florian Delatowski[3], Jakob Andreasson[3], Michael Seifert[4], Silvana Botti[4], Chris Sturm[1], and Marius Grundmann[1] — [1]Felix-Bloch Institut für Festkörperphysik, Universität Leipzig, Germany — [2]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [3]ELI Beamlines, Czech Republic — [4]Institut für Festkörpertheorie und Optik, Friedrich-Schiller-Universität Jena, Germany

We report the impact of the carrier dynamics on the dielectric function of CuI thin films by means of femtosecond pump-probe spectroscopic ellipsometry. As expected, we observe a strong decrease of the exciton peak due to the pump pulse, which starts to recover after 200-300 fs. Interestingly, we notice a small increase in absorption below the band gap after a delay time of about 400 fs, which might be explained by valence- to valence-band transitions resulting from the laser-induced increased carrier density. At about 10 ps, the dielectric function has almost fully recovered. We analyze the delay-time dependent dielectric function and discuss possible explanations for the changes related to the carrier density.

HL 13.10 Tue 12:00 H33

Gain recovery dynamics after stimulated emission in type-II semiconductor laser materials — •Markus Stein[1], Felix Schäfer[1], Janine Lorenz[1], Johannes Steiner[2], Jörg Hader[3], Jerry Moloney[3], Torsten Meier[2], Stephan W. Koch[4], and Sangam Chatterjee[1] — [1]Institute of Experimental Physics I and Center for Materials Research, Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany — [2]Department of Physics, Paderborn University, Warburger Strasse 100, D-33098 Paderborn, Germany — [3]Wyant College of Optical Sciences, University of Arizona, 1630 East University Boulevard, Tucson, Arizona 85721, USA — [4]Department of Physics and Material Sciences Center, Philipps-Universität Marburg, Renthof 5, 35032 Marburg, Germany

Type-II active devices combine the advantages of spectrally broad, temperature-stable efficient gain with the potential for electrical injection pumping. Intrinsic charge-carrier relaxation dynamics limit the feasible repetition rates beyond constraints of cavity design and heat removal. Here, we investigate the recovery of material gain after a stimulated emission process in an InGaAs/GaAs/GaAsSb heterostructure, experimentally simulating the operation condition of a pulsed laser system. In an optical pump - optical probe setup, a first optical pulse injects hot charge carriers. Subsequently, a second pulse tuned to the broad spectral region in which gain is observed is used to stimulate emission. A detailed analysis of the dynamics after stimulated emission reveals that the physical limit for the highest possible laser repetition rate for this material system is in the range of 100 GHz.

HL 14: Focus Session: Quantum Properties at Functional Oxide Interfaces (joint session HL/DS)

Modern oxide materials exhibit a rich variety of physical properties that lead to potential applications such as sensors and detectors, solar energy harvesting, transparent and power electronics. Understanding their quantum properties at surfaces and interfaces may play a decisive role for functionalities in high-electron-mobility transistors, quantum electronics or topological quantum computation. These typically require homo- or heteroepitaxial layers of high crystallinity and investigation methods designed to reveal the fascinating physics at (complex) oxide interfaces. This session sets a focus on growth of oxide interfaces, the experimental and theoretical investigation of their novel physical, in particular quantum properties as well as fabrication and characterization of demonstrator devices.

Organized by Martin Albrecht, Oliver Bierwagen, and Saskia F. Fischer

Time: Tuesday 9:30–12:45 Location: H34

Invited Talk HL 14.1 Tue 9:30 H34

Materials and Device Engineering for Gallium Oxide-based Electronics — Nidhin Kurian Kalarickal[1], Sushovan Dhara[1], Ashok Dheenan[1], and •Siddharth Rajan[1,2] — [1]ECE Department, The Ohio State University — [2]MSE Department, The Ohio State University

This presentation will discuss our recent work on epitaxy, heterostructure design, and electrostatics to achieve high-performance β-Ga2O3 lateral and vertical electronic devices. We will discuss some key results in materials growth and device design for lateral structures, including the first β-(Al,Ga)2O3/β-Ga2O3 modulation-doped structures with excellent transport properties, double-heterostructure modulation-doped structures, and scaled delta-doped transistors with cutoff frequency of 27 GHz, and self-aligned lateral field effect transistors with > 900 mA/mm current density. We will discuss the use of a new damage-free epitaxial etching technique using Ga atomic flux that enables highly precise fabrication of 3-dimensional structures, and applications of this etching to realize field termination in vertical diodes, and lateral FINFETs with enhanced performance. Extreme-permittivity dielectrics provide unique opportunities to create devices that can sustain extreme fields without premature breakdown of metal-semiconductor and dielectric-semiconductor interfaces. We will discuss promising results of electrostatic engineering using BaTiO3/Ga2O3 heterojunctions that enable high fields to be sustained within Gallium Oxide diodes and transistors.

Invited Talk HL 14.2 Tue 10:00 H34

Ferroelectric two-dimensional electron gases for oxide spin-orbitronics — •Julien Bréhin — Unité Mixte de Physique CNRS/Thales

Just as the apparent incompatibility between ferroelectricity and magnetism prompted the renaissance of multiferroics, the research on ferroelectric metals conjectured in the 1960s by Anderson and Blount was recently revitalized. Yet, their experimental demonstration remains very challenging due to the contra-indication between the presence of free charge carriers and switchable electric dipoles. In this talk we will report on two-dimensional electron gases (2DEGs) formed on Ca-substituted SrTiO3 (STO). Signatures of the ferroelectric phase transition near 30 K are visible in the temperature dependence of the sheet resistance RS and in a strong, reproducible hysteresis of RS with gate voltage. In addition, spectroscopic measurements of the 2DEG region indicate the presence of switchable ionic displacements. Beyond their fundamental interest in materials physics, ferroelectric 2DEGs offer opportunities in spin-orbitronics: we will show how their spin-charge conversion properties, caused by the inverse Rashba-Edelstein effect, can be electrically tuned in amplitude and sign in a non-volatile way. These results open the way to a whole new class of ultralow-power spin-orbitronic devices operating without the need for magnetization switching. Finally, we will describe how one can introduce magnetism into such systems to achieve multiferroic 2DEGs displaying magneto-electric coupling.

HL 14.3 Tue 10:30 H34

Electron transport of the two-dimensional electron gas in polar-discontinuity doped LaInO3/BaSnO3 heterostructure — Georg Hoffmann[1], Fazeel Zohair[1], Martina Zupancic[2], Martin Albrecht[2], and •Oliver Bierwagen[1] — [1]Paul-Drude-Institut für Festkörperelektronik Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, D-10117 Berlin, Germany — [2]Leibniz-Institut für Kristallzüchtung im Forschungsverbund Berlin e.V., Max-Born-Straße 2 D-12489 Berlin, Germany

Transparent semiconducting oxides (TSOs) are key players for new (opto-)electronic devices and two-dimensional electron gases (2DEGs) are relevant for high-frequency applications. Polar-discontinuity doping (interfacing a polar material with a nonpolar one), has been demonstrated to provide a 2DEG at the interface between the perovskites LaAlO3 and SrTiO3 with a high electron concentration but suffers from low room-temperature (RT) electron mobilities of SrTiO3. In this contribution we demonstrate polar-discontinuity doped 2DEG at the interface between the perovskites LaInO3 and BaSnO3, grown by plasma-assisted molecular beam epitaxy. While the individual, undoped oxide layers were found to be insulating, the formation of the polar-discontinuity doped 2DEG at their interface is confirmed by capacitance-voltage (CV) and van der Pauw-Hall measurements. The extracted sheet electron concentrations >2e13cm^-2 and RT electron mobilities above >50cm^2/Vs are promising for device applications. The transport properties of the 2DEG are compared to those of La-doped BaSnO3 layers.

HL 14.4 Tue 10:45 H34

Non-Abelian braiding of phonons in monolayer oxides — •Bo Peng[1], Adrien Bouhon[1], Bartomeu Monserrat[1,2], and Robert-Jan Slager[1] — [1]TCM Group, Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — [2]Department of Materials Science and Metallurgy, University of Cambridge, 27 Charles Babbage Road, Cambridge CB3 0FS, United Kingdom

Non-Abelian braiding of quasiparticles can encode quantum information immune from environmental noise with the potential to realize topological quantum computation. Here we propose that phonons, a bosonic excitation of lattice vibrations, can carry non-Abelian charges in their band structures that can be braided using external stimuli. Taking some earthly abundant materials such as silicates [1] and aluminium oxide [2] as representative examples, we demonstrate that an external electric field or electrostatic doping can give rise to phonon band inversions that induce the redistribution of non-Abelian charges, leading to non-Abelian braiding of phonons. We show that phonons can be a primary platform to study non-Abelian braiding in the reciprocal space, and we expand the toolset to study such braiding processes.

References: [1] Bo Peng, Adrien Bouhon, Bartomeu Monserrat & Robert-Jan Slager. Nature Communications 13, 423 (2022). [2] Bo Peng, Adrien Bouhon, Robert-Jan Slager & Bartomeu Monserrat. Physical Review B 105, 085115 (2022).

30 min. break

HL 14.5 Tue 11:30 H34

Shift of the absoption onset in corundum-like α-$(Ti_xGa_{1-x})_2O_3$ — •Elias Kluth[1], Michael Fay[2], Christopher Parmenter[3], Joseph Roberts[4], Fabien Massabuau[5], Rüdiger Goldhahn[1], and Martin Feneberg[1] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Advanced Materials Research Group, Faculty of Engineering, University of Nottingham, NG7 2RD, UK — [3]Nottingham Nanotechnology and Nanoscience Centre, University of Nottingham, University Park, Nottingham NG7 2RD, UK — [4]School of Engineering, The University of Liverpool, Liverpool L69 3GH, UK — [5]Department of Physics, SUPA, University of

Strathclyde, Glasgow G4 0NG, UK

Corundum-like α-Ga_2O_3 is a metastable phase of the polymorphic ultra-wide band gap semiconductor Ga_2O_3. While previous resarch has mostly focused on the stable β-phase the α-phase is less discussed, but interesing as well as it allows bandgap-engineering by alloying e.g. with α-Al_2O_3 (sapphire) or In_2O_3.
Since the transition metal oxide Ti_2O_3 as well, has a corundum-like phase (α-phase), with a small latice mismatch of about 3.5% to α-Ga_2O_3, we investigate here (0001) α-Ga_2O_3 thin films alloyed with Ti, grown by ALD (atomic layer deposition).
We use spectroscopic ellipsometry in ultraviolet range to obtain the complex dielectric function (DF) of α-$(Ti_xGa_{1-x})_2O_3$ up to $x = 0.61$. We find a clear red shift of the absorption onset with increasing Ti content, as well as an increase of the amplitude of the DF.

HL 14.6 Tue 11:45 H34

Optical signatures of polarons trapped at ferroelectric domain walls in bismuth ferrite — •Sabine Körbel — Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic — Friedrich Schiller University Jena, Germany

Ferroelectric domain walls are atomically narrow planes that can behave very differently from the surrounding bulk ferroelectric material. For example, the domain walls in many ferroelectrics can collect and conduct charge carriers despite the insulating nature of the host material. Domain walls can be created, moved, and removed again in a controlled way, thus they can be used to alter the electronic properties of the ferroelectric as desired. Charge carriers that accumulate at domain walls may induce metallic or semiconducting behavior depending on whether they are delocalized or form self-trapped small polarons. The latter may be detected, for example, as deep levels within the band gap in absorption or photoluminescence spectra. Here we predict optical signatures of charge carriers trapped as small polarons at ferroelectric domain walls in $BiFeO_3$, using first principles calculations.

HL 14.7 Tue 12:00 H34

Anharmonicity of lattice vibrations in α-Ga_2O_3 investigated by temperature dependent Raman spectroscopy — •Jona Grümbel[1], Rüdiger Goldhahn[1], Dae-Woo Jeon[2], and Martin Feneberg[1] — [1]Otto-von-Guericke Universität, Magdeburg, Germany — [2]Korea Institute of Ceramic Engineering and Technology, Jinju, Republic of Korea

We investigate the Raman excitations of a corundum-like α-Ga_2O_3 thin film under temperature variation from 80K up to 790K. This yields detailed information about anharmonic processes in the crystal. For the two dominant phonon modes for each of the two Raman-active phonon mode symmetries (A_{1g} and E_g) model calculations are performed in order to quantify the contributions of different decay mechanisms. It is shown, that our experimental data can be well described by the applied theoretical models. The determined coefficients of cubic and quartic decay for both, phonon energy and linewidth, are compared with those from hexagonal GaN and AlN as well as with those from α-Al_2O_3. We observe, that for the two selected phonon modes of α-Ga_2O_3 the quartic decay processes are negligible for the phonon frequencies, but not for the phonon linewidths behavior under temperature variation. A quantitative description within the model parameters is presented.

Invited Talk HL 14.8 Tue 12:15 H34

Strain-driven dissociation of water on (incipient) ferroelectrics — Joshua L. Bates and •Chiara Gattinoni — Department of Chemical and Energy Engineering, London South Bank University, London, UK

Functional materials have great promise in catalysis, and especially within dynamic catalytic cycles, where the "functional" properties are used to cyclically modify the local environment of a surface to enhance turnover frequency. In particular, strain-driven mechanisms exploiting the properties of piezo- and ferroelectric materials, are of great interest.

In this work we focus on (incipient) ferroelectric nanomaterials $BiFeO_3$, $BaTiO_3$, $KTaO_3$ and $SrTiO_3$, perovskites presenting a wide range of bulk properties and behaviours. We uncover how interplay between these properties (such as the spontaneous polarization) and nanoscale effects (such as the depolarizing field and the surface structure), affect the strain-driven water-splitting abilities of these nanoscale functional materials. Finally, we identify the most desirable properties for a highly efficient ferroelectric material for dynamic catalysis.

HL 15: 2D Materials 3 (joint session HL/CPP/DS)

Time: Tuesday 9:30–12:00 Location: H36

Invited Talk HL 15.1 Tue 9:30 H36

Ultrafast all-optical modulation and frequency conversion in 2D materials — •Sebastian Klimmer[1], Artem Sinelnik[1,2], Isabelle Staude[1,2], and Giancarlo Soavi[1] — [1]Institute of Solid State Physics, Friedrich Schiller University Jena, Jena, Germany — [2]Institute of Applied Physics, Friedrich Schiller University Jena, Jena, Germany

Large efforts have been devoted in the last years to realizing nonlinear integrated devices for frequency conversion, sensing, signal modulation and quantum optics. Two-dimensional (2D) materials, such as graphene and transition metal dichalcogenides (TMDs), provide distinct advantages in this respect thanks to their ease of integration on photonic platforms[1] and their atomically thin nature, which relaxes phase matching constraints and thus offers a practically unlimited bandwidth for nonlinear optical effects [2]. In this seminar I will present our recent results in the field of nonlinear optics with 2D materials, including ultra-broadband four-wave mixing in the telecom range, ultrafast all-optical modulation of second- and third-harmonic generation in TMDs[3] and graphene and ultrafast polarization-resolved second-harmonic spectroscopy to probe the valley degree of freedom in TMDs.

[1] He, J. *et al.*, Nano Lett. **21**, 7, 2709-2718 (2021)
[2] Trovatello, C. *et al.*, Nat. Photonics. **15**, 6-10 (2021)
[3] Klimmer, S. *et al.*, Nat. Photonics. **15**, 837-842 (2021)

HL 15.2 Tue 10:00 H36

strain tuning of exciton and trion dynamics in monolayer WSe2 at cryogenic temperatures — •zhao an[1], pedro soubelet[2], andreas v. stier[2], michael zopf[1], yaroslav zhumagullov[3], jaroslav fabian[3], paulo e. faria jonior[3], jonathan j. finley[2], and fei ding[1,4] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Walter Schottky Institut and Physik Department, Technische Universität München, 85748 Garching, Germany — [3]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [4]Laboratorium fur Nano- und Quantenengineering, Leibniz Universität Hannover, Schneiderberg 39, 30167 Hannover, Germany

Transition metal dichalcogenides (TMD) receive increasing attention these years. In TMD monolayers, the light-matter interaction is driven by strong excitonic effects. Additional to neutral excitons, singlet/triplet trions are observed, in which the additional charge is either in the same or opposite valley with respect to excitons. We apply dynamic strain at cryogenic temperatures to investigate the exciton dynamics of monolayer WSe2. Biaxial strain is electrically controlled via a piezoelectric actuator and transferred to the hBN/WSe2/hBN. We find that next to changes in the emission energy and intensity, the singlet-triplet trion fine structure is affected. Polarization-resolved PL spectroscopy reveals that biaxial strain alters the polarizations of trions, which is attributed to changes in the pumping of resident electrons and the intervalley scattering of excitons and electrons.

HL 15.3 Tue 10:15 H36

Optical nonlinearities in the excited carrier density of 2d TMDs — •Daniel Erben[1], Alexander Steinhoff[1], Michael Lorke[1,2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen — [2]Bremen Center for Computational Materials Science, University of Bremen

The prospects of using 2d transition metal dichalcogenides (TMDs) in future optoelectronic device application requires insight in the ex-

citation dynamics of photoexcited charge carriers and the resulting optical nonlinearities. Utilizing ab-initio electronic-state calculations combined with many-body treatment of optical excitation, we calculate the excited carrier dynamics and the nonlinear absorption in MoS_2, $MoSe_2$, WS_2, and WSe_2 under various excitation conditions.
We find, that the increase of the carrier density with excitation strength deviates from a linear behaviour. Based on this, the validity range of a linear approximation for the excited carrier density as function of the pump fluence is determined. The use of a linear absorption coefficient of the unexcited system can significantly underestimate the achievable carrier density for strong pump fields. Furthermore, we study the excitation-induced many-body effects of excited charge carriers like band-gap renormalization, dephasing, screening, and scattering processes, that are mediated by the strong Coulomb interaction. Additional contributions to optical nonlinearities originate from phase space filling.

15 min. break

HL 15.4 Tue 10:45 H36

Second order coherence of a condensate of exciton-polaritons in an atomically thin crystal — •Jens-Christian Drawer[1], Hangyong Shan[1], Sven Höfling[2], Carlos Anton-Solanas[3], Martin Esmann[1], and Christian Schneider[1] — [1]Universität Oldenburg, Germany — [2]Universität Würzburg, Germany — [3]Universidad Autónoma de Madrid, Spain

We study the second order coherence of a condensate of exciton-polaritons emerging in a microcavity loaded with an atomically thin $MoSe_2$ crystal. Under cryogenic temperatures, angle-resolved PL and reflectivity measurements reveal the formation of two polariton resonances, as the hallmark of the strong coupling regime. The characteristic condensation threshold manifests via the nonlinear input-output-characteristics of the emission. In order to gain deeper information about the photon statistics emitted from the cavity, we perform the Hanbury Brown- and Twiss experiment as a function of the polariton occupation in the effective ground state. While the emission features a bunching effect below threshold, hinting at a thermal contribution of the polariton emission, above threshold the second order correlation transits towards $g^{(2)}(\tau = 0) = 1$, which is indicative for the formation of a coherent state in the quantum optical sense.

HL 15.5 Tue 11:00 H36

Theoretical description of moiré excitons in twisted $MoSe_2$ homobilayers — •Ruven Hübner[1], Malte Kremser[2], Viviana Villafañe[2], Marko M. Petrić[3], Matthias Florian[4], Alexander Steinhoff[1], Mackillo Kira[4], Nathan P. Wilson[2], Andreas V. Stier[2], Kai Muller[3], and Jonathan J. Finley[2] — [1]Institut für Theoretische Physik, Universität Bremen, Bremen, Germany — [2]Walter Schottky Institut and Physik Department, Technische Universität München, Garching, Germany — [3]Walter Schottky Institut and Department of Electrical and Computer Engineering, Technische Universität München, Garching, Germany — [4]University of Michigan, Dept. of Electrical Engineering and Computer Science, Ann Arbor, MI, USA

By introducing a twist between multiple monolayers of transition metal dichalcogenides we can observe superstructures with a new periodicity - namely the moiré lattice. Its size depends on the twist angle and therefore offers the possibility to modify properties like exciton energies as a function of the twist angle. We demonstrate, how DFT calculations of an untwisted $MoSe_2$ bilayer allow us to locally model the band variation inside the moiré unit cell at all dominant high symmetry points of the Brillouin zone. The resulting model provides access to arbitrary moiré potentials experienced by different exciton species and allows us to calculate their twist angle dependent spectra. For all twist angles we assign the lowest energy to interlayer excitons formed between the Γ- and K-valley. The twist angle dependent shift of 5 meV per degree for small angles is in good agreement with experiment.

HL 15.6 Tue 11:15 H36

Dielectric screening effects on the exciton binding-energy and exciton diffusion in a 2D material — •Lukas Gümbel, Philip Klement, and Sangam Chatterjee — Institute of Experimental Physics I and Center for Materials Research (ZfM/LaMa), Justus Liebig University Giessen, Heinrich-Buff-Ring 16, Giessen D-35392, Germany

Two-dimensional semiconductors have proven to be candidates for numerous applications in the field of optoelectronics. Especially transition-metal dichalcogenides such as WS_2 have attracted extensive research due to the direct band-gap emerging in the monolayer limit. The optoelectronic properties are dominated by tightly-bound excitons denoted as A, B, and C. As the electric field lines of the excitonic states extend into the surrounding material, the energy states are subject to dielectric screening effects. Here we show that stronger dielectric screening equally shifts the excitonic ground state energies of the A-, B-, and C-excitons in WS_2 to lower energies. We find a shift of 20 meV in monolayers encapsulated in hBN and observe a non-hydrogenic Rydberg-series yielding a quasiparticle band-gap energy of 2.33 eV with an 1s excitonic binding energy of 0.30 eV. Additionally, we study exciton diffusion in different dielectric environments yielding a diffusion coefficient of 9 cm^2/s. These results complement the underlying theory and may pave the way to a deeper understanding of screening effects in various 2D-Materials.

HL 15.7 Tue 11:30 H36

Brightening of a dark monolayer semiconductor via strong light-matter coupling in a cavity — •Hangyong Shan[1], Ivan Iorsh[2], Bo Han[1], Falk Eilenberger[4], Martin Esmann[1], Sebastian Klembt[3], Sven Höfling[3], Carlos Antón-Solanas[1], Ivan A. Shelykh[2], and Christian Schneider[1] — [1]Oldenburg University, Oldenburg, Germany. — [2]St. Petersburg, Russia — [3]Universität Würzburg, Würzburg, Germany — [4]Friedrich Schiller University, Jena, Germany

We study the modification of the material properties via strong coupling and demonstrate an effective inversion of the excitonic band-ordering in a monolayer of WSe2 with spin-forbidden, optically dark ground state. In our experiments, we harness the strong light-matter coupling between cavity photon and the high energy, spin-allowed bright exciton, and thus creating two bright polaritonic modes in the optical bandgap with the lower polariton mode pushed below the WSe2 dark state. We demonstrate that in this regime the commonly observed luminescence quenching stemming from the fast relaxation to the dark ground state is prevented, which results in the brightening of this intrinsically dark material. We probe this effective brightening by temperature-dependent photoluminescence, and we find an excellent agreement with a theoretical model accounting for the inversion of the band ordering and phonon-assisted polariton relaxation.

HL 15.8 Tue 11:45 H36

Broadband pump-probe microscopy at 1.5 MHz repetition rate — •Devapriyo Mithun[1], Michael Frosz[2], and Giancarlo Soavi[1] — [1]Institute of Solid State Physics, Friedrich Schiller University Jena, Jena, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany

Ultrafast pump-probe spectroscopy is one of the most commonly used techniques to resolve photoinduced excited states dynamics: a pump pulse excites the system under investigation, which is then monitored by measuring the changes in the differential reflection ($\Delta R/R$) of a temporally delayed probe pulse. Here, we discuss the realization of a pump-probe setup, which exhibits high sensitivity operating with a temporal resolution of $\approx$ 100 fs and spatial resolution of $\approx$ 3 μm with 515 nm pump and a broadband probe spectrum in the range 650-1000 nm, generated with a photonic crystal fiber.

We modulate the pump pulse at 1.5 MHz using an acousto-optic modulator. By doing this, we achieve a sensitivity, defined as the minimum detectable $\Delta R/R$, of 10^{-7} at 10 ms integration time. Finally, we implemented a Fourier transform based interferometric detection scheme to achieve a fast measurement of $\Delta R/R$ over the entire broadband spectrum.

Our pump-probe setup provides a powerful tool for broadband pump-probe microscopy with high sensitivity and high temporal resolution, which is ideal for the study of nanostructures such as carbon nanotubes and layered materials.

HL 16: Focus Session: Quantum Properties at Functional Oxide Interfaces (joint session DS/HL)

Time: Wednesday 9:30–11:00 Location: H17

Invited Talk HL 16.1 Wed 9:30 H17

Facet dependence of reconstructions at quantum material interfaces — •Eva Benckiser — Max Planck Institute for Solid State Research, Stuttgart, Germany

Oxide heterostructures promise a rational design of quantum materials with specific, functional properties such as magnetism and superconductivity. Our research aims to gain a fundamental understanding of spin, orbital, charge and lattice reconstructions at complex transition-metal oxide interfaces, mainly using x-ray spectroscopy.

In my talk, I will focus on implications of the choice of the crystallographic facet of the interface by showing examples of two prototypical correlated-electrons materials. In $NdNiO_3$ epitaxial thin films we observe modifications of the metal-insulator transition, which we explain by the facet dependence of the bond-order instability in the system [1]. The choice of a specific interface facet, in turn, allows to manipulate the complex spin order in ultrathin $NdNiO_3$ slabs [2]. In YVO_3 heterostructures, an artificial, layered orbital occupation pattern can be realized by the choice of the interface facet [3]. I have conducted the above-mentioned studies in collaboration with many scientists who are co-authors of the publications listed below.

[1] Y. E. Suyolcu, K. Fürsich *et al.*, Phys. Rev. Materials **5**, 045001 (2021). [2] M. Hepting *et al.*, Nature Physics **14**, 1097 (2018). [3] P. Radhakrishnan *et al.*, Phys. Rev. B **104**, L121102 (2021); Phys. Rev. B **105**, 165117 (2022).

HL 16.2 Wed 10:00 H17

A detailed interface and surface analysis of $BaSnO_3$ in $LaInO_3/BaSnO_3$ heterostructures — •Martina Zupancic[1], Wahib Aggoune[2], Daniel Pfützenreuter[1], Zbigniew Galazka[1], Houari Amari[1], Claudia Draxl[2], Jutta Schwarzkopf[1], and Martin Albrecht[1] — [1]Leibniz-Institut für Kristallzüchtung, Berlin, Germany — [2]Institut für Physik and IRIS Adlershof, Humboldt-Universität zu Berlin, Berlin, Germany

$LaInO_3/BaSnO_3$ heterostructures have lately attracted a lot of interest due to the high electron mobility of $\sim$300cm^2/Vs in $BaSnO_3$ and the formation of a 2DEG at the interface. In $LaAlO_3/SrTiO_3$ system, the origin of the 2DEG is attributed to the polar discontinuity and an electronic reconstruction at the n-type LaO-TiO_2 interface. Controlling the interface termination is therefore crucial to accomplish heterostructures with desired properties. Here, we combine density-functional theory, atomic resolution transmission electron microscopy, energy dispersive X-ray spectroscopy, and electron energy loss spectroscopy (EELS) to study the $LaInO_3/BaSnO_3$ interface. Experiment and theory are in excellent agreement and show that free $BaSnO_3$ (100) surfaces are BaO terminated, while the interface between $BaSnO_3$ and $LaInO_3$ is SnO_2 terminated. This finding indicates that during the growth of $LaInO_3$ layer on $BaSnO_3$ Ba atoms exchange from the subsurface to the surface. Preliminary EELS analysis of a few monolayer thick $LaInO_3$ grown on $BaSnO_3$ shows indications of Ba atoms on the $LaInO_3$ surface, confirming that atomic exchange in this system promotes the energetically favorable SnO_2-LaO interface.

Invited Talk HL 16.3 Wed 10:15 H17

Designing novel electronic phases at oxide interfaces from first principles — •Rossitza Pentcheva — Department of Physics and Center for Nanointegration (CENIDE), University of Duisburg-Essen, Germany

Transition metal oxide interfaces exhibit a rich plethora of functional properties that are not available in the respective bulk compounds and open possibilities for electronics, spintronics and energy conversion applications. Over the past years several control parameters of novel behavior have been identified and systematically explored such as the symmetry breaking at the interface, the effect of strain, confinement and crystallographic orientation, the electrostatic doping at polar interfaces [1]. Based on the insight from density functional theory calculations including an on-site Hubbard term, I will address the formation of unanticipated charge, spin and orbital reconstructions in perovskite-derived superlattices and thin films with (001) and (111) orientation that can lead to e.g. metal-to-insulator transitions and/or topologically nontrivial states which are fascinating not only from a fundamental point of view but also potentially interesting for thermoelectric applications [2].

Research supported by the German Research Foundation DFG within CRC/TRR80. [1] M. Lorenz et al., J. Phys. D: Appl. Phys. 49, 433001 (2016). [2] B. Geisler, P. Yordanov, M. E. Gruner, B. Keimer, R. Pentcheva, Phys. Status Solidi B 259, 2100270 (2022)

HL 16.4 Wed 10:45 H17

Orbital engineering in vanadate heterostructures — •Padma Radhakrishnan[1], Benjamin Geisler[2], Katrin Fürsich[1], Daniel Putzky[1], Yi Wang[1], Sven Ilse[3], Georg Christiani[1], Gennady Logvenov[1], Peter Wochner[1], Peter van Aken[1], Eberhard Goering[3], Rossitza Pentcheva[2], and Eva Benckiser[1] — [1]Max Planck Institute for Solid State Research, Heisenbergstrasse 1, 70569 Stuttgart, Germany — [2]Department of Physics and Center for Nanointegration (CENIDE), Universität Duisburg-Essen, Lothastrasse 1, 47057 Duisburg, Germany — [3]Max Planck Institute for Intelligent Systems, Heisenbergstrasse 3, 70569 Stuttgart, Germany

A promising approach for the manipulation of quantum states involves the epitaxial stabilization of certain orbital occupations, i.e. orbital engineering. Here we use resonant x-ray reflectometry to extract quantitative depth-dependent x-ray linear dichroism profiles of thin slabs of YVO_3 embedded in a superlattice with $LaAlO_3$. Our data reveal an artificial, layered orbital polarization, where the average occupation of xz and yz orbitals at the interface is inverted compared to the central layers of YVO_3. We attribute this effect to a combination of epitaxial strain and spatial confinement by $LaAlO_3$. Further, insights from *ab initio* calculations and scanning transmission electron microscopy indicate that the selection of a suitable spacer layer material, layer thickness of the transition metal oxide, facet of substrate, and sign of strain can together implement a desired orbital polarization pattern. Our study demonstrates the use of orbital engineering as a promising approach for the theory-guided rational design of quantum materials.

HL 17: Quantum Dots and Wires 4: Devices

Time: Wednesday 9:30–12:30 Location: H32

HL 17.1 Wed 9:30 H32

Highly Pure and Bright Emission of a Telecom C-Band Quantum Dot in a Circular Bragg Grating Cavity — •Raphael Joos, Cornelius Nawrath, Sascha Kolatschek, Stephanie Bauer, Pascal Pruy, Robert Sittig, Ponraj Vijayan, Jiasheng Huang, Michael Jetter, Simone L. Portalupi, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQST) and SCoPE, Universität Stuttgart

Quantum communication schemes, which can prospectively guarantee secure communication by physical laws, rely on the availability of single-photons utilized as flying qubits. For this purpose, InAs quantum dots (QDs) can be employed as single-photon source, particularly, providing access to emission at telecom wavelengths which is highly sought-after for fiber-based applications and will, thus, most probably be the operating regime for real-world applications. However, simple planar QD structures suffer from a low collection efficiency due to the high refractive index contrast at the semiconductor/air interface. This issue can be tackled by the application of photonic nanostructures. This contribution deals with the optical and quantum optical investigation of telecom C-band QDs embedded in circular Bragg grating cavities, which allow for strongly increased light collection in a broad range of wavelengths as well as Purcell enhanced emission of the QDs. In this way, QD emission with a near perfect single-photon purity as well as very high collection efficiency is achieved leading to megahertz count rate of actual single-photons available for further applications.

HL 17.2 Wed 9:45 H32

Realization of Gaussian-shaped micro-cavities for Quantum Dots emitting in the telecom C-band — •Jens Jakschik — Institut für Halbleiteroptik und funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Germany

Semiconductor quantum dots (QDs) are a prime candidate for the generation of efficient single, indistinguishable photons. When utilizing these QDs for e.g. long-distance quantum communication, it is important to operate at the transmission loss minimum of the existing global optical fiber network. Therefore, the QDs have to emit in the telecom C-Band (~1550 nm). To keep the advantages of the mature GaAs technology, the QDs are grown on an InGaAs metamorphic buffer (MMB) layer with high In-content on GaAs. The emission of QDs can be optimized by confining them into cavities. In this work novel Gaussian-shaped micro-cavities based on high-reflective DBRs are used. To reach high quality factors and increase the extraction efficiency in Gaussian-shaped cavities, the radial symmetry given by the wet-chemically etched Gaussian-shaped microlens, forming the center of the cavity has to be preserved over multiple layers of top DBR growth. This has to be realized despite the varying growth rates of InGaAs along different crystal axes. In this contribution, we present the results of the optical simulations for optimizing these cavities for the telecom C-Band, as well as the effect of different growth conditions on the overgrowth of InGaAs on wet-chemically pre-structured substrates to enable the fabrication of novel Gaussian-shaped micro-cavities.

HL 17.3 Wed 10:00 H32

Optically induced in-situ strain-tuning of InGaAs quantum dots for nanophotonic devices — •Ching-Wen Shih[1], Marco Holzer[2], Imad Limame[1], Lasse Kosiol[1], Sourish Banerjee[2], Aris Koulas-Simos[1], Veeresh Deshpande[2], Cathrine Dubourdieu[2,3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Berlin, Germany — [3]Freie Universität Berlin, Physical Chemistry, Berlin, Germany

Self-assembled semiconductor quantum dots (QDs) have been widely incorporated in solid-state cavities to enable quantum technologies. However, the nature of self-assembled QDs poses a big challenge to achieving controlled emitter-cavity and emitter-emitter coupling as it not only requires an accurate spatial positioning, but also a precise spectral matching of the system. Here, we report on the MOCVD growth and fabrication of micropillar-like nanophotonic light sources consisting of strain-tunable InGaAs QDs with ALD-deposited HfO2 thin film cladding. We show that the emission energy of QDs can be in-situ tuned by thermally annealing the HfO2 film with a focused laser beam integrated in a μ-photoluminescence setup under cryogenic temperature. We demonstrate a tunability up to 2 meV without QDs degradation. Furthermore, we successfully tuned two separated QD emission peaks from the same structure into resonance. The developed technique paves the path for scaling up the number of coupled QDs in semiconductor nanophotonic devices.

HL 17.4 Wed 10:15 H32

Optical properties of In(Ga)As QDs emitting in the telecom C-band grown on a non-linear metamorphic buffer layer — •Pascal Pruy, Cornelius Nawrath, Robert Sittig, 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

Semiconductor Quantum Dots (QDs) are excellent structures for the generation of non-classical light states with outstanding performance regarding single-photon purity, photon indistinguishability and entanglement fidelity, making them promising sources for currently researched subjects such as quantum computation and quantum communication. The telecom C-band (1530-1565 nm) spectral regime is especially sought-after for fiber-based implementations of these applications due to the absorption minimum in the globally used silica fiber network. On the mature and promising GaAs material platform, the telecom C-band can be reached using a metamorphic buffer (MMB) layer and the recent progress on such QDs has attracted great interest.

While so far MMBs with a thickness of 1080nm have been employed resulting in a nominal 3-λ cavity, a 1-λ cavity would be greatly beneficial for more elaborate photonic structures regarding brightness and coherence. Here we report on the optical properties such as brightness, coherence and purity of In(Ga)As Quantum Dots emitting in the telecom C-band spectral regime on a novel metamorphic buffer layer compatible with 1-λ cavities.

HL 17.5 Wed 10:30 H32

Optical properties of semiconductor quantum dots embedded in an open, fiber-based cavity emitting in the telecom regime — •Julia Wecker[1], Thomas Herzog[1], Jonas Grammel[2], Ponraj Vijayan[1], Robert Sittig[1], Michael Jetter[1], Simone Luca Portalupi[1], David Hunger[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Stuttgart, Germany — [2]Physikalisches Institut, Karlsruher Institut für Technologie (KIT), Karlsruhe, Germany

Enhancing the brightness of quantum emitters can be achieved by coupling them to optical microcavities. Together with an enhanced light extraction, shortening of the spontaneous emission rate can be achieved via the Purcell effect. In this work, we investigate In(Ga)As quantum dots embedded in an open fiber-based Fabry-Pérot cavity. On the bottom distributed Bragg reflector, quantum dots operating at the telecom O- and telecom C-Band are grown, while the top mirror is deposited on a silica fiber which can be moved with nanometric precision across the sample. Therefore, the cavity mode can be tuned in order to achieve spatial and spectral matching with the investigated emitter. The emitted photons are then directly coupled into the telecom fiber, making this fiber-coupled single-photon source promising for quantum communication applications.

30 min. break

HL 17.6 Wed 11:15 H32

GaSb quantum dots surrounded by AlGaSb with indirect-direct bandgap crossover at telecom range — •Lucie Leguay and Andrei Schliwa — Institut für Festkörperphysik, Technische Universität Berlin

We report the modeling and theoretical characterization of a new type-I semiconductor material based on GaSb quantum dots embedded into AlGaSb with GaSb as substrate. The calculations are performed by the nextnano++ solver, using both the effective mass and the 8-band k·p method.

Experimental work shows the formation of nano-holes with a wide range of tunability in depth and density by the local droplet etching of a surface of AlGaSb by liquid gallium [1]. Then, optically active quantum dots are obtained by filling those nano-holes with GaSb and by the deposition of a GaSb quantum well on top [2].

Our calculations demonstrate an indirect-direct bandgap crossover as the thickness of the quantum well increases, which allows control of the system's luminescence. In the direct bandgap regime, the quantum dots emit narrow excitonic spectral lines in the telecom wavelength range. These properties, as well as the low density of the quantum dots, show a lot of promise for applications in the field of infrared quantum optics.

[1] J. Hilska, A. Chellu, T. Hakkarainen, Cryst. Growth Des. 2021, 21, 1917-1923

[2] A. Chellu, J. Hilska, J-P Penttinen, T. Hakkarainen, APL Mater. 9, 051116 (2021)

HL 17.7 Wed 11:30 H32

Coherent Spin Control in InAs Quantum Dots Emitting in the Telecom C-Band — •Johannes Michl[1], Łukasz Dusanowski[1,3], Cornelius Nawrath[2], Michael Jetter[2], Simone L. Portalupi[2], Tobias Huber[1], Peter Michler[2], and Sven Höfling[1] — [1]Technische Physik, Julius-Maximilians University of Würzburg — [2]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), University of Stuttgart — [3]Princeton University

Semiconductor quantum dots can be used as spin-photon interfaces, enabling the preparation of photonic cluster states with a single spin in the quantum dot acting as the entangler. This leads the way towards memory-less quantum repeater protocols for quantum network applications. InAs quantum dots can be grown on metamorphic buffer layers, leading to strain relaxed growth and therefore light emission directly into the telecom C-band. Here we show magneto and polarization resolved photoluminescence experiments conducted to characterize the different charge complexes in a single quantum dot. Furthermore, we implement laser pulse sequences to gain full coherent control over a

hole qubit.

HL 17.8 Wed 11:45 H32

Quantum Dot Localization Methodology based on Imaging — •Marc Sartison, Eva Schöll, Lukas Hanschke, Ioannis Caltzidis, Oscar Camacho Ibarra, and Klaus D. Jöns — PhoQS, CeOPP, and Department of Physics, Paderborn University, Germany

Since the discovery of the triggered generation of single photons in 2000, quantum dots have proven to be one of the most versatile quantum light sources for pure, indistinguishable, entangled photons while maintaining high brightness. Before developing deterministic integration techniques, high yield in device fabrication remained elusive due to the statistical growth properties in high-quality self-assembled growth modes. Several methods have been developed, providing the quantum dot location and its spectral information, namely in-situ optical lithography, in-situ electron beam lithography, and quantum dot localization using quantum dot imaging. Our work describes a methodological workflow using computational, and image processing approaches in python to precisely determine the quantum dot position concerning pre-deposited metal marker structures. Here, we investigate different hardware, marker geometries, and software methods. Furthermore, we quantify the expectable upper bound accuracy for device integration. Importantly, our presented methods are not developed for a fixed emitter wavelength or type. With the right choice of optical elements within the setup, it is possible to cover the wavelengths from the visible up to the telecom C-band. The presented technique can, in principle, be applied to any type of solid-state quantum emitters.

HL 17.9 Wed 12:00 H32

Fabrication and Electrical Characterisation of Junctionless Nanowire Transistors for Detection of Atmospheric Radicals and Other Gases — •Sayantan Ghosh[1], Muhammad Bilal Khan[1], Vaishali Vardhan[2], Ulrich Kentsch[1], Slawomir Prucnal[1], Subhajit Biswas[2], Justin Holmes[2], Artur Erbe[1], and Yordan M. Georgiev[1,3] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]School of Chemistry, University College Cork, Cork, Ireland — [3]Institute of Electronics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Silicon junctionless nanowire transistors (JNTs) have shown excellent sensitivity to record-low concentrations of the protein streptavidin in liquid phase. However, JNTs have not yet been tested for sensing in gas phase. Here we present the fabrication and initial electrical characterisation of JNT-based electronic sensors for detection of atmospheric free radicals such as hydroxyl (*OH) and nitrate (*NO3), which are the main drivers of chemical processes in the atmosphere. The aim of this work is to develop small, low-cost JNT-based nanosensors for radical detection. Silicon-on-insulator wafers were doped by ion implantation and flash-lamp annealing. Device patterning was based on electron beam lithography, inductively-coupled reactive ion etching, metal deposition and lift-off. Initial electrical characterisation and gas sensing experiments on fabricated devices proved their good performance and potential suitability for detection of atmospheric free radicals.

HL 17.10 Wed 12:15 H32

Single photons from Semiconductor Quantum Dots in Circular Bragg Gratings for Quantum Cryptography — •Daniel Vajner, Lucas Rickert, Timm Gao, Koray Kaymazlar, Jan-Niklas Donges, Johannes Schall, Sven Rodt, Stpehan Reitzenstein, and Tobias Heindel — Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany

Semiconductor quantum dots are an excellent source of single photons for future quantum networks [1]. In order to enhance their properties they are typically incorporated into photonic structures. Among these, circular bragg gratings (CBG) are a promising way to further enhance the outcoupling efficiency [2]. Additionally, they are especially suited for fiber-coupling to achieve more compact plug-and-play single photon sources [3]. In this work we deterministically integrate single InGaAs quantum dots in CBG structures, which have been numerically optimized beforehand. We characterize the properties of the CBGs and quantify the purity and indistinguishability of the emitted photons. Finally, we aim for the implementation of cryptographic primitives such as strong quantum coin flipping using single photons.

[1] D. Vajner et al., Adv. Quantum Technol. 2100116 (2022)
[2] L. Rickert et al., Optics Express 27.25 (2019)
[3] T. Gao et al., Applied Physics Reviews 9.1 (2022)

HL 18: Oxide Semiconductors (joint session HL/KFM)

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

HL 18.1 Wed 9:30 H33

Heavily doped Zinc Oxide with plasma frequencies in the telecommunication wavelength range — •Alexander Koch[1], Hongyan Mei[2], Jura Rensberg[1], Martin Hafermann[1], Jad Salman[2], Chenghao Wan[2,5], Raymond Wambold[2], Daniel Blascke[3], Heidemarie Schmidt[3], Jürgen Saalfeld[4], Sebastian Geburt[4], Mikhail Kats[2,5,6], and Carsten Ronning[1] — [1]Institute for Solid State Physics, Friedrich Schiller University Jena, 07743 Jena, Germany — [2]Department of Electrical and Computer Engineering, University of Wisconsin Madison, Madison, Wisconsin 53706, USA — [3]Leibniz Institute of Photonic Technology, 07745 Jena, Germany — [4]Innovavent GmbH, 37077 Göttingen, Germany — [5]Department of Materials Science and Engineering, University of Wisconsin Madison, Madison, Wisconsin 53706, USA — [6]Department of Physics, University of Wisconsin Madison, Madison, Wisconsin 53706, USA

We demonstrate high doping of ZnO by a combination of Ga ion implantation using a focused ion beam (FIB) system and post-implantation laser and flash lamp annealing. While ion implantation allows for the incorporation of impurities with nearly arbitrary concentrations, the additional optical annealing processes enable dopant activation close to the solid-solubility limit of Ga in ZnO. By this means, we achieved highly-doped ZnO:Ga with free-carrier concentrations of $9.5 \cdot 10^{20}$ cm^{-3}, which results in a plasma wavelength shorter than the telecommunication wavelength of 1.55 μm. Thus, ZnO:Ga is a very promising plasmonic material for optical applications in the near-infrared spectral region.

HL 18.2 Wed 9:45 H33

Side-by-side display of optical and resistive H_2S gas sensing properties of pristine and gold functionalized ZnO nanowires — •Angelika Kaiser[1], Tanja Mauritz[1], Joachim Bansmann[3], Ulrich Herr[1], and Klaus Thonke[2] — [1]Institute of Functional Nanosystems, University Ulm, 89081 Ulm, Germany — [2]Institute of Quantum Matter, Semiconductor Physics Group, University Ulm, 89081 Ulm, Germany — [3]Institute for Surface Chemistry and Catalysis, University Ulm, 89081 Ulm, Germany

We investigate the mechanism of hydrogen sulfide (H_2S) gas sensing in pristine and gold functionalized zinc oxide (ZnO) nanowires (NW), two potent nanomaterial systems with an enlarged surface-area-to-volume ratio for medical breath analysis in the sub-ppm regime through the "electronic nose" approach. Pristine ZnO NWs (ZnO(NM)) are grown by high-temperature chemical vapor deposition (CVD) and functionalized with gold (Au) nanoparticles by magnetron sputtering (ZnO(Au)). The sensor response is studied by photoluminescence (PL) and electrical conductivity measurements of as-grown ZnO NWs and open gate ZnO NW ChemFET structures. A systematical side-by-side comparison of PL-intensity-time measurements and current-time measurements reveal a two-step detection process between 1 ppm of H_2S and ZnO(NM)/ZnO(Au) NWs. Temperature series hints at underlying gas adsorption/desorption processes. Additional X-ray photoelectron spectroscopy (XPS) confirms the beneficial gas-sensitive affinity between Au functionalization and H_2S gas, which leads to a significant improvement of the sensitivity for H_2S detection.

HL 18.3 Wed 10:00 H33

Growth window of α-Ga_2O_3 on m-plane sapphire by pulsed laser deposition — •C. Petersen, S. Vogt, M. Kneiss, H. von Wenckstern, and M. Grundmann — Universität Leipzig, Felix Bloch Institute for Solid State Physics, Semiconductor Physics Group, Leipzig, Germany

Due to its high bandgap of 4.6-5.3 eV and high predicted breakdown field of 8 MV/cm [1], much attention is drawn to the wide bandgap

semiconductor Ga_2O_3 for applications in high-power devices. However, besides the well-studied thermodynamically stable monoclinic β-phase of Ga_2O_3, the metastable α-polymorph with corundum structure is gaining scientists' interest. Since it is isostructural to Al_2O_3, miscibility over the entire composition range of α-$(Al_xGa_{1-x})_2O_3$ can be achieved [2] and the growth on cost-effective sapphire substrates becomes feasible. Thereby m-plane sapphire facilitates the growth of the corundum phase [3] and allows for thin films with electron mobilities as high as 65 $cm^2(Vs)^{-1}$ [4]. We present phase-pure α-Ga_2O_3 thin films grown on m-plane sapphire over a wide temperature range of 565 °C up to 750 °C with high cristallinity and surface roughnesses as low as 0.7 nm (RMS). We further demonstrate that for oxygen partial pressures above 0.001 mbar the formation of the monoclinical β-phase and spinel-defective γ-phase occurs and provide a corresponding phase diagram. Resulting samples were investigated employing X-ray diffraction, reciprocal space maps and atomic force microscopy. [1] Higashiwaki, Sc. Sci. Tech., 034001, 2016. [2] Hassa, pss-b, 2000394, 2020. [3] Kneiß, jmr, 4816-4831, 2021. [4] Akaiwa, pss-a, 1900632, 2020.

HL 18.4 Wed 10:15 H33

Simulation of Switching Processes Inside Bilayer Valence Change Memory Cells by a Drift-Diffusion Model — •Nils Sommer[1], Stephan Menzel[1], and Rainer Waser[1,2] — [1]Peter Grünberg Institut 7, Forschungszentrum Jülich, Germany — [2]Institut für Werkstoffe der Elektrotechnik 2, RWTH Aachen, Germany

Valence change memory (VCM) cells are promising candidates for future nonvolatile storage devices [1]. VCM cells are characterized by their ability to switch between at least two stable resistance states by applying suitable bias voltages. A special structure of VCM cells are bilayer cells consisting of two semiconducting oxide layers, with one oxide serving as a tunnel barrier. Experiments show that a change in resistance of the cell can be caused by the exchange of oxygen between the two oxide layers [2]. However, the processes taking place are not yet well understood. We use a drift-diffusion model to simulate the movement of oxygen inside the semiconductor to gain a better understanding of the exchange process between the layers. We investigate the internal electric fields acting as a driving force on the oxygen, as well as the oxygen diffusion process that causes it to return to an equilibrium state. We show that an oxygen exchange deforms the shape of the tunnel barrier and by this changing the resistance of the cell. Further, we show that the change in resistance depends on the permittivity of the oxides.

[1] R. Waser, R. Dittmann, G. Staikov, K. Szot, Adv. Mater. 2009, 21, 2632 [2] A. Gutsche, S. Siegel, J. Zhang, S. Hambsch, R. Dittmann, Frontires in Neuroscience,2021, 15, 661261

HL 18.5 Wed 10:30 H33

Phonons, Isotope Effects, and Point Defects in β-Ga2O3 — •Benjamin M. Janzen[1], Piero Mazzolini[2,3], Roland Gillen[4], Andreas Falkenstein[5], Vivien F. S. Peltason[1], Hans Tornatzky[1], Daniel Cierpinsky[1], Andrea Ardenghi[2], Manfred Martin[5], Janina Maultzsch[4], Roberto Fornari[2,3], Zbigniew Galazka[6], Oliver Bierwagen[2], and Markus R. Wagner[1] — [1]Technische Universität Berlin, Institute of Solid State Physics, Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V, Germany — [3]Department of Mathematical, Physical and Computer Sciences, University of Parma, Italy — [4]Chair of Experimental Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [5]Institute of Physical Chemistry, RWTH Aachen University, Germany — [6]Leibniz-Institut für Kristallzüchtung, Berlin, Germany

We present a combined experimental and theoretical study of lattice vibrations in a homoepitaxial β-Ga2O3 thin film grown by MBE with different oxygen isotopes (16O, 18O). Using polarized first- and second order micro-Raman spectroscopy, we identified all 15 first-order Raman modes of β-Ga2O3. In combination with density functional perturbation theory calculations, we identify the atomistic origins (Ga-Ga, Ga-O or O-O) of all Raman active phonon modes in β-Ga2O3 by quantifying the isotopically-induced relative frequency shifts of the individual Raman modes and investigate the presence of point defects on specific lattice sites.

HL 18.6 Wed 10:45 H33

Epitaxial ZnO thin films and NWs — •Maximilian Kolhep[1], Margit Zacharias[1], and Jürgen Bläsing[2] — [1]Laboratory for Nanotechnology, Department of Microsystems Engineering (IMTEK), University of Freiburg, Freiburg 79110, Germany — [2]Otto-von-Guericke-University Magdeburg, Institute of Physics, Magdeburg, Germany

Due to its high piezoelectric coefficient and direct band gap of 3.37 eV, ZnO and especially ZnO nanowires are of interest for numerous future applications. We demonstrate the epitaxial growth of ZnO on Si(111) substrates using an AlN buffer layer by atomic layer deposition (ALD). ALD is a promising technique as it allows the deposition of extremely thin films with precise thickness control and excellent conformality over large areas. The crystalline quality of ZnO thin films determined by XRD increases with increasing deposition temperature and an additional post-annealing step. These thin films have a great potential as a substrate for the subsequent catalyst-free and epitaxial growth of ZnO NWs by CVD. The influence of growth parameters on the morphology of ZnO NWs will be discussed.

15 min. break

HL 18.7 Wed 11:15 H33

Investigation of $CuBr_xI_{1-x}$ thin films and CuI bulk material — •Michael Bar[1], Evgeny Krüger[1], Steffen Blaurock[2], Stefan Merker[2], Holger von Wenckstern[1], Harald Krautscheid[2], and Marius Grundmann[1] — [1]Universität Leipzig, Felix-Bloch Institute, Germany — [2]Universität Leipzig, Institute of Inorganic Chemistry, Germany

Oxide based wide-bandgap materials with suitable transparency in the visible range are typically unipolar, such that heterostructures are needed for complementary devices. The search for a suitable p-type candidate has led to copper iodide (CuI), which unites transparency in the visible spectral range with exceptional hole mobility, therefore sharing and yet complementing typical properties of oxides. Fabrication methods include sputtering, spin coating and molecular beam epitaxy. [1,2] We present structural, electrical and optical properties of CuI bulk material, and thin films which were grown by pulsed laser deposition (PLD). Furthermore, alloyed thin films of $CuBr_xI_{1-x}$ were deposited with a segmented target PLD approach and investigated using x-ray diffraction, transmission and photoluminescence measurements. This PLD approach allows for deposition of thin films in the full composition range using only a single target without the need of sintering. [3] A systematic shift of lattice constants as well as the excitonic features can be observed as function of alloy composition.

[1] C. Yang *et al.*, Proc. Natl. Acad. Sci. USA, **113**(46), 12929, (2016).
[2] S. Inagaki *et al.*, Appl. Phys. Lett., **116**(19), 192105, (2020).
[3] H. Wenckstern *et al.*, Phys. Stat. Sol. (b), **257**(7), 1900626, (2020).

HL 18.8 Wed 11:30 H33

A Koopman's compliant exchange correlation potential for semiconductors — •Michael Lorke[1], Peter Deak[2], and Thomas Frauenheim[2] — [1]Institute for Theoretical Physics, University of Bremen, Germany — [2]BCCMS, University of Bremen, Germany

Density functional theory is the workhorse of theoretical materials investigations. Due to the shortcoming of (semi-)local exchange correlation potentials, hybrid functionals have been established for practical calculations to describe surfaces, molecular adsorption, and defects. These functionals operate by mixing between semi-local and Hartree-Fock exchange semi-emprically. However, their parameters have to be optimized for every material separately. To treat materials with a more physics driven approach and without the need of parameter optimization is possible with many-body approaches like GW, but at an immense increase in computational costs and without the access to total energies and hence geometry optimization.

We propose a novel exchange correlation potential[1] for semiconductor materials, that is based on physical properties of the underlying microscopic screening. We demonstrate that it reprocuduces the low temperature band gap of several materials. Moreover it respects the required linearity condition of the total energy with the fractional occupation number, as expressed by the generalized Koopman's theorem. We also show that this novel functional can be used as a kernel in linear response TDDFT to reproduce excitonic effects in optical spectra

[1] Physical Review B 102 (23), 235168 (2020)

HL 18.9 Wed 11:45 H33

The role of defects in polaron hopping transport in epitaxial BiVO4 for solar water splitting — •Malte Luca Weber, Viktoria Franziska Kunzelmann, and Ian Sharp — Walter Schottky Institute, TUM, Am Coulombwall 4, 85748 Garching, Germany

Use of green hydrogen as a fuel, energy storage medium, and reactant in chemical industry is one of the key strategies on the way to a

sustainable economy. In this regard, solar driven water splitting using semiconductor photoelectrodes is a promising approach for sustainable production of hydrogen. Among various investigated semiconductor photoelectrodes, BiVO4 offers several desirable characteristics, including favourable band edge energetics, high carrier separation efficiency, and potential for stable operation under photoelectrochemical conditions. However, the material is characterised by very low carrier mobilities due to self-trapping formation of small polarons. Here, the effect of intentionally introduced defects on charge carrier mobility is investigated. Using a novel solution-based synthesis technique, high-quality epitaxial BiVO4 thin films were grown on YSZ (001). Post-synthetic vacuum annealing enables tuneable introduction of tuneable concentrations of oxygen vacancy defects. Optical characterisation by photothermal deflection spectroscopy clearly indicates an increase of the sub-bandgap absorption for an increasing defect concentration, leaving unaltered the bandgap. Temperature-dependent electrical conductivity measurements indicate a thermally-activated hopping behaviour, which is characterised by higher conductivities and lower hopping behaviours with increasing native point defect concentrations.

HL 18.10 Wed 12:00 H33

Conduction channels in polycrystalline copper iodede thin films — •Tillmann Stralka — Universtität Leipzig, Felix Bloch Institute for Solid State Physics, Linnéstr. 5, 04103 Leipzig, Germany

The search for high-performance, transparent p-type conductive materials has been a major challenge for decades [1]. Copper iodide (CuI) or alloys based on CuI [2] could offer a solution, since CuI does outperform all other known p-type TCMs, concerning transmittance in the visible spectrum as well as electrical conductivity at room temperature [3]. In this contribution polycrystalline CuI thin films, grown by sputtering, are investigated. Hereby we try to understand and differentiate the contribution of grains and grain boundaries (GBs) to electrical transport. Extended structural defects such as GBs lead to a depletion of majority charge carriers in their vicinity and even a localised inversion (two dimensional electron gas) within GBs was reported [4]. To acquire morphological (grain and GBs) and electrical properties with a high spatial resolution we employ current probe atomic force microscopy and Kelvin probe force microscopy. We evaluate these measurements with a novel approach that offers the possibility to correlate topographic and electrical properties over a whole series of scans in dependence on an externally applied voltage [5], measuring temperature, probe force, plasma treatment and degradation over time.

[1] M. Grundmann et al., J.Phys.D.Apps.Phys., 49(213001), 2016 [2] T. Jun et al., Adv. Mater., 30(1706573), 2018 [3] C. Yang et al., PNAS 113(412929), 2016 [4] M. Kneiß et al., Adv. Mater. Interfaces, 5(6), 2018 [5] I. Visoly-Fisher et al., Adv. Funct. Mater., 16(649), 2016

HL 18.11 Wed 12:15 H33

First-Principles Studies of Defects in Bismuth Vanadate — •Nicklas Österbacka[1], Francesco Ambrosio[2], and Julia Wiktor[1] — [1]Chalmers University of Technology, Gothenburg, Sweden — [2]University of Salerno, Fisciano, Italy

Bismuth vanadate, a transition-metal oxide semiconductor with a bandgap of 2.4 eV, has shown great promise as a water-splitting photocatalyst. Its practical performance remains limited due to slow hole transfer, high charge recombination rates, and low conductivity, however. An atomistic understanding of the relationship between the material's structure and its properties is key to solving these issues. To this end, we have performed first-principles calculations on the native defects of bismuth vanadate, revealing their structural complexity and highlighting the importance of taking charge localization into account for this class of materials. Additionally, we show that oxygen vacancy-induced distortions in the material complicates phase identification of synthesized samples by making powder X-ray diffraction ambiguous.

HL 19: Materials and Devices for Quantum Technology 1

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

Invited Talk HL 19.1 Wed 9:30 H34

Quantum Interference of Identical Photons from Remote GaAs Quantum Dots — •Giang Nam Nguyen[1], Liang Zhai[1], Clemens Spinnler[1], Julian Ritzmann[2], Mattias C. Löbl[1], Andreas D. Wieck[2], Arne Ludwig[2], Alisa Javadi[1], and Richard J. Warburton[1] — [1]Department of Physics, University of Basel — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum

Efficient generation and detection of coherent single photons are key to advances in photonic quantum technologies such as quantum computation, quantum simulation, and quantum communication. For applications, a significant roadblock is the poor quantum coherence upon interfering single photons created by independent emitters.

Here, we present near-unity two-photon interference visibilities from two separate GaAs quantum dots [1]. This high visibility (˜93%) is achieved under rigorous conditions: there is no Purcell enhancement, no temporal post-selection, no narrow spectral-filtering, nor frequency stabilization. Using photons emitted from two remote quantum dots, we demonstrate a photonic CNOT gate. Interfering photons in this quantum logic gate, we generate an entangled two-photon state using photons from separate semiconductor chips. We obtain an entanglement fidelity of (85 +- 1)%, exceeding the CHSH threshold for violating Bell inequalities. This result highlights the importance of the high two-photon visibility for high fidelity entanglement operations.

[1] L. Zhai et al., Nature Nanotechnol. (2022)

HL 19.2 Wed 10:00 H34

Optimizing quantum teleportation with imperfect quantum dot sources — •Francesco Salusti[1], Francesco Basso Basset[2], Lucas Schweickert[3], Michele B Rota[2], Davide Tedeschi[2], Saimon Filipe Covre da Silva[4], Emanuele Roccia[2], Val Zwiller[3], Klaus D Jöns[1], Armando Rastelli[4], and Rinaldo Trotta[2] — [1]Department of Physics, Paderborn University, Paderborn, Germany — [2]Department of Physics, Sapienza University of Rome, Rome, Italy — [3]Department of Applied Physics, Royal Institute of Technology, Stockholm, Sweden — [4]Institute of Semiconductor and Solid State Physics, Johannes Kepler University, Linz, Austria

All-optical quantum communication protocols such as teleportation and entanglement swapping require the generation of entangled photons. Quantum dots, with their on-demand generation and low unwanted multi-photon emission are excellent candidates to realize these protocols. However, finding quantum dots with near-perfect quantum optical properties remains challenging. Instead, in our work we demonstrate that it is possible to improve a quantum teleportation protocol by acting exclusively on the experimental setup. [1] Despite selecting a source with non-ideal figures of merit, we have been able to enhance the overall protocol fidelity. The obtained values agree with our developed model, taking the quantum dot properties into account. Our model provides predictive power for future source optimization. Reference: [1] F. Basso Basset, F. Salusti et al., npj Quantum Information 7, 7 (2021)

HL 19.3 Wed 10:15 H34

Time Dependent Redfield Dynamics of Semiconductor Quantum-Dot Molecules — •Steffen Wilksen, Isabell Hüllen, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Bremen, Germany

Semiconductor quantum dots provide a promising platform for applications in quantum information technologies, like quantum repeaters, which enable secure quantum communication over long distances. Two quantum dots, seperated by a small tunneling layer, can be combined into so-called quantum dot molecules (QDMs) which exhibit properties similar to classical molecules. These properties can be tuned by applying an external electric field, which allows to perform switching operations on QDM-based qubits.

The QDM can not be treated in isolation, since the electron-phonon interaction plays a crucial role in the systems dynamics. We thus treat the QDM as an open quantum system coupled to the external phonon reservoir. The application of a time-dependent electric field not only changes the QDM's properties, but also the form of the electron-phonon interaction, which allows for a time dependent tuning of dissipative effects.

We investigate the behaviour of the system for different switching speeds of the electric field using a time-dependent Redfield master equation approach. Slow switching leads to predictable and controlled

adiabatic behaviour but limits the clock rate of the quantum repeater, whereas fast switching allows for higher clock rates but leads to non-adiabatic behaviour.

HL 19.4 Wed 10:30 H34

Three-dimensional electrical control of the excitonic fine structure for a quantum dot in a cavity — •Martin Esmann[1,2], Hélène Ollivier[1], Priya Priya[1], Abdelmounaim Harouri[1], Isabelle Sagnes[1], Aristide Lemaître[1], Olivier Krebs[1], Loic Lanco[1], Daniel Lanzillotti-Kimura[1], and Pascale Senellart[1] — [1]Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies (C2N), Palaiseau, France — [2]Institut für Physik, Universität Oldenburg, Germany

The excitonic fine structure plays a key role for the quantum light generated by semiconductor quantum dots, both for entangled photon pairs and single photons [1]. Controlling the excitonic fine structure has been demonstrated using electric, magnetic, or strain fields, but not for quantum dots in optical cavities, a key requirement to obtain high source efficiency and near-unity photon indistinguishability [2]. Here, we demonstrate the control of the fine structure splitting for quantum dots embedded in micropillar cavities. We propose and implement a scheme based on remote electrical contacts connected to the pillar cavity through narrow ridges. Numerical simulations show that such a geometry allows for a three-dimensional control of the electrical field. We experimentally demonstrate tuning and reproducible canceling of the fine structure, a crucial step for the reproducibility of quantum light source technology.

[1] P. Senellart, G. Solomon, and A. White, Nature Nanotechnology 12, 1026 (2017). [2] R. Trotta et al. PRL 114, 150502 (2015). [3] H. Ollivier et al. arXiv:2112.00400.

HL 19.5 Wed 10:45 H34

Design study of electrically contacted quantum dot circular Bragg gratings — •Quirin Buchinger, Tobias Huber, and Sven Höfling — Technische Physik, Universität Würzburg, 97074 Würzburg, Germany

Recently, photonic quantum networks receive a lot research interest. Semiconductor quantum dots offer a local memory, utilizing single spins and are highly efficient single or entangled photon sources. Therefore, they are among suitable candidates for a scalable hardware platform for quantum networks. To enhance brightness and extraction efficiency the quantum dots are typically embedded into microcavities, here circular Bragg gratings. By incorporating the quantum dots into a diode structure they can be charged with a single electron or hole and thus generate a ground state spin qubit [1]. This provides opportunity for spin photon coupling [2]. To apply voltage to the quantum dot inside of a circular Bragg grating, bridges through the etched rings have to be leaved unetched as a path for the current to the central disc of the microcavity. We discuss different layouts of these bridges and their influence on cavity wavelength, quality factor and polarisation.

[1] Warburton, R., Nature Mater 12, 483-493 (2013)
[2] De Greve, K., et al. Nature 491, 421-425 (2012)

30 min. break

HL 19.6 Wed 11:30 H34

Influence of extended defects on the formation energy, hyperfine structure, and zero-field splitting of NV centers in diamond — Wolfgang Körner[1], •Daniel Urban[1], and Christian Elsässer[1,2] — [1]Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstr. 11, 79108 Freiburg, Germany — [2]University of Freiburg, Freiburg Materials Research Center (FMF), Stefan-Meier-Straße 21, 79104 Freiburg, Germany

We present a density-functional theory analysis of nitrogen-vacancy (NV) centers in diamond, which are located in the vicinity of extended defects, namely, intrinsic stacking faults, extrinsic stacking faults, and coherent twin boundaries on 111 planes in diamond crystals [1]. Several sites for NV centers close to the extended defects are energetically preferred with respect to the bulk crystal. This indicates that NV centers may be enriched at extended defects. We report the hyperfine structure and zero-field splitting parameters of the NV centers at the extended defects, which typically deviate by about 10% but in some cases up to 90% from their bulk values. Furthermore, we find that the influence of the extended defects on the NV centers is of short range: NV centers that are about three double layers (corresponding to ~ 6) away from defect planes already show bulklike behavior.

[1] W. Körner, D. F. Urban, and C. Elsässer, Phys. Rev. B 103, 085305 (2021).

HL 19.7 Wed 11:45 H34

Topological insulator based axial DC SQUID quantum interferometer structure — •Erik Zimmermann[1,2], Benedikt Frohn[1,2], Jan Karthein[1,2], Gerrit Behner[1,2], Abdur Rehman Jalil[1,2], Tobias Schmitt[2,3], Michael Schleenvoigt[1,2], Gregor Mussler[1,2], Peter Schüffelgen[1,2], Hans Lüth[1,2], Detlev Grützmacher[1,2,3], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany — [3]Peter Grünberg Institut (PGI-10), Forschungszentrum Jülich, 52425 Jülich, Germany

Three-dimensional topological insulators (TIs) form a new material class that may enable robust topological quantum computing when combining them with a superconductor by using so-called Majorana zero modes. Recently, Josephson junctions and SQUIDs using a TI as a weak link are investigated for interface characterization. We present the in-situ fabrication of an interferometer structure formed by an axial DC SQUID that is based on a ternary TI with a $Bi_{0.18}Sb_{1.82}Te_3$ composition. For the in-situ fabrication shadow mask techniques and selective area growth by molecular beam epitaxy are used. Furthermore, magnetotransport measurements are shown, revealing induced superconductivity in both Josephson junctions and an in-plane magnetic field dependent interference pattern corresponding to SQUID oscillations. Lastly, the Shapiro response of the device is investigated.

HL 19.8 Wed 12:00 H34

Top-down nanofabrication of silicon nanopillars hosting telecom photon emitters — •Nagesh S. Jagtap[1,2], Michael Hollenbach[1,2], Ciarán Fowley[1], Juan Baratech[1], Verónica Guardia-Arce[1], Ulrich Kentsch[1], Anna Eichler-Volf[1], Nikolay V. Abrosimov[3], Artur Erbe[1], ChaeHo Shin[4], Hakseong Kim[4], Manfred Helm[1,2], Woo Lee[4], Georgy V. Astakhov[1], and Yonder Berencén[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Leibniz-Institut für Kristallzüchtung, 12489 Berlin, Germany — [4]Korea Research Institute of Standards and Science, 34113 Daejeon, Republic of Korea

Silicon, a ubiquitous material in modern computing, is an emerging platform for realizing a source of indistinguishable single-photons on demand. The integration of recently discovered single-photon emitters in silicon into photonic structures is advantageous to exploit their full potential for integrated photonic quantum technologies [1] [2]. Here, we show the integration of an ensemble of telecom photon emitters in a two-dimensional array of silicon nanopillars. We developed a top-down nanofabrication method, enabling the production of thousands of individual nanopillars per square millimeter with state-of-the-art photonic-circuit pitch, all the while being free of fabrication-related radiation damage defects. We found a waveguiding effect of the 1278 nm G-center emission along individual pillars accompanied by improved brightness, compared to that of bulk silicon.

HL 19.9 Wed 12:15 H34

Large hBN single-photon emitter arrays fabricated by capillary assembly — •Johann Adrian Preuss, Eduard Rudi, Johannes Kern, Robert Schmidt, Rudolf Bratschitsch, and Steffen Michaelis de Vasconcellos — University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Convenient and readily available quantum light sources are a crucial building block for quantum photonic technologies. Recently, single-photon emitters have been discovered in hexagonal boron nitride (hBN), which efficiently emit single photons even at room temperature. Controlling the positioning of nanocrystals hosting these light emitters is an important technique for the bottom-up fabrication of functional nanostructures. Here, we demonstrate the fabrication of mm^2-sized rectangular arrays formed by tens of thousands of hBN nanoplatelets [1]. Using capillary assembly, we arrange commercially available hBN nanopowder. Positioning yields of >95% are achieved on individual fields. We find stable and spectrally narrow quantum optical light emitters in 16% of the positions. Our preparation method opens the way for the combination of quantum light emitters in hBN with further fabrication steps for integrated photonic chips, which can provide

thousands of single-photon sources at different emission energies.

[1] J. A. Preuß et al., 2D Materials 8, 035005 (2021)

HL 19.10 Wed 12:30 H34

Single-electron Shuttling by Si/SiGe Quantum Bus — •Ran Xue, Inga Seidler, Tom Struck, Simon Humphol, Tobias Hangleiter, Hendrik Bluhm, and Lars R. Schreiber — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, Aachen, Germany

The electron-spin in gate-defined quantum dots in a Si/SiGe heterostructure is one of the most promising qubits for scalable quantum computing. Qubit gates beyond the error-correction threshold have been widely investigated, however, the long range coupling of qubits remains challenging. Here we study the feasibility of single electron shuttling by forming a propagating sinusoidal potential in a gate-defined 1-dimensional channel. A $99.42 \pm 0.02\%$ high single-electron shuttle fidelity over a distance of 420 nm has been demonstrated in our recent research. [1] It provides adiabatic movement of a quantum dot filled by a single electron representing the qubit. An extension to $10\,\mu m$ long devices is in progress. The number of control lines is intrinsically independent from the shuttle length, therefore, no additional scalability complexity regarding signal generation and wiring is expected. Our concept is compatible with industrial CMOS fabrication lines and ultimately might lead to transport spin qubit information without much loss of spin-coherence.

[1] Seidler, I. *et al.*, Conveyor-mode single-electron shuttling in Si/SiGe for a scalable quantum computing architecture. arXiv:2108.00879 (2021).

HL 19.11 Wed 12:45 H34

Device-Scale Modeling and Simulation of Solid State Spin-Qubit-Shuttles — •Lasse Ermoneit, Markus Kantner, and Thomas Koprucki — Weierstrass Institute for Applied Analysis and Stochastics (WIAS), 10117 Berlin, Germany

We develop a theoretical model and a numerical simulation framework for a spin-qubit shuttling device for coherent transfer of quantum information between remote arrays of gate-defined quantum dots. The goal is to provide a device-scale simulation environment that solves the Schrödinger wave packet propagation problem in the presence of specific disorder potentials inside the shuttling device. Time-dependent electrostatic potentials of the gate electrodes and perturbations are obtained as solutions of Poisson's equation. We present our modeling approach together with first simulations results and outline how methods of model order reduction and optimal control theory can be employed to find a solution that ensures a high transmission fidelity in the presence of dephasing.

HL 20: 2D Materials 4 (joint session HL/CPP/DS)

Time: Wednesday 9:30–12:00 Location: H36

HL 20.1 Wed 9:30 H36

Dark exciton anti-funneling in monolayer transition metal dichalcogenides — •Roberto Rosati[1], Robert Schmidt[2], Samuel Brem[1], Raül Perea-Causín[3], Iris Niehues[4], Johannes Kern[2], Johann Adrian Preuss[2], Robert Schneider[2], Steffen Michaelis de Vasconcellos[2], Rudolf Bratschitsch[2], and Ermin Malic[1,3] — [1]Philipps-Universität Marburg — [2]University of Münster — [3]Chalmers University of Technology — [4]CIC nanoGUNE BRTA

Current nanoelectronics relies on transport. While charged carriers can be controlled by electric fields, atomically thin semiconductors are governed by excitons, which are neutral electron-hole pairs. Recently, strain engineering has been introduced to manipulate exciton diffusion [1] and propagation [2] in monolayer transition metal dichalcogenides. Strain-induced energy gradients give rise to exciton funneling up to a micrometer range. Combining spatiotemporal photoluminescence measurements with microscopic theory, here we track the way of excitons in time, space and energy. Surprisingly we find that in WS_2 excitons move away from high-strain regions, contrary to what we observe in $MoSe_2$ [2]. This anti-funneling behavior can be ascribed to dark excitons, whose strain-induced energy variations are opposite compared to bright excitons. Our findings open new possibilities to control transport in exciton-dominated materials.

[1] R. Rosati et al., 2D Mater. 8, 015030 (2021).
[2] R. Rosati, R. Schmidt et al., Nat. Commun. 12, 7221 (2021).

HL 20.2 Wed 9:45 H36

Ultrafast nanoscopy of a Mott transition in twisted bilayer WSe_2 — •Svenja Nerreter[1], Thomas Siday[1], Fabian Sandner[1], Samuel Brem[2,3], Martin Zizlsperger[1], Felix Schiegl[1], Raul Perea-Causin[3], Markus Plankl[1], Philipp Merkl[1], Fabian Mooshammer[1,4], Markus A. Huber[1], Ermin Malic[2,3], and Rupert Huber[1] — [1]Department of Physics and Regensburg Center for Ultrafast Nanoscopy, University of Regensburg, 93040 Regensburg — [2]Department of Physics, Philipps-Universität Marburg, 35032 Marburg, Germany — [3]Department of Physics, Chalmers University of Technology, 41296 Gothenburg, Sweden — [4]Department of Physics, Columbia University, New York, NY 10027, USA

The density-driven transition of an exciton gas into a Fermi liquid of unbound electron-hole pairs has formed a compelling testing ground of many-body physics. Layered transition metal dichalcogenides feature advantageous conditions, yet nanoscale inhomogeneities have complicated quantitative studies of this elusive transition. Here, we use ultrafast polarization nanoscopy to trace optically bright and dark electron-hole pairs during an exciton Mott transition in a twisted homobilayer of WSe_2. At elevated densities, initially monomolecular recombination dynamics of optically dark excitons continuously evolve into the bimolecular recombination of unbound electron-hole pairs. We directly reveal how the Mott transition varies over nanometer length scales, evidencing strong spatial disorder in stacked monolayers and demonstrating the capabilities of our technique to resolve the local interplay of strong electronic correlations.

HL 20.3 Wed 10:00 H36

Rashba excitons in the 2D Ruddlesden-Popper perovskite (BA)MAPI — •Philipp Moser[1], Martin Schalk[1], Atsuhiko Miyata[2], Joachim Wosnitza[2], Andreas Stier[1], and Jonathan Finley[1] — [1]Walter Schottky Institute, Garching, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

Two-dimensional organic-inorganic perovskites have emerged as remarkable materials for energy conversion, optoelectronic and spintronic applications. Recently, the role of spin-orbit (SO) coupling and the resulting effects on the band-structure and dark/bright optical transitions has become a key topic of interest. The necessary structural inversion asymmetry for SO-coupling is predicted to stem from the organic cations comprising the crystals. As a result, dark excitons, red detuned from the bright exciton, have been discussed in this material system. Here, we investigate the exciton physics of the 2D Ruddlesden-Popper perovskite (BA)MAPI. By performing one-photon absorption, -PL and two-photon PLE spectroscopy, we investigate the optical transitions close to the R-point of the Brillouin zone and find distinct 2-photon transitions blue detuned from the ground state exciton that can be explained by a Rashba-split band-structure. Utilizing high-field magneto-spectroscopy up to B=60T, we determine that these absorption features are due to Wannier excitons. We determine the size and binding energy from the diamagnetic shift of the features and obtain evidence that 2D (BA)MAPI hosts strongly bound Rashba excitons.

HL 20.4 Wed 10:15 H36

Ultrafast pseudospin quantum beats in multilayer WSe2 and MoSe2 — •Simon Raiber[1], Paulo E. Faria Junior[2], Dennis Falter[1], Simon Feldl[1], Petter Marzena[1], Kenji Watanabe[3], Takashi Taniguchi[4], Jaroslav Fabian[2], and Christian Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [3]Research Center for Functional Materials, NIMS, Tsukuba, Japan — [4]International Center for Materials Nanoarchitectonics, NIMS, Tsukuba, Japan

We present investigations of excitonic transitions in mono- and multilayer WSe2 and MoSe2 materials by time-resolved Faraday ellipticity (TRFE) with in-plane magnetic fields, of up to B = 9 T. In monolayer samples, the measured TRFE time traces are almost independent of B,

which confirms a close to zero in-plane exciton g factor, consistent with first-principles calculations. In stark contrast, we observe pronounced temporal oscillations in multilayer samples for B > 0. Remarkably, the extracted in-plane g factors are very close to reported out-of-plane exciton g factors of the materials, namely |g< 1s| = 3.1 +/- 0.2 and 2.5 +/- 0.2 for the 1s A excitons in WSe2 and MoSe2 multilayers, respectively. Our first-principles calculations nicely confirm the presence of a non-zero in-plane g for the multilayer samples. We propose that the oscillatory TRFE signal in the multilayer samples is caused by pseudospin quantum beats of excitons, which is a manifestation of spin- and pseudospin layer locking in the multilayer samples.

HL 20.5 Wed 10:30 H36

Nonlinear Exciton Dynamics in Layered Heterostructures — •Vipin Krishna[1], Xiao Chen[2], Tarlan Hamzayev[1], Silvana Botti[2], and Giancarlo Soavi[1] — [1]Institute of Solid state Physics,Friedrich-Schiller-University,Jena — [2]Institute of Theoretical Solid State Theory and Optics,Friedrich-Schiller-University,Jena

Transition-metal-dichalcogenides and related heterostructures(HS) are promising candidates for photonic and optoelectronic applications owing to strong light-matter coupling and electrically-tunable carrier dynamics.However,the presence of intense nonlinear effects such as Exciton-Exciton Annihilation(EEA)[1] limits the maximum realizable exciton-density,and is particularly efficient for interlayer-excitons(IL) due to their out-of-plane dipole nature[2].In this work,we systematically study the onset of EEA in type-II WS2/WSe2 HS by steady-state and nonlinear time-resolved PL.We infer that in HS the generation-rate is at least one order of magnitude larger for interlayer compared to intralayer-excitons for a given excitation-fluence, as expected from the ultrafast interlayer-charge-transfer and consequent IL formation.However,we do not observe stronger EEA for interlayer compared to intralayer-excitons and observe that for HS the recombination-dynamics are identical for both,suggesting that the EEA mechanism is dominated by the total excitonic-density via intra and interlayer-exciton interactions.Our work provides new insights on EEA mechanism, which is of paramount importance for optoelectronic-devices and study of excitonic-condensates with layered-materials.[1]Kuechle et.Al.J.OMX(2021),12.[2]Sigl et.Al.Phys.Rev.B 105,035417.

15 min. break

HL 20.6 Wed 11:00 H36

Tunable exciton-polaritons emerging from WS_2 monolayer excitons in a photonic lattice at room temperature — •Lukas Lackner[1], Marco Dusel[2], Oleg Egorov[3], Bo Han[1], Heiko Knopf[3], Falk Eilenberger[3], Carlos Anton-Solanas[1], Sven Höfling[2], and Christian Schneider[1] — [1]University of Oldenburg, Oldenburg, Germany — [2]University of Würzburg, Würzburg, Germany — [3]Friedrich Schiller University Jena, Jena, Germany

The engineering of non-linear light-matter states in optical lattices has emerged as a key research strategy for the exploration of Hamiltonians in the spirit of ultrafast- and possibly quantum-simulation. It furthermore has revealed its potential to probe non-trivial topology phenomena. Excitons in atomically thin crystals have emerged as an ideal active medium for such purposes, since they couple strongly with light, and bear the potential to harness giant non-linearities and interactions.

In this work, we present an experiment conducted at room temperature in an open optical cavity of high quality, with an implemented one-dimensional photonic lattice. In our present work we integrate an atomically thin layer of WS_2 in such a device. We discuss the emergence and tunability of a lattice-band-structure in the tight-binding configuration at room temperature, fuelled by the emission from monolayer excitons[1].

References

[1] L. Lackner *et al., Nat Commun* **12**, 4933 (2021).

HL 20.7 Wed 11:15 H36

Optical Spectroscopy of Colloidal Transition Metal Dichalcogenides — •André Philipp Frauendorf[1], André Niebur[2], Jens Hübner[1], Jannika Lauth[2,3], and Michael Oestreich[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover — [2]Institut für Physikalische Chemie und Elektrochemie, Leibniz Universität Hannover — [3]Institut für Physikalische und Theoretische Chemie, Universität Tübingen

Atomically thin transition metal dichalcogenides (TMDs) are at the forefront of a new generation of two-dimensional semiconductor systems and experience an increasing research interest due to their unique optical properties. As an additional fabrication approach the wet-chemical synthesis has emerged as a promising method for the straightforward solution-processing of these materials. [1] Nevertheless, the optical properties of colloidal TMD mono- and few-layer structures have been sparsely studied.

Here, we demonstrate room-temperature micro-photoluminescence of colloidal TMD nanosheets. Both, mono-and multilayer photoluminescence are observed rendering these delicate structures fully competitive with conventionally fabricated TMDs. [1] In addition temperature-dependent transient absorption measurements are presented as a convincing technique for the exploration of the ultra-fast recombination dynamics of two-dimensional materials. [2]

[1] A. Frauendorf et al., J. Phys. Chem. C 125, 18841 (2021).
[2] A. Frauendorf et al., Manuscript in preparation (2022).

HL 20.8 Wed 11:30 H36

Capacitively and inductively coupled excitons in bilayer MoS_2 — •Lukas Sponfeldner[1], Nadine Leisgang[1], Shivangi Shree[2], Ioannis Paradisanos[2], Kenji Watanabe[3], Takashi Taniguchi[4], Cedric Robert[2], Delphine Lagarde[2], Andrea Balocchi[2], Xavier Marie[2], Iann C. Gerber[2], Bernhard Urbaszek[2], and Richard J. Warburton[1] — [1]Department of Physics, University of Basel — [2]Université de Toulouse, INSA-CNRS-UPS, LPCNO — [3]Research Center for Functional Materials, National Institute for Materials Science — [4]International Center for Materials Nanoarchitectonics, National Institute for Materials Science

Exciton-exciton couplings in semiconductors lead to a plethora of phenomena such as nonlinear optical effects and quantum condensation. Transition-metal dichalcogenides constitute a versatile platform to study these effects as the excitons are very robust and their couplings can be controlled by exploiting their spin and valley properties.

Here, we probe exciton-exciton couplings in gated-homobilayer MoS_2. Using a driven-coupled oscillator model it is shown that the measured optical susceptibility reveals both the magnitude and the phase of the coupling constants. The interlayer excitons (IE) and intralayer B-excitons couple via a 0-phase (capacitive) coupling; the IE and the intralayer A-excitons couple via a π-phase (inductive) coupling. Using the IE as a sensor, the A-B intravalley exchange coupling is determined, a result which is also relevant for a monolayer. Finally, we realize a bright and highly tunable lowest-energy momentum-direct exciton at high electric fields.

HL 20.9 Wed 11:45 H36

Controlling the non-linearity in two dimensional materials — •Mathias Federolf and Sven Höfling — Technische Physik, Universität Würzburg, 97074 Würzburg, Germany

Recently Datta et al. [1] have shown that exciton-polaritons in bilayer MoS_2 experience a blueshift due to interacting with other exciton-polaritons. The observed blueshift is non-linear with respect to the laser power used for excitation. Due to the bilayer's nature interlayer-excitons can occur, which exhibit an out of plane dipole moment. Using an electric field along the out of plane axis those dipoles can be aligned and used to influence the exciton-exciton interaction. By using a varying electric field, we map the parameter space to gain deterministic control over the blueshift. Understanding and controlling the system allows us to tune the polariton-polariton interaction such that they can be used in future application i.e., single-photon sources.

[1] Datta, Biswajit, et al. arXiv preprint arXiv:2110.13326 (2021).

HL 21: Optical Properties 1

Time: Wednesday 15:00–18:30 Location: H32

HL 21.1 Wed 15:00 H32

Dynamics of exciton-polariton emission in CuI — •E. Krüger[1], M. Bar[1], S. Blaurock[2], L. Trefflich[1], R. Hildebrandt[1], A. Müller[1], O. Herrfurth[1,3], G. Benndorf[1], H. von Wenckstern[1], H. Krautscheid[2], M. Grundmann[1], and C. Sturm[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Germany — [2]Universität Leipzig, Institut für Anorganische Chemie, Germany — [3]now at: Active Fiber Systems GmbH, Germany

Copper iodide (CuI) is a promising candidate for transparent optoelectronic applications due to its large band gap of 3.1 eV and high exciton binding energy of 62 meV [1]. Here we present spectral- and time-resolved measurements of the near-band-edge luminescence of CuI bulk crystals for temperatures between 10 K and 250 K. The line shape of the emission lines at low temperatures is interpreted in terms of defect-bound exitons and exciton-polaritons [2]. The different decay characteristics of free and localized exciton states are explained by their coupled interaction. Based on the rise time of bound excitons, the defect density is estimated to be about $1{\times}10^{17}\mathrm{cm}^{-3}$, which is in good agreement with the density of free holes at room temperature. The decay times of the free exciton polaritons increase with increasing temperature up to 360 ps. For the emission of bound excitons, decay times between 180 ps and 380 ps are observed at low temperatures.

[1] M. Grundmann et al., pss (a) **210**, 1671 (2013)
[2] E. Krüger et al., APL Mater. **9**, 121102 (2021)

HL 21.2 Wed 15:15 H32

Coherent phonon oscillations and transient critical-point parameters in femtosecond pump-probe ellipsometry spectra — •S Zollner[1], C Emminger[1,2,3,4], S Espinoza[5], S Richter[3,5,6], M Rebarz[5], O Herrfurth[3,7], M Zahradnik[5], R Schmidt-Grund[8], and J Andreasson[5] — [1]NMSU, Las Cruces, NM, USA — [2]Masaryk University, Brno — [3]Uni Leipzig — [4]Humboldt Universität, Berlin — [5]ELI Beamlines, Dolni Brezany, Czech Republic — [6]Lund University — [7]Active Fiber Systems GmbH, Jena — [8]TU Ilmenau

Spectroscopic ellipsometry measures the dielectric function of materials, which is related to the electronic band structure of semiconductors, and allows the study of critical points and their parameters (energy, broadening, amplitude, phase angle). At ELI Beamlines, femtosecond pump probe ellipsometry measurements can be performed with a white-light continuum probe beam, resulting in a time resolution of 120 fs. We report the transient dielectric function of Ge as a function of delay time between the pump and probe beams near the E_1 and $E_1 + \Delta_1$ critical points. The changes of the critical-point amplitudes are attributed to band filling at the L-point, intervalley scattering, carrier diffusion, lattice heating, and recombination. We also calculate the derivatives of these spectra using a novel Fourier analysis technique and determine the critical point parameters. We find oscillations of the critical-point energies with a period of 11 ps, related to the propagation of coherent acoustic phonons (strain waves) generated by the pump pulse. The amplitude of these oscillations shows that the strain is hydrostatic (isotropic) and has a magnitude of 0.1%.

HL 21.3 Wed 15:30 H32

Temperature dependence of the mid-infrared dielectric function of InSb from 80 to 800 K — Melissa Rivero Arias[1], Cesy Zamarripa[1], Jaden Love[1], Carola Emminger[1,2,3,4], and •Stefan Zollner[1] — [1]New Mexico State University, Las Cruces, NM, USA — [2]Masaryk University, Brno, Czech Republic — [3]Uni Leipzig — [4]Humboldt Universität, Berlin

We describe measurements of the mid-infrared dielectric function of bulk InSb near the direct band gap using Fourier-transform infrared spectroscopic ellipsometry from 80 to 800 K in an ultra-high vacuum cryostat. Indium antimonide is the zinc blende compound semiconductor with the smallest direct band gap (E_0=0.18 eV at 300K) due to its heavy elements, the large resulting spin-orbit splitting and Darwin shifts. It has a low melting point of 800 K. Previously, the band gap of InSb has only been measured up to room temperature and estimated from Hall effect measurements of the effective mass up to 470 K. Calculations indicate that InSb should undergo a topological phase transition from semiconductor to semi-metal at 600 K. It is interesting to see in the data if this transition occurs below the melting point of InSb.

HL 21.4 Wed 15:45 H32

Ultra-fast change of the absorption onset in undoped cubic GaN — •Elias Baron[1], Martin Feneberg[1], Rüdiger Goldhahn[1], Michael Deppe[2], Donat J. As[2], Shirly Espinoza[3], and Martin Zahradník[3] — [1]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany — [2]Department Physik, Universität Paderborn, Germany — [3]ELI Beamlines, Institute of Physics, Czech Academy of Science, Dolní Břežany, Czech Republic

Nitride semiconductors are essential for modern applications, which means that an example for nitride research is necessary. For this, the cubic zincblende phase is predestined on account of isotropic properties. We present our investigation of thin film zincblende GaN, deposited by plasma-assisted molecular beam epitaxy on 3C-SiC/Si substrates in (001) orientation, by time-resolved spectroscopic ellipsometry, based on a pump-probe approach in the visible and ultra violet spectral range. The 266nm pump beam excites the cubic GaN far above the band gap and therefore creates up to $\approx 5 \times 10^{20}\mathrm{cm}^{-3}$ electron-hole pairs, which influence the dielectric function due to many-body effects like band gap renormalization and Burstein-Moss shift. By varying the delay time between pump and probe beam from femto- to nanoseconds, a time-resolved change of the absorption onset due to the relaxation and recombination of electron-hole pairs in the context of many-body effects is observed and concur with comparable steady-state measurements of highly n-type doped GaN.

15 min. break

HL 21.5 Wed 16:15 H32

Strain-induced bandgap transition in III-V semiconductors — •Badal Mondal and Ralf Tonner-Zech — Wilhelm-Ostwald-Institut für Physikalische und Theoretische Chemie, Universität Leipzig, 04103 Leipzig, Germany

In the interest of a deep and thorough understanding of the effect of strain on the electronic properties, we have developed a systematic strategy for the analysis of composition-strain-bandgap relationship in III-V semiconductors. Using the tool of computational method, modern *ab-initio* density functional theory (DFT), we have shown that depending on the nature and strength of applied strain in the system the material behavior can change substantially. Namely, a direct bandgap semiconductor can transform to an indirect bandgap semiconductor and vice versa. This ultimately enables us to construct the 'bandgap phase diagram' [1] by mapping the different direct-indirect transition points with composition and strain. By combining the advanced tools of machine learning with DFT, we have further developed an efficient approach to extend the scope in multinary systems. In combination with the thermodynamic phase diagram, we have shown that this new way of mapping the effect of strain will significantly improve the future developments in terms of strategic choice of certain application-oriented best-suited material systems or vice versa.

[1] https://bmondal94.github.io/Bandgap-Phase-Diagram/, 2022

Acknowledgments: This work is supported by the German Research Foundation (DFG) in the framework of the Research Training Group "Functionalization of Semiconductors" (GRK 1728).

HL 21.6 Wed 16:30 H32

Probing free carrier and exciton dynamics in bulk gallium selenide with two-dimensional electronic spectroscopy — •Jonas Allerbeck[1,2], Thomas Deckert[2], Laurens Spitzner[3], and Daniele Brida[2] — [1]nanotech@surfaces Laboratory, Empa, Überlandstrasse 129, 8600 Dübendorf, Switzerland — [2]Department of Physics and Materials Science, Université du Luxembourg, 162a Avenue de la Faïencerie, L-1511 Luxembourg, Luxembourg — [3]Department of Physics, University of Konstanz, Universitätsstrasse 10, 78457 Konstanz, Germany

Multidimensional optical spectroscopy employing a sequence of three or more pulses is a powerful technique to disentangle energetic correlations. While the technique has been used to study molecular systems, its application to femtosecond dynamics in solid state materials remains new. In this work, we investigate the ultrafast response of excitons and free carriers in the technologically important semiconductor gallium selenide (GaSe) with 10 fs temporal and 1 THz (4 meV) spectral resolution. 2D spectra resolve the excitation energy of broadband

pulses and reveal strong bleaching at the exciton resonance, which is hidden by the free carrier response in standard pump-probe measurements, allowing to extract an exciton relaxation time of 112 fs at room temperature. Our quantitative mapping of carrier thermalization shows the interplay of spectral diffusion, induced absorption and dephasing, motivating ongoing theoretical investigation and paving the way for future investigation of quasiparticle correlations in functional material systems.

HL 21.7 Wed 16:45 H32

Multistable, co- and counterflowing currents of polariton condensates in concentric ring-shaped and elliptical potentials — •Franziska Barkhausen, Matthias Pukrop, Xuekai Ma, and Stefan Schumacher — Department of Physics and CeOPP, Paderborn University, Germany

Vortices occur in a broad range of nonlinear systems. They have been widely investigated in many physical systems and different materials for their fundamental interest and for applications in data storage and information processing. In polariton condensates in semiconductor microcavities vortices can be supported and trapped by including a ring-shaped potential, for example optically induced using spatially structured non-resonant excitation [1]. Here we theoretically study vortices excited non-resonantly in different fabricated ring-shaped and elliptical external potentials. These kinds of potentials trap the polariton condensate such that different steady-state solutions, oscillating or co- and counterrotating solutions can be formed, depending on the size and number of the potential wells. A single ring potential can stabilize multistable solutions carrying different orbital angular momenta (OAM) which can lead to the beating of different modes and spatially rotating solutions. A concentric arrangement of many rings enables the excitation of Bessel-like solutions [2]. Embedding a standard ring potential in an elliptical one gives rise to phase differences of the condensates in the two rings and to counterflowing condensate currents.

[1] X. Ma, et al., Nat Commun 11, 897 (2020).
[2] F. Barkhausen, et al., Phys. Rev. B 103, 075305 (2021).

HL 21.8 Wed 17:00 H32

Optical properties of transition metal oxide perovskites by the Bethe-Salpeter equation — •Lorenzo Varrassi[1], Peitao Liu[2], Zeynep Ergönenc Yavas[3], Menno Bokdam[4], Georg Kresse[2], and Cesare Franchini[1,2] — [1]Department of Physics, University of Bologna — [2]Faculty of Physics, University of Vienna — [3]Turkish Aerospace Industries- Department of Materials Engineering — [4]University of Twente, Faculty of Science and Technology

The accurate account of optical spectra of semiconductors and insulators requires the explicit treatment of the electron-hole (e-h) interaction. This talk will present a systematic investigation of the role of excitonic effects on the optical properties of transitions metal oxide perovskites. A representative set of fourteen compounds has been selected, including 3d, 4d, and 5d perovskites. Optical conductivities and exciton binding energies are calculated through the Bethe-Salpeter equation (BSE) based on G0W0 approximation. Results are compared with the experimental data.

The origin of spectra's main peaks are investigated through the analysis of the e-h coupling coefficients. A particular emphasis in our analysis was placed on how differences between the electronic band-structures of the studied compounds impact the optical properties and e-h coupling coefficients.

A computationally cheaper model-BSE approach, based on a model dielectric screening, was employed for the calculations of the excitonic binding energies. The quality and validity of the the approach was assessed through a comparison with reference G0W0+BSE values.

15 min. break

HL 21.9 Wed 17:30 H32

Dynamics of phase defects trapped in optically imprinted orbits in dissipative binary polariton condensates — •Jan Wingenbach, Matthias Pukrop, Stefan Schumacher, and Xuekai Ma — Physics Department and CeOPP, Paderborn University, Germany

Polaritons are quasiparticles, formed due to the strong coupling of photons and excitons in planar semiconductor microcavities. In polariton condensates, quantized vortices can form, which makes them promising candidates for novel quantum technological devices [1]. By nonresonant excitation of the condensate, periodic potentials can be generated, which can be used to trap vortices and stabilize phase defects, so-called dark solitons [2]. We study the dynamics of phase defects trapped in a finite, optically imprinted ring lattice in binary polariton condensates. Depending on their topological charge a Magnus force leads to the circulation of vortices in these orbits. This is investigated considering the cross interaction (CI) between the condensates in different spin components and the spin-orbit interaction (SOI). We observe elongated vortices and frozen phase defects, which resemble dark solitons showing finite size in both spin components. When the entire orbit is occupied, a snake instability is triggered, leading to the decay of the dark ring solution. In our system, the motion of vortex constellations is affected by the SOI. [1] X. Ma, et al., Nature Communications 11, 1 (2020). [2] X. Ma, et al., Phys. Rev. Lett. 118, 157401 (2017).

HL 21.10 Wed 17:45 H32

Optimization of Silicon Nanoantenna for Optical Phased Arrays — •Andreas Strauch, Henna Farheen, Viktor Myroshnychenko, and Jens Förstner — University Paderborn - Department of Electrical Engineering and Information Technology, Paderborn, Germany

The classical microwave phased array is a proven antenna technology since the beginning of the last century. Among other things, it leads to significant improvements in radar technology as well as mobile, radio and satellite communications. Beyond that, this principal is not limited to the microwave band and can transfer into the optical spectrum, such as for light detection and ranging (LIDAR). The specific, technical features of the optical phased array (OPA) are the fast, non mechanical variation of directional characteristic (beam steering) during the operation and the great beam focusing through an ensemble of sophisticatedly, interacting single antennas. Besides them, the usage of serveral single antennas increases the redundancy and gives a high operational reliability and signal-to-noise ratio.

We designed, numerically analyzed, and optimized an efficient Silicon on Insulator (SOI) based photonic light transmitter, working in the infrared band, with high antenna gain and sidelobe attenuation (super resolution in principle), high redundancy and noise robustness and most important an electronically, configurable farfield characteristic. In comparison to a reference design, we increased the radiation efficiency from 2.66 to 9% by numerical optimization using evolutionary and natural analogue approaches.

HL 21.11 Wed 18:00 H32

Spatially Resolved Dynamics of Intra 3d Luminescence of Co in ZnO Nanowires Revealed by Nanoscale X-ray Analysis — •Christian Plass[1], Valentina Bonino[2], Maurizio Ritzer[1], Lukas Jäger[1], Jaime Segura-Ruiz[2], Gema Martinez-Criado[2], and Carsten Ronning[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743, Jena — [2]ESRF - The European Synchrotron, 71 Avenue des Martyrs, 38043 Grenoble, France

Color centers in semiconductors have drawn a lot of interest in recent years. They are able to provide high quality single photon sources. Such color centers can for example be obtained by doping ZnO with Co. The underlying emission processes have to be determined in order to achieve quantum emission by such a system. Hence, there is a strong need to evaluate how the dynamics of the luminescence is influenced by elemental composition and local environment of the color centers. High resolution synchrotron based methods like X-ray fluorescence (XRF) and X-ray excited optical luminescence (XEOL) enable insight into such compositional and functional variations. Simultaneous XRF and XEOL measurements of Co doped ZnO nanowires were conducted: The highly focused X-ray nanobeam at the ID16B-NA station of the European Synchrotron Radiation Facility scanned the nanowire and by analyzing the emitted X-ray fluorescence radiation together with the corresponding optical luminescence correlating maps were obtained. As the spatial resolution is about 50nm, we can show how the local composition influences the spectral dynamics of the obtained emission.

HL 21.12 Wed 18:15 H32

Fröhlich polarons in cubic materials — •B. Guster[1], P.M.M.C. Melo[2], B.A.A. Martin[3], V. Brousseau-Couture[4], J.C. de Abreu[2], A. Miglio[1], M. Giantomassi[1], M. Côté[4], J.M. Frost[3], M.J. Verstraete[2], and X. Gonze[1,5] — [1]UCLouvain(UCL), IMCN, Louvain-la-Neuve, Belgium — [2]NanoMat/Q-Mat/CESAM, Université de Liège, Liège, Belgium — [3]Department of Physics, Imperial College London, London, UK — [4]Département de Physique, Université

de Montréal, Montréal, Canada — [5]Moscow, Russia

Most works on polaron models, to understand their characteristics such as radius, effective mass, mobility and energy dispersion, have focused on the original Fröhlich model. Real cubic materials have electronic band extrema that are often degenerate, or anisotropic. In this work, we keep the continuum hypothesis inherent to large polaron models, but go beyond the existing isotropic and nondegeneracy hypotheses, and also include multiple phonon modes. For polaron effective masses, we provide (i) the analytical result for the case of anisotropic electronic energy dispersion, with two distinctive effective masses (uniaxial), (ii) an approximate expression for the case of three distinctive axes (ellipsoidal), (iii) numerical simulations for the 3-band degenerate case, typical of III-V and II-VI semiconductor valence bands. We also deal with the strong-coupling limit, using a variational treatment: we propose trial wavefunctions for the three above-mentioned cases as well, providing polaron radii and energies. We gauge such approaches for the case of a dozen of II-VI and III-V semiconductors, and oxides.

HL 22: Heterostructures, Interfaces and Surfaces

Time: Wednesday 15:00–18:00 Location: H33

HL 22.1 Wed 15:00 H33

Band-gap and strain engineering in GeSn alloys using post-growth pulsed laser melting — •O. Steuer[1], D. Schwarz[2], M. Oehme[2], J. Schulze[3], H. Maczko[4], R. Kudrawiec[4], I. Fischer[5], R. Heller[1], R. Hübner[1], M. Khan[1], Y. Georgiev[1], S. Zhou[1], M. Helm[1], and S. Prucnal[1] — [1]Helmholtz-Zentrum HZDR, GER — [2]University of Stuttgart, GER — [3]Fraunhofer IIS, GER — [4]Wroclaw University, POL — [5]TU Cottbus-Senftenberg, GER

Alloying Ge with Sn enables effective band-gap engineering and improves significantly the charge carrier mobility. The pseudomorphic growth of Ge1-xSnx on Ge causes in-plane compressive strain, which degrades the superior properties of the Ge1-xSnx alloys. Therefore, efficient strain engineering is required. In this talk, we will present strain and band-gap engineering in GeSn alloys grown on a Ge virtual substrate using post-growth nanosecond pulsed laser melting (PLM). Micro-Raman spectroscopy and X-ray diffraction show that the initial in-plane compressive strain is removed. Moreover, for PLM energy densities higher than 0.5 J cm-2, the Ge0.89Sn0.11 layer becomes tensile strained. Simultaneously, as revealed by Rutherford Backscattering spectrometry, cross-sectional transmission electron microscopy investigations and X-ray diffraction, the crystalline quality and Sn-distribution in PLM-treated Ge0.89Sn0.11 layers are only slightly affected. Additionally, the change of the band structure after PLM is confirmed by low-temperature photoreflectance measurements. The presented results prove that post-growth ns-range PLM is an effective way for band-gap and strain engineering in highly-mismatched alloys.

HL 22.2 Wed 15:15 H33

Reconfigurable Complementary and Combinational Logic based on Monolithic and Single-Crystalline Al-Si Heterostructures — •Raphael Böckle[1], Masiar Sistani[1], Martina Bažíková[1], Lukas Wind[1], Zahra Sadre-Momtaz[2], Martien I. den Hertog[2], Corban G.E. Murphey[3], James F. Cahoon[3], and Walter M. Weber[1] — [1]Institute of Solide State Electronics, TU Wien, Vienna, Austria — [2]Institut Néel, CNRS, Grenoble, France — [3]Department of Chemistry, University of North Carolina, Chapel Hill, North Carolina, United States

Overcoming the difficulty in reproducibility and deterministically defining the metal phase of metal-Si heterostructures is among the key prerequisites to enable next-generation nanoelectronic devices. Here, the formation of monolithic Al-Si-Al heterostructures obtained from Si nanowires and Al contacts is presented. Transmission electron microscopy and energy-dispersive X-ray spectroscopy confirmed both the composition and crystalline nature of the presented Al-Si-Al heterostructures, with no intermetallic phases formed during the exchange process in contrast to state-of-the-art metal silicides. In this context, reconfigurable field-effect transistors (RFET), capable of dynamically altering the operation mode between n- or p-type are realized. Having devised symmetric on-currents as well as threshold voltages for n- and p-type operation as a necessary requirement to exploit complementary reconfigurable circuits, selected implementations of logic gates such as inverters and combinational wired-AND gates are built from single elementary RFETs.

HL 22.3 Wed 15:30 H33

Investigations on graphene-oxide-silicon structures for field emission — •Alexander Mai[1], Florian Herdl[2], Simon Edler[1], Andreas Schels[2], Michael Bachmann[1], Felix Düsberg[1], Andreas Pahlke[1], and Georg Duesberg[2] — [1]Ketek GmbH, Hofer Str. 3, 81737 Munich, Germany — [2]University of the Bundeswehr Munich, Institute of Physics, Werner-Heisenberg-Weg 39, 85577 Neubiberg, Germany

In field emission (FE) electrons can tunnel through a potential barrier by applying a large electric field ($>$ 1 V/nm), which is required to obtain a reasonable current. Therefore, often high voltages ($>$ 300 V) and sharp tip geometries are used. However, a high sensitivity to poor vacuum makes these emitters unsuitable for many applications. Planar devices like graphene-oxide-semiconductor (GOS) structures are promising candidates as they are independent on the ambient pressure level. The necessary electric fields are achieved by applying a low operation voltage ($<$ 20 V) on a thin oxide barrier (5 - 20 nm). The maximum emission to tunnel current ratio (efficiency) achieved in a GOS structure to this date is 48.5%. In this presentation, results of recent measurements and simulations on GOS structures are shown. The measured structures show efficiencies between 0.1 and 23%, mainly depending on the thickness of the gate electrode, while an emission current of at least about 1 nA was achieved in most samples. Simulations show a voltage drop near the contact pad resulting from the sheet resistance of the gate electrode, which limits the maximum tunnel current in the GOS structure.

HL 22.4 Wed 15:45 H33

Topological photonics for optoelectronic sensing — •Jakob Lindenthal[1,2], Johannes Benduhn[1], and Karl Leo[1,2] — [1]Institute of Applied Physics, Technische Universität Dresden — [2]ct.qmat - Würzburg-Dresden Cluster of Excellence

Topological properties of photonic systems are a quickly emerging research field. The physical realisation of topological invariants allows the creation of photonic states with strong protection of the state's existence against perturbation. The energy levels of topological states can be made highly sensitive to external influences, enabling the design of novel optoelectronic sensing devices. Theoretical concepts of different topological photonic systems are discussed, and experimental systems are showcased. The presentation reports about an optoelectronic pressure sensor developed at the Institute of Applied Physics at TU Dresden and other devices fabricated by partnering organisations. Key concepts and technological advantages of topological systems are summarised, highlighting the prospects for incorporating topology in optoelectronic sensing devices.

HL 22.5 Wed 16:00 H33

Interplay of anomalous strain relaxation and minimization of polarization changes at nitride semiconductor heterointerfaces — Yuhan Wang[1,2], •Michael Schnedler[1,2], Qianqian Lan[1,2], Fengshan Zheng[1,2], Lars Freter[1,2], Yan Lu[1,2], Uwe Breuer[3], Holger Eisele[4], Jean-François Carlin[5], Raphaël Butté[5], Nicolas Grandjean[5], Rafal E. Dunin-Borkowski[1,2], and Philipp Ebert[1,2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [2]Ernst Ruska Centrum, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [3]Zentralinstitut für Engineering, Elektronik und Analytik (ZEA-3), Forschungszentrum Jülich GmbH, 52425 Jülich, Germany — [4]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [5]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland

Polarization and electron affinity changes at $Al_{0.06}Ga_{0.94}N$/GaN and $In_{0.05}Ga_{0.95}N/Al_{0.06}Ga_{0.94}N$ interfaces are quantified by combining off-axis electron holography in transmission electron microscopy, scanning tunneling microscopy, and simulations of the electrostatic potential and electron phase maps. The $In_{0.05}Ga_{0.95}N/Al_{0.06}Ga_{0.94}N$ interface reveals, as expected, biaxial relaxation as well as polarization and

electron affinity changes. However, at the $Al_{0.06}Ga_{0.94}N$/GaN interface anomalous lattice relaxations and vanishing polarization and electron affinity changes occur, whose underlying physical origin is anticipated to be total energy minimization by the minimization of Coulomb interactions between the polarization-induced interface charges.

30 min. break

HL 22.6 Wed 16:45 H33

Determination of relaxation in thin InGaAs-films by Raman spectroscopy — •Johann Friedemann Schulz[1], Tobias Henksmeier[2], Martin Feneberg[1], Elias Kluth[1], Dirk Reuter[2], and Rüdiger Goldhahn[1] — [1]Otto von Guericke University, Institute of Physics, Universitätsplatz 2, 39106 Magdeburg, Germany — [2]Paderborn University, Department of Physics, Warburger Str. 100, 33089 Paderborn, Germany

Semiconductor heterostructures suffer inherently from differences in their lattice parameters. This causes strain and, in the worst case, crystal defects in the material, rendering it potentially unusable for electronic or optical devices. The relaxation of thin mismatched films is therefore important for assessing the crystal quality. One possibility to experimentally access the degree of relaxation is to accuractely determine the phonon frequencies of the strained material, as Phonon frequencies depend on composition and lattice parameters. Such measurements can be carried out quickly and easily using Raman spectroscopy. Here, we present results on $In_xGa_{1-x}As$ grown on GaAs-substrates by molecular beam epitaxy. We investigate different strained films with varied composition and several different film thicknesses. We find Raman spectroscopy a viable tool to determine the degree of relaxation even in films which are too thin for usual reciprocal space map experiments.

HL 22.7 Wed 17:00 H33

Time-resolved measurement of propagating exciton-polariton condensates in confined systems using a streak camera — •Christian Mayer, Simon Betzold, Philipp Gagel, Tristan H. Harder, Monika Emmerling, Adriana Wolf, Fauzia Jabeen, Sven Höfling, and Sebastian Klembt — Technische Physik, RCCM and Würzburg-Dresden Cluster of Excellence ct.qmat, University of Würzburg, Germany

Strong coupling between photons and excitons in an optical microcavity leads to the formation of hybrid light-matter quasiparticles called exciton-polaritons. In the low-density regime, these particles follow bosonic statistics and can therefore undergo dynamical condensation above a critical particle density by stimulated relaxation to the ground state. The low effective mass of polaritons compared to excitons, which results from the photonic fraction, leads to comparatively long diffusion lengths. The excitonic fraction, on the other hand, is responsible for relevant polariton-polariton interaction, which leads to a repulsive behavior. Exciting non-resonantly with a pulsed laser results in an additional repulsive force at finite wavevector due to the exciton reservoir. These factors can lead to a significant propagation of the polariton condensate, with relevant effects already taking place on the time scale of a few picoseconds.

Here, we utilize electron beam lithography and etching techniques to form potential landscapes such as coupled resonator lattices and waveguides. We use a streak camera to resolve and visualize the propagation of polaritons in these systems.

HL 22.8 Wed 17:15 H33

Towards predictive modeling of optical properties of quantum dots under externally applied stress — •Petr Klenovsky[1,2], Xueyong Yuan[3], Saimon Filipe Covre da Silva[3], and Armando Rastelli[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Brno, Czech Republic — [2]Czech Metrology Institute, Brno, Czech Republic — [3]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, Austria

GaAs quantum dots (QDs) have been found in the past to be an exceptionally good platform for construction of the light emitters. They have also advantageous properties for spin physics because of the absence of strain and strain inhomogeneity. Still, strain is important to achieve quadrupolar splitting, e.g., to build up a quantum register with nuclear spins. Understanding and quantitative prediction of strain-induced effects will be important to guide future optimization, since a trial and error procedure is not acceptable in view of the huge parameter space available for GaAs QDs (e.g. WL thickness tunable at will). Former attempts have qualitatively reproduced results but failed to achieve the quantitative agreement, e.g., bright-dark exciton splitting or used unphysical assumptions. That was further exacerbated by the lack of knowledge of the exact applied strain configuration.

Here we go beyond by combining precisely determined strain and QD properties with dedicated calculations using $\mathbf{k} \cdot \mathbf{p}$ and correlated configuration interaction (CI) methods. We show for the first time quantitative agreement between experiment and theory for strained GaAs QDs.

HL 22.9 Wed 17:30 H33

Growth of epitaxial GaN by reactive magnetron sputtering — •Ralf Borgmann, Florian Hörich, Jürgen Bläsing, Armin Dadgar, André Strittmatter, Anja Dempewolf, Frank Bertram, Jürgen Christen, and Gordon Schmidt — Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

For high power transistors GaN is an excellent base material semiconductor with a high bandgap and a high breakdown field which is often realized on Si substrates. A specific buffer arrangement is needed for MOVPE grown structures, to achieve these properties. Especially doping with Fe or C is essential for insulating sheets. In comparison with reactive magnetron sputtering uses pure metal targets and does not necessarily require Fe or C doping to achieve highly insulating GaN. We investigated growth parameters like growth temperature and reactive gas flow on various templates. An important parameter determining the material quality is the reactive gas. Ga droplets occur on the wafer surface, when using nitrogen. Investigations on growth temperature reveal a narrow growth window. An optimum growth temperature was by around 715 °C. With low ammonia gas flow the AFM measurement shows a grainy surface. By using a higher ammonia gas flow, the growth rate decreases and a closed meandering surface structure appears. Full sputtered undoped layers show a vertical breakdown field strength of > 2.5 MV/cm for 200 nm AlN 2x 200 nm transition layer AlGaN and 820 nm GaN.

HL 22.10 Wed 17:45 H33

Ultrafast transient spectroscopy of Cu(In,Ga)Se_2 coupled to different buffer layers. — •Pirmin Schweizer, Ricardo Rojas-Aedo, Alice Debot, Philip Dale, and Daniele Brida — Department of Physics and Materials Science, University of Luxembourg, 162a avenue de la Faïencerie, L-1511 Luxembourg, Luxembourg

The dynamic parameters of photo-induced electron-hole pairs, such as recombination time and charge conductivity, play a major role in the efficiency of photovoltaic devices. Among thin film materials for photovoltaics, one of the most interesting is the p-type Cu(In,Ga)Se_2 alloy (CIGS) on which an n-type buffer layer is deposited, forming the initial part of the device p-n junction. The inter-material transport dynamics strongly depend on how the band structure is affected by the buffer layer, and also on the quality of the CIGS / buffer layer interface which may contain defects. In our experiments we have compared the ultrafast transient reflectivity on CIGS epitaxially grown on a GaAs substrate. New Cd free buffer layers In_2S_3 and band offset tunable Zn(O,S), are compared to the most commonly used buffer layer, CdS. The transient reflection measurements allows for the extraction of the electronic transport dynamics at the interface with the buffer. This study allows us to draw conclusions about the pair formation capacity mediated by the transport properties between the CIGS and the buffer layer. The results can guide the development of Cd free buffer layers thus reducing the environmental impact caused by CdS in traditional CIGS solar cells.

HL 23: Perovskite and Photovoltaics 2 (joint session HL/CPP/KFM)

Time: Wednesday 15:00–18:15 Location: H34

HL 23.1 Wed 15:00 H34

Electronic structure analysis of the interface of a TiO_2 electron-transport layer with a perovskite $CsPbI_3$ photovoltaic absorption layer — •Amirhossein Bayani[1], Julian Gebhardt[1], and Christian Elsässer[1,2] — [1]Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstrasse 11, 79108 Freiburg, Germany — [2]Freiburg Materials Research Center (FMF), Albert-Ludwigs-University Freiburg, 79104 Freiburg, Germany

Lead-based hybrid perovskite halides are currently the most promising light absorbing materials to supplement or even replace Si in next generation solar cells. With intensive research of the bulk material properties in recent years, a strong interest emerges in studying the interfaces to the contact layers in order to reach the final boost of solar efficiency in devices. Here, we study the interface of $CsPbI_3$ with TiO_2 as model interface for a perovskite with an electron transport layer. In particular, we investigate the rutile-TiO_2(001)[001] / $CsPbI_3$(001)[100] interface using self-energy corrected density functional theory. By this state-of-the art modeling technique, we analyze the alignment of work-functions and investigate the band alignment at the interface.

HL 23.2 Wed 15:15 H34

Influence of the Ionic Liquid $BMIMBF_4$ on the film formation and optoelectronic properties of $MAPbI_3$ — •Simon Biberger, Konstantin Schötz, Philipp Ramming, Nico Leupold, Ralf Moos, Anna Köhler, Helen Grüninger, and Fabian Panzer — University of Bayreuth, Bayreuth, Germany

Today, metal halide perovskite solar cells (PSCs) are one of the most promising emerging photovoltaic technologies. However, their still limited stability is a main hurdle for their successful commercialization. In the past, various approaches have been developed to improve the long-term stability and performance of PSCs. Here ionic liquids (IL) as additives have attracted much attention as they passivate defects and suppress ion migration. In this work, we investigate the effect of the IL $BMIMBF_4$ on the film formation and optoelectronic properties of the model halide perovskite $MAPbI_3$. By multimodal in situ optical spectroscopy, we investigate the formation of the perovskite film during solution processing via one-step spin coating and a solvent engineering approach and how the film formation alters when the IL is added to the precursor solution. We find that the IL does not impact the formation of perovskite-solvent complexes, but the perovskite growth rate decreases with increasing IL content in the precursor solution. Additionally, we reveal that the IL already interacts with precursor materials and changes the evolution of the PbI_4^{2-} properties. Thus, our work provides important insights into how decisive ILs impact the sensitive interconnection between precursor properties, film formation process and final optoelectronic functionality of perovskite thin films.

HL 23.3 Wed 15:30 H34

Transversal halide motion enables sharp optical absorption profiles in halide perovskites — •Sebastián Caicedo-Dávila, Christian Gehrmann, Xiangzhou Zhu, and David A. Egger — Department of Physics, Technical University of Munich, Garching, Germany

Despite their strong vibrational anharmonicity, halide perovskites (HaPs) exhibit favorable optoelectronic properties, which facilitate their outstanding performance in solar cells, comparable to high-quality inorganic semiconductors. In this contribution, we explore the mechanisms and consequences of dynamic structural flexibility in $CsPbBr_3$ using first-principles molecular dynamics based on density-functional theory. We show that large Br displacements occur on planes that are transversal to the Pb-Br-Pb bonding axis. This *transversality* is concurrent with vibrational anharmonicity, results in short-ranged disorder correlations, and sharpens the joint-density of states rise at finite temperature. Finally, we contrast these results to the case of PbTe, which shares key properties with $CsPbBr_3$ but cannot exhibit any *transversality*, to show that this system features wider band-edge distributions and longer-ranged disorder correlations. These findings are relevant for connecting the structural flexibility and bonding of the halide perovskite structure with the sharp optical absorption of these materials.

HL 23.4 Wed 15:45 H34

Investigating underlying mechanisms of K doping on stability of single- and mixed-cation perovskite solar cells with experimental and computational informed modelling — Saied Mollavali, Mohammad Moaddeli, and •Mansour Kanani — Department of Materials Science and Engineering, School of Engineering, Shiraz University, Shiraz, Iran

Recent studies revealed that the interstitial occupancy of potassium in single/mixed-cation based perovskite structures could hinder the ion migration mechanisms near interfaces, and therefore leads to a better structural stability. However, the underlying stability enhancement mechanisms and probable side effects of additional K atoms in corporate with other organic/inorganic constituents, with a long-range electronic bonding character, is not clear completely. In this study, the effect of doping K on the structural, morphological, electronic, and optical properties of different perovskite structures is investigated experimentally and computationally. The beneficial effect of interstitial K atom on long-range bonding of I atoms with organic molecules is observed. Furthermore, no degradation from additional K is detected for specific range of doping. This result opens a new insight on constructive impact of inorganic dopant on stability issue in perovskite solar cells. SEM, XRD, Photoluminescence and optical absorbance analysis were performed on the perovskite layer. The one layer-based experimental data incorporation with DFT based results were informed into the SCAPS-1D solar cell simulator package to predict cell efficiency, systematically.

HL 23.5 Wed 16:00 H34

Revealing efficiency losses due to mobile ions in perovskite solar cells — •Sahil Shah, Jarla Thiesbrummel, and Jonas Diekmann — University of Potsdam, Germany

Perovskite semiconductors are distinct from most other semiconductors due to a large number of mobile ions in the active layer (e.g., iodide and methylammonium ions and vacancies, and others). Thus, ion dynamics have a critical impact on the performance and stability of perovskite-based applications.

In this work, we will show how the ionic density and induced losses change with device degradation under elevated temperatures and continuous light illumination. This is investigated via a simple and newly developed method *fast-hysteresis* which is a JV scan at a faster rate (~1000 Vs-1) which prevents the perturbation of mobile ions and we get the true ion free potential of the device. The fast-hysteresis measurements are corroborated by transient charge extraction and capacitance measurements as well as numerical simulations, which provide important insights into the dynamics of free electronic charges and mobile ions. We will then demonstrate how the mobile ions affect a range of commonly used mixed cation metal halide perovskite compositions and how the ionic losses vary with the charge transport layer.

Overall, the proposed methods quantify the ion-induced field screening, shed light on the complex device degradation process and PCE losses allow for a better understanding of several key phenomena in perovskite solar cells, and open up a large range of future experiments.

HL 23.6 Wed 16:15 H34

Dissecting Ultrafast Polarization Responses in Lead Halide Perovskites via the THz-induced Kerr Effect — •Maximilian Frenzel[1], Marie Cherasse[1,2], Joanna Urban[1], Feifan Wang[3], Bo Xiang[3], Leona Nest[1], Lucas Huber[3], Martin Wolf[1], X.-Y. Zhu[3], and Sebastian F. Maehrlein[1] — [1]Fritz Haber Institute of the Max Planck Society, Department of Physical Chemistry, Berlin, Germany — [2]LSI, CEA/DRF/IRAMIS, CNRS, Ecole Polytechnique, Institut Polytechnique de Paris, Palaiseau, France — [3]Columbia University, Department of Chemistry, New York City, USA

The microscopic origin of the surprising optoelectronic properties of lead halide perovskite (LHP) semiconductors is still under debate. One hypothesis is that the highly polar and anharmonic lattice of LHPs influences their optoelectronic properties through dynamic charge carrier screening. We therefore study the ultrafast polarization response of the hybrid LHP $MAPbBr_3$ when exposed to transient electric fields in the form of intense, single-cycle THz pulses. By probing the THz-induced Kerr effect (TKE), we observe strong THz polarizability and complex ultrafast polarization dynamics. We perform 4-wave-mixing simulations, which show that it is crucial to account for anisotropic

and dispersive light propagation for the correct interpretation of the measured TKE signals. Finally, we unveil a coherent phonon response in $MAPbBr_3$, which we assign to the inorganic cage and conclude to be the dominating polarizable mode in this material. This finding highlights the role of the inorganic lattice for dynamic carrier screening and the related mechanism of charge carrier protection.

30 min. break

HL 23.7 Wed 17:00 H34

Calculating the temperature-dependent band gap of the halide perovskite $CsPbBr_3$ — •Stefan Seidl, Christian Gehrmann, Xiangzhou Zhu, Sebastian Caicedo Davila, and David A. Egger — Department of Physics, Technical University of Munich, Garching, Germany

Theoretical calculations based on density functional theory (DFT) can predict thermal effects in the electronic structure by considering important phenomena, such as thermal lattice expansion and electron-phonon coupling. The latter can be calculated using a Monte-Carlo (MC) sampling approach that is formally rooted within the harmonic approximation, which has recently been shown to yield accurate temperature-dependent band gaps for inorganic semiconductors [1]. A complementary approach to predict thermal effects in the electronic structure is first-principles molecular dynamics (MD), which can account for vibrational anharmonicity that is an important effect for certain technologically relevant materials. Here, we assess the temperature-dependent band gap of the halide perovskite $CsPbBr_3$ in the cubic and orthorhombic phases employing the two different methods, MC and MD, and compare our findings with experimental results. This includes a discussion about the role of anharmonicity and the contributions from spin-orbit coupling and thermal lattice expansion.

[1] F. Karsai et al, New J. Phys. 20, 123008 (2018)

HL 23.8 Wed 17:15 H34

Electronic structure prediction of hybrid organic-inorganic metal halide perovskites using cost-effective DFT-1/2 method — Mohammad Moaddeli und •Mansour Kanani — Department of Materials Science and Engineering, School of Engineering, Shiraz University, Shiraz, Iran

Hybrid organic-inorganic metal halide perovskites (OIHPs) have attracted much attention in the last decade because of tunable photovoltaic performance and low fabrication cost. Regarding the tunable parameters for controlling the fundamental properties of OIHPs, recent computational and data-driven based approaches can accelerate new material prediction procedure significantly. Density functional theory (DFT) is considered as fundamental block of many multiscale, high-throughput and data-driven approaches typically. However, because of complexity of electronic orbital in OIHP as well as high sensitivity of regarding properties to atomistic configuration, employing conventional computational approaches faces many obstacles or needs very expensive corrections. Underestimation of routine functionals used in DFT calculations push people apply expensive approaches such as hybrid functionals and GW approximation. Here, DFT-1/2 method with a normal computational cost has been used for determining not only the band gap but also the true form of valence and conduction bands of OIHPs. The results showed that, the method could preserve the known Rashba band splitting in the conduction band of mixed-cation perovskites, which is the source of longer carrier lifetime behavior.

HL 23.9 Wed 17:30 H34

Phonon Signatures for Polaron Formation in an Anharmonic Semiconductor — •Feifan Wang[1,2], Weibin Chu[3], Jin Zhao[3], and X.-Y. Zhu[1] — [1]Columbia University, New York, NY, 10027 USA — [2]Dept. of Materials, ETH Zurich, Switzerland — [3]University of Science and Technology of China, Hefei, Anhui 230026, China

Polaron formation, in which charge carriers are dressed by a cloud of lattice distortions, is partially responsible for the long carrier lifetimes and diffusion lengths in the lead halide perovskite (LHP), a superior optoelectronic material. Considerations of ferroelectric-like phonon anharmonicities of this system lead to the recent proposal of ferroelectric large polarons, which attributes efficient charge-carrier screening to the extended ordering of dipoles associated with inversion-symmetry-breaking unit cells. Here, we study electron-phonon coupling in Bi_2O_2Se, a semiconductor which bears resemblance to LHPs in ionic bonding, band transport with long carrier diffusion lengths, and dynamical phonon disorder as revealed by low-frequency Raman spectroscopy. Using coherent phonon spectroscopy, we show the strong coupling of an anharmonic phonon mode to photo-excited charge carriers, while the Raman excitation of this mode is symmetry-forbidden in the ground-state. Density functional theory calculations verify that the phonon mode originates from the symmetry reduction after charge injection and indicate the local dipole ordering induced by photo-excited electrons. This study provides an initial attempt to generalize the proposed charge-carrier screening model to account for the outstanding optoelectronic properties of defect-tolerant semiconductors.

HL 23.10 Wed 17:45 H34

Tuning Perovskite Crystallization in the Hybrid Route — •Mohamed Mahmoud, Patricia Schulze, Andreas Bett, and Oussama Er-raji — Fraunhofer ISE

In 2009, perovskite solar cells were discovered in the solid-state that can be used not only as a single junction absorber but also in tandem configuration thanks to their bandgap tunability. It is a combination of organic and inorganic lead halide materials and they have the advantage of a strong absorption edge, defect tolerance and potential cheap production due to easy production methods such as spin coating or slot-die coating as a highly scalable production method. In the industry, double-sided textured silicon (DSTS) is commonly produced to overcome the reflection losses at surfaces. Spin coating of perovskite on top of DSTS resulted in low conformality which resulted in shunts and non-working solar cells. To overcome this issue, the hybrid route was developed, in which inorganic materials are co-evaporated using the thermal vapour deposition technique and then organic materials are spin-coated. By doing that, the high conformality of the thin film on top of the c-Si is achieved. However, the resulting perovskite grain size is in the nanometer scale. To increase the grain size - which results in higher short circuit current, lower grain boundaries and thus a more stable device - thermodynamics of the crystallization process need to be studied. In this work, using the thermodynamics fundamentals of crystallization, we tune the grain size of perovskite deposited via the hybrid route. In addition, we study the consequences of different grain sizes on the efficiency of the solar cell and especially on the stability.

HL 23.11 Wed 18:00 H34

Dynamic nuclear spin polarization in lead halide perovskites — •Natalia Kopteva[1], Dennis Kudlacik[1], Marek Karzel[1], Mladen Kotur[1], Dmitri Yakovlev[1], Oleh Hordiichuk[2], Olga Nazarenko[2], Dmitry Dirin[2], Maksym Kovalenko[2,3], and Manfred Bayer[1] — [1]Experimentelle Physik 2, TU Dortmund, 44221 Dortmund, Germany — [2]Laboratory of Inorganic Chemistry Department of Chemistry and Applied Biosciences, ETH Zürich, CH-8093 Zürich, Switzerland — [3]Laboratory for Thin Films and Photovoltaics Empa-Swiss Federal Laboratories for Materials Science and Technology, CH-8600 Dübendorf, Switzerland

Lead halide perovskites are promising for applications in spintronics due to the nanosecond coherence time of the resident carriers [1]. The primary source of losing spin coherence is the interaction with the fluctuating nuclear spin environment [2]. Optically oriented carrier spins polarize nuclei, which create an Overhauser field. Due to the different strengths of the hyperfine interaction with the nuclear spins, the electron and hole experience different magnitude and directions of the Overhauser field. To study the degree of nuclear spin polarization and fluctuation, we investigate the interaction of resident and optically created carrier spins with nuclei using the Hanle effect in the tilted magnetic field in bulk formamidinium caesium lead iodine bromide.

[1] V. V. Belykh et al., Nat. Commun. 10, 673 (2019)
[2] I. A. Merkulov et al., Phys. Rev. B 65, 205309 (2002)

HL 24: Functional Semiconductors for Renewable Energy Solutions (joint session HL/KFM)

Time: Wednesday 15:00–18:30 Location: H36

HL 24.1 Wed 15:00 H36

A facile freeze-thaw ultrasonic assisted circulation method of graphite flakes prepared by anode graphite from spent lithium-ion batteries — •Yu Qiao[1,2], Zhonghao Rao[3,4], Huaping Zhao[1], and Yong Lei[1] — [1]Fachgebiet Angewandte Nanophysik, Institut für Physik & IMN MacroNano, Technische Universität Ilmenau, 98693 Ilmenau, Germany — [2]School of Electrical and Power Engineering, China University of Mining and Technology, 221116, Xuzhou, China — [3]School of Energy and Environmental Engineering, Hebei University of Technology, 300401, Tianjin, China — [4]Hebei Key Laboratory of Thermal Science and Energy Clean Utilization, Hebei University of Technology, 300401, Tianjin, China

Lithium-ion batteries (LIBs) have been widely employed in fast-growing mobile devices, stationary storage devices and electric vehicles. However, limited by particular service life, the booming increase in LIBs production will result in a large retirement wave. As the most common anode material in LIBs, waste graphite has also developed into a mode of high production capacity with the retirement of spent LIBs. Anode graphite (AG) of spent LIBs has the characteristics of large layer spacing and ease of being intercalated due to the reduced interlamination force after repeated charge and discharge cycles. This study presents a facile freeze-thaw ultrasonicassisted circulation method to prepare two-dimensional low-layer graphite flakes (GFs) using AG from spent LIBs. The results indicate that the freeze-thaw ultrasonic-assisted circulation method is feasible for preparing two-dimensional laminar materials.

HL 24.2 Wed 15:15 H36

How could the heating process reduce the crystal damage of semiconductors? — •Khalid Lahmidi, Jale Schneider, Andreas Brand, Sebastian Roder, and Andreas Bett — Fraunhofer Institute for Solar Energy Systems, Heidenhofstr. 2, 79110 Freiburg, Germany

Laser material processing can no longer be imagined away from the production chains in semiconductor industries. While being a precise, fast and wear-free processing tool, high intensity laser irradiation can also induce damage within the material, e.g. crystal damage, compromising the device quality. However, this damage can partly be healed or even prevented by an accompanying (laser) heating process.

In our laser lab, we built up a flexible laser heating setup with a spatial light modulator (SLM) as the core element. The setup allows to locally heat work pieces with different beam shapes with an intensity up to 220 W/cm* employing a cw-infrared laser source. Current research focuses on the temperature distribution in dependence of beam shape and beam dwell time on a specific position. Comsol based simulations support the experiments. Eventually, the heating beam will be overlaid to the process beam in use cases such as laser contact opening at lowered ablation thresholds or laser metal bonding for solar cell manufacturing. The damage after laser process with and without heating will be analyzed via microscopy.

HL 24.3 Wed 15:30 H36

Energy landscape of the Boron and Indium single-atom defects in Silicon calculated by DFT — •Aaron Flötotto, Wichard Beenken, and Erich Runge — Institut für Physik, Technische Universität Ilmenau, Weimarer Str. 32, 98693 Ilmenau, Germany

The III group elements Boron and Indium form not only substitutional defects, which are important as electron acceptors, but also interstitial defects. Different configurations are possible for a single impurity atom: (i) the impurity atom on an interstitional site, (ii) a substitutional impurity near a single interstitial Si atom, or (iii) the impurity and one Si atom form a pair of interstitials around an empty lattice point. We calculated within DFT the stable configurations of these defects for the Si:B and the Si:In system. We utilized the Nudged Elastic Band algorithm for finding minimal paths between these energetic minima in order to explore the energy landscape and to derive transition probabilities. The results are discussed with respect to the dynamical model suggested by K. Lauer et al. [1] for the explanation of PL-spectra of In-doped Si. [1] Lauer, K.; Möller, C.; Schulze, D. & Ahrens, C.; AIP Adv. 5 (2015) 017101

HL 24.4 Wed 15:45 H36

Effects of Defects on the Optoelectronic Properties of Ta_3N_5 Thin Films — •Lukas M. Wolz, Gabriel Grötzner, Laura I. Wagner, Ian D. Sharp, and Johanna Eichhorn — Walter Schottky Institut, Technische Universität München

For photoelectrochemical energy conversion, metal nitride semiconductors have the potential to overcome several limitations associated with the more intensively investigated class of metal oxides. Among these materials, Ta_3N_5 is especially promising, possessing a bandgap of ∼2.2 eV and effective long-range charge transport. However, the (opto)electronic and photoelectrochemical properties of Ta_3N_5 photoelectrodes are often dominated by defects, such as oxygen impurities, nitrogen vacancies, and low-valent Ta cations. To identify the impact of such defects on the material properties, we prepare Ta_3N_5 via two different synthetic routes. As precursor, Ta_xN_y and Ta_xO_y thin films were deposited by magnetron sputtering and were subsequently annealed at high temperatures in NH_3 to form Ta_3N_5. Both films are homogenous and reveal the formation of phase-pure orthorhombic Ta_3N_5. Compared to nitride-derived Ta_3N_5, the oxide-derived films are characterized by higher structural disorder as well as higher oxygen and lower nitrogen concentrations. Despite these higher defect concentrations, the oxide-derived Ta_3N_5 films exhibit improved stability under photoelectrochemical operation conditions, though both films show similar photoelectrochemical performance. The improved understanding of defect properties and their impact on PEC stability provides a path to tailored optimization of photoelectrode properties.

HL 24.5 Wed 16:00 H36

Investigation of various quenching materials on the P-line — •Dominik Bratek, Katharina Peh, Kevin Lauer, Aaron Flötotto, Dirk Schulze, and Stefan Krischok — Institut für Physik, Technische Universität Ilmenau, Weimarer Str. 32, 98693 Ilmenau, Germany

Solar-grade Si shows degradation effects and a lowering of the charge carrier lifetimes after illumination [1]. For In implanted Si this effect was shown to be connected to the P-line in photoluminescence spectra [2]. This P-line can furthermore be influenced by applying a strong quenching after an anneal. The intensity of the P-line increases by several orders of magnitude depending on the cooling rate [3]. In this contribution we investigate the influence of four different quenching liquids on the P-line. From an experimental point of view we discuss the applicability of each used liquid in consideration of P-Line intensity and probe integrity. [1] C. Möller and K. Lauer, Physica Status Solidi (RRL) 7, 461 (2013). [2] K. Lauer, C. Möller, D. Schulze, and C. Ahrens, AIP Advances 5, 017101 (20125). [3] M. L. W. Thewalt, U. O. Ziemelis, and P. R. Parsons, Solid State Communications 39, 27 (1981).

HL 24.6 Wed 16:15 H36

Simulation of the reaction kinetics of the A_{Si}-Si_i-defect — •Kevin Lauer[1,2], Katharina Peh[2], Wichard Beenken[2], Erich Runge[2], and Stefan Krischok[2] — [1]CiS Forschungsinstitut für Mikrosensorik GmbH, Konrad-Zuse-Str. 14, 99099 Erfurt, Germany — [2]TU Ilmenau, Institut für Physik und Institut für Mikro- und Nanotechnologien, 98693 Ilmenau, Germany

Light-induced degradation (LID) is a severe problem for silicon photosensitive devices like solar cells and photo detectors. LID reaction kinetics may be explained by the A_{Si}-Si_i-defect model. [1] This model consists of seven states. The transitions between these states are assumed to be first order equilibrium reactions, which can be mathematically treated by a system of linear differential equation. [1] This is numerically solved and compared to the LID cycle using well-known together with some estimated reaction constants.

[1] K. Lauer, C. Möller, C. Tessmann, D. Schulze, and N. V. Abrosimov, "Activation energies of the In_{Si}-Si_i defect transitions obtained by carrier lifetime measurements", physica status solidi (c), vol. 14, no. 5, p. 1600033, 2017.

30 min. break

HL 24.7 Wed 17:00 H36

Exploring Zirconium-doped Tantalum Nitride as a Photoan-

ode for Solar Energy Conversion — •Oliver Brune, Laura I. Wagner, Verena Streibel, and Ian D. Sharp — Walter Schottky Institut and Physics Department, Technical University of Munich, Am Coulombwall 4, 85748 Garching, Germany

Solar water splitting could pave the way to carbon-free hydrogen production as it allows for direct transformation of sunlight into chemical energy. While the oxygen evolution reaction is a crucial step in generating green hydrogen, there remains a lack of semiconductor photoanode materials that can simultaneously fulfill three key requirements: long-term chemical stability, high photocarrier extraction efficiencies, and appropriate bandgap for harvesting solar radiation. Nevertheless, among the various materials that have been investigated, the transition metal nitride Ta3N5 offers significant promise as an efficient n-type photoanode. Building upon this established material, we use reactive co-sputtering and subsequent ammonia annealing to introduce Zr into Ta3N5, with the aim of investigating how the ternary nitride character of Zr-Ta-N(O) enables tuning of key semiconductor properties. Using a range of complementary characterization methods, we show that synthesis parameters and Zr content have a significant influence on the crystal structure, morphology, and optoelectronic properties of this ternary compound. Based on these insights, we optimize the composition and synthesis processes to achieve a highly stable and efficient photoanode material, which is a key requirement for solar water splitting.

HL 24.8 Wed 17:15 H36

Defect-Engineered Atomic Layer Deposited TaO_x Protection Layers for Photoelectrochemistry — •Tim Rieth, Clara Scherm, and Ian Sharp — Walter Schottky Institute and Physics Department, Technical University of Munich, Am Coulombwall 4, 85748 Garching, Germany

Photoelectrochemical (PEC) energy conversion provides a viable route to the generation of chemical fuels from solar light. In this approach, charge carriers generated within a semiconductor light absorber immersed in an electrolyte are used to drive water splitting or carbon dioxide reduction reactions. A particularly relevant PEC configuration uses photovoltaic absorbers coated with transparent and conductive protection layers that prevent chemical corrosion of the semiconductor components. However, ensuring that the protection layer simultaneously fulfills the criteria for chemical stability, electronic conductivity, and optical transparency remains a challenging task. Here, we utilize plasma enhanced atomic layer deposition (PE-ALD) to create defect engineered and ultra-thin tantalum oxide (TaO_x) protection layers for PEC applications. In addition to their optical transparency, the TaO_x films form continuous coatings on the photoabsorber and provide improved chemical stability compared to titanium dioxide. A sufficiently high film conductivity is obtained by intentionally introducing electronic defects from hydrogen plasma sub-cycles during the ALD process. The demonstrated defect engineering mechanism and achieved TaO_x protection layers represent an advance towards efficient and stable PEC devices.

HL 24.9 Wed 17:30 H36

Exploring novel ternary nitride semiconductor photoabsorbers for solar energy conversion applications — •Laura I. Wagner[1], Elise Sirotti[1], Johanna Eichhorn[1], Chang-Ming Jiang[1], Matthias Kuhl[1], Verena Streibel[1], David Egger[2], and Ian D. Sharp[1] — [1]Walter schottky Institut und TUM, München, Germany — [2]TUM, München, Germany

Solar water splitting offers the possibility to harvest the sunlight and store it in the chemical bonds of hydrogen. Exploratory research has revealed several possible photoanode materials, but until now no material meets the core requirements for photochemical stability, carrier extraction efficiency, and moderate band gap in the visible range. In this context, transition metal nitride semiconductors are underexplored and offer promise as new photoanode materials candidates. As a non-equilibrium synthesis approach, reactive magnetron co-sputtering enables the synthesis of novel ternary nitride photoabsorbers. In this work, a new ternary metal nitride photoanode material, cubic bixbyite-type ZrTaN3, is presented. We observe the reactively sputtered ZrTaN3 thin films to exhibit an optical bandgap at 2.4 eV and n-type behavior. Most importantly, the resulting polycrystalline films exhibit appreciable photoactivity when implemented as a photoanode in a photoelectrochemical cell. Benefiting from the tunability of cation (Ta,Zr) ratio of reactive sputtering and anion (N,O) ratio with post annealing treatments, the solid solution of ZrxTa2-xN3(O) offers a large parameter space to tune and optimize optoelectronic properties for various applications, including for PEC applications.

HL 24.10 Wed 17:45 H36

Electrical transport across catalyst/defect-engineered titania corrosion protection layer interfaces for light-driven CO2 reduction — •Julius Kühne, Oliver Bienek, Tim Rieth, and Ian D. Sharp — Walter Schottky Institute and Physics Department, Technical University of Munich, Am Coulombwall 4, 85748 Garching, Germany

Producing value-added products via light-driven CO2 reduction represents a promising approach to sustainably address increasing CO2 emissions and meet the growing global energy demand. However, such solar fuels systems require passivating layers to chemically protect semiconductor light absorbers from harsh reaction environments. Despite great progress in the development of atomic layer deposited (ALD) protection layers, the factors governing efficient charge injection into the catalytic component are not yet well understood. Here, the charge transport characteristics between various defect-engineered TiO2 protection layers grown with ALD and metal catalyst layers including Ag, Au, Pt, Ni and Ti are analyzed. This work aims to get a deeper understanding of the interface between catalyst and protection layer in terms of contact resistivity, carrier transport, and interface kinetics. Additionally, results of EC and PEC measurements are compared to assess the stability and activity of these systems under CO2 reduction conditions in a two-compartment cell with ion exchange membrane. The selectivity of selected catalyst layers is evaluated by gas chromatography of the reaction products, thereby enabling a quantification of their overall performance characteristics.

HL 24.11 Wed 18:00 H36

Finite supercell charge correction for electronic transitions in defects including electronic and ionic screening — •Christoph Freysoldt[1], Baoying Dou[1], Stefano Falletta[2], and Jörg Neugebauer[1] — [1]Max-Planck-Institut für Eisenforschung GmbH, Max-Planck-Str. 1, 40237 Düsseldorf — [2]Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

Charged point defects play an important role in the function of (opto)electronic devices. Theoretical investigations have proven valuable to understand quantitatively their stability, electrical and optical properties, and hence their beneficial or detrimental role in device performance. Electronic transitions involving localized defect states have recently moved into the focus. Similar to formation energies, also the transition energies suffer from artifacts due the long-range Coulomb interactions and the artificial periodicity in supercell models of defects. While the initial charge state is subject to full electronic and ionic screening, the changes upon the transition are screened by electrons only. Yet, the required charge corrections cannot be derived by cleverly combining traditional corrections for formation energies of initial and final state. I will present an overview of how these artifacts can be understood and corrected for. I will show applications for vertical transitions and non-radiative carrier capture.

HL 24.12 Wed 18:15 H36

Influence of Sr concentration on atomic, magnetic, and electronic structure of Ruddlesden-Popper oxide $La_{2-x}Sr_xCo_{1-y}Fe_yO_4$ — •Dina I. Mazitova[1], Debalaya Sarker[1,2], and Sergey V. Levchenko[1] — [1]Moscow, Russia — [2]UGC-DAE CSR, Indore, India

Ruddlesden-Popper oxides were demonstrated to be promising catalysts for oxygen evolution reaction. There are numerous attempts in the literature to find descriptors for predicting a catalytic activity. However, the descriptors may depend on the distribution of ions of different types in these multi-component systems.

We calculated atomic, electronic, and magnetic structure of $La_2Co_{0.5}Fe_{0.5}O_4$, $LaSrCo_{0.5}Fe_{0.5}O4$ (LSCFO), and $Sr_2Co_{0.5}Fe_{0.5}O_4$ for different distributions of iron and cobalt using all-electron DFT in GGA and GGA+U approximations. Our calculations show that the favorable distribution of transition metal cations depends on the amount of Sr substituted in the A site. The electronic and magnetic structures depend strongly on the Fe/Co distribution. For example, GGA-RPBE calculations in LSCFO showed charge-ordered ferromagnetic structure in the Co layer and antiferromagnetic structure in the Fe layer when Co and Fe layers interchange with one another, but for uniform distribution of iron and cobalt ions, LSCFO becomes ferromagnetic.

HL 25: Poster 1

Topics:
- 2D semiconductors and van der Waals heterostructures
- Acoustic waves and nanomechanics
- Focus Session: Perspectives in Cu(In,Ga)Se2: How to go beyond 23.4 percent
- Focus Session: Quantum Properties at Functional Oxide Interfaces
- Functional semiconductors for renewable energy solutions
- Heterostructures, interfaces and surfaces
- Optical properties
- Organic semiconductors
- Quantum dots and wires
- Quantum transport and quantum Hall effects
- Semiconductor lasers
- Spin phenomena in semiconductors
- Thermal properties
- THz and MIR physics in semiconductors
- Transport properties

Time: Wednesday 18:00–20:00 Location: P2

HL 25.1 Wed 18:00 P2

A versatile transfer printing toolbox for 2D material stacking — •Ioannis Caltzidis, Maja Groll, Julius Bürger, Marc Satison, Jörg K. N. Lindner, and Klaus D. Jöns — Institute for Photonic Quantum Systems, Center for Optoelectronics and Photonics Paderborn, and Department of Physics, Paderborn University, 33098 Paderborn, Germany

2D materials are of great interest to scientists due to the versatile integration with other materials into, for example, Van-der-Waals heterostructures. The resulting nanoscale Moiré superlattices have applications in electronic and photonic quantum technologies. In 2D materials, the electronic band structure is generally determined by the number of layers, species of materials, as well as their angular and relative translational orientation. Transfer printing 2D materials on top of each other or onto different platforms is a frequently used fabrication method for 2D devices in state-of-the-art laboratories worldwide. Here we show how our transfer printing apparatus can be used to deterministically transfer tungsten diselenide (WSe_2) on transmission electron microscope (TEM) grids for high-resolution differential phase contrast measurements, revealing the electronic field distribution. We employ water-assisted and dry transfer methods with WSe_2 on a polyvinylalcohol (PVA) - polymethylmethacrylate (PMMA) or polydimethylsiloxane (PDMS) polymer substrate. The transfer stage's translational, rotational, and azimuthal degrees of freedom enable deterministic positioning and control in the fabrication process.

HL 25.2 Wed 18:00 P2

Enhancement of Raman and Defect Photoluminescence Emission in Hexagonal Boron Nitride (h-BN) — •Felix Schaumburg, Marcel Zöllner, Vasilis Dergainlis, Axel Lorke, Martin Geller, and Günther Prinz — Faculty of Physics and CENIDE, University Duisburg-Essen, Germany

Optical spectroscopy, especially Raman- and photoluminescence (PL)-spectroscopy, is commonly used to study the optical properties of two-dimensional materials. In order to obtain the highest Raman/PL-signals, it is important to reduce the reflection of the excitation laser. We studied a number of exfoliated h-BN flakes with different thicknesses on a Si substrate with a 300 nm SiO_2 top-layer. By changing the h-BN layer-thickness, we found a specific thickness, where all Raman signals showed maximum intensity, whereas the backscattered laser light was almost completely suppressed. To explain the increased intensities, we calculated the reflectivity of the layer system (air, h-BN, SiO_2, Si) for different h-BN layer thicknesses and used the transfer-matrix-algorithm. For our 532 nm excitation laser, the minimum reflectivity was found for a h-BN flake thickness of about 160 nm. Using AFM measurements, we were able to confirm that the thickness of the h-BN flakes having the strongest Raman signals correspond almost exactly to the calculated thickness. Our results suggest, that the PL from defects will also be strongly enhanced for an h-BN thickness of 160 nm and an excitation laser wavelength of 532 nm. This optimal thickness for the defect state PL emission can easily be calculated for other excitation laser wavelengths, as well as for other materials.

HL 25.3 Wed 18:00 P2

Surface acoustic wave modulation of optical and electrical properties in TMDC monolayers — •Clemens Strobl, Benjamin Mayer, Hendrik Lambers, Ursula Wurstbauer, and Hubert Krenner — Institute of Physics, University of Münster, Germany

Two-dimensional transition metal dichalcogenides (TMDCs) such as WSe2 exhibit large exciton binding energies combined with a high sensitivity of their bandgap energy to mechanical stimuli [1]. Excitons in these materials can be generated either optically by above bandgap illumination or via two electrodes. Similarly, excitons in TMDCs can be studied optically via photoluminescence and absorption spectroscopy, electrically by detecting a photocurrent or via the interaction with surface acoustic waves (SAWs).

The aim of this project is to investigate SAW-dependent photoconductance in exfoliated monolayers [2] and to determine the influence of SAWs on the optical and optoelectronic properties in TMDCs. We study the SAW-driven exciton transport in monolayers and thus the change in the exciton decay rate [1]. For all experiments lithium niobite (LiNbO3) substrates and interdigitated electrodes (IDTs) operating at a frequency range from 300MHz up to 1GHz are used.

[1] Datta et al. Nat. Photon. 16, 242-247 (2022). [2] Preciado, E., Schülein, F., Nguyen, A. et al. Nat Commun 6, 8593 (2015).

HL 25.4 Wed 18:00 P2

Raman fingerprint of twisted TMDC bilayers — •Sina Bahmanyar, Nihit Saigal, Hendrik Lambers, Laura Schusser, Clemens Strobl, and Ursula Wurstbauer — Institute of Physics, University of Münster, Münster, Germany

The discovery of superconductivity and other correlated phases in twisted bilayer graphene opened up a new field of research aimed at understanding the many body physics and strong electronic interactions in twisted van der Waals bilayers. [1] Such bilayer systems provide an ideal platform for simulation of Hubbard model physics and its control using the relative twist angle between the layers [2] in order to tune interlayer interaction and electronic correlations. [1,2] We have fabricated twisted WSe2 bilayers with various twist angles between the monolayers and characterized them using low and high energy Raman spectroscopy and photoluminescence spectroscopy. The low-frequency Raman spectra shows the shear modes that are highly sensitive to the twist angle and interlayer coupling between the monolayers. Our measurements establish Raman spectroscopy as a non-destructive way to characterize the interlayer coupling in twisted TMDC bilayers to study electronic and excitonic correlation physics [3]. We acknowledge financial support via WU 637/7-1 and SPP2244. [1] Y. Cao et al., Nature 556, 23 (2018). [2] Y. Tang et al., Nature 579, 353 (2020) [3] L. Sigl. et al. Phys. Rev. Res. 2, 042044(R) (2020)

HL 25.5 Wed 18:00 P2

Nonlinear spectroscopy of valley polarization in transition metal dichalcogenides — •Paul Herrmann[1], Sebastian Klimmer[1], and Giancarlo Soavi[1,2] — [1]Institute of Solid State Physics, Friedrich Schiller University Jena, Jena, Germany — [2]Abbe Center of Photonics, Friedrich Schiller University Jena, Jena, Germany

Valleytronics is the branch of science that aims at controlling the valley (i.e., local maximaminima in the valenceconduction bands) degree of freedom to store, manipulate and read information. Monolayer transition metal dichalcogenides (TMDs) are promising candidates for valleytronic applications their hexagonal symmetry in the real and reciprocal space leads to the appearance of two energetically degenerate but non-equivalent valleys at the K and -K points. In addition, their direct bandgap nature in the monolayer limit enables direct optical excitation into these valleys, which can be achieved in a highly selective fashion by means of circularly polarized light [1]. All-optical control of the valley population would enable information processing at optical frequencies, thus overcoming by three to six orders of magnitude the speed of current electronic devices [2]. Here, we perform non-linear and time-resolved optical spectroscopy to study the purity and temporal evolution of the valley population in TMDs. In particular, we combine 2-photon-photoluminescence and time-resolved second harmonic measurements to investigate the impact of intra-valley relaxation and inter-valley scattering on the degree of valley polarization.

[1] Xu X. *et al.*, NPhys **10**, 5 (2014) 343-350
[2] Mitchell Waldrop M. *et al.* Nature **530**, (2016) 144-147

HL 25.6 Wed 18:00 P2

Charge carrier dependent Raman response in WS2 monolayers — •Hendrik Lambers, Nihit Saigal, and Ursula Wurstbauer — Institute of Physics, University of Münster, Münster, Germany

Semiconducting transition metal dichalcogenides such as WS2 and MoS2 are among the most widely studied 2D materials due to their unique optical and electronic properties. Monolayers of these materials show a large exciton dominated light matter coupling. Exciton-phonon and electron-phonon interaction effects are prone to modification of the charge carrier density and impacts the optical and electronic behavior of the atomically thin semiconductors [1]. Here we report on a detailed Raman study of the charge carrier dependent evolution of the phonon modes in WS2 monolayer embedded in a field effect structure using a solid-state electrolyte [2]. The optimized field effect structure using a polymer electrolyte top gating allows tuning the fermi-energy cross the band gap and hence enables ambipolar doping.

We acknowledge financial support via DFG WU 637/7-1 and SPP2244.

[1] B. Miller et al., Nat Commun 10, 807 (2019).
[2] B. Miller at al., APL 106, 122103 (2015).

HL 25.7 Wed 18:00 P2

Tuning exciton recombination rates in doped transition metal dichalcogenides — •Theresa Kuechle, Sebastian Klimmer, Marco Gruenewald, and Giancarlo Soavi — Institute of Solid State Physics, Friedrich Schiller University Jena, Helmholtzweg 5, 07743 Jena, Germany

Monolayer transition metal dichalcogenides (TMDs) are direct gap semiconductors that hold great promise for advanced applications in photonics and optoelectronics such as integrated, flexible and high-speed light emitting devices [1]. Understanding the interplay between their radiative and non-radiative recombination pathways is thus of crucial importance not only for fundamental studies but also for the design of future nanoscale on-chip devices. Here, we investigate the interplay between doping and exciton-exciton annihilation (EEA) and their impact on the photoluminescence quantum yield in different TMD samples and related heterostructures. We demonstrate that the EEA threshold increases in highly doped samples, where the radiative and non-radiative recombination of trions dominates [2]. The results are interpreted with a rate equation model that takes into account all radiative and non-radiative recombination pathways of excitons and trions in TMDs as a function of doping (*i.e.*, trion concentration) and generation rate (*i.e.*, photoexcited carrier concentration).

[1] Wang *et al.*, *Nanoscale Adv.* **2**, 4323 (2020)
[2] Kuechle *et al.*, *Opt. Mat.: X* **12**, 100097 (2021)

HL 25.8 Wed 18:00 P2

Destructive Photon Echo Formation in Six-Wave Mixing Signals Induced by Local Field Effects — •Thilo Hahn[1], Jacek Kasprzak[2], Tilmann Kuhn[1], and Daniel Wigger[3] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]Université Grenoble Alpes, CNRS, France — [3]School of Physics, Trinity College Dublin, Ireland

The optical properties of transition metal dichalcogenides have emerged as an outstanding topic in nanoscience. In these materials, tightly bound excitons dominate the optical response. Ultrafast nonlinear spectroscopy is an ideal tool to study the excitonic properties and their dynamics. To model the dynamics of excitonic transitions we use a few-level system with an additional local field (LF) effect to describe exciton-exciton interaction [1]. Effectively, the LF shifts the transition energy depending on the exciton occupation, which is directly visible in pump-probe experiments [2]. In this contribution we consider six-wave mixing spectroscopy [3], where we discover a new destructive photon echo effect, that is produced by the LF contribution. In contrast to the traditional echo formed by constructive interference [4], the signal is temporarily suppressed due to destructive quantum interference.

[1] T. Hahn, et al., *New J. Phys.* 23, 023036 (2021), [2] A. Rodek et al., *Nanophotonics* 10, 2717 (2021), [3] T. Hahn, et al., *Adv. Sci.* 9, 2103813 (2021), [4] E. L. Hahn, *Phys. Rev.* 80, 580 (1950)

HL 25.9 Wed 18:00 P2

Signature of lattice dynamics in twisted 2D homo/heterobilayers — •Yang Pan[1,2], Shutong Li[3], Mahfujur Rahaman[1,2], Ilya Milekhin[1,2], and Dietrich R. T. Zahn[1,2] — [1]Semiconductor Physics, Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [2]Center for Materials, Architectures, and Integration of Nanomembranes (MAIN), Chemnitz, Germany — [3]Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota, USA

Twisted 2D bilayer materials are created by artificial stacking of two monolayer crystal networks of 2D materials with a desired twisting angle θ. The material forms a moiré superlattice due to the periodicity of both top and bottom layer crystal structure. The optical properties are modified by lattice reconstruction and phonon renormalization, which makes optical spectroscopy an ideal characterization tool to study novel physics phenomena. Here, we report a Raman investigation on a full period of the twisted bilayer (tB) WSe_2 moiré superlattice (*i.e.* $0° \leq \theta \leq 60°$). We observe that the intensity ratio of two Raman peaks, B_{2g} and E_{2g}/A_{1g} correlates with the evolution of moiré period. Using a series of temperature-dependent Raman and photoluminescence (PL) measurements as well as *ab initio* calculations, the intensity ratio $I_{B_{2g}}/I_{E_{2g}/A_{1g}}$ is explained as a signature of lattice dynamics in tB WSe_2 moiré superlattices. By further exploring different material combinations of twisted hetero-bilayers, the results are extended for all kinds of Mo- and W-based TMDCs.

HL 25.10 Wed 18:00 P2

Transport Measurements on Twisted Graphene Heterostructures around Magic Angle — •Bei Zheng, Xiao Yue Zhang, Jun Hui Huang, Lina Bockhorn, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany

The twisting of graphene layers opens up a whole new field of rich physics [1]. Especially, the electronic properties of twisted (double Bernal-stacked) bilayer graphene layers depend strongly on the twist angle, owing to the energy band modulation from the corresponding Moiré superlattice [2,3]. Furthermore, twisted graphene structures around the magic angle were the first systems that show new many-body phases, as e. g. superconductivity or Mott insulator phases [4].

We fabricated twisted graphene heterostructures around the magic angle encapsulated in hexagonal boron via 'tear and stack' method and investigated their transport characteristics at low temperature down to 1.5 K. The longitudinal resistance was observed to periodically change with charge carrier concentration. The periodicity is relative to the superlattice density n_s and depends on how the degenerated superlattice sub-bands are filled.

[1] H. Schmidt et al., Nat. Commun. 5, 5742 (2014)
[2] J. C. Rode et al., 2D Mater. 3, 035005 (2016)
[3] S. J. Hong et al., 2D Mater. 8, 045009 (2021)
[4] Y. Cao et al., Nat. 556, 43-50 (2018)

HL 25.11 Wed 18:00 P2

Rashba Splitting Modulated by Tuned Intrinsic Dipole Moment in MoSSe/WSSe Heterostructures — •hamid mehdipour and peter kratzer — Faculty of Physics, University of Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany

First-principles calculations in the framework of the density-functional theory are performed to study the van der Waals heterostructures of two Janus transition metal dichalcogenide (TMDC) monolayers, MoSSe and WSSe. Sixteen possible heterostructures of the two monolayers and their associated stackings (AA, AB) are studied. Thermal stability and electric and optical properties of all possible heterostructure configurations are investigated and compared. Owing to the lack of structural mirror symmetry in this class of TMDCs, a non-zero electric dipole moment exists for each Janus monolayer. The intrinsic dipole moments of the monolayers could build up an inter-monolayer coupling, which varies in magnitude across the possible heterostructure configuration spectrum. The total electric moment modulated by stacking could impact the overall stability of the heterostructures and their electronic and linear optical responses. Most intriguing for this class of material is the Rashba splitting of band structures for each Janus monolayer, which strongly depends on the intrinsic electric field associated with the non-zero electric moment due to the lack of mirror symmetry. By combining the DFT calculation and charge analysis, we quantify the Rashba effect for each heterostructure of MoSSe/WSSe and bring into the spotlight the role the stacking plays in modulating this effect.

HL 25.12 Wed 18:00 P2

Valley dynamics in WSe_2 monolayers and $MoSe_2$-WSe_2 heterobilayers — •Philipp Parzefall, Matthias Brem, and Christian Schüller — Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Deutschland

We have performed an in depth study of the valley coherence and polarization in hBN-encapsulated WSe_2 monolayers, which shall be extended to WSe_2-$MoSe_2$ heterostructures.

Therefore, we investigate first the excitonic properties and possible exciton-phonon coupling in hBN-encapsulated WSe_2 monolayers via micro-photoluminescence and resonant Raman spectroscopy measurements with excitation energies close to the A-exciton's fine-structure. Hereby, the valley polarization and -coherence are of special interest as possible resonant phonon excitation influences the valley dynamics behavior tremendously.

Afterwards, the resulting understanding is used to investigate interlayer excitons and trions on $MoSe_2$-WSe_2 heterobilayers with 0° or 60° relative twist between the layers, similarly, with an excitation energy close to the resonances of the WSe_2's A-exciton.

HL 25.13 Wed 18:00 P2

Electrical control of orbital and vibrational interlayer coupling in bi- and trilayer 2H-MoS_2. — Julian Klein[1,2], Jakob Wierzbowski[1], •Pedro Soubelet[1], Thomas Brumme[3,4], Lorenzo Maschio[5], Agnieszka Kuc[6,7], Kai Müller[1], Andreas V. Stier[1], and Jonathan J. Finley[1] — [1]Walter Schottky Institut, TU München, Germany — [2]Department of Materials Science and Engineering, MIT, USA. — [3]Wilhelm-Ostwald-Institute for Physical and Theoretical Chemistry, Leipzig University, Germany. — [4]Faculty for Chemistry and Food Chemistry, TU Dresden, Germany. — [5]Dipartimento di Chimica and Centre of Excellence NIS, Università di Torino, Italy. — [6]Helmholtz-Zentrum Dresden-Rossendorf, Abteilung Ressourcenökologie, Forschungsstelle Leipzig, Germany — [7]Department of Physics and Earth Sciences, Jacobs University Bremen, Germany.

Manipulating electronic interlayer coupling in layered vdW materials is essential for designing optoelectronic devices. Here, we control vibrational and electronic interlayer coupling in bi- and trilayer 2H-MoS_2 using large external electric fields in a microcapacitor device. The electric field lifts Raman selection rules and activates phonon modes in excellent agreement with ab initio calculations. Through polarizationresolved photoluminescence spectroscopy, we observe a strongly tunable valley dichroism. By modeling our result using rate equations, we have explained the valley dichroism tunability using realistic material parameters.

HL 25.14 Wed 18:00 P2

Assigning excitonic transitions in reconstructed $MoSe_2$-WSe_2 heterostacks — •Christos Paspalides[1], Mirco Troue[1], Lukas Sigl[1], Johannes Figueiredo[1], Manuel Katzer[2], Malte Selig[2], Florian Sigger[1], Roland Gillen[3], Jonas Kiemle[1], Andreas Knorr[2], Ursula Wurstbauer[4], and Alexander Holleitner[1] — [1]TU Munich — [2]Technische Universität Berlin — [3]Friedrich-Alexander-Universität Erlangen-Nürnberg — [4]University of Münster

Transition metal dichalcogenide monolayers exhibit strong light-matter interactions, which promotes them as ideal candidates for novel 2D optoelectronic applications. The vertically stacked Van der Waals heterostacks facilitate the emergence of a type-II band alignment, which leads to the formation of long-lived interlayer excitons. We present g-factors for three distinct interlayer exciton emissions in $MoSe_2$-WSe_2 heterostacks measured up to 9 T. Theoretical considerations including density functional theory lead to the assignment of the characteristic emission lines to optical transitions inside an atomically reconstructed H-type heterostack with a near-zero twist-angle. Here, the H_h^h atomic registry is able to fill sizable commensurate domains within the reconstructed lattice while the corresponding selection rules are found to govern the optical response of the system.

Following the attribution of the interlayer exciton emissions, we provide a deeper insight into the effect of atomic reconstruction in $MoSe_2$-WSe_2 heterostacks and discuss the possibility for a macroscopic occupation of the ground-state leading to unique many-body effects of interlayer excitons in such systems.

HL 25.15 Wed 18:00 P2

Fabrication and Characterization of Twisted TMDC Bilayer — •Laura Nicolette Schusser, Sina Bahmanyar, Nihit Saigal, Hendrik Lambers, Hossein Ostovar, and Ursula Wurstbauer — Institute of Physics, University of Münster, Münster, Germany

Semiconducting 2D materials such as transition metal dichalcogenides (SC-TMDCs) excel due to their strong exciton dominated light matter interaction [1]. Van der Waals (VdW) heterobilayers prepared from SC-TMDCs are ideal systems for the realization and study of dense exciton ensmebles [2,3] and correlated phases phases of matter [4]. We are working to improve the fabrication protocol for high-quality twisted TMDC bilayers. We obtain monolayers by micro-mechanical exfoliation along with a deterministic pick-up and dry transfer using a viscoelastic stamp and to create vdW heterostacks with several layers. The twist angle between the layers is precisely controlled by a using a rotation stage. We use hexagonal boron nitride (hBN) as an encapsulating material. Photoluminescence (PL) spectroscopy combined with Raman spectroscopy is utilized for characterization. While the former technique probes the intralayer and interlayer exciton transitions, the latter one is used for the investigation of the phonon fingerprints of the system. [1] [1] U. Wurstbauer et al. J. Phys. D: Appl. Phys. 50, 173001 (2017). [2] L. Sigl et al. Physical Review Research 2, 042044(R) (2020). [3] J. Kiemle et al. Phys. Rev. B 101, 121404(R) (2020). [4] Y. Tang et al., Nature 579, 353 (2020).

HL 25.16 Wed 18:00 P2

Optical characterization of van der Waals WS2 Monolayer-Pyrenemethylammonium chloride few-layer vertical heterointerfaces — •Mohammed Adel Aly[1,2], Hilary Masenda[1,3], Arslan Usman[1,4], Bettina Wagner[5], Johanna Heine[5], Marina Gerhard[1], and Martin Koch[1] — [1]Department of Physics and Materials Sciences Center, Philipps-Universität, Marburg, 35032 Germany — [2]Department of Physics, Faculty of Science, Ain Shams University, Cairo, 11566 Egypt — [3]School of Physics, University of the Witwatersrand, Johannesburg, 2050 South Africa — [4]Department of Physics, COMSATS University Islamabad - Lahore Campus, Lahore, 54000 Pakistan — [5]Department of Chemistry and Material Sciences Center, Philipps-Universität Marburg, 35043 Marburg, Germany

Van-der-Waals transition metal dichalcogenides(vdW-TMDCs) layered materials have received huge attention due to their strong light-matter interaction. Moreover, combining 2D TMDCs with different organic materials opened a new line in heterostructure(Hs) research, providing unprecedented tunability for heterostructure(Hs) engineering. Few layers Pyrenemethylammonium chloride (PyMACL) is an emerging exfoliable organic material that offers distinct properties and could be attractive for photonic and optoelectronic applications. Here, we present our work on WS2/PyMACL vdW-HS. We have investigated our specimen using micro-photoluminescence and time-resolved photoluminescence shedding light on exciton dynamics in such structures, and possible recombination channels. Moreover, investigating possible charge transfer between the different layers of the Hs.

HL 25.17 Wed 18:00 P2

Modification of charge transport in single layer MoS2 — •Zahra Fekri[1], Phanish Chava[1], Gregor Hlawacek[1], Vivek Koladi[2], Tommaso Venanzi[3], Wajid Awan[1], Antony George[4], Andrey Turchanin[4], Kenji Watanabe[5], Takashi Taniguchi[5], Manfred Helm[1], and Artur Erbe[1] — [1]Helmholtz Zentrum Dresden Rossendorf, Dresden, Germany — [2]Imec, Leuven, Belgium —

[3]Sapienza University of Rome, Rome, Italy — [4]Friedrich Schiller University, Jena, Germany — [5]National Institute for Materials Science, Tsukuba, Japan

Ion beam irradiation is a technique that can be used to alter the electrical and optical properties of two-dimensional (2D) materials through defect creation. In this work, we used 5-7.5 keV helium and neon ions to modify charge transport in monolayer molybdenum disulfide (MoS_2). Electrical characterization was performed in-situ immediately after ion beam irradiation. Raman and photoluminescence spectroscopy were implemented to further characterize the effect of ion irradiation on MoS_2. Our experiments show that the electrical properties of MoS_2-based transistors strongly depend on the nature of the substrate and the specific ion and dose used. Although 10^{12}-10^{13} helium ions/cm^2 contribute to the increase in the current level, a similar dose of neon ions deteriorates the channel. To examine the role of the substrate, few-layer hexagonal boron nitride (h-BN) was used as an intermediate layer between MoS_2 and the Si/SiO_2 substrate. MoS_2 samples on h-BN show different electrical behaviour during ion irradiation as compared to the MoS_2 flakes which were directly placed on SiO_2.

HL 25.18 Wed 18:00 P2

Tunable THz-absorption and gain in transition metal dichalcogenides — •Josefine Neuhaus, Tineke Stroucken, and Stephan W. Koch — Philipps University, Marburg, Germany

Exhibiting linear optical spectra that are dominated by strongly bound excitonic features, transition metal dichalcogenides have attracted considerable interest in the past decade. In a properly pre-excited system, it is possible to study intra-excitonic transitions between optically bright s- and dark p-type excitons by their THz-absorption. In particular, as p-type states lie energetically below s-type states of equal main quantum number, not only absorptive but also gain features can be observed. Furthermore, the application of an external magnetic field perpendicular to the sample results in a shift of the various excitonic resonances. As the induced Zeeman shift depends on the angular momentum quantum number, the magnetic field induced shift differs for s- and p-type excitonic states, enabeling a tunability of the intra-excitonic transitions. Here, we study the tunability of the intra-excitonic absorption and gain spectra upon the interplay of an applied magnetic field, the dielectric environment and the material parameters by means of a combined approach based on DFT and a Semiconductor-Bloch equation approach.

HL 25.19 Wed 18:00 P2

Contact engineering of black phosphorus field-effect transistors — •Yagnika Vekariya[1], Phanish Chava[1], Zahra Fekri[1], Kenji Watanabe[3], Takashi Taniguchi[3], Sibylle Gemming[2], and Artur Erbe[1] — [1]Helmholtz Zentrum Dresden Rossendorf, 01328 Dresden, Germany — [2]Technische Universität Chemnitz, 09126 Chemnitz, Germany — [3]National Institute for Materials Science, Tsukuba 305-0044, Japan

Black phosphorus (BP) has recently emerged as new semiconducting two-dimensional (2D) material because of its unique properties such as tunable direct bandgap, high field-effect mobility, and good on/off ratio. In this work, we fabricated and characterized field-effect transistors (FETs) based on a few layers of black phosphorus, in order to evaluate the performance of devices using different contact materials like Graphene, Nickel (Ni), Titanium (Ti), and Chromium (Cr). We observed that the polarity and mobility value of transistors strongly depend on the contact material.

HL 25.20 Wed 18:00 P2

Single photon emitters study in hBN via low power implantation approach — •Renu Rani[1], Minh Bui[1,2], Bilal Malik[1,2], Manuel Auge[3], Thorsten Brazda[1], Hans Hofsäss[3], Detlev Grützmacher[1,2], and Beata Kardynał[1,2] — [1]Peter Grünberg Institut-9, Forschungszentrum Jülich, Jülich — [2]Department of Physics, RWTH Aachen, Aachen — [3]II. Physikalisches Institut, Georg-August-Universität Göttingen

A discovery of quantum emitters in hexagonal boron nitride (hBN) has recently incited immense interest in the field of quantum technologies. It offers not only a platform for fundamental science but is of interest for applications in quantum photonics owing to its robust single photon emission at room temperature. Recent studies have suggested that these SPEs are associated with intrinsic defects, which led to efforts to engineer the SPE in hBN by various such as plasma treatment, annealing, laser, e-beam and ion irradiation methods. Despite these efforts, the origin of single photon emission and the correlation of emission with particular defects still need to be scrutinized. Here we propose to use low-energy ion implantation to introduce the different defects in hBN. We will show results of optical characterization of hBN implanted with various noble gas ions with different energies, which depending on their atomic mass generate different vacancies and at different depths. We will discuss the viability of creating localized emitters throughout the surface, not only edges or grain boundaries. We will use Raman spectra to show that implanted material is free of contamination and damage associated with energetic particle beams.

HL 25.21 Wed 18:00 P2

Twist angle dependent proximity induced spin-orbit coupling in graphene/WSe_2/hBN heterostructures — •Tobias Rockinger[1], Antony George[2], Andrey Turchanin[2], Ziyang Gan[2], Kenji Watanabe[3], Takashi Taniguchi[3], Dieter Weiss[1], and Jonathan Eroms[1] — [1]University of Regensburg, DE-93040 Regensburg, Germany — [2]Friedrich-Schiller-Universität, DE-07743 Jena , Germany — [3]NIMS, Tsukuba 305-0044, Japan

Recently, theoretical calculations predicted a strong dependence of the proximity-induced SOC on the twist angle between SLG and TMDCs [1]. To prove this, we fabricated SLG/WSe_2/hBN heterostructures with well-defined twist angles between the SLG and WSe_2 layers in two ways. For the first type, we exfoliated SLG and WSe_2 which often break along zigzag or armchair edges [2]. This was used to align and estimate the rotation angles between the flakes (zigzag/armchair edges not distinguishable). For the other type of samples, we used CVD-grown WSe_2 on anisotropically etched SLG to align and determine the twist angles exactly (zigzag/armchair edges distinguishable) [3]. Strong SOC causes weak anti-localization, which we used to determine the strength of the Rasbha type SOC (λ_R) and the valley-Zeeman type SOC (λ_{VZ}). We found that samples with an angle around 15° or 22° show a much stronger SOC in both cases, for λ_R as well as for λ_{VZ}, compared to samples, with twist angles around 0°/30° or 11°. This is in qualitative agreement with theoretical predictions [1]. [1]Y. Li and M. Koshino, Phys. Rev. B **99**, (2019) 075438; [2]Y. Guo *et al.*, ACS Nano **10**, (2016) 8980; [3]P. Incze *et al.*, Nano Res **3**, (2010) 110

HL 25.22 Wed 18:00 P2

Nucleation of hBN on HOPG in conventional MBE — •Constantin Hilbrunner, Juli Zhang, Joerg Malindretos, and Angela Rizzi — IV. Physikalisches Institut - Georg-August-Univiersität Göttingen

Due to its large bandgap of around 5.9 eV and due to its high breakdown voltage as well as its natural inertness, hexagonal boron nitride (hBN) is a promising substrate and encapsulation material to study the intrinsic properties of two-dimensional materials. Due to thermodynamics, the growth of hBN requires very high substrate temperatures. At present, the hBN films grown by molecular beam epitaxy (MBE) on non-metallic substrates with highest structural quality were fabricated using substrate temperatures between 1300°C and 1600°C not achievable using conventional systems.

In a different approach, we intend to utilize laser assisted heating during MBE. Here, we report on our preliminary results concerning the nucleation of hBN on HOPG at conventional substrate temperatures for varying B fluxes and the heating characteristic of the substrate surface in response to ns laser pulses.

HL 25.23 Wed 18:00 P2

Ultra-sensitive extinction measurements of optically active defects in monolayer MoS_2 — •Ines Amersdorffer[1], Florian Sigger[2], Alexander Hötger[2], Manuel Nutz[1], Alexander Högele[1], David Hunger[3], Thomas Hümmer[1], and Christoph Kastl[2] — [1]Faculty of physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Walter Schottky Institute and Physics Department, Technical University of Munich, Germany — [3]Physikalisches Institut, Karlsruhe Institute of Technology, Germany

Measurements of the marginal absorption of nanomaterials are challenging. One way to address this issue is the use of an optical resonator in which the light passes the sample multiple times and thereby enhances the absorption of nanoscale objects to a measurable amount. Here, we demonstrate how a high-finesse microcavity can be exploited in order to measure the extinction by defects in monolayer MoS_2. Such atomistic defects embedded in nanomaterials are a promising candidate for single-photon sources. However, to make them optically accessible, it is beneficial to know their absorption properties. To this end, we performed wavelength-dependent extinction measurements. The abso-

lute values of extinction were recorded with a detection limit of down to 0.01% and agree in the order of magnitude with theoretical predictions. In case of neglectable scattering, the extinction values can be interpreted as absorption. The results show advances towards routine hyperspectral absorption measurements on the nanoscale.

HL 25.24 Wed 18:00 P2

Electrical tuning of excitonic complexes in twisted van-der-Waals heterostructures — •Barbara Rosa, Chirag Palekar, and Stephan Reitzenstein — Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany

Moiré excitons arising from transition metal dichalcogenides (TMDs) bilayers are directly controlled by the twist angle between the monolayers[1]. Noteworthy features of that new class of excitons, such as their ultrafast formation and charger transfer, long population recombination lifetimes, and binding energy of ∼150 meV[2,3], turn TMD heterostructures into an attractive device for the study and manipulation of optical and transport properties via electrical fields. Here, we explore the ability to modulate interlayer exciton states in homo- and heterobilayers (HB) throughout electrical tuning. By fabricating TMD heterostructures using CVD and exfoliated monolayers, we study the effects of an out-of-plane applied electrical field in heterostructures with distinct twist angles. Our work aims to achieve control of optical and transport properties of interlayer excitons, which have shown energy tunability that ranges over several hundreds of meV[2,3]. Furthermore, we intend to discuss our first results in exploring light-matter interaction of an HB embedded in a photonic microcavity by electrically manipulating the Moiré excitonic response.

[1] K. L. Seyler et al., Nature 567, 66-70 (2019)
[2] A. Ciarrocchi et al. Nature Photon. 13, 131 (2019)
[3] H. Baek et al. Science Advances 6, 37 (2020)

HL 25.25 Wed 18:00 P2

Optical excitations in 2D material heterostructures under pressure — •Devika Sivankutty, Paul Steeger, Johann Preuss, Robert Schmidt, Steffen Michaelis de Vasconcellos, and Rudolf Bratschitsch — University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm Str. 10, 48149 Münster

Heterostructures of transition metal dichalcogenides (TMDCs) have attracted a lot of attention due to their unique optical and electronic properties and easy fabrication by stacking distinct TMDC monolayers on top of each other. Depending on the material choice, the heterostructures can also exhibit interlayer excitons, where the hole resides in one layer and the electron in the other. The coupling between the layers, and thereby the optical and electronic properties of the heterostructure, are expected to be strongly dependent on the interlayer distance, which can be tuned by applying pressure to the heterostructure. Here, we investigate the optical properties of TMDC heterostructures under high pressure in a diamond anvil cell. We use a home-built stamping setup to fabricate the heterostructures and perform optical spectroscopy at various pressure values to investigate the excitonic resonances.

HL 25.26 Wed 18:00 P2

Optical properties of multilayer MoS_2 under high pressure — •Paul Steeger[1], Robert Schmidt[1], Ilya Kupenko[2], Carmen Sanchez-Valle[2], Steffen Michaelis de Vasconcellos[1], and Rudolf Bratschitsch[1] — [1]University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]University of Münster, Institute for Mineralogy, Corrensstr. 24, 48149 Münster, Germany

Vertically stacked homo- and heterostructures of 2D semiconductors have recently attracted a lot of attention. One of the most critical parameters affecting their optical and electronic properties is the interlayer coupling. Controlling the distance between the layers by applying pressure to the sample allows to tune the interlayer interaction in-situ and opens up new ways to investigate its influence on the physical properties of multi-layered 2D materials. Here, we use a diamond anvil cell to measure how absorption and emission properties of multilayer MoS_2 crystals change under pressure, highlighting the differences between inter- and intralayer excitons.

HL 25.27 Wed 18:00 P2

Deterministic creation of strain gradients in 2D materials — •Robert Schmidt, Johannes Kern, Jannis Bensmann, Paul Steeger, Robert Schneider, Helge Gehring, Wolfram H. P. Pernice, Steffen Michaelis de Vasconcellos, and Rudolf Bratschitsch — University of Münster, Institute of Physics and Center for Nanotechnology, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Strain is a powerful tool to modify the optical and electrical properties of 2D materials. While the controlled application of homogeneous strain to 2D materials is feasible, the creation of deterministic strain gradients over distances of several micrometers is still challenging. Commonly, monolayers or few-layers are manually transferred onto a pre-patterned substrate, which often results in strain gradients differing from sample to sample.

In this work, we imprint structures into 2D materials. Using a home-built nanoimprint setup and SiO_2 stamps produced by reactive ion etching, we print into 2D materials with lateral precision below one micrometer. The strain fields induced by this deformation are analyzed using optical absorption mapping.

HL 25.28 Wed 18:00 P2

"Ghupft und Gschobm": An ab initio multi-scale approach to bands and electron-phonon coupling in twisted WSe_2 bilayers — •Michael Winter and Tim Wehling — I. Institute of Theoretical Physics, Universität Hamburg

Transition metal dichalcogenide bilayers host electron correlation effects like superconductivity, exciton condensation, and Mott insulation. These phenomena are tuneable via charge doping, optical excitation, dielectric environment, and twist angle. The complex interplay of Coulomb and electron-phonon interactions with multi-orbital and multi-valley physics behind the aforementioned correlation effects remains to be understood.

We study the twisted homo-bilayer of tungsten diselenide by construction of many-body quantum lattice models describing the electronic and phonon degrees of freedom as well as their coupling. From ab initio DFT and DFPT calculations with subsequent Wannier constructions on untwisted snapshots of commensurate structures corresponding lattice models are compiled. With an automated interpolation we are able to address twisted systems.

HL 25.29 Wed 18:00 P2

Ultrafast dynamics of dark states in photocurrent of TMD heterostructures — •Denis Yagodkin, Elias Ankerhold, Abhijeet Kumar, Johanna Richter, Firas Ben Moussa, Cornelius Gahl, and Kirill Bolotin — Freie Universitat Berlin

We study the photocurrent response of TMD heterostructures $MoS_2/MoSe_2$ with 150 femtosecond time resolution. In order to study the dynamics of transport at the interface of the heterostructure, we tune one pulse to MoS_2 excitation resonance and the second, time-delayed pulse, to that of $MoSe_2$. We find stark asymmetry between negative and positive delays. We attribute this asymmetry to the formation of interlayer excitons. Using a simple model of charge carriers decaying in optically dark states we successfully describe both time-resolved reflectivity and photocurrent response of heterostructures. Extracted formation time of interlayer excitons is similar to that observed in ARPES and TR-THz at room temperature. Strong response to interlayer excitons shows the potential of our technique in detecting other dark states promising for information storing and processing.

HL 25.30 Wed 18:00 P2

Charge carrier localization in nanobubbles of atomically thin TMD semiconductors — Christian Carmesin[1], Michael Lorke[1,2], Matthias Florian[1], •Daniel Erben[1], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen — [2]Bremen Center for Computational Materials Science, University of Bremen

Atomically thin transition metal dichalcogenides on nanostructured substrate like nanopillar arrays have gained attention as they show single photon emission. In contrast to a prestructured substrates, we investigate TMD nanobubbles that form naturally during stacking processes. Upon optical excitation these bubbles also exhibit quantum light emission, which indicates strong charge carrier confinement.
Starting from atomistic modelling of the strain field and electronic confinement potential of the nanobubble structure, we calculate the excitation spectrum for different bubble geometries. The microscopic origin of this carrier confinement lies in the bending rigidity of these materials leading to wrinkling of the surface. The resulting strain field facilitates nanoscale carrier localization due to its pronounced influence

on the band gap. This localization mechanism is supported by local changes of the dielectric environment. As a result, strongly localized states are formed that lead to emission sites around the periphery of the nanobubble. A specific localization signature allows for experimental identification of this mechanism, which has also been demonstrated in spatially resolved photoluminescence experiments.

HL 25.31 Wed 18:00 P2

Tunable 2D phononic crystals — •Yuefeng Yu, Jan Kirchhof, Bianca Hofer, Oguzhan Yucel, and Kirill Bolotin — Department of Physics, Freie Universität Berlin, 14195 Berlin, Germany

In the field of phononics, periodic patterning controls vibration and thereby flow of heat and sounds based on its phononic band structure. This kind of structures name as phononic crystals (PnCs). Bandgaps of PnCs arise their potentials in low-dissipation mechanical states towards efficient waveguide and stable mechanical qubit. By combining highly flexible suspended two-dimension (2D) materials and PnCs into 2D-capacitor framework, applying pressure through voltage and thereby changing the unit size of periodic pattern to tune the phononic bandgap is accomplishable. For now, we are playing the PnCs in graphene and 2D MoS2 with hexagonal lattice and microscale cavity. From cavity interferometric measurement, the periodic pattern can effectively block a frequency-range of vibration modes and establish the 1.5MHz-wide phononic bandgap of 2D-MoS2 PnCs. By varying the incident-laser power and gating voltage, position of bandgap moves in MHz-frequency-range. With the supporting of simulation, graphene shows a much higher tunability of the width and position in frequency of phononic bandgap than MoS2. All of these suggests a potential playground for quantum information and phase transition in mechanical.

HL 25.32 Wed 18:00 P2

Effect of gallium content on the grain boundary properties of polycrystalline Cu(In,Ga)Se2 absorber layers in thin-film solar cells — •Sinju Thomas[1], Wolfram Witte[2], Dimitrios Hariskos[2], Stefan Paetel[2], Chang-Yun Song[3], Heiko Kempa[3], Nora El-Ganainy[4], and Daniel Abou-Ras[1] — [1]Helmholtz Zentrum Berlin für Materialien und Energie (HZB) — [2]Helmholtz Zentrum Berlin für Materialien und Energie GmbH, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [3]Martin-Luther-Universität Halle-Wittenberg, Institut für Physik, Fachgruppe Photovoltaik — [4]Competence Centre Photovoltaics Berlin (PVcomB)/(HZB)

In the present work, we apply several scanning electron microscopy techniques in a correlative manner on five solar cells with different ([Ga]/([Ga]+[In]) GGIs (0.13, 0.34, 0.51, 0.67, and 0.83) in the Cu(In,Ga)Se2 photoabsorbers, in addition to time-resolved photoluminescence and quantum-efficiency measurements. Grain sizes, electron lifetimes, grain-boundary (GB) recombination velocities, elemental distributions within the absorber layer, as well as luminescence emission distributions were assessed for all five samples. Owing to much reduced grain size at a GGI of 0.83,there is a high density of GBs that serve as active recombination centers. At this GGI, Voc losses via non-radiative recombination deteriorates the device efficiency However, the effective GB recombination velocity does not vary linearly with the increasing GGI. Distribution of the recombination velocities at individual GBs suggests that upward and downward band bending at GBs is independent of the Ga concentration

HL 25.33 Wed 18:00 P2

Phonon Transport in Thin Homoepitaxial β-Ga_2O_3 Films — •Robin Ahrling[1], Olivio Chiatti[1], Rüdiger Mitdank[1], Zbigniew Galazka[2], Andreas Popp[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Leibniz Institute for Crystal Growth, 12489 Berlin, Germany

As a wide-band gap semiconductor with a high breakthrough field, gallium oxide (Ga_2O_3) has shown to be a promising material for applications in high power electronics. However, due to the materials low thermal conductivity [1,2] heat dissipation is a challenge for future device applications. By photolithography, magnetron sputtering and subsequent liftoff we prepare structures for investigating the thermal transport in the bulk Ga_2O_3 substrate and the thin homoepitaxial β-Ga_2O_3 films by applying the 2-ω and 3-ω measurement techniques.

For the substrate, we observe a dominance of phonon-phonon Umklapp scattering for high temperatures (>90 K) and a combination of point defect scattering and boundary effects for low temperatures. The phonon mean free path reaches a limit for low temperatures that can be explained with the crystal thickness. We aim to investigate the thermal transport exclusively in the thin films by producing sub-μm heater widths using electron beam lithography and performing measurements at higher frequencies.

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

HL 25.34 Wed 18:00 P2

Towards Heat Transport in Exfoliated β-Ga_2O_3 Flakes — •Sakhir Shibli[1], Robin Ahrling[1], Olivio Chiatti[1], Rüdiger Mitdank[1], Zbigniew Galazka[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Leibniz Institute for Crystal Growth, 12489 Berlin, Germany.

Heat transport is known as a diffusive process that is characterized as a slow process compared to other physical processes. Nevertheless, heat transport can also occur ballistically in the speed of sound within a material over distances comparable to the phonon's mean free path, known as Casimir limit [1]. Therefore, thin-layer materials are of interest for detecting ballistic heat transport [2]. As a model system with large potential of application, e.g. in power electronics, we are investigating exfoliated thin-layer flakes of β-Ga_2O_3 single crystal [3][4]. As a wide-band gap semiconductor with a high-breakthrough field, β-Ga_2O_3 has shown to be a promising material for applications in high power electronics [5]. In this work, we fabricate and pattern micro-heater lines in order to employ the 3ω- and 2ω- methods [3].

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[3] M. Handwerg, *Sci. Technol.* **30** (2015) 024006.
[4] Galazka, Zbigniew *et al.* **45** (2010): 1229-1236.
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HL 25.35 Wed 18:00 P2

Investigation of pinhole defects in ALD TiO_{2-x} corrosion protection layers on III-V semiconductor photocathodes — •Nicola Taffertshofer, Tim Rieth, and Ian Sharp — Walter Schottky Institute and Physics Department, Technical University of Munich, Am Coulombwall 4, 85748 Garching, Germany

The application of semiconducting photoabsorbers for photoelectrochemistry (PEC) provides a relevant path to solar fuel generation. However, a major challenge is the chemical instability of many potentially suitable semiconductors in PEC applications. Titania (TiO_{2-x}) protection layers with defined properties can be conformally deposited by atomic layer deposition (ALD) and have been shown to improve chemical stability of photoelectrodes in PEC cells. Despite these benefits, TiO_{2-x} ALD protection layers exhibit structural imperfections, including pinholes, that limit the long-term stability of underlying semiconductor photoelectrodes under PEC conditions. In our work, we quantify the pin-hole density in TiO_{2-x} ALD protection layers, synthesized under different growth conditions, by combining controlled etching experiments with inductively coupled plasma mass spectrometry (ICP-MS). Using the high sensitivity of ICP-MS, the unprotected substrate area associated with existing and emerging pinholes can be deduced by an increase of the substrate elements concentrations dissolved in liquid. Overall, this method provides crucial information for the development of pinhole mitigation strategies in the TiO_{2-x} ALD growth process and, hence, is an important step towards an increased lifetime of photoelectrodes.

HL 25.36 Wed 18:00 P2

Investigation of Electrically-Active Dopants in Sulfur-Hyperdoped Silicon Using Resistance Measurements — •Skrollan Detzler, Christoph Flathmann, and Michael Seibt — 4th Institute of Physics - Solids and Nanostructures, University of Goettingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Due to its abundance and particularly adjustable electric properties, silicon has become the dominating material in solar cell fabrication as of today. One approach to further increase the efficiency of silicon solar cells is to introduce an intermediate band into the band gap, allowing for broader absorption of the sunlight spectrum. This could be realized by doping the material with deep-level impurities far beyond its equilibrium solubility limit. In this study, we analyze sulfur-hyperdoped silicon, produced by femtosecond pulsed laser annealing, resulting in inhomogeneous regions reaching from the surface into the bulk material. To gain information on electrically-active dopants across different regions, resistance measurements using micromanipulators and scanning electron microscopy imaging were performed.

HL 25.37 Wed 18:00 P2

Automation of band structure simulations to determine Si-dopant efficiency in AlGaAs — •Maximilian Kristo, Nico Brosda, Andreas D. Wieck, and Arne Ludwig — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44801 Bochum, Germany

The potential landscape for electrons in semiconductor heterostructures is represented by its band structure.Their simulations can significantly help in the design of devices with new functionality. In order to systematically evaluate the doping efficiency in heterostructure samples, we automatized band structure calculations in a feedback loop with experimentally determined Hall parameters. These were determined by Van der Pauw measurements at 4.2 K.

The effective dopant concentration in the simulations was adapted to fit the experimental results and thus allowed to determine the effective dopant efficiency of Si doped AlGaAs HEMT structures to be compared with the dopant efficiency in Si doped GaAs samples. A majority of the dopant atoms are present in AlGaAs (with an aluminium concentration above 20 %) as deep impurities (Donor CompleX (DX) centers), which do not contribute to the electrical conductivity at 4.2 K if cooled in dark without bias. Therefore, these DX centers in Si doped AlGaAs lower the doping efficiency compared to Si doped GaAs. For AlGaAs with an aluminium concentration of 34 %, an average dopant efficiency of 14 ± 3 % and a negative correlation of -0.83 with the thickness of the doped layer could be found this way.

HL 25.38 Wed 18:00 P2

Electrochemical epitaxial (200) PbSe submicron plates on single layer graphene for ultrafast infrared response — •Chan Yang, Shuanglong Feng, Yinye Yu, Jun Shen, Xingzhan Wei, and Haofei Shi — Chongqing Institute of Green and Intelligent Technology, Chinese Academy of Sciences

Highly efficient near and medium-wave infrared detection at room temperature is considered one of the most intensive studies due to their robust detection in foggy weather or other low visibility conditions. 2D atomic layer graphene has an unconventional broad optical spectrum and high carrier mobility properties for the next generation electronics and optoelectronics device. The single-layer graphene has a lower quantum efficiency, and the PbSe has a direct narrow bandgap with a highly sensitive infrared response. Here, we examine the growth mechanism of high quality-oriented (200) PbSe crystals on a single atomic layer graphene using the electrochemical atomic layer epitaxy growth method in an aqueous electrolyte. The crystalline phase and density of nucleating seeds controlled by changing electrodeposition parameters are crucial for determining the submicron-crystal geometry. It is revealed that the controllable growth orientation and nucleation of PbSe crystals are realized by combining underpotential deposition of Pb and overpotential deposition of Se. The PbSe crystals/graphene hybrid photodetector indicates the benefit of infrared absorption. The extraordinary response speed of 1.8 ms, photo-responsivity in exceeding 36 AW^{-1}, and figure-of-merit detectivity $D^* > 2.7 \times 10^9$ Jones have been demonstrated in 2.7 μm at room temperature.

HL 25.39 Wed 18:00 P2

Reconstructions of the As-terminated GaAs(001) surface exposed to atomic hydrogen — Marsel Karmo[1], Isaac Azahel Ruiz Alvarado[2], Wolf Gero Schmidt[2], and •Erich Runge[1] — [1]Technische Universität Ilmenau — [2]Universität Paderborn

We explore the atomic structures and electronic properties of the As-terminated GaAs(001) surface in the presence of hydrogen based on ab-initio density functional theory. We calculate a phase diagram dependent on the chemical potentials of As and H, showing which surface reconstruction is the most stable for a given set of chemical potentials. The findings are supported by the calculation of energy landscapes of the surfaces, which indicate possible H bonding sites as well as the density of states, which show the effect of hydrogen adsorption on the states near the fundamental band gap [1]. Extension to the $GaAs_xP_{1-x}$(001) surfaces are presented.

[1] M. Karmo et al., ACS Omega 7, 5064-5068 (2022), https://doi.org/10.1021/acsomega.1c06019

HL 25.40 Wed 18:00 P2

Remote Heteroepitaxy of In(x)Ga(1-x)As on Graphene Covered GaAs(001) Substrates — •Tobias Henksmeier[1], Friedemann Schulz[2], Elias Kluth[2], Martin Feneberg[2], Rüdiger Goldhahn[2], and Dirk Reuter[1] — [1]Paderborn University, Warburger Str. 100, 33089 Paderborn, Germany — [2]Otto von Guericke University, Magdeburg, Universitätsplatz 2, 39106 Magdeburg, Germany

Recently, remote epitaxy on monolayer graphene covered substrates has attracted considerable attention as a way to improve lattice mismatched growth. It was reported that placing a monolayer graphene on a substrate offers a relaxation pathway different to the creation of crystal defects. Here, we present a study on solid source molecular beam epitaxy of In(x)Ga(1-x)As-layers ($0<x<0.5$) on chemical vapor deposition monolayer-graphene covered GaAs-(001) substrates. We show detailed investigations on the low temperature In(x)Ga(1-x)As nucleation and on the strain relaxation of 200 nm thick In(x)Ga(1-x)As-layers on graphene coved GaAs and for comparison on bare GaAs. The samples were analyzed by atomic force microscopy (AFM), scanning electron microscopy (SEM), Raman-spectroscopy and high-resolution X-ray diffraction measurements (HRXRD). We see the same crystal orientation and similar root-mean-square roughness for films grown on graphene and on bare GaAs substrates. Further, the layers grown on graphene show a more symmetric strain relaxation and a larger degree of strain relaxation compared to films grown on bare GaAs where the strain relaxation is larger along [110].

HL 25.41 Wed 18:00 P2

Nonlinear dynamics of Dirac fermions in topological HgTe structures — •Tatiana Aureliia Uaman Svetikova[1], Alexej Pashkin[1], Thales Oliveira[1], Florian Bayer[2], Christian Berger[2], Lena Fürst[2], Hartmut Buhmann[2], Laurens W. Molenkamp[2,3], Manfred Helm[1], Tobias Kiessling[2], Stephan Winnerl[1], Sergey Kovalev[1], and Georgy V. Astakhov[1] — [1]HZDR, Dresden, Germany — [2]Physikalisches Institut (EP3), Universität Würzburg, Würzburg, Germany — [3]Institute for Topological Insulators, Würzburg, Germany

High harmonic generation has applications in various fields, including ultrashort pulse measurements, material characterization and imaging microscopy. Strong THz nonlinearity and efficient third harmonic generation (THG) were demonstrated in graphene [1], therefore it is natural to assume the presence of the same effect in other Dirac materials, such as topological insulators (TI)[2].

We used a series of HgTe samples corresponding to three qualitatively different cases: 2D trivial and topological structures and 3D TIs. By using moderate THz fields, the presence of highly efficient THG was measured at different temperatures and THz powers. This provides insight into physical mechanisms leading to THG in TIs. For in-depth understanding of Dirac fermions dynamics and dominating scattering mechanisms in HgTe TI, we conducted THz pump-probe experiments that reveal several relaxation time scales.

[1] Hafez, H. A. et al., Nature 561, 507 (2018).
[2] Kovalev, S. et al., Quantum Mater. 6, 84 (2021

HL 25.42 Wed 18:00 P2

Graphitic Carbon Nitride/Semiconductor Quantum Dots 2D/0D Heterostructures — •Thuy Linh Nguyen Thi, Oleksandr Selyshchev, and Dietrich R.T. Zahn — Semiconductor Physics, TU Chemnitz, Chemnitz D-09107, Germany

The 2D semiconductor graphitic carbon nitride (g-C3N4) is of great interest due to its photocatalytic properties and potential application in optoelectronic devices. However, a relatively large bandgap of 2.7 eV [1] requires its additional sensibilization to extend the photosensitivity to entire visible range. Here, we investigate heterostructures of n-type g-C3N4 and p-type semiconductor quantum dots (QDs), e.g. AgInS2. The single-layered g-C3N4 flakes exfoliated from bulk material using tetraethylammonium hydroxide (TEA-OH) ligands [1] and AgInS2 QDs with a size of ˜3.5 nm [2] were used in aqueous solutions. X-ray Diffraction (XRD) indicates the intercalation of TEA-OH ligands between the flakes of g-C3N4. The thickness of the carbon nitride flakes of 0.3 +/- 0.1 nm, corresponding to a monolayer, and lateral sizes in the range of 35 - 55 nm are confirmed by Atomic Force Microscopy (AFM). Photoluminescence (PL) quenching of both g-C3N4 and QDs indicates an electronic interaction. A model photodetector device based on a thin film of a g-C3N4 and QD mixture, a TiO2 transport layer, indium-tin-oxide and gold electrodes was utilized for investigating the photoconductivity.

[1] O. Stroyuk et al., Phys. Status Solidi B, 2018, 256, 2, 1800279.
[2] A. Raevskaya et al., J. Phys. Chem. C, 2017, 121,16, 9032.

HL 25.43 Wed 18:00 P2

Contactless mapping of the sheet resistance of GaAs samples — •Timo A. Kurschat, Arne Ludwig, and Andreas D. Wieck

— Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

Measurements of the sheet resistance without the need to break the sample and integrate electrical contacts enable the evaluation of the homogeneity and quality of samples before further processing. Spatially resolved maps can be created without destroying or modifying the wafer.

The sheet resistance is measured by placing the sample on top of two circular electrodes. These couple capacitively with the conducting layer through the substrate. When applying a high frequency alternating voltage at one electrode, a signal can be measured at the other one. The sheet resistance is measured by sweeping the frequency from 1 MHz to 400 MHz and applying a fit. The setup works for sheet resistances between 300 Ω/□ and 50 kΩ/□.

The measured resistance and the coupling capacitances depend on the geometry of the sample and the electrodes. The changes at the edges of a sample are shown with line scans across a quarter 3" wafer and across a 5 mm wide sample. To show the effect of changes in the sheet resistance, the conducting layer was partly removed by etching. This shows artifacts especially if one electrode is completely below an isolating region. The spatial resolution depends strongly on the orientation of the electrodes.

HL 25.44 Wed 18:00 P2

GW benchmarks — •Maryam Azizi, Matteo Giantomassi, and Xavier Gonze — Université Catholique de Louvain, Louvain-la-Neuve, Belgium

GW is presently the best available first-principles methodology for the prediction of electronic structure, including band gaps. However, dealing with GW calculations is always challenging, not simply due to unfavorable scaling with system size, or possible lack of symmetry, but also due to the large number of parameters of such calculations. As a consequence, systematic GW benchmarks for large sets of materials are much more limited than for density-functional theory.

In the present work, we pave the way beyond the study of Van Setten and coworkers, who examined 70 materials, however aiming to a limited target accuracy. Indeed we consider a convergence criterion of 0.02 eV in the GW band gap, more stringent than the 0.05 eV target of this previous study. Moreover, the latter relied on a plasmon-pole model, while the present analysis also focus on contour-deformation and analytic continuation methodologies which are computationally more expensive and theoretically better justified. Like Van Setten et al, we use ABINIT, and stay at the non-self-consistent G_0W_0 level. Besides, the parallel speedup and efficiency of the implementation have been investigated.

HL 25.45 Wed 18:00 P2

Two-Photon Absorption Induced Photoluminescence in CuI Single Crystals — •Andreas Müller[1], Evgeny Krüger[1], Lukas Trefflich[1], Steffen Blaurock[2], Harald Krautscheid[2], Marius Grundmann[1], and Chris Sturm[1] — [1]Felix-Bloch-Institut für Festkörperphysik, Universität Leipzig — [2]Institut für Anorganische Chemie, Universität Leipzig

The intrinsically *p*-type copper iodide (CuI) with a direct band gap of 2.95 eV at 300 K [1] and high exciton binding energy is a promising material for transparent semiconductor devices. The photoluminescence (PL) emission properties of CuI crystals have been recently reported [2]. However, the PL emission induced by two-photon absorption (TPA-PL) has not been discussed in detail, so far.

We report on TPA-PL phenomena in CuI single crystals. A redshift compared to the conventional PL emission was observed. The TPA-PL spectrum can be nicely described by means of a simplified approach which takes into account the internal emission spectrum at the focal point, the propagation of the emitted photons inside the crystal and the absorption coefficient of CuI (determined by ellipsometry and taken from [2]). For the entire TPA-PL intensity we observed a non-linear power dependence, namely $I \propto P^{\gamma}$. The exponent γ depends on the excitation wavelength and ranges from 2 (expected for TPA-PL excitation via a virtual state) down to 1.5. The latter value was justified by a two-step TPA-PL process via a real state i.e. defect level.

[1] M. Grundmann *et al.*, Phys. Status Solidi A **210**, 1671 (2013)
[2] E. Krüger *et al.*, APL Mater. **9**, 121102 (2021)

HL 25.46 Wed 18:00 P2

Time-Resolved Nanoscale X-ray Analysis to Investigate Luminescence Dynamics of Co in ZnO-Material Systems — •Adrian Nowotnick[1], Christian Plass[1], Valentina Bonino[2], Maurizio Ritzer[1], Lukas Jäger[1], Jaime Segura-Ruiz[2], Gema Martinez-Criado[2], and Carsten Ronning[1] — [1]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743, Jena — [2]ESRF - The European Synchrotron, 71 Avenue des Martyrs, 38043 Grenoble, France

High resolution synchrotron based methods like X-ray fluorescence (XRF) and X-ray exited optical luminescence (XEOL) are well established characterization techniques. A highly focused X-ray nanobeam at the ID16B-NA station of the European Synchrotron Radiation Facility provides an excellent spatial resolution of about 50nm. This enables compositional mapping of nanometerials. Uniquely, the beam line was equipped with a streak camera allowing analysis of the spectral dynamics of optical luminescence. Consequently, one can investigate the influence of elemental compositions and local environments on the emission properties of e.g. color centers in semiconductor nanomaterials. These are able to provide high quality single photon emitters, which have drawn a lot of interest in recent years. Simultaneous XRF and XEOL measurements of Co in ZnO systems were conducted and by analyzing the emitted X-ray fluorescence radiation together with the corresponding optical luminescence correlating maps were obtained. Additionally, the dynamic of the luminescence could be determined depending on the Cobalt concentration and the system morphology.

HL 25.47 Wed 18:00 P2

Photoluminescence observation of Erbium implanted semiconductor nanostructures — •Nico Brosda, Cristian Düputell, Arne Ludwig, and Andreas Wieck — Lehrstuhl für angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44801 Bochum, Germany

The rare earth element Erbium is known for its spectral transitions around 1.5 μm. This wavelength region coincides with the absorption minimum of optical fibers. How to maximize the photoluminescence of Er doped semiconductor nanostructure is therefore a reasonable research topic.

The doping of GaAs semiconductor structures was achieved with focussed ion beam implantation. To recover the crystal structure and activate the Er atoms the samples are thermally annealed. Finding the optimal annealing parameters requires PL measurements in the near-infrared regime. A suitable PL setup was build around an InGaAs detector and a He-flow cryostat, allowing to measure the PL signal of Er. A 805 nm laser diode was used for the excitation. Optical parts in the setup were chosen with an antireflection coating for light around 1.5 μm.

The comparison between different annealing respectively implantation parameters allowed to identify values resulting in a brighter PL spectrum of the Er.

HL 25.48 Wed 18:00 P2

Semiclassical and quantum optical field dynamics in an optical cavity with a finite number of quantum emitters — •Kevin Jürgens[1], Frank Lengers[1], Daniel Groll[1], Doris E. Reiter[1,2], Daniel Wigger[3], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]Condensed Matter Theory, Technische Universität Dortmund, Germany — [3]School of Physics, Trinity College Dublin, Ireland

Ensembles of quantum emitters (QE) coupled to the quantized light field inside a photonic cavity are promising building blocks in quantum technologies. Due to the interaction of several QEs with a single light mode, the emitters can produce interesting collective behavior. We calculate the spectra and dynamics of such an ensemble with up to $N = 60$ emitters after excitation by a short external laser pulse within the Tavis-Cummings model and compare the findings with those obtained in the semiclassical limit ($N \to \infty$) [1]. When increasing the pulse amplitude we find a sharp transition in the semiclassical limit from exciton-polariton-like behavior to Rabi oscillations. The full quantum calculations reproduce such a transition behavior independent of N, but in particular for smaller N the transition between these regimes is broadened over a certain range of pulse amplitudes.

Wigner functions are calculated to investigate the properties of the light field and show the emergence of quantum features [1]. On longer time scales we see the formation of $N + 1$ quasi coherent states with Schrödinger-cat-like interferences between each pair.

[1] Jürgens et al., Phys. Rev. B 104, 205308 (2021)

HL 25.49 Wed 18:00 P2

Temperature dependence of phonons of CuI — •R. Hildebrandt[1], M. Seifert[2], S. Botti[2], C. Sturm[1], and M.

Grundmann[1] — [1]Universität Leipzig, Felix Bloch Institute for Solid State Physics, Germany — [2]Fridrich-Schiller-Universität Jena, Institute of Condensed Matter Theory and Optics, Germany

Cuprous iodide (CuI) is unique as intrinsic transparent p-type semiconductor with high figure of merit regarding various optical and electrical properties [1]. Properties and processes like thermal conductivity, electron-phonon coupling, phonon scattering, phonon-decay and elastic constants are influenced or mediated by different types of phonons. Their characteristics will be investigated here by Raman scattering.

We present temperature dependent Raman scattering spectra for CuI by using a 532nm incident laser source on solution grown single crystals. The allowed TO and LO modes are observed as well as the weaker second order Raman spectrum, which contains the full information of CuI's phonon dispersion [2]. It is used to determine the energy of the - usually forbidden - acustic and optic zone boundary phonons by modeling the two-phonon sum spectrum [3].

Up to about 170 K the temperature dependence of the acustic phonons could be tracked and compared with computational as well as other experimental results [3]. All results are in agreement and provide high accuracy information for the phonon dispersion of CuI.

[1] M. Grundmann *et al.*, Phys. Stat. Sol. (a), **210**, 1671, 2013.
[2] J. Birman, J., Phys. Rev., **131**, 1489, 1963.
[3] Z. Vardeny *et al.*, Phys. Rev. B, **18**, 44876, 1978.

HL 25.50 Wed 18:00 P2

Manipulating light-emission in direct band gap hexagonal Silicon Germanium nanowire arrays — •David Busse[1], Victor van Lange[2], Elham Fadaly[2], Wouter Peeters[2], Marco Vettori[2], Jos Haverkort[2], Erik Bakkers[2], Gregor Koblmüller[1], and Jonathan Finley[1] — [1]Walter Schottky Institut, Garching near Munich, Germany — [2]Eindhoven University of Technology, Eindhoven, Netherlands

We present results on the redistribution and enhancement of light within a 2D photonic crystal array formed by a hexagonal array of standing $Si_{1-x}-Ge_x$ nanowires (NWs). It was previously shown that these NWs are direct bandgap semiconductors when the crystal lattice has a hexagonal crystal structure. Fully 3D FDTD-simulations were performed to calculate the frequency of the photonic bands and their dependence on the lattice pitch and radius of the NW array. Essentially, the peak of the photoluminescence (PL) emission from the $Si_{1-x}-Ge_x$ NWs at 0.352eV, can be continuously tuned through the dielectric and air photonic band edges by changing lattice pitch and radius. For NW radius r=210nm, length l=6mu and variable distance between the NWs (pitch a = 0.8mu up to 1.95mu) we tune the photonic band edges through NW PL emission. Crucially, for situations close to resonance we observe an increase in the time-integrated PL intensity and transient carrier recombination dynamics measured using time-resolved pump-probe reflectance spectroscopy.

HL 25.51 Wed 18:00 P2

Influence of encapsulation material on organic magnetoconductance effect in organic light emitting diodes (OLED) — •Annika Morgenstern[1], Dominik Weber[2], Apoorva Sharma[1], Daniel Schondelmaier[2], Dietrich R.T. Zahn[1,3], and Georgeta Salvan[1,3] — [1]Semiconductor Physics, TU Chemnitz, 09107 Chemnitz, Germany — [2]Nanotechnology and Functionalized Surfaces, Westsächsische Hochschule Zwickau, 08056 Zwickau, Germany — [3]Center of Materials, Architectures and Integration of Nanomembranes, TU Chemnitz, 09126 Chemnitz, Germany

Organic semiconductors are the basic building block of organic light-emitting diodes (OLED). It was reported that certain OLEDs based on Alq3, P3HT, etc. when exposed to an external magnetic field show a change in the electrical resistance. This phenomenon is called the organic magnetoconductance (OMC) effect, which stems from the influence of the magnetic field on the charge carrier density and/or mobility. OLEDs are also known to degrade due to the infiltration of oxygen and moisture into the constituting layers. In this work, we present a systematic study of the influence of polymethyl methacrylate (PMMA) and soda-lime glass encapsulation layer on the OMC effect, using a homebuilt electrical test bench based on a magnetic field modulation technique to remove the time-dependent change in the current. Additionally, we compare the passivation efficacy of the investigated encapsulation material on the lifetime of OLEDs. The lifetime of the studied OLEDs were measured using a test setup equipped with a photodiode, allowing to record the OLED light output over time.

HL 25.52 Wed 18:00 P2

The Impact of Mechanical Stress on Structural, Morphological and Electrical Properties of Transferable Organic Semiconductor Nanosheets — •Veronika Reisner, Sirri Batuhan Kalkan, and Bert Nickel — Faculty of Physics and CeNS, Ludwig-Maximilians-Universität, Geschwister-Scholl-Platz 1, 80539 Munich, Germany

Recently, we presented a technique to transfer organic small-molecule nanosheets using a sacrificial water-soluble polymer layer. This approach enables the transfer of highly ordered organic films on substrates, which are unfavorable for direct growth by physical vapor deposition. However, the transferable nanosheets experience a considerable amount of mechanical stress during the release and transfer process. Here, we investigate the structural and morphological changes induced in the transferable nanosheets to optimize the transfer technique. For this purpose, we use pentacene films as stress sensors. Pentacene films show a distinct response to the mechanical stress by an irreversible phase change from the thin-film phase to the Campbell bulk phase. To reveal these structural and morphological changes, we employ X-ray diffraction analysis and atomic force microscopy technique. We find that thinner pentacene nanosheets show a lower Campbell bulk phase contribution after the transfer process. Finally, we use an optimized transfer technique to fabricate transistors based on the transferable organic small-molecule DNTT. DNTT nanosheets are more brittle compared to pentacene nanosheets but exhibit superior device performance.

HL 25.53 Wed 18:00 P2

Damping and detecting vibrational modes in organic semiconductors with tunable graphene cavities — •Lukas Renn and Thomas Weitz — I. Physical Institute, Georg-August-University, Friedrich-Hund-Platz 1, 37077, Göttingen

The true nature of charge transport in organic semiconductors (OSC) is still not fully understood. A novel picture to describe the charge transport is the so-called transient localization, where the charge transport is intrinsically limited by inter- and intramolecular vibrations, which are a direct consequence of the weak van der Waals interactions in OSCs. Recently it was discovered that the mobility in OSCs is mainly hampered by single low-frequency sliding modes, which in some molecules contribute more than 80% of the total thermal disorder. (1) The aim of this work is to first detect the lattice vibrations in OSCs and subsequently manipulate them using 2D cavities. To this end, we deposit monolayer thin, highly crystalline OSC films (PDI1MPCN2) from solution onto graphene flakes, which should result in quenching of a broad spectral range of IR-active vibrational modes in the OSC. First measurements show that we are able to detect the vibrational modes via Raman and a SNOM-based Nano-FTIR measurement setup. One step further, we want to tune the plasmon frequencies of the graphene cavities via lithography-patterning and thereby selectively couple to molecular vibrations in this frequency range and measure their relative impact on the charge carrier mobility. (1) Schweicher et al., Adv. Mat. 1902407 (2019)

HL 25.54 Wed 18:00 P2

Towards charge-carrier transport studies in organic semiconductors strongly coupled to the electromagnetic vacuum field — •Daniel Vitroler[1,2], James W. Borchert[1], and R. Thomas Weitz[1] — [1]Universität Göttingen, Göttingen, Deutschland — [2]LMU München, München, Deutschland

Strong coupling between the vacuum field and an excitonic transition in a semiconductor using plasmonic resonators or optical cavities leads to the formation of exciton polaritons [1]. Among the many prospective uses of strong coupling, recent studies have demonstrated that the formation of polaritons is an intriguing potential approach for improving charge transport in e.g. organic semiconductors [2]. However, there have so far been limited experimental demonstrations of strongly-coupled organic transistors [3], leaving many questions about the detailed physics of charge-carrier transport in these devices. In this work, we investigate light-matter coupling in thin films based on a perylene diimide derivate (PDI1MPCN2) which has previously shown electron mobilities as high as 4 cm^2/Vs in organic transistors [4]. Tuned Fabry-Pérot cavities were implemented to achieve strong coupling to an excitonic transition of PDI1MPCN2 dispersed in a polymer matrix.

[1] Garcia-Vidal, F. J. *et al. Science.* **373**, eabd0336 (2021).
[2] Hagenmüller, D. *et al. Phys. Rev. Lett.* **119**, 223601 (2017).
[3] Orgiu, E. *et al. Nature Mater.* **14**, 1123-1129 (2015).
[4] Vladimirov, I. *et al. Nano Lett.* **18**, 9-14 (2018).

HL 25.55 Wed 18:00 P2

Influence of the probe-to-semiconductor contact on the electrical characterization of nanowire structures — •Juliane Koch[1], Lisa Liborius[2], Peter Kleinschmidt[1], Nils Weimann[2], Werner Prost[2], and Thomas Hannappel[1] — [1]Fundamentals of energy materials, Ilmenau University of Technology, Germany — [2]Components for high frequency Electronics (BHE), University of Duisburg-Essen, Germany

For the purpose of well-defined III-V semiconductor junctions, various sophisticated tip-based methods such as multi-tip scanning tunnelling microscopy (MTSTM) can be employed to study the electrical behaviour with high spatial resolution. We investigated a variety of upright, freestanding GaAs-based axial as well as co-axial nanowires on the growth substrates covered with native oxide. Based on our studies with MTSTM, we demonstrate that in tip-based measurement methods, the probe-to-semiconductor contact is essential for interpreting the properties of the sample. Our investigation reveals charging currents at the interface between the measuring tip and the semiconductor via the native insulating oxide, which acts as a MIS-capacitor in the operating voltage range. All the samples investigated displayed a strong dependency of the overall electrical behaviour on the condition of the tip-to-semiconductor contact. We analyse in detail the observed I-V characteristics and propose a strategy to achieve an optimized measuring tip-to-semiconductor junction which minimizes the influence of the native oxide layer on the overall electrical measurements.

HL 25.56 Wed 18:00 P2

Efficient spectral separation of single and entangled photons — •Patricia Kallert, Lukas Hanschke, Eva Schöll, Björn Jonas, and Klaus D. Jöns — Institute for Photonic Quantum Systems, Center for Optoelectronics and Photonics Paderborn, and Department of Physics, Paderborn University, 33098 Paderborn, Germany

Experiments and protocols based on single-photons with different properties are crucial to develop photonic quantum technologies. Semiconductor quantum dots are a promising platform for the emission of single, indistinguishable, and entangled photons. The efficient routing and filtering of frequency-mismatched photons, for example, from the biexciton-exciton cascade, is crucial to facilitate the full potential of quantum dots. The separation of photons of different energies allows for efficient entanglement swapping and teleportation experiments, which rely on multiphoton coincidences. Spectral separation and simultaneous detection of adjacent wavelengths are complex to realise. Here we exploit a strategy to build a blaze grating-based transmission spectrometer with outstanding figures of merit. We shed light on the basic principle and the pitfalls that lead to a severe decrease of the efficiency or deterioration of the resolution and how to overcome them. Balancing the main properties, our overall efficiency exceeds 66 %, and our resolution is 21 GHz. Simultaneously, wavelengths distanced by 0.2 nm can be separated. Our self-built setup offers all functionalities to characterise single-photon sources and efficiently incorporate them in modern quantum optics experiments.

HL 25.57 Wed 18:00 P2

Telecom wavelength InP based quantum dots: Growth and characterization — •Ranbir Kaur, Mohanad Alkaales, Johann Peter Reithmaier, and Mohamed Benyoucef — Institute of Nanostructure Technologies and Analytics, University of Kassel, Kassel, Germany

InP-based semiconductor quantum dots (QDs) represent an attractive light source for quantum communication applications due to their ability to emit photons at the telecom C-band. Self-assembled low-density QDs can be realized by careful control of the growth conditions. Here, we investigate the effect of different growth parameters to optimize telecom wavelengths

InP-based QD structures using molecular beam epitaxy with controlled properties in photonic and pin-diode structures. The QDs structures with and without doping were grown on distributed Bragg reflectors to enhance the light emission. Using proper doping levels, high-quality QDs can be embedded in pin-diode structures. Low-temperature *-PL measurements show bright single QD emission around 1.55 *m with narrow linewidth and low fine-structure splitting. Furthermore, studies related to doped QD structures and fabrication of pin-diode structures emitting at telecom wavelength are presented.

HL 25.58 Wed 18:00 P2

Energy dependent tunnel coupling of QDs to a reservoir at elevated temperatures — •Ismail Bölükbasi[1], Ibrahim Engin[1], Patrick Lindner[2], Arn Baudzus[1], Andreas D. Wieck[1], Björn Sothmann[3], and Arne Ludwig[1] — [1]Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]TU Dortmund, D-44221, Dortmund, Germany — [3]Theoretische Physik, Universität Duisburg-Essen and CENIDE, D-47048 Duisburg, Germany

Quantum dots have interesting physical properties and allow research in zero dimensional systems. They are used in modern displays and are highly efficient sources of high-fidelity single photons [1]. For their applicability, it is advantageous to understand the electrical properties and tunnelling behaviours of QDs coupled to a charge reservoir. Capacitance-voltage spectroscopy is used to characterize quantum dots by electronically accessing the quantized states. A resonance shift with temperature in the ground-state charging peaks, the s-type states [2] originates from the degeneracy of the one- and two electron quantum states. An approach to model these measurements with a master equation [3] can describe these shifts including excitonic and non-equilibrium states. It is however limited to constant tunnel-coupling. We present experimental observations like frequency dependent peak shifts that need an extended model and propose an improved master equation approach to address this behaviour.

[1] Tomm et al. (2021) Nat. Nanotechnol. 16(4) [2] Brinks et al. (2016) New Journal of Physics, 18(12). [3] Valentin et al. (2018) Physical Review B, 97(4).

HL 25.59 Wed 18:00 P2

Auger Recombination Rate: Magnetic Field Dependence in a Self-Assembled Quantum Dot — •Fabio Rimek[1], Hendrik Mannel[1], Marcel Zöllner[1], Arne Ludwig[2], Andreas D. Wieck[2], 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

A quantum dot (QD) is an ideal system to study electron-electron interaction in a confined nanostructure [1]. The Auger recombination is a special case, where the recombination energy is transferred to a third charge carrier that leaves the dot [2] or is excited to a higher energy level. Therefore, the Auger effect destroys the radiative recombination of the charged exciton (trion) - an effect, which should be minimized for future applications of QDs that use spin states as stationary qubits, which can be transferred to photons via the trion transition.

In this work, we investigate how the Auger rate is affected by an external magnetic field, applied perpendicular to the plane of the dots. In the magnetic field, the trion transition of a QD is no longer spin degenerate and splits up. We use two-color, time-resolved resonance fluorescence to investigate the quenching of the trion recombination by the Auger effect. Two-color excitation allows us to excite two quantum dot transitions and neglect spin relaxation as well as spin-flip Raman scattering. This ensures that we can directly measure the Auger and the tunneling rate of an electron into the dot.

[1] A. Kurzmann et al., Nano Lett. 16, 3367-3372 (2016)
[2] P. Lochner et al., Nano Lett. 20, 1631-1636 (2020)

HL 25.60 Wed 18:00 P2

Effects of bias-cooling on charge noise in gated Si/SiGe quantum dots — •Julian Ferrero[1], Daniel Schroller[1], Thomas Koch[1], Viktor Adam[1], Ran Xue[2], Inga Seidler[2], Lars Schreiber[2], Hendrik Bluhm[2], and Wolfgang Wernsdorfer[1] — [1]Physikalisches Institut, KIT Karlsruhe — [2]II. Physikalisches Institut, RWTH Aachen

Electron spins in gated Si/SiGe quantum dots provide a great potential in scalable quantum-computing platforms due to their long coherence times and wide tunability. However, charge noise in the vicinity of the qubit region decreases the two-qubit gate fidelities that are needed for up-scaled error correction. Furthermore, the devices drift to different working points and need to be retuned regularly. The source of fast charge noise is thought to arise from twolevel fluctuators in the aluminium oxide dielectric, whereas the drift can be caused by slow charging of the silicon cap. A feasible possibility to suppress such noise and drift is the application of a bias voltage on all gates during cool down. This project strives to investigate the effects of different bias-coolings on charge noise using simultaneous current spectroscopy and peak tracking of two single electron transistors. Since the involved processes range on a wide time scale, the noise spectrum is investigated between 50 microhertz and 1 kilohertz.

HL 25.61 Wed 18:00 P2

Characterization of InGaAs quantum dots as active region

for edge emitting laser with emission in the telecom O-band — •Philipp Noack — Institut für Halbleiteroptik und funktionelle Grenzflächen, Universität Stuttgart, Deutschland

Generally, laser diodes with quantum dots as active region are superior to quantum well laser diodes in terms of threshold current and temperature stability. Additionally, stacking of quantum dot layers can provide a broad gain spectrum, which can be ideally used for the fabrication of tunable laser devices with large bandwidth.

To this end, indium gallium arsenide quantum dots with emission in the telecom O-band wavelength range around 1300nm are grown at high densities with MOVPE and characterized with photoluminescence and atomic force microscopy measurements. We have designed edge emitting structures with waveguide simulations and characterized them using the segmented contact method. Parameters for the growth, like the V/III material ratio, were adjusted to create high density InGaAs quantum dots in a single layer. The emission intensity was further enhanced by the incorporation of a dots in well structure, an arsine interruption during growth and vertical stacking of quantum dot layers.

Following the design of the laser device, characterizations of edge emitting structures with one and multiple QD layer with regards to absorption characteristics were performed, which allowed for the characterization of the intrinsic losses of differently structured devices.

HL 25.62 Wed 18:00 P2

Wavelength tuning mechanisms in GaAs based-photonic integrated circuits — •Ulrich Pfister[1], Florian Hornung[1], Stephanie Bauer[1], Eric Reutter[2], Michael Jetter[1], Simone L. Portalupi[1], Jürgen Weis[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQST) and SCoPE, Universität Stuttgart — [2]Max-Planck-Institut für Festkörperforschung (MPI)

InGaAs quantum dots (QDs) grown in GaAs-based photonic integrated circuits are promising candidates to fulfill the requirements for basic on-chip photonic quantum computing gates. The necessary optical elements like beam splitters, on-chip detectors and waveguide structures have already been realized. An important step towards more complex experiments is to control the emission wavelength of the QDs. Recently, we matched the emission wavelength of a QD with a cavity-waveguide mode by applying strain with piezo electric actuators, resulting in Purcell enhancement [1]. Additionally, we discuss other tuning mechanisms like the crystallization of HfO_2 which has been already demonstrated for self-standing GaAs waveguides [2].

[1] Hepp, Stefan et al. Appl. Phys. Lett. 117, 254002 (2020)
[2] Grim, Joel Q. et al. Nat. Mater. 18, 963-969 (2019)

HL 25.63 Wed 18:00 P2

High-resolution spectroscopy of single photons from a self-assembled quantum dot — •Lucas Stahl[1], Hendrik Mannel[1], Fabio Rimek[1], Marcel Zöllner[1], Andreas Wieck[2], Arne Ludwig[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Duisburg, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

Self-assembled quantum dots (QD) are highly promising as building blocks for applications in future quantum information technologies, where single confined spin states can form a qubit that can be transferred to a single photon. This requires long spin and photon coherence times [1], which have been demonstrated to be limited by spin- and charge-noise as well as co-tunneling with a reservoir [1]. These dephasing mechanisms affect the linewidth of the emitted photons.

In order to study various dephasing processes that occur on the exciton and trion transition in resonance fluorescence on a single dot, we set up a laser-stabilized high-finesse Fabry-Perot-interferometer. By using a single-photon detector in combination with a picosecond time-tagger and a newly-developed post-processing method for stabilization, we obtained an interferometer resolution of 8 MHz.

This high-resolution enables us to detect dephasing mechanisms in the linewidth of the dot and to understand the influence of the Auger-scattering [2] of the trion transition in resonance fluorescence.

[1] G. Gillard et al., Quant. Inf. **7**, 43 (2021). [2] A. Kurzmann et al., Nano Lett. **16**, 5, 3367-3372 (2016).

HL 25.64 Wed 18:00 P2

Growth and characterisation of local droplet etched InAs quantum dots in an InGaAs matrix — •Nikolai Spitzer, Arne Ludwig, and Andreas Wieck — Ruhr- Universitaet Bochum, Lehrstuhl fuer Angewandte Festkoerperphysik, Universitaetsstraße 150, 44801 Bochum, Germany

We present a new local droplet etching (LDE) method for selforganized InGaAs quantum dots (QDs). We use gallium droplets to etch on an InGaAs matrix layer and fill the nanoholes with InAs. The impact of the indium concentration in the InGaAs-layer and of the deposited InAs amount after etching is investigated by atomic force microscopy and photoluminescence spectroscopy.

HL 25.65 Wed 18:00 P2

Three-photon excitation of InGaN quantum dots — •Viviana Villafane[1], Bianca Scaparra[1], Manuel Rieger[1], Stephan Appel[1], Rahul Trivedi[2], Tongtong Zhu[3], John Jarman[3], Rachel Oliver[3], Robert Taylor[4], Jonathan Finley[1], and Kai Mueller[1] — [1]Walter Schottky Institut, TUM, Garching, Germany — [2]Max-Planck-Institute for Quantum Optics, Garching, Germany — [3]Department of Materials Science, University of Cambridge, UK — [4]Clarendon Laboratory, University of Oxford, UK

Solid-state quantum emitters are prominent examples of systems showing excellent agreement between theoretical predictions and experimental measurements, being commonly taken as evidence that the fundamental physics of quasi two-level quantum emitters is almost fully understood. In our work, we explore multi-photon absorption selection rules in semiconductor quantum dots within the dipole approximation. It can be proven that given a two-level quantum system, if the excitation scheme involves N-photons of the same energy and polarization, either all even or odd resonances are enhanced, based on the parity of the ground and excited states. We demonstrate that semiconductor quantum dots can be excited efficiently in a resonant three-photon process, whilst resonant two-photon excitation is highly suppressed. Time-dependent Floquet theory is used to quantify the strength of the multi-photon processes and model the experimental results. Our resonant three-photon excitation scheme alows us to measure directly the radiative lifetime of InGaN QDs and obtain a greater degree of linear polarization.

HL 25.66 Wed 18:00 P2

Lattice thermal expansion of as-grown GaAs nanowires due to optical excitation measured by X-ray pump probe experiment — •Taseer Anjum[1,2], Francisca Largo[2], Waheed Salehi[1], Matthias Rössle[3], Oliver Brandt[2], Lutz Geelhaar[2], and Ullrich Pietsch[1] — [1]Festkörperphysik, Universität Siegen, Siegen, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Berlin, Germany — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, Wilhelm-Conrad-Röntgen Campus, BESSY II, Berlin, Germany

We investigated the transient structural response in the ensemble of AlxIn1-xAs/GaAs core-shell NWs, grown on Si (111) substrate when irradiated with femtosecond laser pulses via x-ray pump-probe experiment at KMC3-XPP & P08 beamlines of Bessy II & PETRA III respectively. Femtosecond laser irradiation of solids excites photoelectrons from valance band to conduction and triggers a cascade of fundamental dynamical processes that occur on the picosecond to nanosecond time scales such as excitation and thermal equilibration of phonons. We observe a linear behavior of strain and temperature for the first few hundreds of picoseconds followed by the thermal relaxation up to few ns. Thinner NWs cool down slowly in comparison to thicker NWs which suggests a direct dependence of thermal conductivity on the diameter. Through time-resolved x-ray pump-probe experiments we identified the thermal relaxation processes and the dynamics of the structural response of two NW samples.

HL 25.67 Wed 18:00 P2

Investigation of the Correlation between Quantum Dot Density and Photoluminescence Intensity — •Simon Schlombs, Nikolai Spitzer, Nikolai Bart, Andreas Wieck, and Arne Ludwig — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

Semiconductor devices based on quantum dots (QDs) require good knowledge of the QD density. Capacitance voltage spectroscopy (C(V)) enables the measurement of buried QDs; however, it requires extensive prior processing of the samples and only allows small areas to be measured. In this work the correlation between QD density and photoluminescence (PL) intensity is investigated. For this purpose, the quantum dot density along a density gradient has been determined and

compared to PL measurements. The measured intensity is strongly dependent on the sample structure (absorption, thin-film interference). Because of this the intensity is corrected by an experimentally determined factor. The results allow for an optical determination of the QD density of entire wafers for an arbitrary sample structure.

HL 25.68 Wed 18:00 P2

Metallic nanowires assembled by DNA Origami — •Borja Rodríguez-Barea[1], Shima Jazavandi-Ghamsari[1], Archa Jain[1], Türkan Bayrak[1], Jingjing Ye[2], Ralf Seide[2], Enrique Samano[3], and Artur Erbe[1] — [1]Institute of Ion Beam Physics and Material Science, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Peter Debye Institute for Soft Matter Physics, Universität Leipzig, Germany — [3]Centro de Nanociencias y Nanotecnología-UNAM, Ensenada, B.C., México

In the pursuing to increase the processing power, electronic circuits look for new bottom-up strategies. Namely, (DNA) nanotechnology has shown valuable tools for the creation of nanostructures of arbitrary shape that can be used as templates. Here we demonstrate the formation of 1D Au nanostructures based on DNA Origami templates. DNA nanomolds are employed, inside which gold deposition is employed by site-specific attached seeds. To prove their metallic nature, top-down approach allows us to perform temperature-dependent charge transport measurements along the nanostructures. Transport through these assemblies is strongly nonlinear and shows a decrease in conductance towards low temperatures. Thanks to the converging of both fabrication approaches, the shape of the nanowires can be controlled and measured. We use DNA-origami templates which are functionalized on their surface in order to create desired shapes of the metallic nanostructures and the nanoparticles show temperature dependent charge transport measurements reveal the dominating charge transport mechanisms along these wires.

HL 25.69 Wed 18:00 P2

Multi-Orbital Kondo Effect in Few-Electron Quantum Dots — •Olfa Dani[1], Johannes Bayer[1], Timo Wagner[1], Gertrud Zwicknagl[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]nstitut für Mathematische Physik, Technis- che Universität Braunschweig, Germany

The Kondo effect is a many particle entangled system, that involves the interaction between a localized spin in the quantum dot and free electrons in the electron reservoirs. This entanglement can be calculated using simplifying assumptions concerning the electronic structure of the quantum dot.

We investigate a lateral quantum dot with a small number of electrons, formed electrostatically in a two-dimensional electron gas using top-gates. A quantum point contact was operated as a sensitive charge detector allowing the detection of single-electron tunneling through the system, which enables us to know the exact number of electrons N in the quantum dot. The latter is varied by changing the applied gate voltage.

For a strong coupling to the leads and possible symmetrical tunnel barriers, a Zero-bias anomaly (ZBA) is observed. This Kondo resonance appears for successive N showing a deviation from the conjectured odd-even behavior. The observed ZBA is strongest for N=9 and displays a particle-hole symmetry for N=7,..,11. It is absent for N=6 and N= 12. This observations indicate the influence of the shell structure of the electronic states in the quantum dot where orbital degeneracy is present.

HL 25.70 Wed 18:00 P2

Grating Couplers on a III-V Semiconductor Platform for Single-Photon Applications — •Valentino Merkl, Stephanie Bauer, Robert Sittig, 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

Photonic quantum computing is one of the most studied fields of the 21st century, with the potential to revolutionize computation as we know it today. Using integrated quantum photonics to miniaturize setups, it is possible to increase the computation complexity drastically. For this purpose a III-V semiconductor platform is highly advantageous, as it enables the possibility of integrating quantum dots as single photon sources, which cannot be done on silicon based platforms. They utilize the beneficial aspects of non-classical light for the computation. In some applications it is necessary to couple light from a chip into single mode fibers or vice versa. For this purpose, grating couplers, which demonstrated high coupling efficiencies of up to 89% on the silicon platform, are a highly versatile and promising method. In this contribution, we will present simulation results, fabrication steps and measurements on grating couplers constructed on the GaAs/AlOx platform. Using 2D and 3D FDTD simulations, these structures are optimized to have high coupling efficiencies in the near infrared regime and common telecom frequencies matching the emission wavelength of the QDs.

HL 25.71 Wed 18:00 P2

Heat Radiation of Semiconductor Wafers — •Bastian Schmülling, Timo Kruck, Andreas D. Wieck, and Arne Ludwig — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Uni Bochum

This work is about the struggles of pyrometer measurements of substrate temperature during molecular beam epitaxy (MBE) growth. During the growth of a typical GaAs wafer, a substrate temperature of 300 to 650 degree celsius is required. In our setup, a wafer is mounted in front of a radiation heater. To measure the substrate temperature, a pyrometer measures the thermal radiation. During growth, the substrate temperature is of utmost importance. However, the reflectivity and thus the emissivity changes with each additional layer deposited and the temperature measured by the pyrometer varies accordingly. These pyrometer measurements can be used to measure the growth rate. We plan to combining reflectometry and pyrometry during growth, to determine the actual temperature of the wafer.

HL 25.72 Wed 18:00 P2

Density Modulation of InAs/GaAs Quantum Dots and Pre Dots — •Peter Zajac[1], Nikolai Bart[1], Christian Dangel[2], Kai Müller[3], Andreas D. Wieck[1], Jonathan Finley[2], and Arne Ludwig[1] — [1]Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany — [2]Walter Schottky Institut and Physik Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany — [3]Walter Schottky Institut and Department of Electrical and Computer Engineering, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

Epitaxial layer-by-layer growth without rotation of the substrate creates a thickness gradient along the surface with alternating smooth and rough layer areas. InAs quantum dots (QDs) grown on top of a GaAs gradient layer exhibit a density modulation along this gradient, which is studied with macro photoluminescence spectroscopy and atomic force microscopy (AFM). The periodicity of the modulation can be varied from a few hundred microns to several millimeters, depending on the thickness of the underlying gradient layer. Automated AFM measurements, covering multiple modulation periods along the gradient allow the investigation of wetting layer roughness, QD density and density of a smaller species of QDs, termed pre dots. AFM data analysis and extraction of parameters such as QD and monolayer step density is presented.

Bart, N., Dangel, C. et al. Wafer-scale epitaxial modulation of quantum dot density. *Nat Commun* **13**, 1633 (2022).

HL 25.73 Wed 18:00 P2

Calibrating Photoluminescence Yield for Quantum Emitters in Planar Photonic Heterostructures — •Timo Kruck, Hans-Georg Babin, Danial Kohminaei, Sayed Sadat, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität-Bochum; Lehrstuhl für angewandte Festkörperphysik, Bochum, Deutschland

When performing photoluminescence (PL) measurements, the spectral intensity of the emitted radiation strongly depends on the dielectric structure sourrounding the quantum emitter. Here we show a method for calibrating PL measurements to obtain the unaltered spectrum of the optically active medium. For this purpose, the spectral reflectivity and the wavelength dependent standing wave field are used. The reflectivity is determined by reflectometer measurements and a simulation based on the transfer matrix method are used to compensate for the true layer thickness. This is then used to calculate the standing wave field, the outcoupling efficiency and the quantum yield. To validate the method, the calibrated spectra are compared with cleaved-edge PL measurements where the QDs are excited from the side and the light is also collected from the side.

HL 25.74 Wed 18:00 P2

Development of deterministic fabrication of quantum systems for single photon delay at Cesium wavelength — •Avijit

Barua[1], Monica Pengerla[1], Lucas Bremer[1], Lucas Rickert[1], Jin-Dong Song[2], and Stephan Reitzenstein[1] — [1]Technische Universität Berlin, Berlin, Germany — [2]Korea Institute of Science and Technology, Seoul, Republic of Korea

Semiconductor QDs are extensively investigated as single-photon sources for photonic quantum technology. The information that is encoded in single photons may be used as quantum interfaces between stationary and flying qubits. Here, we develop bright and strain-tunable QD single-photon sources at the Cs D1 transition wavelength (894 nm) to explore the storage ability of semiconductor QD in atomic quantum memories. The devices are designed and numerically optimized to maximize the extraction efficiency using the FEM solver JCMSuite. By considering circular Bragg resonators with up to 2 rings with integrated QDs and an Au-backside mirror we numerically demonstrate a photon extraction efficiency as high as 65% (NA = 0.4) and a Purcell factor of 0.72. In the experimental development, we realized hybrid CBGs which facilitate Piezo-strain tuning of the QD device. We then implement in-situ electron-beam lithography to precisely integrate the selected single QD at 894 nm in such a structure to create bright single-photon sources. Furthermore, the emission from the developed structures is studied by means of photon autocorrelation measurements, and light-matter interaction with Cs vapor is investigated.

HL 25.75 Wed 18:00 P2

Purcell enhanced two indistinguishable emissions from two separated quantum dots for on-chip complex photonics quantum circuits — •Yuhui Yang[1], Shulun Li[1,2], Johannes Schall[1], Sven Rodt[1], Zhichuan Niu[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, TU Berlin, Berlin, Germany — [2]State Key Laboratory for Superlattice and Microstructures, Institute of Semiconductors, Chinese Academy of Sciences, Beijing, China

Quantum dots (QDs) are excellent single-photon emitters with a close to ideal quantum nature of emission. For large-scale integrated photonic quantum circuits, indistinguishable and bright single photons emitted by independent QDs are required. In this regard, QDs integrated into nanocavities that are compatible with on-chip waveguide systems are highly interesting since they have a small footprint while providing strong Purcell enhancement.

Here, we demonstrate the deterministic integration of two spectrally similar single QDs in separate, one-dimensional photonic crystal nanobeam cavities with significant Purcell enhancement. Our flexible and accurate deterministic fabrication concept allows us to combine the nanobeam waveguides with integrated QDs into a 2 2 on-chip multimode interferometer (MMI) beam splitter with a 50/50 splitting ratio to perform on-chip Hanbury Brown and Twiss (HBT) and Hong-Ou-Mandel (HOM) measurements. The obtained results demonstrate that our approach is very promising toward two-photon interference from monolithic independent single-photon emitters, and fully integrated photonic quantum circuits.

HL 25.76 Wed 18:00 P2

Experimental and numerical investigation of the evanescent coupling between an integrated micropillar laser and a ridge waveguide — •Léo Roche[1], Imad Limame[1], Ching-Wen Shih[1], Yuhui Yang[1], Shulun Li[1,2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]State Key Laboratory for Superlattice and Microstructures, Institute of Semiconductors, Chinese Academy of Sciences, Beijing 100083, China

Integrated Quantum Photonic Circuits (IQPCs) are very promising candidates for scalable and flexible on-chip quantum computation and quantum communication hardware. One critical requirement for their realization is the scalable integration of on-demand indistinguishable single-photon emitters. This is potentially possible through the resonant excitation of an integrated QD in a waveguide by means of an on-chip integrated coherent light microlaser. Towards this goal, we investigate the coupling and lasing properties of coherent light laterally emitted from a whispering gallery mode (WGM) type micropillar laser evanescently coupled to a single mode ridge waveguide. Using finite element method (FEM) simulations, we investigate the coupling efficiency and the Q-factor of the pillar-waveguide system for different angular mode number and various pillar-waveguide air gap distances. The III-V semiconductor type nanostructures composed of a GaAs cavity with InAs QDs and distributed Bragg reflectors are carefully processed using electron beam lithography and then measured using micro-photoluminescence spectroscopy.

HL 25.77 Wed 18:00 P2

Building charge detection in indium antimonide nanowires for scanning tunneling microscopy using gate-defined quantum dots — •Kanji Furuta[1], Felix Jekat[1], Benjamin Pestka[1], Sasa Gazibegovic[2], Diana Car[2], Sebastian Heedt[3], Marcus Liebmann[1], Thomas Schäpers[3], Erik Bakkers[2], and Markus Morgenstern[1] — [1]II. Phys. Inst. B, RWTH Aachen Univ., Germany — [2]Dept. of Appl. Phys., Eindhoven Univ., The Netherlands — [3]PGI-9, FZ Jülich, Germany

InSb nanowires are investigated with respect to suitability as a charge detector to be combined with scanning tunneling microscopy. Mechanically exfoliated hexagonal boron nitride (h-BN) as a dielectric is placed onto bottom finger gates (50 nm wide, 30 nm spacing). The nanowires are then aligned and placed mechanically onto h-BN. We present transport measurements on gate-defined quantum dots at temperatures down to 300 mK. Due to the dielectric, the time stability of our device improved to around 5 μeV/h. The charge stability diagram shows Coulomb diamonds with a charging energy of 2.5 meV and an orbital energy of 0.3 meV. Depending on the gate and magnetic field, additional transport channels are occasionally observed, causing additional lines in the charge stability diagram and a shift of the Coulomb peak pattern around a magnetic field of $\approx$ 400 mT. This points to the presence of an unintentional second quantum dot in the gate region. Different configurations are discussed in terms of their coupling to the leads and the main dot, and their effects on charge detection.

HL 25.78 Wed 18:00 P2

Coherent manipulation of GaAs quantum dot spin qubits using microwaves — •Ankita Choudhary[1], Nand lal Sharma[1], Moritz Langer[1], Ghata Satish Bhayani[1], Uri Vool[2], and Caspar Hopfmann[1] — [1]Leibniz Institute for Solid State and Materials Research, Dresden — [2]Max Planck Institute for Chemical Physics of Solids, Dresden

Spin qubits in semiconductor quantum dots are attractive resources for performing quantum computations. In these systems single optically addressable spin qubits can be realized by single confined charge carriers, electrons, heavy holes, and their excited states. The quantum dot spin qubit coherence is however limited due to their semiconductor environment due to spin-orbit coupling to the magnetic moments of the atomic nuclei. Our goal is to facilitate the heralded and deterministic spin state preparation as well as to minimize the decoherence. While the all-optical heralded preparation of spin states in GaAs quantum dots has been demonstrated by us [1], the latter may be achieved by coherent manipulation of the spin states using the spin echo technique [2]. Our immediate goal is therefore to enable coherent manipulation of quantum dot spin qubits via injection of microwave pulses by superconducting co-planar waveguide structures. This technique will allow us to achieve full manipulation of the quantum dot and we expect to be able to achieve strong interaction between microwaves and quantum dot spin qubits, which could enable the coherent coupling between superconducting and quantum dot qubits. [1] C. Hopfmann et al, PRB 104, 75301 (2021). [2]F. H. L. Koppens et al, PRL 100 (2008).

HL 25.79 Wed 18:00 P2

Synthesis of ZnS nanoparticles investigated by in-situ X-ray scattering and spectroscopy — •Lars Klemeyer, Tjark Groene, Olga Vasylieva, Francesco Caddeo, Sani Harouna-Mayer, and Dorota Koziej — Universität Hamburg, Insititut für Nanostruktur- und Festkörperphysik, Center for Hybide Nanostructures, Luruper Chaussee 149, 22761 Hamburg

Transition metal sulfides are promising materials for a variety of applications. Especially the electronic configuration of the d-orbitals leads to unique electronic properties of transition metals and their compounds. Zinc sulfide (ZnS) is one of the most widely used transition metal sulfide due to its broad availability and relatively low toxicity as well as saturated d-orbitals. However, the synthesis approaches of ZnS nanoparticles in solution are not fully understood. We show complementary analysis with in-situ pair distribution function (PDF) and in-situ X-ray spectroscopy of the solvothermal synthesis of ZnS for a comprehensive picture of the nucleation and growth from precursors to nanoparticles.

HL 25.80 Wed 18:00 P2

Efficient frequency filtering of quantum dot photons using a self-constructed transmission grating monochromator — •Moritz Meinecke, Sven Höfling, and Tobias Huber — Lehrstuhl für Technische Physik, Universität Würzburg, 97074

Würzburg, Germany

Many spectroscopic measurements for characterizing quantum dot emission lines require spectral signal filtering that is narrower or matched to the expected line widths to analyze photons from different single excitonic charge complexes. Furthermore, to use the quantum dot photons for applications, this filtering should be efficient. A classical reflection monochromator is not ideal for this purpose, since it often comes with a low filter efficiency when the light is coupled to fiber, which is required for photon detection with superconducting nanowire detectors and for usage in any application. Furthermore, a reflection monochromator is strongly polarization dependent, which limits its use to non-polarization sensitive measurements, or requires polarization projection before frequency filtering. Alternative filter optics, like bandpass filters, have low flexibility and often need time consuming adjustments.

Here, we present a self-constructed transmission grating monochromator. It allows efficient, frequency filtering of quantum dot emission lines in the near infrared region. It is fully automatized and precise in approaching any filter position. Furthermore, the nearly polarization independent performance allows for polarization sensitive measurements.

HL 25.81 Wed 18:00 P2

Establishment of a method to make PL measurements on optically active layers in different dielectric structures comparable — •Sayed Shkeebullah Sadat, Danial Kohminaei, Timo Kruck, Hans-Georg Babin, Andreas Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Bochum, Deutschland

To improve extraction of photoemission from optically active layers such as quantum dots (QDs) or quantum wells (QWs) one can e.g. grow them inside dielectric structures (DBR - distributed Bragg reflector). However, the emerging wavelength-dependent standing wave field alters the spectral intensity of the quantum emitters, which means straightforward comparisons of photoluminescence (PL) measurements are no longer possible. Therefore we present a method by which you can obtain the unaltered spectrum. To calculate the standing field we determine the specific reflectivity first and adjust it to the true thickness of the layers. From here it is possible to determine the efficiency of the photon extraction and thus the quantum yield, which allows us to calibrate and transfer the spectra back to its unmodified form. Since this can be performed on any dielectric structure it now is possible to compare the calibrated spectra with each other. Furthermore there is a possibility to automate this process, allowing the instantaneous comparison of PL measurements on optically active layers in DBR surroundings. To verify the validity of this method the calibrated spectrum is compared to the spectra of cleaved-edge probes, where the DBR has no notable influence since the photons are detected from the side here.

HL 25.82 Wed 18:00 P2

Quantum efficiency boost by photoneutralization of charges in GaAs quantum dots based entangled photon emitters — Jingzhong Yang[1], •Tom Fandrich[1], Frederik Benthin[1], Robert Keil[2], Nand Lal Sharma[2], Weijie Nie[2], Caspar Hopfmann[2], Oliver G. Schmidt[2,3,4], Michael Zopf[1], and Fei Ding[1,5] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover — [2]Institute for Integrative Nanosciences, Leibniz IFW Dresden — [3]Material Systems for Nanoelectronics, Technische Universität Chemnitz — [4]Nanophysics, Faculty of Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, TU Dresden — [5]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover

Single- and entangled-photon sources are a key component of photonic applications in i.e. quantum communication. GaAs quantum dots are very promising candidates because of their compatibility to integrated photonic structures and the ability to generate photons on demand with low multiphoton emission, near-unity entanglement fidelity and high indistinguishability. One limiting factor is the emission blinking of the resonance fluorescence. This reduces the efficiency and limits the scalability in quantum networks. The neutral biexciton is resonantly excited via two-photon excitation displaying such blinking behavior. By introducing an additional weak off-resonant excitation, the balance of free charges close to the quantum dot was controlled. This leads to a reduction of blinking caused by the intrinsic Coulomb blockade due to captured charges. This method increases the excitation efficiency by 30% while maintaining the fidelity of the entangled-photon pairs.

HL 25.83 Wed 18:00 P2

Frequency Shift of Electronic Resonances in Self Assembled InAs Quantum Dots — •Ibrahim Azad Engin[1], Ismail Bölükbasi[1], Arn Baudzus[1], Patrick Lindner[2], Andreas Wieck[1], Björn Sothmann[3], and Arne Ludwig[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, 44801 Bochum — [2]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund — [3]Fakultät für Physik, Universität Duisburg-Essen, 47048 Duisburg

Self-assembled InAs quantum dots (SAQD) proved to be promising semiconductor structures for applications as single-photon sources [1]. Especially, charge stabilization by coupling to a reservoir is important for quantum memory resources [2].

In this contribution, we investigate InAs SAQDs in a diode structure coupled to an electron reservoir by capacitance-voltage-spectroscopy to electrically probe QD energy levels and vary parameters like ac-frequency and bath temperature. For the lowest energy s-states a thermal shift in equilibrium has been reported [3]. Non-equilibrium coupling has been observed and described with a master equation [4], where resonance shifts at higher frequencies and temperature remain unexplored. We rectify this here by proposing a more elaborated model and experimental data interpretation.

[1] Tomm, N. et al., Nat. Nanotechnol. 16, 399-403 (2021). [2] Prechtel, J. et al., Nat. Mater. 15, 981-986 (2016) [3] Brinks, F. et al., New J. Phys. 18, 123019 (2016). [4] Valentin, S. et al., Phys. Rev. B 97, 045416 (2018).

HL 25.84 Wed 18:00 P2

Droplet epitaxy of InGaAs quantum dots for spin-photon interface devices — •Xuelin Jin[1,2], David Fricker[1,2], Nils Von den driesch[1,3], Alexander Pawlis[1,3], Renu Rani[1,3], Minh Bui[1,3], Detlev Grützmacher[1,2], and Beata Kardynal[1,2] — [1]PGI 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen, 52074 Aachen, Germany — [3]PGI 10, Forschungszentrum Jülich, 52425 Jülich, Germany

Abstract. Quantum networks use photonic qubits to send information, that means photonic qubits need to be converted into stationary qubits at the network nodes. A transfer information from a photonic to a spin qubit has been already demonstrated. Here we study the possibility of transferring photonic qubits into spin qubits which offer a potential of scaling into quantum processors, ones in gate-defined quantum dots in GaAs. Since gate-defined quantum dots do not confine holes, a direct conversion of photon qubits into spin qubits in these quantum dots is not possible. Here, we explore the possibility of using self-assembled InGaAs quantum dots grown by droplet epitaxy as an optical interface to the gated quantum dots defined in GaAs. We will discuss the conditions that the heterostructure has to fulfil to facilitate tunable tunnel coupling between the two quantum dots and we will show the progress in its growth and characterisation. In order to maintain the stable operation of the gated quantum dots, we use droplet epitaxy to grow InGaAs QDs. We will show that this method allows us to create quantum dots with energies suitable for tunnel coupling and minimize the impact of the wetting layer on the two-dimensional electron gas.

HL 25.85 Wed 18:00 P2

Deterministic Coupling of Gold Nanorods with GaAs Quantum Dots — •Yinan Wang[1], Pengji Li[1], Chenxi Ma[1], Andreas Schell[1,2], Michael Zopf[1], and Fei Ding[1,2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Schneiderberg 39, 30167 Hannover, Germany

Coupling single-photon sources with metal nanoparticles is an emerging topic in quantum optics. Thus the deterministic fabrication of metal nanoantennas is crucial. Here we report our recent efforts on coupling single gold nanorods to single GaAs quantum dots. Two different techniques were investigated: (1) drop-casting a gold nanorod containing solution on the quantum dot sample, and (2) deterministic nano-manipulation of gold nanorods via Pick-and-Place functionalities of an atomic force microscope. We observed the modified photoluminescence of quantum dots, due to their coupling to the localized surface plasmons of the gold nanoparticles. The experimental details and also kinetic modeling will be also shown in detail.

HL 25.86 Wed 18:00 P2

Measurement and calculation of spectral emissivity of semiconductor quantum emitters in dielectric environments — •Danial Kohminaei, Sayed Shkeebullah Sadat, Timo Kruck,

Hans-Georg Babin, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum; Lehrstuhl für angewandte Festkörperphysik, Deutschland

Quantum dots (QDs) emit light divergently. For improved outcoupling of this photon emission, QDs are grown above so-called distributed Bragg reflectors (DBRs), which have a maximum reflectivity at the wavelength of the light of the QDs. Reflection also occurs unwantedly at the interface of the semiconductor to the vacuum. Therefore, when performing photoluminescence (PL) measurements, the measured spectral intensity of the emitted radiation strongly depends on the (dielectric) structure of the sample. Here we show a method for calibrating PL measurements to obtain the unaltered spectrum of the optically active medium. First, the spectral reflectivity is determined by reflectometer measurements, and compared to a simulation based on the transfer matrix method for the true layer thickness. This is then used to calculate the wavelength dependent standing wave field, the outcoupling efficiency and the quantum yield. Furthermore, the influence of the absorption of the exciting laser light in the semiconductor, on the overall spectrum will be analyzed. To validate the method, the calibrated spectra are compared with cleaved-edge PL measurements, where the QDs are excited from the side and the light is also collected from the side.

HL 25.87 Wed 18:00 P2

Fabrication & Electrical Characterization of Silicon-Germanium Nanowire Schottky Barrier Transistors — •Muhammad Moazzam Khan[1], Oliver Steuer[1], Slawomir Prucnal[1], and Yordan M Georgiev[1,2] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, D-01328 Dresden, Germany — [2]Institute of Electronics at the Bulgarian Academy of Sciences, 72, Tzarigradsko chaussee blvd, 1784-Sofia, Bulgaria

CMOS scaling is reaching physical limits in near future. Therefore, new approaches are required to continue achieving high speed and high performance devices. Replacing silicon with silicon-germanium alloy as a channel material having higher mobility contributes to faster and energy-efficient devices. In this work, we are investigating the transistor properties built from silicon germanium based nanowire channel. Schottky Barrier Field Effect Transistors are fabricated, which also have an additional functionality of re-configurability. This means that a single device can be operated as an N or P channel just by controlling the electric potential applied at the gate terminals. The devices are fabricated by top-down approach with nickel metal pads on both sides of the silicon-germanium nanowire. To form schottky junctions, flash lamp annealing is performed to diffuse metal into the nanowires. The schottky junctions formed at the interface between nickel-germanosilicide and nanowire are electrically controlled to operate the device. Transfer characteristics of these devices are measured to investigate the transistor properties.

HL 25.88 Wed 18:00 P2

realization of on-chip wavelength multiplexing with self-assembly InGaAs quantum dot in telecom C-band — •Dongze Wang, Stephanie Bauer, Michael Jetter, Simone Portalupi, and Peter Michler — Institut für Halbleiteroptik und Funktionelle Grenzflächen, Stuttgart, Germany

Photonic integrated circuits (PIC) are a highly appealing platform for the realization of quantum photonic devices on a scalable dimension. The technology of PIC has enabled the generation, processing, and detection of the quantum state of light. Several different material platforms for the realization of PIC were proposed and are currently under intense investigation. Gallium arsenide-based (GaAs) PIC provides a straightforward combination with a self-assembled quantum dot (QD), which can serve as an efficient on-demand single-photon source with high purity and indistinguishability. In this work, we present a wavelength-division multiplexing system based on indium gallium arsenide (InGaAs) waveguides containing self-assembled InGaAs QDs located at the telecom C-band. The waveguide core is deposited on aluminum gallium arsenide (AlGaAs), which provides large refractive index contrast resulting in good confinement for the propagating photons. The dimensional parameters of the single-mode waveguide were simulated by a finite-difference time-domain method. Afterwards, standard semiconducting nanofabrication processes including electron beam lithography and inductively coupled plasma-reactive ion etching technology were used to fabricate the InGaAs photonic chip.

HL 25.89 Wed 18:00 P2

Magnetotransport in narrow-gap semiconductors with nanostructured constrictions — •Olivio Chiatti[1], Johannes Boy[1], Christian Riha[1], Christian Heyn[2], Wolfgang Hansen[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg, 20355 Hamburg, Germany

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

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

HL 25.90 Wed 18:00 P2

Acquisition and analysis of photocurrent spectra for 850 nm oxide-confined vertical-cavity surface-emitting lasers — Arndt Jaeger[1], Marwan Bou Sanayeh[2], Helmut Meinert[1], •Manuel Haerer[1], Oleg Yu. Makarov[2], Ilya E. Titkov[2], Nikolay Ledentsov Jr.[2], and Nikolay N. Ledentsov[2] — [1]Esslingen University of Applied Sciences, Flandernstrasse 101, 73732 Esslingen, Germany — [2]VI Systems GmbH, Hardenbergstrasse 7, 10623 Berlin, Germany

Vertical-cavity surface-emitting lasers (VCSELs) are of utmost importance as key components for high-speed datacom, sensor and free-space applications. Therefore, for a successful further optimization of their performance, understanding their aging behavior is of crucial importance. The 850 nm oxide-confined VCSELs used in this study were intentionally operated at extreme conditions to accelerate their degradation until reaching optical damage. For monitoring operation-induced changes, a photocurrent spectroscopy (PCS) setup was established and applied before and after accelerated aging. The PCS results at different reverse biases reveal changes that can be explained by non-radiative recombination centers generated during accelerated aging. This finding contributes to the understanding of the aging mechanisms in these tiny devices.

HL 25.91 Wed 18:00 P2

Polariton condensation with extreme confinement of light — •Maria Vittoria Gurrieri[1], Philip Kristensen[1], Jesper Mork[1], and Emil Denning[2] — [1]Department of Electrical and Photonics Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark — [2]Nonlinear Optics and Quantum Electronics, Technical University of Berlin, 10623 Berlin, Germany

Strong coupling between light and electronic excitations mixes the constituent eigenstates into hybrid polaritonic quasiparticles. Under certain conditions it is possible to predict the formation of a polariton condensate with macroscopic occupation number and spontaneous coherence in the ground state. This condensate is a source of coherent matter waves and photons.

In this work we theoretically investigate the possibility of achieving polariton condensation in an extended sheet of 2D semiconductor coupled to a novel dielectric nanocavity with deep subwavelength confinement and featuring a spectrally isolated mode. Such coupling leads to the formation of a spatially localized polariton state, which interacts with the continuum of excitons through Coulomb interaction. The system is modelled by a Born-Markov master equation for the polariton subsystem, where the exciton continuum is traced out. This enables the derivation of a rate equation model to describe the dynamics of the lower polariton population.

HL 25.92 Wed 18:00 P2

Time resolved spin dynamics in lead halide hybrid organic perovskite $Fa_{0.9}Cs_{0.1}PbI_{2.8}Br_{0.2}$ — •Erik Kirstein[1], Eiko Evers[1], Vasilli V. Belykh[1,2], Evgeny A. Zhukov[1], Dennis Kudlacik[1], Ina V. Kalitukha[3], Olga Nazarenko[4], Maxim V.

Kovalenko[4,5], Dmtri R. Yakovlev[1,3], and Manfred Bayer[1,3] — [1]Experimentelle Physik 2, Technische Universität Dortmund, D-44227 Dortmund, Germany — [2]Moscow, Russia — [3]St. Petersburg, Russia — [4]Laboratory of Inorganic Chemistry, ETH Zürich, CH-8093 Zürich, Switzerland — [5]Laboratory for Thin Films and Photovoltaics, Empa-Swiss Federal Laboratories for Materials Science and Technology, CH-8600 Dübendorf, Switzerland

Lead halide hybrid organic perovskites attract increased attention due their promising applications, related to their high quantum efficiency and easy synthesis. The spin dynamics in perovskite materials is not studied in detail so far, but shows promising results. The studied $Fa_{0.9}Cs_{0.1}PbI_{2.8}Br_{0.2}$ bulk sample was grown out of solution of respective ions in polar solvents. Its bandgap of 1.51 eV makes this material well-suited for the resonant excitation with Ti:Sapphire laser. We study the coherent spin dynamics of electrons and holes by means of time-resolved pump-probe Kerr rotation technique at cryogenic temperatures and magnetic fields up to 6 T. We measure longitudinal spin relaxation times T_1, transverse dephasing times T_2^*, g-factor values and their spread Δg.

HL 25.93 Wed 18:00 P2

Temperature dependence of the bandgap of ^{28}Si and its use as time-resolved, high precision thermometer — Eduard Sauter[1], Nicolay V. Abrosimov[2], •Jens Hübner[1], and Michael Oestreich[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Leibniz-Institut für Kristallzüchtung, Max-Born-Straße 2, 12489 Berlin, Germany

We measure by high resolution absorption spectroscopy of the extremely narrow donor bound trion ^{28}Si:P transition the precise temperature dependence of the indirect bandgap of isotopically purified ^{28}Si in helium exchange gas in the regime from 0.1 K to 2 K. The measurements evidence that the trion frequency can be used as an efficient, contactless, local temperature sensor with a demonstrated time-resolution of a few microseconds. Furthermore, the all-optical sensor is also quite sensitive to changes of the local electric field and of the helium cooling gas pressure allowing detailed studies of the complex ^{28}Si:P system dynamics after perturbations.

[1] M. Beck, N. V. Abrosimov, J. Hübner, and M. Oestreich, Phys. Rev. B, **99**, 245201 (2019).
[2] E. Sauter, N. V. Abrosimov, J. Hübner, and M. Oestreich, Phys. Rev. Lett. **126**, 137402 (2021).

HL 25.94 Wed 18:00 P2

Spin noise spectroscopy of a single InGaAs quantum dot at high magnetic fields — •Kai Hühn, Pavel Sterin, Jens Hübner, and Michael Oestreich — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

Single holes in InGaAs quantum dots hold great promise as potential qubits due to the slow relaxation of selected spin degrees of freedom. However, the impact of phonon induced spin relaxation and occupancy noise for high magnetic fields remained unclear so far. Here, we use the method of spin noise spectroscopy (SNS) to gain a detailed insight into such mechanisms and measure the spin and charge dynamics for magnetic fields up to 4T and temperatures between 1.8K and 10K. Here, we combine, the quasi non-disturbant measurement scheme of SNS with an extrapolation to truly zero disturbance of the QD system. We find that the total noise power originates not just only from the hole-spin but from several processes including the relaxation of the hole spin and the charge state dynamics of the QD due to Auger recombination. In addition, our measurements indicate a long term stability of the intrinsic hole spin life time on the order of months. We compare our results with theoretical calculations which explicitly address one and two phonon processes as the limiting mechanism of the intrinsic hole spin relaxation.

HL 25.95 Wed 18:00 P2

Thermal Transport in c-plane GaN Membranes Characterized by Raman Thermometry — •Wilken Seemann[1], Joachim Ciers[2], Isabell Hüllen[1], Mahmoud Elhajhasan[1], Jean-François Carlin[3], Nicolas Grandjean[3], Åsa Haglund[2], and Gordon Callsen[1] — [1]Institute of Solid State Physics, University of Bremen, Germany — [2]Department of Microtechnology and Nanoscience, Chalmers University of Technology, Gothenburg, Sweden — [3]Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), Switzerland

Excess heat often limits the lifetime or stability of semiconductor devices, like laser strcutures, e.g. by affecting the refractive index or defect formation. It is therefore vital to understand how thermal energy is dissipated from the active region. In this contribution, we analyze the in-plane thermal transport in GaN-based membranes which can be applied in UV-visible light emission. The temperature of the material is probed by the shift and width of Raman modes under heating with a UV laser. This method allows for a contactless characterization without the need for additional processing steps often needed for alternative thermometry. We find, that the thermal conductivity, κ, is significantly reduced compared to bulk GaN due to the finite thickness of the analyzed membranes. Phonon scattering due to roughness and porosity of the membrane is found to further reduce κ. Studying in-plane thermal transport lays the foundation for subsequent thermal studies on entire device structures; exploiting a subtle balance of in- and cross-plane thermal transport which could improve device designs.

HL 25.96 Wed 18:00 P2

A ultrafast Optical-pump/THz-probe spectrometer based on sub-diffraction field confinement — •Julia A. Lang, Michael Seidel, and Georg Herink — Experimental Physics VIII, University of Bayreuth, Germany

Time-resolved THz spectroscopy is a powerful tool for characterizing transient carrier dynamics in electronic materials and devices. In this contribution, we present an optical-pump/THz-probe spectrometer based on a high-repetition rate femtosecond fiber laser and photoconductive antennas combined with resonant microstructures for signal amplification. In particular, this approach exploits sub-diffraction Terahertz confinement in metallic microstructures to reduce the large mismatch between optical and THz foci. We demonstrate local spectroscopy of carrier dynamics in a semiconductor material inside a single resonator and corroborate our findings with finite-element simulations.

HL 25.97 Wed 18:00 P2

In depth comparison of Raman and Hall measurements for the determination of the electrical transport parameters of N-doped 4H-SiC — •Hannes Hergert[1,2], Matthias T. Elm[1,2,3], and Peter J. Klar[1] — [1]Institute of Experimental Physics I, Giessen, Germany — [2]Center for Materials Research, Giessen, Germany — [3]Institute of Physical Chemistry, Justus Liebig University, 35392 Giessen, Germany

A precise characterisation of the impact of doping on the electronic transport properties is necessary for the application of silicon carbid (SiC) in semiconductor devices. Hall effect measurements yield reliable results for mobility and carrier density but electrical contacts are needed. These are often not desired. An alternative approach is the analysis of the longitudinal optical phonon electron plasma coupled (LOPC) mode using Raman spectroscopy. This approach also delivers non-invasively information about the charge carrier density and the electron mobility. In this work, we compare the results obtained by Hall and Raman measurements. We show that the effective carrier density and the mobility obtained by Hall measurements deviate from those determined using Raman spectroscopy. The deviations arise as only electrons in the conduction band couple to the LO mode, while electrons in the impurity band do not, but still contribute to the electrical transport. To extract the charge carrier density in the conduction band from Hall measurements, a three-band model is employed. In addition, the two measurement methods yield different values of the mobility due to its frequency-dependence.

HL 25.98 Wed 18:00 P2

Electrical characterization of core/shell GaAs/InAs/Al nanowire-based Josephson junctions — •Farah Basaric[1], Anton Faustmann[1], Marvin M. Jansen[1], Alexander Pawlis[1,2], Erik Zimmermann[1], Hans Lüth[1,2], Detlev Grützmacher[1,2], and Thomas Schäpers[1,2] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich-Aachen Research Alliance, Forschungszentrum Jülich and RWTH Aachen University, Germany

Epitaxially grown phase-pure GaAs/InAs core/shell nanowires offer uniformity in their electrical, mechanical and optical properties. High electron mobility, large g-factor and strong Rashba spin-orbit coupling in combination with phase-pure wurtzite GaAs core offer heterostructure with transport properties governed by the presence of confined states in the InAs shell. A Josephson junction was realized by wet chemical etching of an *in-situ* deposited Al half-shell. Clean

semiconductor-superconductor interface by such deposition was important for obtaining high critical current and good electrical transport control. The nanowire system was fabricated fully *in-situ* in a state-of-the-art nanofabrication clustertool, enabling precisely defined interfaces. Magnetotransport measurements at variable temperature regime were carried out for structures with normal and superconducting contacts under applied in-plane magnetic field, with varying gate potential. Such hybrid structure represents a promising candidate in realizing superconducting qubits and Majorana circuits.

HL 26: Quantum Dots and Wires 5: Optics 2

Time: Thursday 9:30–12:45 Location: H32

HL 26.1 Thu 9:30 H32

All-optical polarization control of single photons emitted by a quantum dot — •Björn Jonas, Dirk Heinze, Eva Schöll, Patricia Kallert, Timo Langer, Sebastian Krehs, Alex Widhalm, Klaus D. Jöns, Dirk Reuter, Stefan Schumacher, and Artur Zrenner — Paderborn University, Physics Department, Warburger Straße 100, 33098 Paderborn, Germany

In our work we employ an all-optical approach based on nonlinear principles to control the polarization of single photon emission from a single quantum dot. To achieve this, we make use of a nonlinear down-conversion process from the biexciton to the ground state [1]. This opens an alternative decay path in addition to the biexciton cascade. Previous theoretical work suggests the possibility to manipulate the properties of the emitted photons by tuning the respective properties of a control laser [2].
By exploiting this mechanism, we were able to demonstrate polarization control of the emitted photons for linear and circular polarization. Our findings show no influence of the fine-structure splitting on the polarization of the emitted photons. We furthermore present a theoretical model to describe our results and we find excellent agreement between experiment and theory.
[1] B. Jonas et al., Nature Communications **13**, 1387 (2022)
[2] D. Heinze et al., Nature Communications **6**, 8473 (2015)

HL 26.2 Thu 9:45 H32

Temporal evolution of line broadening in charge controlled quantum dots — •Tim Strobel[1], Jonas H. Weber[1], Marcel Schmidt[2], Lukas Wagner[1], Andreas D. Wieck[2], Michael Jetter[1], Simone L. Portalupi[1], Arne Ludwig[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Center for Integrated Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany

Self-assembled semiconductor quantum dots (QDs) present themselves as an attractive platform for the implementation of scalable hybrid quantum-information schemes. On-demand emission of high-quality single photons demonstrates the potential of such systems. Sources of noise, caused by the interaction with the solid-state environment can lead to an inhomogeneous broadening of the emission line. The magnitudes and timescales of such dephasing mechanisms vary strongly with the material composition and heterostructure of a sample. Here, we employ Photon-correlation Fourier spectroscopy as a powerful experimental method to study the spectral dynamics of single emitters, with high spectral and temporal resolution. In particular, the broadening mechanisms of QDs embedded in a novel type of gated structure, based on a n-i-n-diode are investigated.

HL 26.3 Thu 10:00 H32

High-quality single-photons from hybrid MOVPE/MBE grown n-i-n quantum-dot structures — •Lukas Wagner[1], Tim Strobel[1], Marcel Schmidt[2], Jonas H. Weber[1], Lena Engel[1], Andreas D. Wieck[2], Michael Jetter[1], Simone L. Portalupi[1], Arne Ludwig[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen (IHFG), Center for Integrated Quantum Science and Technology (IQST) and SCoPE, University of Stuttgart, Allmandring 3, 70569 Stuttgart, Germany — [2]Lehrstuhl für angewandte Festkörperphysik, Ruhr-University Bochum, Universitätsstraße 150, 44801 Bochum, Germany

Photonic quantum operations require sources of photons with Fourier-limited linewidth and high brightness. Stark-shift tuning of the emission wavelength can be of interest in upscaling the complexity, employing multiple quantum dots (QDs) tuned at the same emission wavelength. QDs in gated structure can provide a stabilization of the electric field environment, pushing the photon linewidth close to the Fourier limit. In addition, the embedding diode structure can be used to electrically tune the emission wavelength. The growth of self-assembled semiconductor QDs is usually carried out via metal-organic vapor-phase epitaxy (MOVPE) or molecular-beam epitaxy (MBE). This work combines MOVPE and MBE techniques for hybrid growth of gated semiconductor QD samples. This provides spectrally tunable InAs QDs with narrow emission linewidth. High single-photon purity and indistinguishability are proven via Hanbury-Brown and Twiss, and Hong-Ou-Mandel experiments in resonant excitation.

HL 26.4 Thu 10:15 H32

Ultrafast electric control of cavity mediated photons from a semiconductor quantum-dot — •David Bauch[1], Dirk Heinze[1], Jens Förstner[1], Klaus D. Jöns[1], and Stefan Schumacher[1,2] — [1]Department of Physics and CeOPP, Paderborn University, Germany — [2]College of Optical Sciences, University of Arizona, Tucson, USA

On demand sources for single photon and photon pairs are essential for quantum communication protocols. Exciton and cascaded biexciton-exciton transitions in semiconductor quantum dots offer the potential for optically controlled generation of a single photon [1] and polarization-entangled twin photons [2]. In addition to pure optical control, externally applied time-dependent electric fields enable control of the (bi-)exciton resonance through the quantum confined Stark effect, resulting in changes of the (bi-)exciton dynamics and the resulting photon emission. Here we investigate theoretically the optical excitation of the (bi-)exciton state off-resonant to a cavity mode followed by ultrafast control of the states, which then allows for cavity-resonant emission of the photons. Our scheme allows for high preparation fidelities followed by the generation of highly indistinguishable single photons and polarization entangled twin-photons via the biexciton-exciton cascade and biexciton two-photon emission with high emission probabilities [3].

[1] D. Heinze, D. Breddermann, A. Zrenner, S. Schumacher, Nat. Commun. 6, 8473 (2015). [2] D. Heinze, A. Zrenner, S. Schumacher, Phys. Rev. B 95, 245306 (2017). [3] D. Bauch, D. Heinze, J. Förstner, K. D. Jöns, S. Schumacher, Phys. Rev. B 104, 085308 (2021).

HL 26.5 Thu 10:30 H32

Sub- and Superradiant Effects in Bimodal Quantum-Dot Microcavity Lasers — •Isa Hedda Grothe and Jan Wiersig — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany

In standard nanolasers with a single cavity mode a strong influence of inter-emitter correlations on the input-output dynamics as well as the statistical properties of the emitted light has been described [1]. Below threshold subradiant emission emerges with superthermal values of the autocorrelation function $g^{(2)}(0)$, which is associated with strong bunching of the emitted photons. Similarly high values of $g^{(2)}(0)$ have also been found for the weak mode in micropillar lasers with two orthogonally polarized modes [2,3]. Here, however, this phenomenon is rooted in the interaction of both modes with a common gain medium which leads to gain competition between the two modes.

Making use of a theoretical semiconductor laser model based on the cluster-expansion method, we include correlations between the emitters in the description of bimodal microcavity lasers. This enables us to compare the influence of sub- and superradiant effects on the emission of bimodal lasers to that on lasers with a single mode. Additionally, we are able to distinguish features of the statistical properties of the emitted light that characterize either subradiance or gain competition as the source of superthermal photon bunching in bimodal lasers.

[1] H. A. M. Leymann et al., Phys. Rev. Applied **4**, 044018 (2015).
[2] H. A. M. Leymann et al., Phys. Rev. A **87**, 053819 (2013).
[3] M. Schmidt et al., Phys. Rev. Research **3**, 013263 (2021).

HL 26.6 Thu 10:45 H32

GaAs Droplet Epitaxy Quantum Dots as Deterministic Single Photon Sources for Entangling SiV-Centers in Diamond — •Manuel Rieger[1], Viviana Villafane[1], Andreas Nickl[1], Christian Dangel[1], Hans-Georg Babin[2], Tim Schröder[3], Arne Ludwig[2], Andreas Wieck[2], Kai Müller[1], and Jonathan Finley[1] — [1]Walter Schottky Institut/Physik Department, TUM, 85748 Garching, Germany — [2]Physik Department, RU Bochum, Universitätsstraße 150, 44801 Bochum, Germany — [3]Physik Department, HU Berlin, Newtonstraße 15, 12489 Berlin, Germany

Quantum algorithms promise acceleration of tasks like computational chemistry and machine learning. In this context, diamond-based quantum hardware capable of interfacing spins and photons in a scalable network [1] is particularly advantageous since it combines excellent coherence times, gate fidelities and the possibility for on-chip integration. We demonstrate GaAs based quantum dot (QD) deterministic single photon sources grown using droplet epitaxy (DE) and resonant with the the SiV- center in diamond at 737nm. By characterizing single dots using low temperature optical spectroscopy, we measure a non-classical second order photon intensity correlation function ($g^2(0)<0.3$), demonstrate electrical tunability of the charge occupancy and show wide tunability of the emission frequency over 250GHz. Furthermore, we show that the optical lifetimes of the DE-QDs lie in the range 1-1.5ns, similar to those of SiV^- (1-2ns), a prerequisite for high-fidelity photon mediated entanglement [1,2]. [1] K. Nemoto et al., Phys. Rev. X (2014). [2] C. Dangel et al., arXiv preprint (2022).

30 min. break

HL 26.7 Thu 11:30 H32

To boldy excite where no one has excited before — Thomas K. Bracht[1], Yusuf Karli[2], Florian Kappe[2], Vikas Remesh[2], Tim Seidelmann[3], Armando Rastelli[4], Gregor Weihs[2], Vollrath Martin Axt[3], and •Doris E. Reiter[1,5] — [1]Institut für Festkörpertheorie, Universität Münster, 48149 Münster, Germany — [2]Institute für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [3]Institute of Semiconductor and Solid State Physics, JKU Linz, Linz, Austria — [4]Theoretische Physik III, Universität Bayreuth, 95440 Bayreuth, Germany — [5]Condensed Matter Theory, TU Dortmund, 44221 Dortmund, Germany

In the Rabi scheme, off-resonant excitations of a two-level system do not lead to a full inversion, when no further auxiliary particles are participating. Surprisingly, the Swing-UP of the quantum EmitteR population (SUPER) scheme uses off-resonant excitations to fully bring a two-level system from the ground to excited state [PRX Quantum 2, 040354 (2021)]. The scheme relies on a gradual swing-up, which can be achieved by modulation of the excitation frequency or amplitude. Here, we discuss the theory of the SUPER scheme and how it can implemented for a semiconductor quantum dot by using a two-color excitation with pulses detuned by several meV. Due to the electron-phonon interaction, the SUPER scheme results in the emission of phonon wave packets [pssb, 2100649 (2022)], but overall the phonon influence is rather small. The experimental realization of SUPER scheme [arXiv:2203.00712 (2022)], as will be presented in a different contribution, shows great agreement with the theoretical prediction.

HL 26.8 Thu 11:45 H32

Internal Photoeffect from a Single Quantum Emitter — Pia Lochner[1], Jens Kerski[1], Annika Kurzmann[2], Hendrik Mannel[1], •Marcel Zöllner[1], Andreas D. Wieck[3], Arne Ludwig[3], Martin P. Geller[1], and Axel Lorke[1] — [1]University of Duisburg-Essen and CENIDE, Germany — [2]RWTH Aachen University, Germany — [3]Ruhr-University Bochum, Germany

As quantum information technologies require long spin coherence times in qubits and highly indistinguishable photons [1], we present a new and mostly neglected mechanism in self-assembled quantum dots that fundamentally limits the coherence times in optical quantum devices. By time-resolved resonance fluorescence (RF) measurements on a single quantum dot, we demonstrate an internal photoeffect [2] that emits electrons from the dot by an intra-band excitation. While the tunneling rate of an electron into the quantum dot is constant for increasing non-resonant laser intensity, the emission rate by the photoeffect increases linearly with increasing excitation intensity. This way, the emission rate is tunable over several orders of magnitude by adjusting the non-resonant laser excitation intensity.
Our findings show that a process, which is well known in single atom spectroscopy (i.e. photo ionization) can also be observed for a solid-state quantum emitter and has to be avoided or reduced to push the limits towards long qubit coherence times.
[1] T. D. Ladd et al., Nature 464, 45-53 (2010)
[2] P. Lochner et al., Phys. Rev. B 103, 075426 (2021)

HL 26.9 Thu 12:00 H32

Nuclear Spin Polarization by Electron Spin Mode Dragging in an Ensemble of (In,Ga)As Quantum Dots — •Eiko Evers[1], Nataliia E. Kopteva[1,2], Irina A. Yugova[2,3], Dmitri R. Yakovlev[1,4], Manfred Bayer[1], and Alex Greilich[1] — [1]Experimentelle Physik 2, TU Dortmund, 44221 Dortmund, Germany — [2]Spin Optics Laboratory of St. Petersburg State University, 198504 St. Petersburg, Russia — [3]St. Petersburg, Russia — [4]St. Petersburg, Russia

The electron-nuclear spin system in singly charged (In,Ga)As quantum dots (QDs) promises to combine the efficient optical electron spin (ES) orientation with the long coherence time in the nuclear spin (NS) system [1]. To come closer to a state of large NS polarization, we synchronize an ensemble of QDs, inhomogeneous in size, g factor, and resident ES precession frequency in a transverse external field, to a laser with a pulse repetition frequency of 1 GHz. As a result, the ensemble of ESs is homogenized by focusing it on a single precession mode by nuclei-induced frequency focusing [2]. In a substantial external field range, the single mode is fixed by a simultaneous build-up of an anti-parallel Overhauser field B_N caused by the polarization of NSs. The Overhauser field achievable in each QD differs and leads to the surprising emergence of equally spaced ES precession components in the ensemble.
[1] D. Gangloff et al., Science **364**, 62 (2019)
[2] A. Greilich et al., Science **317** 1896 (2007)

HL 26.10 Thu 12:15 H32

Auger-assisted electron spin-flips in a single quantum dot — •Hendrik Mannel[1], Jens Kerski[1], Pia Lochner[1], Marcel Zöllner[1], Fabio Rimek[1], Arne Ludwig[2], Andreas Wieck[2], Axel Lorke[1], and Martin Geller[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Duisburg, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

A long electron spin coherence lifetime is the key requirement for future solid-state spin qubits. However, for instance, in self-assembled quantum dots the coupling to nuclei, co-tunneling with a nearby reservoir, and spin-orbit coupling limit the spin-lifetime.

Using resonance fluorescence, we here demonstrate an additional fundamental process that can lead to a single electron spin-flip via an Auger recombination [1]. The quantum dot is placed in a magnetic field in Faraday geometry and charged with one (spin-up or spin-down) electron [2]. In time-resolved resonant fluorescence measurements and using a rate equation model, we can determine the Auger and spin-flip rates in a magnetic field.

Our results reveal an additional, so far neglected Auger-assisted spin-flip process: Auger recombination with subsequent electron tunneling from the reservoir. The present dot is weakly coupled to an electron reservoir. A strong coupling will enhance this Auger-assisted spin-flip rate and thus reveal an important mechanism limiting the spin lifetime due to a strong coupling to a nearby reservoir.

[1] A. Kurzmann et al., Nano Lett. **16**, 3367 (2016). [2] J. Dreiser et al., Phys. Rev. B **77**, 075317 (2008).

HL 26.11 Thu 12:30 H32

Spin control of single spins in semiconductor quantum dots placed in a microcavity — •Marco De Gregorio, Tobias Huber, and Sven Höfling — Technische Physik, Julius-Maximilians-Universität, Würzburg, Deutschland

Implementation of secure communication with entangled photons is a continuously evolving field. Different platforms have been investigated during the last decades and quantum dots have been proven to be a promising candidate as source for entangled photons. Despite their deterministic photon creation and excellent multi-photon suppression, quantum dot sources suffer from outcoupling efficiencies, when not embedded into photonic structures. Here, we present a low quality factor micropillar cavity, which is broadband, but still enhances the photon extraction efficiency. Analysis of deterministically placed low-q micropillars, characterization and optimization of the emission behavior and control of the spin are necessary steps paving the way towards the generation of a quantum repeater.

HL 27: Focus Session: Perspectives in Cu(In,Ga)Se 1

The chalcopyrite Cu(In,Ga)Se2 is currently one of the few photovoltaic materials with an active participation in the market share of thin-film technologies, offering also the advantage of having a low production carbon footprint. After a rapid increase in its record power conversion efficiency during the last decade, the technology seems to have stagnated at 23.4 percent, a record achieved in 2019. Several strategies, which have been partially responsible of the newest record efficiencies, have been developed in order to push Cu(In,Ga)Se2 further by targeting the improvement of the bulk properties and the interfaces: post-deposition treatments with heavy alkali metal fluorides, incorporation of other metals like silver and the mixture with other chalcogens like sulfur, are just some examples. The aim of this focus session is to bring Cu(In,Ga)Se2 experts together in order to discuss the current limitations and propose new routes and concepts that could lead to a further improvement in this technology.

Organized by AK-jDPG (Aubin Prot, Omar Ramirez and Taowen Wang)

Time: Thursday 9:30–11:00 Location: H33

Invited Talk HL 27.1 Thu 9:30 H33

What limits state-of-the-art chalcopyrite solar cells? — •Susanne Siebentritt — Laboratory for Photovoltaics, Department of Physics and Materials Science, University of Luxembourg

Chalcopyrite solar cells have reached 23.4% efficiency, less than Si solar cells. Why are chalcopyrite solar cells not better? State of the art chalcopyrite solar cells are based on an absorber with a band gap gradient in depth, to keep electrons from the back contact and to reduce non-radiative recombination at the back contact. However, this graded band gap profile can decrease the short circuit current because of a rather low absorptance near the absorption edge. Additionally, the gradual increase of the absorptance leads to radiative loss in the open circuit voltage (VOC). Additional fluctuations and disorder lead to exponential band tails and to radiative and non-radiative VOC losses. These Urbach tails are larger in polycrystalline films than in epitaxial films, indicating a contribution of grain boundaries, however, the difference is only a few meV in Urbach energy, indicating a common source independent of grain boudaries. The dependence of the Urbach energy on the net doping level hints to electrostatic fluctuations as a main source of tail states. In addition to these limitations of the short circuit current and the open circuit voltage, the diode factor of most chalcopyrite solar cells is high, implying a low fill factor. It became only recently clear, that metastable defects contribute massively to the increased diode factor of these solar cells.

Invited Talk HL 27.2 Thu 10:00 H33

Approaches to improve CIGS absorber quality and the CIGS/buffer interface to reach 24% efficiency and beyond — •Wolfram Witte — Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), Stuttgart, Germany

Cu(In,Ga)Se2 (CIGS) thin-film solar cells with polycrystalline absorber layers exhibit high power conversion efficiencies above 23% for small-area devices. The bandgap energy (Eg) of CIGS is tunable and the material can be used either as bottom cell within a tandem device, e. g. in combination with perovskite as a top cell or the CIGS cell can be applied as wide-bandgap top cell and combined with e. g. a silicon bottom cell. In spite of their excellent photovoltaic (PV) performance, it is apparent, when comparing the PV parameters of record single junction CIGS devices with the theoretical radiative limit, that various loss mechanisms are present in the devices. As few examples, the open-circuit voltage (Voc) and the fill factor (FF) are limited by non-radiative recombination and additional parasitic absorption takes place in the buffer and adjunct high-resistive (HR) layer, which can limit the short-circuit current (Jsc).

This contribution gives an overview on approaches to improve CIGS single-junction solar cells beyond 24%. Increasing grain size and/or eliminate the Ga/(Ga+In) grading in the absorber can reduce Voc losses and alloying of silver to CIGS can increase FF values.

To overcome parasitic absorption of the standard buffer system CdS/i-ZnO, the application of wide-bandgap buffer or HR materials such as Ga2O3 with Eg>4 eV can be an option to increase Jsc further.

HL 27.3 Thu 10:30 H33

Role of Na in interconnection between chemical composition and electrical properties of grain boundaries in Cu(In, Ga)Se2 — •Azam Karami[1], Marcin Morawski[2], Heiko Kempa[2], Roland Scheer[2], and Oana Cojocaru-Mirédin[1] — [1]RWTH Aachen University, Aachen, Germany — [2]Martin-Luther-Universität Halle-Wittenberg, Halle, Germany

Nowadays, the polycrystalline Cu(In,Ga)Se2 thin-film solar cells have attained increased interest due to their lower costs and higher cell efficiency in energy conversion. These polycrystalline absorbers contain a large ratio of grain boundaries which can be detrimental (increase in recombination activity compared to the bulk), neutral (no change in electrical properties relative to grains) or benign (increase in electrical properties) for the cell performance. In the present work, different techniques such as atom probe tomography and electron backscattered diffraction are used to investigate different grain boundaries in order to illustrate the relation between the chemical composition and the electrical properties of the grain boundaries. It is shown that the elemental changes at the grain boundaries such as Cu depletion, In enrichment and segregation of alkali dopants like Na, can directly affect their beneficial behavior in favor of cell performance. The experimental findings prove the significant role of Na addition in improving the cell parameters such as open circuit voltage and fill factor. Although it is also shown that the excessive addition of Na dopant can have a detrimental effect on the cell efficiency by increasing the density of dislocations and interference of deep defects with dopants.

HL 27.4 Thu 10:45 H33

Electronic properties of the back contact in Cu(In,Ga)Se2 solar cells — Torsten Hölscher, Thomas Schneider, Merve Demir, Julia Horstmann, Melina Kristen, Heiko Kempa, and •Roland Scheer — Martin-Luther-Universität Halle/Wittenberg, Naturwissenschaftliche Fakultät II, Institut für Physik, Fachgruppe Photovoltaik, Von-Danckelmann-Platz 3, 06120 Halle/Saale

Cu(In,Ga)Se2 solar cells are interesting for single junction and multijunction (tandem) photovoltaic energy conversion. Although not being ideal, their back contact may exhibit a secondary junction. This is the case for low bandgap Cu(In,Ga)Se2 with a molybdenum back contact. Here, the secondary junction leads to a certain admittance step, a saturation in the Voc(T) plot, but has little impact on the device performance for thick Cu(In,Ga)Se2 layers: The barrier typically is small enough to allow for majority carrier transport and sufficiently far away from the main junction to impede minority carrier recombination. Only for ultrathin Cu(In,Ga)Se2 solar cells, the barrier can limit the device performance. For wide bandgap Cu(In,Ga)Se2 on molybdenum, the barrier appears to be even smaller. The situation is much less clear for Cu(In,Ga)Se2 on a transparent ITO back contact for tandem applications. For low bandgap Cu(In,Ga)Se2, no barrier is to be detected by admittance and Voc(T) experiments. For widegap Cu(In,Ga)Se2, the barrier formation in addition depends on the type of dopant. In this contribution, we used different experimental techniques in order to develop electronic models for opaque (Molybdenum) and transparent (ITO) back contacts.

HL 28: Organic Semiconductors 1

Time: Thursday 9:30–11:45 Location: H34

HL 28.1 Thu 9:30 H34

Dual-color organic LEDs for on demand activation and inhibition of cellular activity — •Giuseppe Ciccone[1], Ilenia Meloni[2], Rodrigo Gaston Fernandez Lahore[3], Hans Kleeman[1], Peter Hegemann[3], Karl Leo[1], and Caroline Murawski[2] — [1]Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and Institute for Applied Physics, Technische Universität Dresden, Dresden, Germany. — [2]Kurt-Schwabe-Institut für Mess- und Sensortechnik Meinsberg e.V., Waldheim, Germany — [3]Institute for Biology, Experimental Biophysics, Humboldt-Universität zu Berlin, Berlin, Germany

Optical stimulation of light sensitive proteins in neurons allows optogenetics to stimulate and probe cellular activity with high spatial and temporal resolution. Multiple light sources with different wavelengths are usually required to stimulate light-sensitive proteins that combine a cation-conducting and an anion-conducting channel. Here, we present two stacked OLED architectures that can emit light with two different emission colors from the same pixel, addressing the single domains of bidirectional ion channels expressed in Drosophila melanogaster larvae and ND7/23 cells with one single, organic device. Tuning of microcavities allowed us to well match the OLED emission spectra to the activation spectra of the combined photo-sensitive proteins BiPOLES and BiPOLES-ChRmine. Our work shows that OLEDs can provide narrowband light emission with minimal crosstalk between sub-pixels, enabling us to switch between optogenetic activation and inhibition of living systems with a single device.

HL 28.2 Thu 9:45 H34

Revealing the origin of short channel effects in organic electrochemical transistors — •Anton Weissbach[1], Hsin Tseng[1], Laurie E. Calvet[2], Hans Kleemann[1], and Karl Leo[1] — [1]Technische Universität Dresden, Germany — [2]Université Paris-Saclay-CNRS, Palaiseau, France

Organic electrochemical transistors (OECTs) emerged as promising building blocks for brain-inspired hardware. Several studies demonstrated the synaptic-like properties of OECTs. However, the fabrication of integrated hardware with OECTs is hampered by the nature of the electrolyte. In particular, liquid electrolytes are prone to evaporation and cover multiple devices. Here, we present an OECT with photopatternable solid electrolyte that we structure down to 10 micrometer resolution. The patternability of the electrolyte allows us to integrate OECTs in circuitry without crosstalk between devices. On the single-device-level, it exhibits an on-off ratio of 10^6, and a subthreshold swing of 61 mv/dec, close to the thermodynamic minimum.

Moreover, we show that these devices exhibit short channel effects, even at large channel lengths up to 100 micrometers. We reveal that the origin lies in the capacitive coupling of the drain electrode with the electrolyte. We then quantify and systematically study the strength of the coupling and show that it can be altered by the overlap of the semiconductor with the drain electrode. Our results reveal that the capacitive drain coupling can be more than 50 % compared to the gate coupling. Based on that, we provide a design principle for diminishing the detrimental short channel effect in OECTs.

HL 28.3 Thu 10:00 H34

Laser induced fluorescence spectroscopy of TIPS pentacene attached to rare gas cluster — •Michelbach Moritz, Demianenko Alexander, Hartweg Sebastian, and Stienkemeier Frank — Institute of Physics, University of Freiburg, Germany

In the recent years bis(triisopropylsilylethynyl (TIPS)) pentacene has gained interest in the field of singlet fission. Originally developed for field-effect transistors, the TIPS side groups of the pentacene lead to favourable intermolecular orientation, high hole mobility in thin films and better solubility in organic solvents [1]. We present a comparison study of the pentacene and its derivate, in which we cover the energetic structure of the excited states, the influence of the surrounding medium and the effect of neighbouring molecules. Especially the collective effects are investigated with a lifetime analysis and give a direct hint for lifetime reducing effects like superradiance and singlet fission [2], [3].

[1] Giri et. al., Nature 480, 504-508 (2011)
[2] Bohlen, M. et al., J. Chem. Phys. 156, 034305 (2022)
[3] Izadnia, S. et al.. J. Phys. Chem. Lett. 8, 2068*2073 (2017)

HL 28.4 Thu 10:15 H34

Heterostructure photodiodes of PbS nanocrystals with different types of ligands — •Shaimaa Abdalbaqi[1], Florian Grassl[1], Alexander Hofmann[1], Ahmed Mansour[2], Aladin Ullrich[1], Norbert Koch[2], Andreas Opitz[2], Marcus Scheele[3], and Wolfgang Brütting[1] — [1]Institut für Physik, Universität Augsburg, Germany — [2]Institut für Physik & IRIS Adlershof, Humboldt-Universität zu Berlin, Berlin, Germany — [3]Institut für Physikalische und Theoretische Chemie, Universität Tübingen, Tübingen, Germany

The influence of the ligands in coupled organic-inorganic nanostructures (COINs) on the performance of optoelectronic devices is investigated. We fabricate photodiodes based on pentacene and PbS nanocrystals coupled to organic ligands like 1,2-ethanedithiol (EDT) and tetrabutylammonium iodide (TBAI) and a combination of both as a heterostructure. These ligands were first separately used to fabricate a single ligand-type of organic-inorganic device and later compared with a heterostructure of PbS-EDT and PbS-TBAI. To tune the optical energy gap of COINs to align with the triplet level of pentacene, it was necessary to choose the suitable particle size. For this purpose, ultraviolet photo-emission spectroscopy (UPS) was used to determine the energy of the highest occupied molecular orbital (HOMO) and the work function of COINs. Devices with heterostructure COINs achieve a higher short circuit current than COINs with a single type of ligands. Incident photon to current efficiency (IPCE) shows different excitonic absorption peaks in the visible range for different stacks.

15 min. break

HL 28.5 Thu 10:45 H34

Development of an OLED as excitation light source for photocatalytic active materials — •Dominik Weber[1], Daniel Schondelmaier[1], Dietrich R.T. Zahn[2], Teresa Isabel Picoto Pena Madeira[2], Salvan Georgeta[2], and Annika Morgenstern[2] — [1]Westsächsische Hochschule Zwickau, Faculty of Physical Engineering and Computer Sciences/ Nanotechnology, Zwickau, Deutschland — [2]Technische Universität Chemnitz, Physics Department / Semiconductor Physics, Chemnitz, Deutschland

Since its first publication in 1987 by Tang and VanSlyke, organic light-emitting diodes (OLEDs) have been in the focus of science for more than 3 decades and have been continuously improved. Especially in the field of RGB OLEDs, substantial progress has been achieved in terms of lifetime and efficiency, which is why they are used today in particular in the display and solid-state lighting technology.

The work presented focuses on the optimization of UV-to-blue OLEDs for use as an illumination source and a source of excitation for photocatalytic active layers. Therefore, an OLED with a suitable characteristic (wavelength, lifetime, efficiency) is developed, by studying the influences of different materials, layer systems, and the integration of nanostructures. Additionally, the photocatalytic active layer titanium dioxide is generated and optimized (absorption behavior, effectiveness), which can be realized by thermally excited phase conversion. The relationship between photocatalytic activity and the phase composition will be investigated here.

HL 28.6 Thu 11:00 H34

Photoexcited charge carrier and spin dynamics in methylammonium lead bromide doped by magnetic transition metals — •Stanislav Bodnar[1], Jonathan Zerhoch[1,2], Andrii Shcherbakov[1,2], Shangpu Liu[1,2], Lissa Eyre[1], and Felix Deschler[1,2] — [1]Walter Schottky Institut, Physik Department, Technische Universität München, Garching, Germany — [2]Heidelberg University, Heidelberg, Germany

One of the most challenging tasks for LED applications is emitting 100% polarized light from the device. Typically, this is achieved by introducing an additional layer of polarization filter which leads to losing half of the light intensity. To overcome this issue, one has to find a system with a high degree of photoluminescence (PL) polarization. A promising approach here is using magnetic metal doping in combination with a highly efficient semiconductor. We have chosen to use transient absorption (TA) spectroscopy at cryogenic temperatures to

investigate changes in the optical properties induced by magnetic metal doping in CH3NH3PbBr3 since it gives spectral information about the energies of electronic states and dynamic properties of the photoexcited carriers. We find a change in the main ground state bleach (GSB) peak position in doped CH3NH3PbBr3, which depends on the transition metal used. The main GSB peak of pure CH3NH3PbBr3 at 4 K is at 2.32 eV. Doping CH3NH3PbBr3 with Mn leads to a shift of the main peak to lower energies by 0.04 eV and 0.08 eV, respectively. The modifications of the TA spectra are associated with changes in the bandgap energy, which is the result of doping-induced lattice expansion.

HL 28.7 Thu 11:15 H34

Ultrastrong light-matter interaction of J-aggregated squaraine in an open cavity for polariton lattices — •Christoph Bennenhei[1], Lukas Lackner[1], Moritz Gittinger[1], Heiko Knopf[2], Falk Eilenberger[2], Jennifer Zablocki[3], Arne Lützen[3], Christoph Lienau[1], Martin Silies[1], Martin Esmann[1], and Christian Schneider[1] — [1]Institute of Physics, University of Oldenburg — [2]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, Jena — [3]Kekulé Institute of Organic Chemistry and Biochemistry, University of Bonn

Organic molecule exciton-polaritons in artificial lattices are an emerging platform to emulate complex electronic Hamiltonians at ambient conditions. We present J-aggregated squaraine dye (SQ) thin films [1] as a promising candidate for exciton-polaritons in optical cavities due to its high oscillator strength and tunable resonance. Using white light reflection spectroscopy, we demonstrate tunable ultrastrong coupling of light to the SQ thin film in an open cavity at room temperature [2], which we support by transfer matrix calculations. In ongoing experiments, we introduce structured photonic lattices to the open cavity to investigate the coupling of the polaritons to tailored potential landscapes.

[1] M. Schulz, et al., Nat Commun 9, 2413 (2018).
[2] L. Lackner, et al., Nat Commun 12, 4933 (2021).

HL 28.8 Thu 11:30 H34

Exploring the Device Physics of Photomultiplication in Organic Photodetectors — •Louis Conrad Winkler, Jonas Kublitski, Johannes Benduhn, and Karl Leo — TU Dresden, Germany

Recently, photomultiplication (PM) in organic photodetectors has been achieved, but working mechanism and physics are not fully understood. Contrary to inorganic photodiodes, impact ionization and avalanche breakdown cannot be achieved in organic semiconductors. Instead, the accumulation of one charge carrier type close to an electrode leads to a strong energy level bending, which increases the tunnelling probability of the opposite charge carrier type under reverse bias from the metal contact into the device. In this contribution, we investigate the well-known donor-acceptor system ZnPc:C60, using the acceptor as an electron trapping state to inject holes into the donor phase. Since the effective electron mobility is strongly decreased, we investigate whether shifting the generation location influences the device operation, e.g. the response speed and external quantum efficiency. Furthermore, a gradient donor-acceptor mixing ratio is introduced to increase both response speed and free charge carrier generation efficiency via an enlarged donor-acceptor interface. We also investigate the effect of trapping time being larger than the carrier transit time, leading to reduced cut-off frequencies.

HL 29: 2D Materials: Graphene

Time: Thursday 9:30–11:00 Location: H36

HL 29.1 Thu 9:30 H36

Twist angle engineering of proximity exchange in graphene/$Cr_2Ge_2Te_6$ bilayers — •Klaus Zollner and Jaroslav Fabian — Institute for Theoretical Physics, University of Regensburg, 93053 Regensburg, Germany

Van der Waals heterostructures composed of twisted monolayers promise great tunability of electronic, optical, and magnetic properties. The most prominent example is twisted bilayer graphene, exhibiting magnetism and superconductivity due to strong correlations [1]. In addition, twistronics has already demonstrated its potential in tuning proximity spin-orbit coupling in graphene/TMDC heterostructures [2]. In this talk, we present the twist-angle and gate dependence of the proximity exchange coupling in graphene/$Cr_2Ge_2Te_6$ bilayers from first principles [3]. The proximitized Dirac band dispersions of graphene show a continuous tunability of the ferromagnetic exchange from 4 to −4 meV, when twisting from 0° to 30°. Remarkably, at 19.1° the induced exchange coupling becomes even antiferromagnetic. Further tuning is provided by a transverse electric field and the interlayer distance.

This work was supported by DFG SFB 1277, DFG SPP 2244, and the EU Horizon 2020 Research and Innovation Program (Graphene Flagship).

[1] X. Lu *et al.*, Nature 574, 653 (2019). [2] T. Naimer *et al.*, Phys. Rev. B 104, 195156 (2021). [3] K. Zollner and J. Fabian, arXiv:2108.03984 (2021).

HL 29.2 Thu 9:45 H36

Direct observation of ultraclean tunable band gaps in bilayer graphene — •Eike Thomas Icking[1,2], Luca Banszerus[1,2], Philipp Schmidt[1,2], Corinne Steiner[1,2], Frederike Wörtche[1], Frank Volmer[1], Stephan Engels[1,2], Jonas Hesselmann[1], Matthias Goldsche[1,2], Kenji Watanabe[3], Takashi Taniguchi[4], Christian Volk[1,2], Bernd Beschoten[1], and Christoph Stampfer[1,2] — [1]RWTH Aachen University, Germany — [2]Forschungszentrum Jülich, Germany — [3]Research Center for Functional Material, Japan — [4]International Center for Materials Nanoarchitectonics, Japan

Control over the charge carrier density and the band gap size of a semiconductor paves the way for a wide range of applications, such as highly-tunable transistors, photodetectors, and lasers. Bernal-stacked bilayer graphene (BLG) allows tuning the band gap by an out-of-plane electric displacement field. The first evidence of this unique band gap tunability was found ten years ago, but it took until recently to fabricate sufficiently clean heterostructures to use the band gap to suppress electric current or confine charge carriers. We present a detailed study of the tunable band gap in gated BLG characterized by temperature-activated transport and finite-bias spectroscopy measurements. The latter method allows comparing different gate materials and device technologies that directly affect the effective disorder potential. We show that in graphite-gated BLG there are as good as no sub-gap states resulting in ultraclean band gaps with values in good agreement with theory, allowing to achieve band gaps up to 120 meV.

HL 29.3 Thu 10:00 H36

Domain determination of rhombohedral multilayer graphene devices for magnetotransport measurements — •Christian Eckel, Anna Seiler, Francesca Falorsi, Niklas Kohlrautz, and Thomas Weitz — 1. Physikalische Institut, Universität Göttingen, Friedrich-Hund Platz 1 37077 Göttingen

Graphene as the most prominent example of a 2D-material exhibits relatively different electronic band properties compared to its bulk counterpart. For monolayer, bi-layer or tri-layer the electronic properties have already been explored by multiple groups in the past. However, studies on higher layer number rhombohedral graphene (5 layers in this work) with respect to magnetoelectrical transport measurement are still pending. Finding and determining the rhombohedral domains in mechanically exfoliated flakes is the first bottleneck in the fabrication procedure. Raman spectroscopy is a well-established technique for layer number determination but often lacks a high lateral resolution. Kelvin-probe-force- microscopy (KPFM) allows a lateral resolution of the domains where the different stackings exhibit a distinguishable 15meV work function difference. Additionally, a cryogenic scanning near field optical microscopy (Cryo-SNOM) allows to depict the domains in a temperature dependent manner. The combination of all measurements will be discussed on the poster. A second challenge is the fabrication process of high quality devices for magnetotransport measurements in the milli Kelvin regime. Therefore, encapsulation in hexagonal Boron Nitride (hBN) together with graphite contacts and gates are necessary.

HL 29.4 Thu 10:15 H36

All-optical modulation of third harmonic generation in graphene — •Omid Ghaebi[1], Sebastian Klimmer[1], Habib Rostami[2], and Giancarlo Soavi[1] — [1]Institute of Solid-State Physics, Friedrich Schiller University, Jena, Germany — [2]Nordita, KTH Royal Institute of Technology and Stockholm University, Sweden

Graphene is a unique platform for non-linear optics thanks to its linear band dispersion that allows gate tunable resonant light-matter interactions [1]. While the gate tunability of THG have been investigated in recent years [1], less is known about the possibility to realize all-optical nonlinear modulators, which could provide higher modulation speed (THz) compared to electrical modulators (GHz) [2]. In this work, we show all-optical TH modulation in graphene at different values of the Fermi level and with a modulation depth up to 85%. First, we demonstrate that it is possible to actively control the THG recombination dynamics by tuning the graphene Fermi level. This is due to phase-space filling and quenching of the scattering between hot electrons and optical phonons [3]. In addition, we reveal the interplay between TH modulation due to increase in the electronic temperature and due to Pauli blocking at different values of the Fermi level. This work offers new insights for the understanding of TH all-optical modulation and thus for the realization of ultrafast frequency converters and nonlinear modulators. [1] Soavi, G. et al. Nature Nanotechnology 13, 583-588 (2018). [2] Cheng, Y. et al. Nano Letters 20, 8053-8058 (2020). [3] Pogna, E. A. et al. ACS Nano 15, 11285-11295 (2021).

HL 29.5 Thu 10:30 H36

Anisotropic transport in 1D graphene superlattices — •Julia Amann[1], Kenji Watanabe[2], Takashi Taniguchi[2], Dieter Weiss[1], and Jonathan Eroms[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Regensburg, Germany — [2]National Institute for Materials Science, Tsukuba, Japan

One-dimensional superlattices (1DSL) in graphene were predicted to show intriguing effects, such as anisotropy in transport, additional Dirac points and a distorted Fermi contour. In contrast to two-dimensional graphene superlattices, which have been widely studied, only very few experiments on graphene 1DSLs have been reported. We use a patterned few-layer graphene gate underneath an encapsulated monolayer graphene to create a 1DSL. With the combined action of a global silicon backgate and the patterned bottom gate we are able to control superlattice potential strength and charge carrier density independently. We show low temperature transport measurements on a gate tunable 1DSL in graphene with a period of 50 nm in directions parallel and perpendicular to the modulation as we use an L-shaped Hall bar. The typical Dirac cone shape gets distorted, and we observe anisotropic transport in x and y direction. We observe the emergence of multiple Dirac points in modulation direction due to band flattening with increasing superlattice potential. These extra Dirac points are represented as additional Landau fans in magnetotransport. Further, Weiss oscillations can be observed which confirm the 1D superlatice modulation and the anisotropy.

HL 29.6 Thu 10:45 H36

Topological Phenomena in Self Assembled Folded Graphene — •Lina Bockhorn[1], Sung Ju Hong[2], Bei Zheng[1], Johannes C. Rode[1], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Division of Science Education, Kangwon National University, Chuncheon, 24341, Republic of Korea

The stacking- and folding angle of 2D materials to 3D structures has emerged as an important, novel tuning parameter for the tailoring of optical, mechanical, electronic and magnetic properties. Here, we investigate the final interlayer configurations of self-assembled folded graphene structures generated via atomic force microscopy technique [1, 2] and its electronic properties [3, 4].

Self-assembled folded graphene shows not only the typical electronic properties of twisted graphene layers but also phenomena due to the folded region [3, 4]. In our magnetotransport measurements, we observe e.g. an additional peak next to the charge neutrality peak which is independent of the magnetic field. This peak at a certain charge carrier density is attributed to the compressive strain due the folded edge [3].

[1] J. C. Rode et al., 2D Mater. 6, 015021 (2018)
[2] L. Bockhorn et al., Appl. Phys. Lett. 118, 173101 (2021)
[3] S. J. Hong et al., 2D Materials, 8, 045009 (2021)
[4] S . J. Hong et al., Phys. Rev . B, 105, 205404 (2022)

HL 30: Poster 2

Topics:
- Materials and devices for quantum technology
- Nitrides: Devices
- Nitrides: Preparation and characterization
- Oxide semiconductors
- Perovskite and photovoltaics
- Ultra-fast phenomena

Time: Thursday 11:00–13:00 Location: P3

HL 30.1 Thu 11:00 P3

NV$^-$ center in the vicinity of linear defects in diamond — •Reyhaneh Ghassemizadeh[1], Wolfgang Krörner[1], Daniel Urban[1], and Christian Elsässer[1,2] — [1]Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstr. 11, 79108 Freiburg, Germany — [2]University of Freiburg, Freiburg Materials Research Center (FMF), Stefan-Meier-Straße 21, 79104 Freiburg, Germany

The NV$^-$ center is a point-defect complex in the diamond crystal with an excellent potential for implementing qubits in future quantum computing hardware. However, the structuring of point defects on the atomic scale remains an experimental challenge. Here we study theoretically the interaction between dislocations and the NV$^-$ center. We evaluate to which extent dislocation lines that are naturally present in the diamond crystal may be used for structuring NV$^-$ center as a first step towards a NV-based quantum register. Using density functional theory (DFT) we model NV$^-$ centers in the vicinity of the most common dislocations in diamond and calculate the defect formation energy, structural geometry, defect levels and zero-field (ZFS) parameters. Our simulations reveal that dislocations potentially trap the NV$^-$ with an energy release of up to 3 eV. Although the analysis of geometry, defect levels and ZFS parameters of NV$^-$ centers being close to dislocations in general show strong deviations from their values in the perfect bulk structure, the lowest energy configuration of a NV$^-$ center at the reconstructed dislocation cores have ZFS values with less than 5% deviation from their NV$^-$ bulk values. Our results opens new insights for the design of NV-based quantum computing devices.

HL 30.2 Thu 11:00 P3

Quantifying Quantum Coherence in Polariton Condensates — •Carolin Lüders[1], Matthias Pukrop[2], Elena Rozas[1], Christian Schneider[3], Sven Höfling[4], Jan Sperling[5], Stefan Schumacher[2,6], and Marc Assmann[1] — [1]Experimentelle Physik 2, TU Dortmund, Germany — [2]Department of Physics and Center for Optoelectronics and Photonics Paderborn (CeOPP), Universität Paderborn, Germany — [3]Institute of Physics, University of Oldenburg, Germany — [4]Technische Physik, Physikalisches Institut and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Germany — [5]Integrated Quantum Optics Group, Institute for Photonic Quantum Systems (PhoQS), Paderborn University, Germany — [6]Wyant College of Optical Sciences, University of Arizona,

USA

We theoretically and experimentally investigate quantum features of an interacting light-matter system from a multidisciplinary perspective, unifying approaches from semiconductor physics, quantum optics, and quantum information science. As an example of a hybrid light-matter interface, we drive a polariton microcavity across the condensation threshold and observe the transition from an incoherent thermal state to a coherent state in the emission. By analyzing the phase-space distributions of the emitted light, we quantify the amount of quantum coherence that results from the quantum superposition of Fock states, constituting a measure of the resourcefulness of the produced state for modern quantum protocols.[1]

[1] C. Lüders et al., PRX Quantum 2, 030320 (2021)

HL 30.3 Thu 11:00 P3

Machine Learning enhanced in-situ electron beam lithography of photonic nano-structures — •Jan Donges, Marvin Schlischka, Ching-Wen Shih, Monica Pengerla, Imad Limame, Johannes Schall, Lucas Rickert, Sven Rodt, and Stephan Reitzenstein — Technische Universitaet Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The unique in-situ electron beam lithography (iEBL) nanotechnology concept enables us to embed single quantum emitters into photonic nano-structures with a 34nm precision. To obtain the fitted position of the quantum emitter with high accuracy, the signal-to-noise ratio of their catholuminescence (CL) needs to be well above unity even for ms integration times. Here we show that for samples with dark quantum emitters, such as telecom quantum dots or low planar photon-extraction efficiency, machine learning (ML) is very well suited to drastically improve the performance of iEBL at low CL intensities. The machine learning software utilizes computer algorithms, which were trained through data samples to denoise data with a barely visible quantum dot emission. We present experimental results for InGaAs quantum dots, which could be successfully embedded into circular Bragg grating structures with the assistance of machine learning. Our experimental results yield that by using ML, the CL sensitivity and the alignment accuracy could be increased by more than an order of magnitude compared to standard iEBL.

HL 30.4 Thu 11:00 P3

Photon propagation between quasinormal mode cavities — •Robert Fuchs, Sebastian Franke, Andreas Knorr, and Marten Richter — Technische Universität Berlin, Berlin, Germany

Quasinormal modes (QNMs) provide a useful and intuitive way to define modes for open cavities. They have been utilized for a variety of problems both in classical electrodynamics, and recently used in a fully quantized description for three dimensional geometries.

We show that a multi-cavity extension of the QNM quantization is possible if the cavities are far away from each other so that retardation effects are important. However, this quantization approach leads to a set of non-bosonic operators with a continuous spectrum. In the multi-cavity theory, this continuum serves as a bath which can be used to describe photon propagation between the separately quantized cavities.

Using a fourth-order Nakajima-Zwanzig equation, we point out how to get equations of motion for the system density matrix that include dissipation as well as inter-cavity transfer terms with significant retardation delays described by microscopic QNM parameters.

HL 30.5 Thu 11:00 P3

Sionludi - A table-top dilution refrigerator — •Viktor Adam, Alexander Zilz, and Wolfgang Wernsdorfer — KIT, Wolfgang-Gaede-Str. 1, 76131 Karlsruhe

Dilution cryostats are the only technology that provides continuous cooling performance from room temperature down to several mK. These devices utilize the endothermic process of diluting liquid He^3 into liquid He^4, which occurs even at 0 K. By evaporating He^3 from this mixture and returning it to the mixing chamber, the refrigerator can be operated continuously.

The Sionludi dilution refrigerator is a unique platform for low-temperature research. The table-top design combined with its small dimensions of approximately 25 cm in diameter and 50 cm in height allow for comfortable mounting of experiments and periphery to the cryostat. The key advancement of this cryostat is the fast injection line, which allows direct cooling of the dilution stage of the cryostat by the circulation of 4 K cold mixture during precooling without affecting the operation at lowest temperatures. As a result, the Sionludi features fast cool-down and warm-up times of less than 3 and 1.5 hours, respectively, while providing cooling powers of up to 200 μW at 100 mK as well as base temperatures of below 20 mK. The fast turnaround time can accelerate sample throughput and thus progress in many research applications such as quantum sensing or quantum computing.

HL 30.6 Thu 11:00 P3

Telecom-band single photons from functionalized carbon nanotubes coupled to a an open cavity — •Lukas Husel[1], Julian Trapp[1], Xiaojian Wu[2], Manuel Nutz[3], Thomas Hümmer[3], YuHuang Wang[2], David Hunger[4], and Alexander Högele[1,5] — [1]Ludwig-Maximilians-Universität, 80539 München — [2]University of Maryland, 20742 Maryland, USA — [3]Qlibri GmbH, 80337 München — [4]Karlsruher Institut für Technologie, 76131 Karlsruhe — [5]Munich Center for Quantum Science and Technology, 80799 München

Quantum light at telecom wavelengths is of fundamental relevance in science and technology. A promising room temperature source of telecom single photons are functionalized carbon nanotubes (CNTs). In this system, dephasing and spectral diffusion limit spectral purity and indistinguishability of the generated photons, which can in principle be overcome by coupling the emitters to a cavity. Here, we demonstrate spectrally narrow single photon emission at wavelengths around 1460 nm from single CNT defects coupled to a fiber-based Fabry-Pérot resonator. We operate the cavity at ambient conditions and in the regime of low Purcell enhancement. By changing the cavity length, we tune the emission wavelength over a range of tens of nm, and the power spectral density by a factor of six. The coherence time of the generated photons matches the cavity linewidth, which constitutes an increase compared to the expected dephasing-limited free-space linewidth. Our results represent a step towards CNT-based sources of telecom-band single photons with high purity and indistinguishability.

HL 30.7 Thu 11:00 P3

Bright Electrically Controllable Quantum-Dot-Molecule Devices Fabricated by In Situ Electron-Beam Lithography — •Johannes Schall[1], Marielle Deconinck[1], Nikolai Bart[2], Matthias Florian[3], Martin von Helversen[1], Christian Dangel[4], Ronny Schmidt[1], Lucas Bremer[1], Frederik Bopp[4], Isabell Hüllen[3], Christopher Gies[3], Dirk Reuter[5], Andreas D. Wieck[2], Sven Rodt[1], Jonathan J. Finley[4], Frank Jahnke[3], Arne Ludwig[2], and Stephan Reitzenstein[1] — [1]IFKP, TU Berlin, Germany — [2]LS AFP, Ruhr-Universität Bochum, Germany — [3]ITP, University of Bremen, Germany — [4]WSI, TU München, Germany — [5]Department Physik, Universität Paderborn, Germany

In quantum repeater networks it is of central importance to temporarily store and retrieve quantum information. Concepts based on quantum dot molecules (QDMs) promise storage times in excess of 1 ms. To make use of QDM based quantum memories, efficient coupling to flying qubits needs to be realized while maintaining precise electrical control. We report on the development of electrically tunable single-QDM devices with strongly enhanced broadband photon extraction efficiency. The quantum devices are based on stacked quantum dots in a pin-diode structure underneath a deterministically defined circular Bragg grating using in situ electron beam lithography. We determine the photon extraction efficiency, demonstrate bias voltage dependent spectroscopy and measure excellent single-photon emission properties. The metrics make the developed QDM device an attractive building block for use in future photonic quantum networks.

HL 30.8 Thu 11:00 P3

Machine Learning-Based Optimization of Chiral Photonic Nanostructures: Evolution- and Neural Network-Based Designs — Oliver Mey[1], •Manan Shah[2], and Arash Rahimi-Iman[2] — [1]Fraunhofer IIS/EAS, Fraunhofer Institute for Integrated Circuits, Division Engineering of Adaptive Systems, Dresden — [2]I. Physikalisches Institut und Zentrum für Materialwissenschaften, Justus-Liebig Universität Gießen, D-35392, Germany

Machine learning (ML) techniques such as deep learning (DL) and evolutionary algorithms (EA) exhibit unprecedented capabilities in the scientific ML realm. DL uses artificial neural networks to infer unintuitive solutions for complicated design requirements and specific functionalities. Likewise, the EA attempts to find the optimized solution by utilizing principles such as mutation of parameters and extinction of less promising solutions. These approaches are faster and more effective in the inference of nanostructure design parameters for desired properties, such as wavelength coverage and peculiar response func-

tions, compared to conventional numeric simulations.

We present a nano-patterned GaP dielectric substrate that favors single-handed circularly polarized light (CPL) in reflection or transmission [1]. The optimization in chiral dichroism (CD) by neural networks is compared with the evolutionary algorithm. The increased CD in simulated spectra for designs with stronger reflectivity of right CPL and lower transmissivity of left CPL makes the ML techniques effective to optimize a myriad of properties for metamaterials and photonic nanostructures. [1] Phys. Status Solidi RRL 2022, 16, 2100571.

HL 30.9 Thu 11:00 P3

Strain-tunable GaAs quantum dot-based circular Bragg gratings towards entangled photon pairs with high indistinguishability — •Chenxi Ma[1], Jingzhong Yang[1], Constantin Schmidt[1], Xin Cao[1], Yiteng Zhang[1], Maximilian Heller[1], Jürgen Becker[2], Eddy P. Rugeramigabo[1], Michael Zopf[1], and Fei Ding[1,3] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Germany — [2]Institut für Mikroproduktionstechnik, Leibniz Universität Hannover, Garbsen, Germany — [3]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Hannover, Germany

The on-demand generation of bright entangled photon pairs is an attractive goal for the realization of quantum communication networks. Epitaxial GaAs quantum dots (QDs), grown via local droplet etching and nanohole infilling, are promising candidates because they are symmetric and strain-free. This leads to small exciton fine structures and high entanglement fidelities of photons emitted from the biexciton-exciton cascade. However, the photon indistinguishability is intrinsically limited in this scheme. GaAs QDs also suffer from inefficient photon extraction, which was addressed by embedding QDs in circular Bragg gratings. Here, we propose to engineer the cavity mode to match the biexciton transition with the assistance of strain-tuning techniques. The resulting asymmetric Purcell enhancement will increase the decay rate of the biexciton transition and consequently improve the photon indistinguishability. This heterogeneous photonic nanostructure can serve as a blueprint for future quantum communication devices.

HL 30.10 Thu 11:00 P3

GaAs heterostructures for coupling of spin qubits to self-assembled quantum dots — •Selma Delić[1,2], Priyabrata Mudi[1,2], Sebastian Kindel[2], Paola Atkinson[3], Detlev Grützmacher[1], and Beata Kardynał[1,2] — [1]Peter Grünberg Institute 9, Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52074 Aachen, Germany — [3]Institut des Nano Sciences de Paris, CNRS UMR 7588, Sorbonne Université, 75005 Paris, France

Operation of quantum networks relies on encoding qubits on photons. These photons can be converted into spin qubits in many material systems. Yet, in order to take full advantage of the electrons with information encoded in their spins, the spin qubits should be scalable or the spin should be transferred to spin qubits that can be scaled into quantum processors. Here, we use singlet-triplet (S-T) qubits defined in a GaAs/AlGaAs gate-defined quantum (double-) dot (GDQD) as a scalable qubit. While GaAs is suitable for a qubit exchange with photons due to its direct bandgap, the GDQD does not confine holes. Therefore, we use a GaAs droplet dot (QD) to achieve a coherent transfer of information between a photon and a spin of an electron before the electron is transferred to the S-T qubit. In this contribution, we show the design of heterostructure that can be used to fabricate S-T qubit coupled to epitaxial GaAs QD. We further report on the progress in optical and electrical characterisation of the device in gated structures aligned to the GaAs QD.

HL 30.11 Thu 11:00 P3

GaN/AlGaN/GaN solution gate field effects transistors as pH- and enzymatic sensors — •Genrietta Steingelb, Alexander Hinz, Stephan Figge, and Martin Eickhoff — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, 28359 Bremen, Germany

A GaN/AlGaN/AlGaN-heterostructure solution gate field effect transistors (SGFETs) as pH-sensors will be presented. We discuss the performance of differential sensors realized by one SGFET with passivated gate and one with a bare GaN cap layer as a gate on one chip. The compensation of drift-effects such as like persistent photocurrent and temperature dependence will be discussed.

We have used such devices to study the time-dependent response of covalently immobilized enzymes on the gate surface towards the presence of their specific substrate molecules with acetylcholinesterase and penicillinase as examples.

HL 30.12 Thu 11:00 P3

Impact of GaN barrier thickness on indium incorporation in GaInN/GaN multiple quantum wells grown via MBE — •Farouk Aljasem, Heiko Bremers, Uwe Rossow Rossow, and Andreas Hangleiter — Institut für Angewandte Physik & Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Germany

The internal quantum efficiency (IQE) of optical devices based on GaInN is highly sensitive to the thickness of GaInN quantum well. The main way to increase the emission wavelength of GaInN quantum wells is to increase the indium content in the quantum well by enhancing the incorporation rate of indium. We grew fivefold GaInN MQWs at a substrate temperature of 580°C and the GaN barrier layer was grown in two steps. The first step is at the same growth temperature of GaInN quantum wells (580°C), called the low-temperature GaN (LT-GaN) layer and the second step is the high-temperature GaN (HT-GaN), which was grown after the ramping of the substrate temperature up to 725°C. From high-resolution XRD and high-resolution TEM measurements, we found that the thickness of the GaInN wells increased significantly with the increase of the growth time of the LT-GaN layer. The effects of changing the growth time of the LT-GaN layer include changing the indium content of the GaInN well and the thickness of the barrier layer. The analysis of GaInN/GaN MQWs samples using different characterization methods such as HR-XRD, HR-TEM, AFM, and PL provides a detailed understanding of the role of the indium adlayer and its impact on the growth mechanism at low temperatures.

HL 30.13 Thu 11:00 P3

Aging of GaN-based laser diodes investigated by micro-EL and micro-PL spectroscopy — •Lukas Uhlig[1], Conny Becht[1], Erik Freier[2], Ji-Hye Kang[2], Veit Hoffmann[2], Christoph Stölmacker[2], Sven Einfeldt[2], and Ulrich T. Schwarz[1] — [1]Institut für Physik, Technische Universität Chemnitz, 09126 Chemnitz, Germany — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

For the work towards long-time reliable GaN-based ridge waveguide laser diodes it is essential to understand the specific degradation effects that occur after some time of operation. Among the reported aging mechanisms are the generation of point defects in the active layer and a decrease in p-side conductivity.

To clarify this, we compare a previously stressed device with a similar but unstressed laser diode using micro-electroluminescence (EL) and confocal micro-photoluminescence (PL) spectroscopy. The devices are mounted p-side-down and the metal layer on the n-side is polished away to allow optical characterization in the plane of the quantum wells.

In contrast to the homogeneous EL-emission from the non-stressed device, the stressed laser diode exhibits bright and dark areas along the ridge on the scale of few 10 μm. The systematic correlation of high intensity with a spectral blue-shift and vice versa indicates local changes in the charge carrier density that we attribute to inhomogeneous electrical pumping. The micro-PL-measurements show an increased defect density in the active region.

HL 30.14 Thu 11:00 P3

Spectral and temporal behavior of the near field of 10 μm broad area blue laser diodes — •Dominic J. Kunzmann[1], Lukas Uhlig[1], Jannina J. Tepass[1], Anna Kafar[2,3], Szymon Stanczyk[2,3], Piotr Perlin[2,3], and Ulrich T. Schwarz[1] — [1]University of Technology Chemnitz, 09126 Chemnitz, Germany — [2]Institute of High Pressure Physics PAS, Warsaw, Poland — [3]TOPGAN Ltd., Warsaw, Poland

We investigate the near field for the laser diodes driven in pulsed conditions with pulse lengths in the range of a few 10 ns up to 100 ns and currents from 1.5 I_{th} to 4 I_{th}. A streak camera image and a high resolved longitudinal mode spectrum are taken at each point of a near field scan for blue laser diodes with a 10 μm broad ridge.

The combination of the streak camera setup and the high resolution spectrometer allows us to investigate: the spectral-lateral-temporal behavior with complex dynamics due to lateral-longitudinal mode competition, the wavelength shift at the lasing onset and on the other hand to get the longitudinal mode spectrum. Different mode combs are interacting in this longitudinal mode spectrum and the predominating mode comb changes for different parts of the spectrum.

An increasing laser current leads to a broadening of the spectrum as well as to the filling of the gain volume, while for higher currents the lateral distribution seems to be similar across the whole spectrum. Comparing these results to previously measured devices with a 40 μm broad ridge, we observe a less homogeneous near field distribution with a slight systematic asymmetry.

HL 30.15 Thu 11:00 P3

Molecular beam epitaxy of ScGaN on 6H-SiC — •Aaron Giess, Fabian Ullmann und Stefan Krischok — Institut für Mikro und Nanotechnologien, Institut für Physik, TU Ilmenau

Group III-nitrides are well-suited semiconductors for optoelectronic and sensor devices. Among them, Sc-containing nitrides are of recent interest as well. In this contribution we report on our present progress in ScGaN PAMBE growth. We grow ScGaN using plasma-assisted molecular beam epitaxy on Si-faced 6H-SiC. Prior growth the SiC-surface is cleaned by a HF-Dip and a gallium anneal. Compared to GaN growth the implementation of scandium poses significant challenges: (i) ScN inclines to cubic growth and (ii) Gallium tends to form liquid droplets. In order to find optimal growth conditions, parameters such as substrate-temperature and nitrogen as well as Sc and Ga flux have been systematically varied. During growth, reflection high-energy electron diffraction (RHEED) diffraction patterns have been monitored. Further characterization has been performed by X-Ray photoelectron spectroscopy (XPS) and scanning electron microscopy (SEM). In future we plan systematic studies on the electronic properties of high quality epitaxial ScGaN thin films as well as their interaction with molecules.

HL 30.16 Thu 11:00 P3

MOVPE-grown optoelectronic devices with GaN:Mg/GaN:Ge tunnel junctions — •Christoph Berger, Armin Dadgar, Jürgen Bläsing, Gordon Schmidt, Hannes Schürmann, Peter Veit, Frank Bertram, Jürgen Christen, and André Strittmatter — Otto-von-Guericke-Universität Magdeburg, Deutschland

We report on low resistive GaN-based tunnel junctions (TJ) and TJ optoelectronic devices grown by metalorganic vapor phase epitaxy. Very high donor concentrations, which are mandatory for low-resistive TJs, are achieved by using germanium instead of commonly used silicon. For efficient activation of GaN:Mg, a growth process was developed that includes an in-situ activation step and overgrowth of the p-type GaN with GaN:Ge in nitrogen ambient to prevent the repassivation of the buried p-type layer. Electrical and optical characterization of the fabricated LEDs shows that GaN:Mg is efficiently activated and additional ex-situ activation is expendable. Tunnel-junction LEDs show an improved light output by approximately 20 % in comparison to conventional LEDs with semitransparent contacts and exhibit a comparable differential resistance of 1.2x10^{-2} Ωcm^2 at a current density of 100 Acm^{-2} without voltage penalty. Such tunnel-junctions were implemented in laser diode structures and were used to realize cascaded LEDs with up to three pn-junctions stacked on top of each other. We will present our latest results on the growth, the challenges and the characteristics of these sophisticated optoelectronic devices.

HL 30.17 Thu 11:00 P3

object detection of patterned GaN using convolutional neural networks and synthetic data — •Mahdi Khalili Hezarjaribi, Uwe Rossow, Markus Etzkorn, Heiko Bremers, and Andreas Hangleiter — Institut für Angewandte Physik, Technische Universität Braunschweig

Employing a practical object detection algorithm, we have developed a process to detect GaN pyramid structures, extracted from SEM images. A procedure has been developed to generate synthetic images for training the algorithm instead of the drudgery of multiple imaging of samples. These synthetic data include noise, blurring, and other contributing factors in order to realize images that are accurate enough to train an object detection algorithm. A MobileNet algorithm has been employed for the Object detection process. The synthetic database proved pragmatic leading to a promising confidence value of 75% for detecting real objects.

HL 30.18 Thu 11:00 P3

Nominally identical GaInN/GaN single quantum wells : variations of optical and structural properties — •Rodrigo De Vasconcellos Lourenco[1,2], Malte Schrader[1,2], Uwe Rossow[1], Heiko Bremers[1,2], and Andreas Hangleiter[1,2] — [1]Institute of Applied Physics, Technische Universität Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Braunschweig, Germany

We have unexpectedly observed differences in luminescence and structural properties in GaInN/GaN single quantum wells (SQW), grown under nominally identical conditions. This may be related to specific growth condition such as variation in substrate temperature or doping level; or substrate characteristics, e.g. bowing and offcut; as well as the status of the growth system. The samples were grown in low-pressure metalorganic vapour-phase epitaxy (MOVPE) on c-plane sapphire substrate. The differences in emission wavelength of the SQWs suggest that either there is a discrepancy in In content or in doping level. From the reference multiple quantum wells samples, a variation of 5 % in In concentration was observed. This fluctuation in In content may explain variations in the lattice constants of the SQWs measured by high-resolution X-ray diffraction (HRXRD). We aim to understand how the In content and among other attributes could influence the internal quantum efficiency at room temperature of GaInN/GaN SQWs ranging from 0.6 to 47%.

HL 30.19 Thu 11:00 P3

Skull-melting technique for the crystal growth of high-melting oxides — •Demian Ranftl, Klaus-Dieter Luther, and Cornelius Krellner — Physikalisches Institut, Goethe-Universität Frankfurt, 60438 Frankfurt/Main, Germany

For growing high melting oxide single crystals a quasi crucible-free induction melting technique can be used. Within a so-called skull-oven a high frequency electric field is applied to a powdered sample. A metallic part in the center of the powder will absorb the field and increase in temperature while also increasing the temperature of the oxides surrounding it. By cooling the outer sections of the sample it is possible to create a melt of a semiconductor in a crucible made out of its own sintered material, thus avoiding integration of unwanted crucible elements and enabling melts even at temperatures where no crucible material exist. This method was developed for the growth of, for example, ZrO_2 crystals with a melting temperature of 2700°C [1]. In this contribution we will present the working principles of the skull-oven built at the Physikalisches Institut (Goethe Universität, Frankfurt) together with a brief introduction to skull-melting and its features. Additionally, we will present first attempts of the single crystal growth of pure titanium(IV) oxide using this skull-melting technique.
[1] Assmus, W. and Whippey, N. Ueber das Skull-Schmelzen. Chem.-Ing.-Tech. 55, 716-717 (1983).

HL 30.20 Thu 11:00 P3

Investigation into the electric properties of α-Ga_2O_3 based Schottky diodes with various Schottky metals — •S. Köpp, C. Petersen, H. von Wenckstern, and M. Grundmann — Universität Leipzig, Felix Bloch Institute for Solid State Physics, Semiconductor Physics Group, Leipzig, Germany

We present current-voltage measurements of α-Ga_2O_3:Sn based Schottky diodes with various Schottky metals and show on/off current ratios of up to 8 orders of magnitude. We thereby evaluate the effective Schottky barrier height by temperature dependent measurements in the range of 40K up to 400K.
Due to its possible applications in high-power electronics, a great deal of attention has been drawn to the wide bandgap semiconductor Ga_2O_3. In recent years, in addition to the well-researched thermodynamically stable monoclinic polymorph β-Ga_2O_3 the metastable corundum-structured α-phase of Ga_2O_3 has shown to have promising physical properties. With a bandgap of 5.0-5.3 eV [1] and a predicted breakdown field of 8 MV/cm [2] it surpasses the theoretical limits of β-Ga_2O_3 in terms of Baliga's figure of merit [1]. Further, α-Ga_2O_3 is isostructural to α-Al_2O_3 and hence epitaxial growth on cost-efficient sapphire substrates is possible.

[1] Yang, D. *et al.*, El. Mat. Letters 18.2 p. 113-118 (2022)
[2] Higashiwaki, M. *et al.*, Semicond. Sci. Technol, 034001, (2016)

HL 30.21 Thu 11:00 P3

Copper tin oxide: An amorphous ternary oxide with tunable optical and electrical properties — •Arne Jörns, Holger von Wenckstern, and Marius Grundmann — University of Leipzig, Felix Bloch Institute for Solid State Physics, Semiconductor Physics Group

Due to the mismatching crystal structures of copper oxide (CuO) and stannic oxide (SnO_2) an amorphous alloy can form when these mate-

rials are combined. Few reports show that the resulting alloy exhibits p-type behavior, but low hole mobility results in unreliable Hall measurements [1]. Nevertheless, optical and electrical properties can be tuned by the alloy composition.

In this work we investigated copper tin oxide thin films deposited by pulsed laser deposition of ceramic CuO and SnO_2 targets at room temperature and in oxygen atmosphere. The resulting samples are highly disordered and n-type semiconducting with room temperature mobilities up to $11\,cm^2V^{-1}s^{-1}$. Optical and electrical properties can be tuned in a wide range by varying composition ratio and chamber pressure. Temperature dependent Hall-measurement for different cation contents and a first approach on Schottky diodes will be reported.

[1] P. J. M. Isherwood *et al.*, J. Appl. Phys., **118**, 105702, 2015

HL 30.22 Thu 11:00 P3

Indium oxide metal-semiconductor field-effect transistors — •Fabian Schöppach, Holger von Wenckstern, and Marius Grundmann — Felix Bloch Institute for Solid State Physics, Universität Leipzig, Germany

Indium oxide (In_2O_3) combines promising physical properties such as high carrier mobility and transparency in the visible. However, In_2O_3 is generally challenging to use in active devices. This is mainly due to its tendency to form an electron accumulation layer on its surface (SEAL) which is reported to be caused by surface near oxygen vacancies [1]. Both, compensating Mg doping and oxygen plasma treatment can be used to suppress the SEAL formation [2,3]. Moreover, as a sesquioxide, In_2O_3 is a very robust material that resists classical patterning processes and cannot be patterned by wet chemical processes.

In this work, In_2O_3 films grown by pulsed laser deposition are structured via dry-etching techniques. With that field-effect transistors were fabricated for the first time, reaching on-off ratios of over 5 orders of magnitude and low sub-threshold swings of about 110 mV/dec. For the source and drain contacts, gold was deposited by inert ambient sputtering. Schottky gate diodes were fabricated in a reactive sputtering process, which is a prerequisite for obtaining electrically rectifying contacts to In_2O_3 [4].

[1] King, et al. Physical Review B 80.8, 081201 (2009)
[2] Schmidt, et al. physica status solidi (b) 252.10, 2304–2308 (2015)
[3] Michel, et al. ACS Appl. Mater. Interf. 11, 27073–27087 (2019)
[4] von Wenckstern, et al. APL Materials 2.4, 046104 (2014)

HL 30.23 Thu 11:00 P3

Electrical transport properties of Sn, Si and Ge doped $\alpha-$Ga2O3 — •Thorben Slotosch, Clemens Petersen, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix Bloch Institute for Solid State Physics, Semiconductor Physics Group, Leipzig, Germany

We present Schottky barrier diodes based on PLD-grown $\alpha-Ga_2O_3$ thin films, doped with the effective mass donors Sn, Si and Ge. By employing temperature dependent current-voltage measurements, Hall-effect measurements and thermal admittance spectroscopy of the space charge region we investigate the electric transport properties of $\alpha-Ga_2O_3$ in relation to the doping levels provided by the combinatorial PLD method.

Materials with large bandgaps (> 3.4 eV) have attracted scientist's interest more and recently. With it's high bandgap of 4.6-5.3 eV Ga_2O_3 is well suited for appilcations in high-power devices [1]. Numerous studies have already reported on the thermodynamically stable monoclinic $\beta-$phase of gallium oxide. However the metastable $\alpha-$polymorph has gained scientist's attention. It's corundum structure allows $\alpha-Ga_2O_3$ to form alloys with other corundum-structured materials like $\alpha-Al_2O_3$ over the whole composition range to tune the bandgap energy up to 8.75 eV [2]. In order to grow $\alpha-Ga_2O_3$ combinatorial pulsed laser deposition can be employed, which offers the advantage of a precise dopant incorporation and lateral continuous doping gradients [3].

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HL 30.24 Thu 11:00 P3

Characterization and optimization of MgZnO thin films with steep lateral composition gradient — •Laurenz Thyen, Max Kneiss, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstraße 5, 04103 Leipzig, Germany

The materials magnesium- and zinc-oxide have been widely investigated in the past. Corresponding step graded ternary alloy thin films of $Mg_xZn_{1-x}O$ have been of great interest [1]. Pulsed laser deposition (PLD) has been used to grow laterally and vertically graded thin films [2]. The precise control of its chemical composition is of great importance for possible applications. Additionally, in the course of miniaturization of electrical devices like wavelength-selective multichannel UV photodetectors, a well-defined steep slope of the material gradient will be beneficial [3,4].

In this contribution the properties of $Mg_xZn_{1-x}O$ thin films with lateral compositional gradient grown by pulsed laser deposition will be discussed. In order to obtain information about the material composition of the thin films, energy-dispersed X-ray spectroscopy, spatially resolved ellipsometry and micro-photoluminescence spectroscopy measurements have been conducted. Moreover, steep lateral gradients with a slope of up to 20 % Mg content per millimeter were realised.

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HL 30.25 Thu 11:00 P3

Characterization of Schottky barrier contacts on a (Mg,Zn)O thin film with lateral composition gradient — •Mauricio Bassallo, Laurenz Thyen, Max Kneiss, Holger von Wenckstern, and Marius Grundmann — Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Linnéstraße 5, 04103 Leipzig, Germany

A lateral chemical gradient composition structure based on (Mg,Zn)O is a promising material that allows a spectrally resolved detection of UV photons due to a systematic shift of the absorption edge with the position. In that sense, N different photodetectors, fabricated at different positions of the gradient, would be sensitive to specific photon energies [1]. Due to the challenges of stable p-type (Mg,Zn)O fabrication with high conductivity and mobility, metal-semiconductor-metal (MSM) structures are preferentially chosen for (Mg,Zn)O-based photodetectors [2]. These consist of two small interdigitated coplanar Schottky contacts, which are 10μm wide and 10μm apart and whose simplicity in fabrication makes the MSM structure promising for photodetection. In this contribution the electrical properties of the Schottky contacts in such MSM structures are discussed using the current-voltage measurements. Additionally, the influence of the surface characteristics on the contacts are discussed using Atomic Force Microscopy measurements.

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HL 30.26 Thu 11:00 P3

Porosity Analysis of Mesoporous Silicon by SEM Images of Polished Cross Sections — •Stefanie Lawundy[1,2], Waldemar Schreiber[1], and Stefan Janz[1] — [1]Fraunhofer ISE, Freiburg i. Br., Germany — [2]University of Freiburg, Germany

Porous silicon fabricated by electrochemical etching is a material known for decades with a wide field of applications ranging from photovoltaics to medicine. Nevertheless, the determination of its key property porosity is still an issue that is to be refined.

Especially, the spatially resolved porosity analysis of layered mesoporous silicon stacks are challenging due to the small structures of only about 10 nm. Current measurement techniques as gas adsorption are not appropriate for such structures since they cannot fully penetrate the pores, cannot resolve the porosity profile over layer depth and lead to no information about the pore morphology.

In order to account for these challenges a new approach has been developed. It is based on the analysis of SEM cross section images where contrast and homogeneity are enhanced by a preceding polishing procedure. Pores are defined by using an image processing software and porosity profiles are calculated.

Results of this procedure are assumed to be an important step towards an accurate description of the etching process.

HL 30.27 Thu 11:00 P3

Temperature dependent light beam induced current (LBIC) investigation of PCMO-STNO interfaces — •Sophie Schaible[1], Tobias Westphal[1], Felix Müller[1], Stephan Melles[2], Christian Jooss[2], and Michael Seibt[1] — [1]IV. Physical Institute, University of Goettingen, Göttingen, Germany — [2]Institute for Materials Physics, University of Goettingen, Göttingen, Germany

Pn-heterojunctions of calcium doped praseodymium manganite $Pr_{0.66}Ca_{0.34}MnO_3$ and niobium doped strontium titanite $SrTi_{0.998}Nb_{0.002}O_3$ (PCMO-STNO) are used as a model system to investigate next generation solar cells going beyond the Shockley-Queisser limit by harvesting hot polaron-type charge carriers. In order to study the photovoltaic response in combination with the temperature and wavelength dependent generation of charge carriers, LBIC is used on a specially grown wedge-shaped PCMO thin film. A position dependent signal is obtained, which translates into the variation of the absorber thickness. PCMO has a perovskite structure and exhibits strong electron-phonon coupling leading to stable polarons. At the charge ordering temperature ($T_{CO} \approx 230\,K$) PCMO undergoes a phase transition from the semiconducting paramagnetic to the charge ordered phase [1]. Liquid nitrogen cooling of the LBIC setup enables temperature dependent LBIC measurements below room temperature and thus gives insights into this transition. Comparison with temperature dependent electron beam induced current (EBIC) measurements highlights differences between photon and electron excitation. [1] L. Wu et al., Phys. Rev. B 76, 174210 (2007)

HL 30.28 Thu 11:00 P3

Mapping Excitonic and Ionic Dynamics in Lead Halide Perovskite Thin Films — •Yenal Yalcinkaya[1], Pascal Rohrbeck[1], Emilia Schütz[2], Lukas Schmidt-Mende[2], and Stefan A.L. Weber[1] — [1]Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany — [2]Department of Physics, University of Konstanz, Universitätsstr. 10, 78464, Germany

Understanding the dynamics of excitons and ions is crucial for improving the lead halide perovskites and related devices. In this study, we fabricated triple cation lead halide perovskite half cells (ITO/SnO2/Perovskite) with small and large grain sizes. We obtained nearly 100 μm large grains by heat treating perovskite films under methylamine gas atmosphere. Since the grain boundaries are known to be the main source of defects and ion migration in lead halide perovskites, a certain change between charge carrier and defect behaviour between these two types of films is expected. Therefore, we utilized Time-resolved Kelvin Probe Force Microscopy (Tr-KPFM) for mapping the recombination of free charge carriers and ion migration in triple cation lead halide perovskite films with varying grain sizes. Mapping these excitonic and ionic components of photovoltage allowed us to map the defects within the perovskite films. Our results showed a significant increase in free electron-hole lifetimes in large grained perovskite films. Furthermore, we demonstrate the ion migration was suppressed by having fewer grain boundaries within the film. Our study shows how grain sizes affect the free charge carrier movements and how we can track these changes on nanoscale via KPFM.

HL 30.29 Thu 11:00 P3

The Effects of Residual Lead Iodide on the Stability of Perovskite Solar Cells — •Xiongzhuo Jiang and Peter Müller-Buschbaum — TU München, Physik-Department, Lehrstuhl für Funktionelle Materialien, 85748 Garching, Deutschland

Over the past few years, hybrid organic-inorganic lead halide perovskite materials have attracted tremendous interest as its excellent photovoltaic properties in perovskite solar cells (PSCs) with record power conversion efficiency. The residual lead iodide is easy to form during the fabrication of perovskite layer, especially for the two-step deposition method. In addition, residual lead iodide has been universally used in the state-of-the-art devices to boost the device performance. However, the effects of residual lead iodide on the stability of PSCs has not been fully understood and, therefore, needs to be deeply investigated for further improvement of device performance. Herein, it is shown that residual lead iodide exhibits insufficient stability under continuous light radiation and heating. The photodecomposition products (lead and iodine) of lead iodide pose a threat to the efficiency and stability of devices. Thus, unstable lead iodide under light radiation and heating is one of the main reasons for the degradation of perovskite device. Therefore, carefully controlling or eliminating the residual lead iodide in perovskite film is one of the critical methods to improve the long-term stability of PSCs.

HL 30.30 Thu 11:00 P3

Multi-photon induced ultrafast absorption dynamics of optical excitons in 2D inorganic-organic hybrid semiconductor — •Mohammad Adnan[1,2], Rudolf Bratschitsch[2], and Gaddam Vijaya Prakash[1] — [1]Nanophotonics Lab, Department of Physics, Indian Institute of Technology Delhi, Hauz Khas, New Delhi 110016 India — [2]Institute of Physics, University of Münster, Wilhelm-Klemm-Straße 10 48149 Münster, Germany

Two-dimensional inorganic-organic (IO) hybrid semiconductors have attracted prodigious attentions due to unique crystal structural packing and tunable exciton characteristics and exhibit strong optical exciton features at room temperature due to their large exciton binding energies (200-250 meV) [1]. These optical excitons are highly sensitive to the layer thickness and demonstrate distinct excitonic behaviors from surface and bulk regions. Multi-photon absorption spectroscopy is a novel probing tool which can monitor excitons from the deeper energy levels [1]. Nonlinear one-photon (3.54 eV), two-photon (1.55 eV) and three-photon (1.21 eV) transient absorption studies have been carried out to have better understanding of hot-carrier relaxations from different lower lying exciton energy levels. Fluence-dependent studies clearly demonstrate various nonlinear effects such as hot phonon bottleneck effect, exciton-exciton annihilation and Auger processes at higher fluences [2]. The results presented here may find interesting applications in developing advanced optoelectronic devices.

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HL 30.31 Thu 11:00 P3

Electron Beam Induced Current (EBIC) Investigations of Femtosecond Laser Sulfur Hyperdoped Silicon — •Mengru Sun[1], Tobias Westphal[1], Simon Paulus[2], Sören Schäfer[2], Stefan Kontermann[2], and Michael Seibt[1] — [1]University of Goettingen, IV. Physical Institute, Göttingen, Germany — [2]Institute for Microtechnologies (IMtech), University of Applied Sciences Rhein- Main, Rüsselsheim, Germany

S hyperdoped Si formed by fs-laser irradiation improves the absorption of the Si-based optoelectronic devices to infrared wavelengths. A p-n junction is created between the B doped p-type Si wafer and the S hyperdoped n-type region produced as a result of fs-laser pulse irradiation of the Si wafer surface under SF_6 atmosphere. The structural and electronic properties of the fs-laser hyperdoped S depend strongly on the laser-processing parameters such as the number of pulses per spot and laser fluence. In this contribution, we focus on S hyperdoped Si fabricated via fs-laser irradiation at 800nm wavelength and various laser processing parameters. Electron Beam Induced Current (EBIC) performed in plan-view and cross-section geometry is used for characterizing the electronic properties of the sample like excess minority carrier diffusion length. Combining EBIC with SEM images, the correlations between electronic properties and the surface textures can be observed. The results of this work show the important role of processing parameters on the surface macro- and microstructure. EBIC data further indicates the different behaviors of the excess carriers within the ridges and the valleys at the surface.

HL 30.32 Thu 11:00 P3

Spin Polarization Dynamics of Photo-excited Carriers in CsPbX3 Nanocrystals — •Ahmet Tosun, Simone Strohmair, Anja Barfüsser, Quinten Akkerman, Tushar Debnath, Amrita Dey, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Nano-Institute Munich and Department of Physics, Ludwig-Maximilians-Universität (LMU), Königinstr. 10, 80539 Munich, Germany

We present results on spin relaxation dynamics of photoexcited carriers in CsPbX3 nanocrystals by employing time-resolved differential transmission spectroscopy. After photoexcitation with circularly polarized light we observe a pronounced spin polarization in CsPbI3 nanocrystals. This spin-polarization is caused by selectively exciting spin-allowed transitions and is lost during thermalization and cooling of the photoexcited charge carriers. From temperature-dependent experiments we conclude that carrier-spin relaxation in CsPbI3 nanocrystals is predominantly caused by carrier-LO phonon scattering and can be described by the Elliot-Yafet mechanism.

HL 30.33 Thu 11:00 P3

Characterizing the conductive channels of 2D perovskite field-effect transistors with Kelvin probe force microscopy — •Konstantinos Bidinakis, Shuanglong Wang, Paul W.M. Blom, Wojciech Pisula, Tomasz Marszalek, and Stefan A.L. Weber — Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz, Germany

Perovskite-based field-effect transistors (FETs) are a promising class of electronic materials, which also provide a basis for understanding the

lateral charge transport within perovskites. Specifically, FETs of 2D perovskite materials exhibit diminished ion migration and improved stability against moisture compared to their 3D counterparts, due to their specific structure. The performance of the transistors is strongly influenced by the nanoscale morphology of the perovskite film. We used Kelvin probe force microscopy (KPFM) to correlate the local morphology and crystallinity with the potential distribution across a bottom-gate top-contact perovskite FET channel under operating conditions. The measured potential distribution from source to drain can indicate unwanted losses, e.g. at grain boundaries or at the electrodes.

In order to increase the crystalline quality of a Sn-based perovskite film, an additive with high Lewis alkalinity is used in the precursor solution, which coordinates with the Sn cation and retards crystallization. Using KPFM, we examined devices with and without such an additive and correlated the measured potential profiles with the charge transport characteristics, as well as ion migration and behavior at the perovskite grain boundaries.

HL 30.34 Thu 11:00 P3

Cross linkable hole transport materials for p-i-n perovskite solar cells — •Mohsen Hosseini Fard, Manuel Neubauer, Ervin Aljic, Simon Ewertowski, Selina Olthof, Dirk Hertel, and Klaus Meerholz — Department of Chemistry, University of Cologne, Germany

The use of hole transport materials (HTMs) in perovskite solar cells (PSCs) is indispensable. Many reports illustrate the importance of layer thickness, energy level alignment, doping and mobility of HTMs on PSCs performance. However, there are ambiguities regarding the properties of HTMs, which invoke further fundamental studies. Here, we investigate a series of cross-linkable hole transport materials (x-HTMs), TPD and TAPC derivatives, with different HOMO and LUMO energy positions. The advantage of HOMO and LUMO tunability of the above-mentioned compounds by exchanging molecular substituents is applied to investigate their hole extraction and electron blocking abilities. J-V characterization was used to investigate changes in the device characteristics. Major improvement in fill factor and Voc of MAPbI3 based solar cells was demonstrated by adjusting the thickness of x-HTMs. As a result, large improvements were observed in power conversion efficiency (PCE). A thin layer application of x-HTMs showed competitive results in PCE performance compared to the commonly used, commercially available materials like PTAA. Nevertheless, the application of a thin layer of QUPD (less than 5 nm) leads to high-efficient PSCs with a shown record PCE up of 19.56% using MAPbI3 as absorber, similar to the performance of a PTAA-based device.

HL 30.35 Thu 11:00 P3

Effect on Surface Morphology on 1.7eV-GaInAsP-layers on GaAs by surfactant-assisted MOVPE growth — •Ivo Rahlff, Patrick Schygulla, Jens Ohlmann, and David Lackner — Fraunhofer ISE, Freiburg i. B., Germany

III-V-compound multi junction solar cells hold record efficiencies since many decades. Recently, we have demonstrated a GaInP(1.9eV)/AlGaAs(1.44eV)//GaInAsP(1.09eV)/GaInAs(0.74eV) 4-junction wafer bonded solar cell that reaches 47.6% under a concentration of 665 suns (AM1.5d). All subcells are epitaxially deposited by MOVPE. To further increase the realistic efficiency potential above 50% a 6-junction device with the following bandgaps (1.94eV/1.71eV/1.42eV//1.19eV/0.98eV/0.74eV) is suggested. One promising candidate for the 1.71eV junction is GaInAsP. The challenge for this material system lies in the compositional regime between 1.60eV and 1.75eV, where phase separation has been reported.

In this work we investigate the effect of surfactant-assisted growth of GaInAsP alloys on the surface morphology during MOVPE growth. It is found that the GaInAsP growth without surfactant leads to severe surface roughening which is believed to be due to the onset of phase separation. XRD measurements revealed further decreasing tensile strain with increasing TMSb/III ratios which is expected, since the surfactant alters the atomic incorporation. Further investigations on the effect of the opto-electrical quality of the surfactant on the GaInAsP 1.7eV material is currently in progress.

HL 30.36 Thu 11:00 P3

Getting started in Perovskite Solar Cells - The little complications that are unmentioned — •Maximilian Spies, Simon Biberger, and Fabian Panzer — University of Bayreuth, Bayreuth, Germany

Due to the current interest in highly efficient perovskite solar cells (PSCs), many groups are attempting to produce such PSCs based on published recipes. Since these recipes often assume a lot of prior knowledge or do not consider environmental conditions in sufficient detail, resulting efficiencies are low. This work shows some of the complications one faces when attempting to build a PSC in n-i-p-structure, considering especially the transport layers. Starting from low single digit power conversion efficiency (PCE), we exceeded PCEs of 12% due to modifications of the production process. We tested different variations of the hole transport layer "on device", including a relatively new approach of solution-based CO_2-doping. With the detrimental factor of humidity to perovskite being known, we show systematically the impact of in-glovebox-processing on PCE and V_{OC}. Further, we found that surface properties of the bottom electrode critically influence the fillfactor.

HL 30.37 Thu 11:00 P3

First-principles study of perovskite/halide interfaces — •Samuele Spreafico and Bernd Meyer — Interdisciplinary Center for Molecular Materials and Computer Chemistry Center, FAU Erlangen-Nürnberg, Germany

Lead halide perovskites are a promising new class of semiconductors, which are easy and cheap to process and show high efficiency in optoelectronic applications. Photovoltaic engineering requires a controlled integration of the photo-active perovskite into a multi-layer heterostructure or quantum dot composite [1]. However, the interfaces in these devices unavoidably affect their optical response, for example the photoluminescence quantum yield. Here we present a density-functional theory investigation on the properties of the interfaces in a composite of $CsPbBr_3$ quantum dots embedded in a CsBr or NaBr matrix. First we performed a systematic screening of the structure and chemical composition of the interfaces. For the most stable configurations we determined the band alignments and we show how the band offsets at these interfaces depend on the interface structure, which can be tuned by changing synthesis conditions.

[1] B. Chaudhary, Y.K. Kshetri, H.S. Kim, S.W. Lee, T.H. Kim, Nanotechnology **32** (2021) 502007

HL 30.38 Thu 11:00 P3

Energy Transfer in Stability-Optimized Perovskite Nanocrystals — •Michèle G. Greiner, Andreas Singldinger, Nina Henke, Carola Lampe, Ulrich Leo, Moritz Gramlich, and Alexander S. Urban — Nanospectroscopy Group and Center for Nanoscience (CeNS), Nano-Institute Munich, Department of Physics, Ludwig Maximilians University Munich, Koeniginstr. 10, 80539 Munich, Germany

Halide perovskites nanocrystals (NCs) are auspicious materials for low-cost, high efficient photovoltaic and light-emitting devices. Nevertheless, the fast degradation in contact with moisture is one critical issue. Another problem constitutes the inefficient charge transfer between different layers. To counteract both problems, we employ micelles made of diblock copolymers filled with methylammonium lead bromide (MAPbBr3) NCs. With this approach, we bypass the charge transfer issue by exploiting energy transfer (ET) between CsPbBr3 nanoplatelets and the MAPbBr3 micelles. We chose micelles with different diameters to find the best balance between protection and ET efficiency. As a result, we found an increase in stability by around 56% from the smallest to the thickest shell and a transfer efficiency up to 73.6% for the smallest micelle. These findings could help improve different optoelectronic devices, such as perovskite-based solar cells or light-emitting devices.

HL 30.39 Thu 11:00 P3

Probing structural dynamics in optically excited 2D heterostructures by Ultrafast Electron Diffraction — •Mashood Tariq Mir, Arne Ungeheuer, Ahmed Hassanien, Lukas Nöding, Arne Senftleben, and Thomas Baumert — University of Kassel, 34132 Kassel, Germany

Layered transition metal dichalcogenides (TMDs) host a rich collection of physical properties, opening many different applications with atomically thin films such as sensors, electronic switching, or energy storage. Among those materials, 1T-TaS2 exhibits a complex phase diagram depending on temperature encompassing charge density waves (CDW) with diverse commensurabilities. New phenomena have been observed and are further expected from combining different materials to 2D heterojunctions. We aim to use femtosecond laser pulses to induce rapid structural changes and probe them with ultrafast electron diffraction

(UED). In this work, free-standing single-crystalline heterostructure samples were prepared down to a few nanometre thicknesses to allow electron diffraction in transmission mode. The preparation method was optimized using atomic force microscopy and optical microscopy to isolate atomically thin flakes. In addition, we present an initial UED study of CDW heterostructure (1T-TaS2 / Graphite). Upon lattice heating, the CDW material undergoes several phase transitions. We focus on the reversible phase transition of 1T-TaS2 from the nearly commensurate to the incommensurate phase and study the effect of interlayer coupling of stacked 1T-TaS2 / Graphite heterostructures.

HL 30.40 Thu 11:00 P3

Theory of non-integer high-harmonic generation in a topological surface state — •Maximilian Graml[1], Maximilian Nitsch[1,2], Adrian Seith[1], Ferdinand Evers[1], and Jan Wilhelm[1] — [1]Institute of Theoretical Physics, University of Regensburg — [2]NanoLund and Solid State Physics, Lund University, Sweden

High-harmonic emission from a topological insulator has been observed recently [1] opening a platform to explore topology and relativistic quantum physics using strong laser fields. Strikingly, the higher order resonance frequencies can be continously shifted to non-integer multiples of the driving frequency by varying the carrier-envelope phase (CEP) of the driving field. Based on a semiclassical model we explain this finding as a characteristic property of the Dirac dispersion. We complement analytical results with numerical simulations based on the semiconductor Bloch equations.[2]

[1] C.P. Schmid, et al.: Tunable non-integer high-harmonic generation in a topological insulator, Nature 593, 385-390 (2021).

[2] M. Graml, et al.: Theory of non-integer high-harmonic generation in a topological surface state, arXiv:2205.02631 (2022)

HL 30.41 Thu 11:00 P3

Ultrafast spectroscopy of single quantum dots utilizing synchronized GHz-Oscillators — •Valentin Dichtl, Michael Seidel, Gerhard Schäfer, and Markus Lippitz — Experimental Physics III, University of Bayreuth, Germany

Ultrafast transient absorption or reflection spectroscopy of single semiconductor quantum dots is a well established technique, typically based on laser oscillators with about 80 MHz repetition rate. The excited state lifetime of the emitter is however much shorter than the pulse separation in these experiments. Most of the time one thus waits for the next laser pulse.

Here we present a modified setup based on two synchronized Ti:Sa lasers operating at 1 GHz repetition rate and a line camera with a spectral rate of 127 kHz. Noise suppression is accomplished via double modulation using a field programmable gate array (FPGA) for synchronizing AOMs with the line camera.

We demonstrate the perturbed free induction decay of single AlGaAs quantum dots at temperatures below 20 K. The total integration time is less than three minutes – currently software limited.

HL 30.42 Thu 11:00 P3

Non-linear optimization and error estimation for the dynamical modelling of photoluminescence spectra — •Sebastian Bohm[1], Max Grossmann[1], Stefan Heyder[1], Klaus Schwarzburg[2], Peter Kleinschmidt[1], Erich Runge[1], and Thomas Hannappel[1] — [1]Fakultät für Mathematik und Naturwissenschaften, Technische Universität Ilmenau, Ehrenbergstraße 29, 98693 Ilmenau — [2]Institut Solare Brennstoffe, Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin

Modern compute power and improved algorithms allow to determine, e.g., the parameters of a kinetic model of time-resolved photoluminescence spectroscopy (TRPL) via the simultaneous fit of many excitation-dependent TRPL spectra. Since our method is based on a maximum likelihood estimator, we obtain information on the reliability of the derived values as well. As example, we use a TRPL model of M. W. Gerber and R. N. Kleiman [J. Appl. Phys. 122, 095705 (2017), URL 10.1063/1.5001128].

HL 30.43 Thu 11:00 P3

Pulse-driven non-adiabatic tunneling in nanocontacts: quasiclassical approach — Sangwon Kim[1], Tobias Schmude[2], Guido Burkard[2], and •Andrey S. Moskalenko[1] — [1]KAIST, Daejeon, Korea — [2]University of Konstanz, Konstanz, Germany

We develop a general quasiclassical theory for the description of the tunneling through time-dependent barriers induced by ultrashort light pulses and apply it to the tunneling induced by such pulses in nanocontacts [1]. In particular, we analyze the situation when the tunneling is driven by ideal half-cycle pulses. Among the numerous solutions that contribute to the tunneling probability, we choose two main solution branches with the largest contributions: The 1st solution exhibits the "tunneling" behavior of a wave packet whereas the 2nd solution exhibits the "evanescent-wave" behavior. For a large enough intercontact distance, the 1st solution dominates in terms of the tunneling probability. However, for minute distances and small field strengths, when the electron does not manage to escape from the classically forbidden region, the 2nd solution starts to dominate. Finally, we study a situation when the tunneling is driven by realistic few-cycle pulses. We see that the direction of the electron transport in the nanocontacts may be altered in dependence on the carrier-envelope phase of the driving pulse. We also find that the time when the electron effectively emerges from under the barrier does not necessarily exactly coincide with one of the peaks of the driving electric field.

[1] Sangwon Kim et al., New J. Phys. 23, 083006 (2021).

HL 30.44 Thu 11:00 P3

Time-resolved broadband transient reflectivity studies in ultrathin bismuth films — •Alexander Kassen[1], Fabian Thiemann[1], Germán Sciani[2], and Michael Horn-von Hoegen[1] — [1]University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany — [2]University of Waterloo, 200 University Avenue West, ON N2L 3G1, Canada

Bismuth, through its Peierls-Jones distorted lattice, offers the possibility to excite coherent phonon modes upon irradiation with ultra-short laserpulses. The optical A_{1g} mode at ≈ 3 THz is triggered by the displacive excitation mechanism due to transient changes of the atomic potential energy surface. These changes arise from optical excitation of the electron system and thus lead to a strong coupling between the phonons and charge carriers. The density of excited charge carriers, which depends on the incident fluence and film thickness, alters the equilibrium position of the atoms and softens the potential energy surface, leading to a redshift of the A_{1g} mode. Conversely, in an all optical pump-probe experiment with a measurement of the relative change of reflectivity $\Delta R/R_0$, we utilized the redshift of the A_{1g} mode to determine the level of excitation of the electron system. In the next step, this allowed us to compare the relaxation behavior and transient optical properties of films with different thicknesses leading to a broader insight in the phonon and carrier excitation mechanisms.

HL 30.45 Thu 11:00 P3

Dimensionality Reduction Techniques in Femtosecond Time-Resolved Ellipsometry Data Analysis and Theory — •Noah Stiehm[1], Yixuan Zhang[2], Erich Runge[3], Stefan Krischok[1], Hongbin Zhang[2], and Rüdiger Schmidt-Grund[1] — [1]Technische Universität Ilmenau, Fachgebiet Technische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany — [2]Technische Universität Darmstadt, Research Group Theory of Magnetic Materials, Otto-Berndt-Straße 3, 64287 Darmstadt — [3]Technische Universität Ilmenau, Fachgebiet Theoretische Physik I, Weimarer Straße 32, 98693 Ilmenau, Germany

Physical modeling and interpretation of the transient dielectric function obtained from femtosecond time-resolved spectroscopic ellipsometry [1] poses a significant challenge, as it consists of many temporally and spectrally overlapping processes that need to be reliably separated to obtain stable and physically meaningful fit results. Ab-initio theory can help to separate these processes, but is not available for the whole time scale (≈100 fs to several ns) of the experiment, due to the associated computational costs.

To help overcome these challenges we investigate the use of dimensionality reduction techniques like dynamic mode decomposition and manifold learning methods like locally-linear embeddings and autoencoders to be applied I) in model approximation of the experimental data and II) on ab-initio results from time-dependent density functional theory to cover larger time scales. By this we identify strategies for a reliable modeling pipeline with minimal human intervention.

[1] S. Richter *et al.*, Rev. Sci. Instrum. 92, 033104 (2021).

HL 30.46 Thu 11:00 P3

Numerically exact simulations of quantum devices coupled to arbitrary environments using tensor networks — •Moritz Cygorek[1], Vollrath Martin Axt[2], Brendon W. Lovett[3], Jonathan Keeling[3], and Erik M. Gauger[1] — [1]Heriot-Watt University, Edinburgh, UK — [2]Universität Bayreuth, Germany —

[3]University of St Andrews, UK

Reliable predictions of the dynamics in nanoscale quantum devices with applications in photonics, transport, quantum information and communication require a careful consideration of environment effects. Here, we present the novel numerical method Automated Compression of Environments (ACE): The open quantum systems dynamics is expressed in terms of a tensor network, where the influence of the environment is incorporated into a matrix product operator in time, the so-called process tensor. ACE provides a direct way to calculate this process tensor numerically exactly with numerical errors originating only from time discretization and matrix product operator compression. As the numerical procedure starts directly from the microscopic Hamiltonian, no problem-specific derivations are required. Thus, as we show on a series of examples, one and the same computer code can be used to simulate the dynamics of open quantum systems with environments as diverse as photons, phonons, electrons, and spins, as well as combinations of multiple environments. This proof of principle demonstrates the tremendous potential of tensor network approaches as one-size-fits-all solutions to open quantum systems dynamics.

HL 30.47 Thu 11:00 P3

Transient negative thermal expansion in HgTe/CdTe heterostructures by heating of transverse phonons — •Matthias Rössle[1], Marc Herzog[2], Jan Pudell[1,3], Wolfram Leitenberger[2], Maximilian Mattern[2], Lukas Lunczer[4], Claus Schumacher[4], Hartmut Buhmann[4], Laurens Molenkamp[4], and Matias Bargheer[1,2] — [1]Helmholtz-Zentrum Berlin, Germany — [2]Institut für Physik und Astronomie, Universität Potsdam, Germany — [3]European XFEL Facility GmbH, Schenefeld, Germany — [4]Physikalisches Institut EP3, Universität Würzburg, Germany

We investigate the transient negative thermal expansion of semimetallic HgTe and semiconducting CdTe by using synchrotron-based time-resolved X-ray diffraction. At $T = 20\,\mathrm{K}$, far below the Debye temperature of both materials, the selective optical excitation of the HgTe top layer with an ultrashort near-infrared laser pulse leads to a rapid expansion of HgTe that is followed by a long lasting contraction. The CdTe substrate is compressed by the HgTe thin film expansion, and subsequently CdTe contracts due to thermally excited transverse phonon modes. This shows that negative thermal expansion is manifest on ultrafast timescales, consistent with the negative Grüneisen coefficient for transverse phonons in semiconducting materials with sphalerite crystal structure. At $T = 200\,\mathrm{K}$, far above the Debye temperature of both materials, the expansion driven by longitudinal acoustic phonons is prevalent. We simulate the lattice dynamics in an elastic model where transient thermal stresses are calculated via heat diffusion based on equilibrium thermoacoustic properties.

HL 30.48 Thu 11:00 P3

Resonant and phonon-assisted ultrafast coherent control of a single hBN color center — •Daniel Groll[1], Johann A. Preuss[2], Robert Schmidt[2], Thilo Hahn[1], Paweł Machnikowski[3], Rudolf Bratschitsch[2], Tilmann Kuhn[1], Steffen Michaelis de Vasconcellos[2], and Daniel Wigger[3,4] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]Institute of Physics, University of Münster, Germany — [3]Department of Theoretical Physics, Wrocław University of Science and Technology, Poland — [4]School of Physics, Trinity College Dublin, Ireland

For the development of scalable quantum technologies, reliable single-photon emitters in solid state systems are required. In this context, promising candidates are the recently discovered color centers in the van der Waals insulator hBN. These single photon emitters are attracting increasing attention due to their quantum performance at room temperature and wide range of transition energies. Here we report on our recent results on the ultrafast optical coherent state manipulation of a single hBN color center [1]. By combining experiment and theory we achieve a sound understanding of the impact of environment noise and the coupling to phonons on the emitter's coherence. Specifically, we detect the decoherence of optical phonon-assisted transitions, stemming in part from the finite lifetime of these phonons. The creation of acoustic phonons manifests in a rapid decrease of the emitter coherence during their emission and can lead to an ultrafast beat of the coherent control signal.

[1] J. Preuss, D. Groll, et al., *Optica* 9, 522-531 (2022)

HL 30.49 Thu 11:00 P3

Coherent acoustic phonons in a Graphite-hBN heterostructure observed by ultrafast electron diffraction — •Arne Ungeheuer[1], Nora Bach[2], Ahmed Hassanien[1], Mashood Mir[1], Lukas Nöding[1], Sascha Schäfer[2], Thomas Baumert[1], and Arne Senftleben[1] — [1]University of Kassel, Institute of Physics, Kassel, Germany — [2]University of Oldenburg, Institute of Physics, Oldenburg, Germany

We investigate the dynamics of photoexcited coherent acoustic phonon modes in a graphite- hexagonal boron nitride (hBN) heterostructure. Since the hBN layer is transparent at our excitation central wavelength of 785 nm we assume that the optically induced stress pulse occurs mainly in the graphite layer. Subsequent lattice coupling to the hBN layer depends on the coupling strength at the bilayer interface and determines the nanomechanical resonance frequencies of the system. Observation of specific coherent acoustic phonon modes in the individual layers is interpreted within the framework of ultrafast electron diffraction [1] and experimental results are compared with numerical simulations based on a discrete numerical linear chain model [2].

[1] Gerbig, C., et al. New Journal of Physics 17.4 (2015): 043050.
[2] Bach, N., and S. Schäfer, Structural Dynamics 8.3 (2021): 035101.

HL 30.50 Thu 11:00 P3

Unraveling electron-phonon and exciton-phonon couplings in transition metal dichalcogenides. — •Ahmed Hasssanien, Arne Ungeheuer, Mashood Tariq Mir, Lukas Nöding, Arne Senftleben, and Thomas Baumert — University of Kassel, Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), D - 34132 Kassel, Germany

The observation of coherent phonons following resonant electronic excitation is a clear sign of the coupling between the electronic and the lattice degrees of freedom [1]. Using a highly compact femtosecond electron diffractometer developed in our group [2], we were able to differentiate between the electron-phonon and exciton-phonon couplings in mechanically exfoliated few-layers WSe2. Based on our results, both free and bound charge carriers couple to the interlayer vibrational modes. Further analysis of our results unveiled the specific modes coupled to either type of charge carrier.

[1] Jeong, Tae Young, et al. ACS Nano 10.5 (2016): 5560-5566
[2] Gerbig, C., et al. New J. Phys. 17.4 (2015):043050.

HL 30.51 Thu 11:00 P3

Measuring ultrashort electron pulse durations by streaking with free electrons — •Lukas Nöding, Arne Ungeheuer, Ahmed Hassanien, Mashood Tariq Mir, Arne Senftleben, and Thomas Baumert — Institute of Physics; Experimental Physics III, Kassel University

Ultrafast electron diffraction is a well-known method for time-resolved measurements on molecules and condensed matter. The duration of the electron pulse directly determines the temporal resolution of the UED setup as it works like the shutter speed of a camera. A streaking setup utilizing free electrons is implemented to measure the duration of the electron pulse. For this, a new measurement device was designed. It consists of an aperture and a metal surface behind the aperture, parallel to the path of the electron pulse. A femtosecond laser pulse is focused onto the metal surface. As the beam incides, electrons are released from the metal surface. Because of their momentum at first, they separate from the surface, create an electric field perpendicular to the surface and then recombine. This short-lived electric field is used to streak the electron pulse. The electron pulse at the front of the pulse should experience a different field strength than the electrons at the end. By that the duration of the pulse is mapped into a spatial extension of the pulse. The spatial and temporal overlap for the electron pulse and the laser beam had to be set exactly. The results are shown with their evaluation and compared to simulations.

HL 31: 2D Materials 5 (joint session HL/CPP/DS)

Time: Thursday 11:15–12:15 Location: H36

HL 31.1 Thu 11:15 H36

Generating extreme electric fields in 1 2D materials by dual ionic gating — •Benjamin Isaac Weintrub[1], Yu-Ling Hsieh[1,2], Jan N. Kirchhof[1], and Kirill I. Bolotin[1] — [1]Department of Physics, Freie Universität Berlin, Berlin, Germany — [2]Department of Mechanical Engineering, National Central University, Taoyuan City, Taiwan

We demonstrate a new type of dual gate transistor to induce record electric fields through two-dimensional materials (2DMs). At the heart of this device is a 2DM suspended between two volumes of ionic liquid (IL) with independently controlled potentials. The potential difference between the ILs falls across an ultrathin layer consisting of the 2DM and the electrical double layers above and below it, thereby producing an intense electric field across the 2DM. We determine the field strength via i) electrical transport measurements and ii) direct measurements of electrochemical potentials of the ILs using semiconducting 2DM, WSe2. The field strength across a bilayer WSe2 sample reaches ~2.5 V/nm, the largest static electric field through the bulk of any electronic device to date. Additionally, we create electric fields strong enough to close the bandgap of 3-layer and 4-layer WSe2 (~1.4 V/nm and ~0.9 V/nm respectively). Our approach grants access to previously-inaccessible phenomena occurring in ultrastrong electric fields.

HL 31.2 Thu 11:30 H36

Tip-enhanced Raman spectroscopy combined with other Scanning Probe Microscopy Methods: Focus on 2D Materials — •Jana Kalbacova — HORIBA Jobin Yvon GmbH, Neuhofstr. 9, Bensheim 64625, Germany

New two dimensional materials are on the rise. After the wonder material graphene, new materials such as MoS2, MoSe2, WSe2 have an intrinsic bandgap and as such are opening new doors for semiconductor applications. Raman spectroscopy offers information on the chemical structure of materials but cannot provide information on the electronic properties such as surface potential or photocurrent of our sample. Colocalized measurements combining scanning probe microscopy (SPM) with Raman spectroscopy can already bring a wealth of information; however, further improvements can be obtained by a tip that will act as an antenna and amplify the Raman signal and thus breaking the diffraction limit in a method called Tip-enhanced Raman spectroscopy (TERS). Typically spatial resolution of 10 - 20 nm can be achieved. In this contribution, we investigate different 2D materials by a combination of TERS, tip-enhanced photoluminescence, Kelvin probe microscopy, and other SPM methods to show very locally for example doping variations or defects that would otherwise go unnoticed with other macro- and microscopic techniques.

HL 31.3 Thu 11:45 H36

Defects in 2D WS_2 monolayers — Aswin Asaithambi[1], Roland Kozubek[1], Francesco Reale[2], Erik Pollmann[1], Marcel Zöllner[1], Cecilia Mattevi[2], Marika Schleberger[1], Axel Lorke[1], and •Günther Prinz[1] — [1]Fakultät für Physik und CENIDE, Universität Duisburg-Essen, Germany — [2]Department of Materials, Imperial College London, UK

In this presentation, we report about optical characterization and manipulation of defects in tungsten disulfide (WS_2) monolayers. WS_2 is one prominent member of the 2D transition metal dichalcogenides (TMDC). In these materials, defects and adsorbates can easily modify e.g., conductivity, optical properties, or even create single photon emitters. For this study we used high quality WS_2 CVD-grown monolayers to purposely introduce defects via irradiating them with Xe^{30+} ions with different fluences [1]. Low temperature photoluminescence (PL) spectra of these irradiated WS_2 monolayers show two defect related broad bands, beside the excitonic contribution. By exposing these flakes to laser light with powers up to 1.5mW, the intensity of these two PL bands can be reduced. By comparing the intensity of the excitonic contribution before and after this laser processing, we don't observe an increase in intensity, leading us to conclude, that the defects aren't getting healed. If the samples are heated to room temperature, the defect luminescence recovers. To interpret our observation, we suggest that the defects might be attributed to vacancy defects together with adsorbates at different defect sites.

[1] A. Asaithambi et al., Phys. Status Solidi RRL 2021, 15, 2000466

HL 31.4 Thu 12:00 H36

Large perpendicular field in bilayer TMD via hybrid molecular gating — •Sviatoslav Kovalchuk[1], Abhijeet Kumar[1], Simon Pessel[1], Kyrylo Greben[1], Dominik Christiansen[2], Malte Selig[2], Andreas Knorr[2], and Kirill Bolotin[1] — [1]Department of Physics, Quantum Nanoelectronics of 2D Materials, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

We consider structures in which bilayer TMDs are sandwiched between a layer of molecules and Si gate. We show that these structure allow increasing, by a factor of 2, maximum electric field achievable in this 2D material. This in turn, allows reaching electric field >0.2 V/nm. In MOS2 this is sufficient to bring interlayer excitons IX into resonance with either A or B intralayer excitons. We study coupling between these excitons, and give an outlook on the new technique to achieve large perpendicular electric fields detectable in optical measurements.

HL 32: Perovskite and Photovoltaics 3 (joint session HL/CPP/KFM)

Time: Thursday 15:00–16:30 Location: H31

HL 32.1 Thu 15:00 H31

Atomically Thin Sheets of Lead-Free 1D Hybrid Perovskites Feature Tunable White-Light Emission from Self-Trapped Excitons — •Philip Klement[1], Natalie Dehnhardt[2], Chuan-Ding Dong[3], Florian Dobener[1], Julius Winkler[2], Samuel Bayliff[4], Detlev M. Hofmann[1], Peter J. Klar[1], Stefan Schumacher[3,5], Sangam Chatterjee[1], and Johanna Heine[2] — [1]Institute of Experimental Physics I and Center for Materials Research (ZfM), Justus Liebig University Giessen, Giessen, Germany — [2]Department of Chemistry and Material Sciences Center, Philipps-Universität Marburg, Marburg, Germany — [3]Department of Physics and Center for Optoelectronics and Photonics Paderborn (CeOPP), Paderborn University, Paderborn, Germany — [4]Department of Chemistry and Biochemistry, University of Oklahoma, Norman, OK, USA — [5]College of Optical Sciences, The University of Arizona, Tucson, AZ, USA

One of the major current challenges in 2D materials' synthesis is the intentional design of building blocks to introducing superior chemical and physical properties. The limiting factor in this approach is the commonly-believed paradigm that in-plane covalent interactions are strictly necessary to form 2D materials, limiting the number of candidates. Here, we go beyond the paradigm that atomically thin materials require in-plane covalent bonding and report single layers of the one-dimensional organic-inorganic perovskite [C7H10N]3[BiCl5]Cl. Its unique 1D-2D structure enables single layers and the formation of self-trapped excitons which show white-light emission.

HL 32.2 Thu 15:15 H31

Multiple spin-flip Raman scattering in bulk lead halide perovskites — •Marek Karzel[1], Dennis Kudlacik[1], Natalia E. Kopteva[1], Ina Kalitukha[2], Maksym V. Kovalenko[3], Dmitri R. Yakovlev[1], and Manfred Bayer[1] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany — [2]St. Petersburg, Russia — [3]Laboratory of Inorganic Chemistry, ETH Zürich, 8093 Zürich, Switzerland

Lead halide perovskites like FACs are promising competitors for conventional semiconductors in spintronics due to their highly efficient light absorption and emission properties. We study spin-flip Raman

scattering (SFRS) of resident carriers and investigate possible carrier exchange interactions. The measurements are performed at low temperatures around 1.6 K and external magnetic fields up to 10 T in Faraday and tilted geometries. This method allows us to observe Raman shifts in high magnetic fields which according to [1] are attributed to the g-factors of resident electrons and holes. The SFRS efficiency significantly increases for resonant probing of the free exciton resonances. We conduct from our measurements, that the creation of the free exciton is the essential requirement for observation of multiple spin-flip Raman scattering.

[1] E. Kirstein et al., Adv. Mater. 34, 2105263 (2022).

HL 32.3 Thu 15:30 H31

Stability Enhancement of perovskite nanoplatelets via crosslinking of ligands — •Maximilian Gruber, Ulrich Leo, Nina Henke, Patrick Ganswindt, Michael Lichtenegger, Connor Heimig, and Alexander Urban — Nanospectroscopy Group and Center for Nanoscience (CeNS), Nano-Institute Munich, Department of Physics, Ludwig-Maximiliäns-Universitat München, Königinstr. 10, 80539 Munich, Germany

In recent years lead halide perovskite nanoplatelets (NPL) have attracted a lot of attention due to low-cost production and excellent spectral tuning. Additionally, perovskite NPLs exhibit the benefit of exciton energy tunability via quantum confinement as well as large photoluminescence quantum yield. The high surface to volume ratio of the NPLs, however, makes them susceptible to degradation by water, air and ion migration.

One solution to these issues of degradation investigated here is a process called crosslinking. Hereby the exposure of a film of NPLs to a dose of electron radiation induces intermolecular bonds between the organic ligands attached to the individual nanocrystals, hence forming a protective matrix around a film of pristine perovskite NPLs.

Varying dosages of irradiation of three monolayer CsPbBr3 NPLs were investigated followed by an exposure to other halides, NPLs with a different halide composition as well as different solvents, showing a drastic increase in stability of the crosslinked compared to untreated NPLs. This enables the possibility of a future application of lead halide perovskite NPLs under ambient conditions.

HL 32.4 Thu 15:45 H31

Enhancing the optical performance of perovskite nanoplatelets — •Stefan Martin[1], Carola Lampe[1], Nina Henke[1], Ioannis Kouroudis[2], Milan Harth[2], Alessio Gagliardi[2], and Alexander Urban[1] — [1]LMU Munich, Nanospectroscopy Group — [2]TU Munich

Lead halide perovskites have been drawing a lot of interest during the last few years due to their unique properties. Their excellent optical performance combined with easy and cost-efficient production are interesting for both light-emitting devices and solar cells. Perovskite nanoplatelets are furthermore convincing with high photoluminescence quantum yields and narrow emission linewidths tunable from 430 to 505 nm. The thickness of these nanoplatelets can be tuned with a monolayer precision and determines the absorption and emission profile of the sample.

By using different machine learning approaches the synthesis parameters were investigated and optimized based on the emission spectrum. With this method, the emission properties of nanoplatelets with thicknesses reaching from 2 to 8 monolayers were enhanced. Additionally, the emission wavelengths can be finetuned using a post-synthetic enhancement treatment comprising a lead halide ligand solution. Depending on the time interval between synthesis and enhancement, a redshift of controllable extent can be introduced while further reducing the emission linewidth. With these strategies, a narrow and symmetric emission peak can be achieved at any desired wavelength. This is particularly interesting for the implementation in optoelectronic devices.

HL 32.5 Thu 16:00 H31

Extensive study on sequential physical vapor deposition of mixed-cation perovskite (Cs,FA)PbI_3 — •Karl Heinze[1], Tobias Schulz[1], Roland Scheer[1], and Paul Pistor[2] — [1]Institute of Physics, Martin-Luther-University Halle-Wittenberg, von-Danckelmann-Platz 3, 06120 Halle (Saale), Germany — [2]Universidad de Pablo Olivade, Carretera de Utrera 1, 41013, Sevilla, Spain

Sequential deposition via physical vapor deposition (PVD) is underexplored, even though it offers precise adjustment of components and composition and a variety of routes to investigate the optimization of perovskite growth. We combine in situ XRD and in situ laser light scattering to monitor phase evolution of (Cs,FA)PbI3 during PVD. We study the influence of deposition sequence of the components PbI2, FAI and CsI on CsFAPbI3 growth. Noticeably, the sequence strongly influences the orientation of deposited components. Similarly, diffusion before and during annealing as well as resulting alpha phase share depend on the evaporation sequence. When depositing PbI2 first, conversion to the perovskite phase was not achieved, unless an over stoichiometric share of FAI was deposited. Depositing FAI first and PbI2 later resulted in a high probability of layer conversion to the perovskite phase without secondary phases being detected. A striking feature during our investigation was the absence of the delta phase during deposition and annealing, seemingly caused solely by the preparation method. We deliver important insight into this poorly investigated preparation path and provide a foundation for further research based on our detailed study of sequence-dependent crystalline growth.

HL 32.6 Thu 16:15 H31

Ultrafast transient spectroscopy of Cu(In,Ga)Se_2 coupled to different buffer layers. — •Pirmin Schweizer, Ricardo Rojas-Aedo, Alice Debot, Philip Dale, and Daniele Brida — Department of Physics and Materials Science, University of Luxembourg, 162a avenue de la Faïencerie, L-1511 Luxembourg, Luxembourg

The dynamic parameters of photo-induced electron-hole pairs, such as recombination time and charge conductivity, play a major role in the efficiency of photovoltaic devices. Among thin film materials for photovoltaics, one of the most interesting is the p-type Cu(In,Ga)Se_2 alloy (CIGS) on which an n-type buffer layer is deposited, forming the initial part of the device p-n junction. The inter-material transport dynamics strongly depend on how the band structure is affected by the buffer layer, and also on the quality of the CIGS \ buffer layer interface which may contain defects. In our experiments we have compared the ultrafast transient reflectivity on CIGS epitaxially grown on a GaAs substrate. New Cd free buffer layers In_2S_3 and band offset tunable Zn(O,S), are compared to the most commonly used buffer layer, CdS. The transient reflection measurements allows for the extraction of the electronic transport dynamics at the interface with the buffer. This study allows us to draw conclusions about the pair formation capacity mediated by the transport properties between the CIGS and the buffer layer. The results can guide the development of Cd free buffer layers thus reducing the environmental impact caused by CdS in traditional CIGS solar cells.

HL 33: Optical Properties 2

Time: Thursday 15:00–18:00 Location: H32

HL 33.1 Thu 15:00 H32

Implementation of the Bethe-Salpeter Equation using Crystal Symmetries — •Jörn Stöhler[1,2], Dmitrii Nabok[1], Stefan Blügel[1], and Christoph Friedrich[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich, Germany — [2]RWTH Aachen University, Germany

The Bethe-Salpeter equation (BSE) and *GW* approximation are two many-body perturbation theory techniques that together form the state-of-the-art method to include electron-hole interaction in periodic systems. The BSE has proven to be the most accurate tool to compute optical absorption for the valence and core energy region, as well as electron energy loss.

We have implemented the BSE in the SPEX code, a full-potential linearized augmented planewave (FLAPW) code that supports Green-function based methods including the *GW* approximation, optical spectra in the random phase approximation, and more. We use crystal symmetries to achieve a significant computational speedup for the construction and diagonalization of an effective electron-hole Hamiltonian in the Tamm-Dancoff approximation, from which we obtain symmetric exciton wavefunctions and energies.

Our code is parallelized and has been tested for various bulk, layered and monolayer semiconductors, among them LiF and MoS_2, and includes spin-orbit coupling. The results agree with available theoretical and experimental spectra from the literature.

HL 33.2 Thu 15:15 H32

The Berry dipole photovoltaic demon and the thermodynamics of photo-current generation within the optical gap of metals — Li-kun Shi[1], Oles Matsyshyn[2,1], Justin C. W. Song[2], and •Inti Sodemann Villadiego[3,1] — [1]Max-Planck-Institut fur Physik komplexer Systeme — [2]Division of Physics and Applied Physics, Nanyang Technological University, Singapore — [3]Institut fur Theoretische Physik, Universitat Leipzig

Berry phase driven photo-voltaic effects offer novel mechanisms that could allow to engineer a new generation of opto-electronic technologies.

We will show that there is a large class of bulk photovoltaic mechanisms that make possible to produce a net rectified photo-voltaic current even when the impinging radiation has a frequency that resides within the optical gap of the material, in contrast to previous claims. We will describe the thermodynamics of these in-gap rectification effects and show that most of these mechanisms are necessarily accompanied by a small but finite irreversible photon absorption in order for them to be consistent with the laws of thermodynamics. There is, however, one remarkable exception: the intra-band non-linear Hall effect arising from the anomalous velocity induced by the Berry curvature. This non-linear Hall effect allows to have a photovoltaic mechanisms whose maximum allowed efficiency can be 100% for the conversion of circularly polarized light onto electricity. More remarkably, because it is a reversible process, this same mechanism can be conversely used as a a highly efficient electrical amplifier of circularly polarized light.

HL 33.3 Thu 15:30 H32

Nonlinear photocurrents induced by terahertz radiation in twisted bilayer graphene — •Stefan Hubmann[1], Philipp Soul[1], Giorgio di Battista[2], Marcel Hild[1], Kenji Watanabe[3], Takashi Taniguchi[3], Dmitri Efetov[2], and Sergey Ganichev[1] — [1]Terahertz Center, University of Regensburg, 93040 Regensburg, Germany — [2]ICFO, Castelldefels, Barcelona 08860, Spain — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

We report on the observation of nonlinear photocurrent and photoconductivity in twisted bilayer graphene (tBLG) with twist angles below 1°. We show that excitation of the tBLG bulk causes a photocurrent, whose sign and magnitude are controlled by the orientation of the radiation electric field and the photon helicity. The developed theory shows that the current is formed by asymmetric scattering in gyrotropic tBLG. For the observed photocurrents, we demonstrate the emergence of pronounced oscillations upon variation of the gate voltage, which correlate with the oscillations of the sample resistance. These photocurrent oscillations originate in interband transitions between a multitude of subbands in tBLG. Furthermore, at higher radiation intensities, we detected a nonlinear intensity dependence of bulk photogalvanic current and photoconductivity. These nonlinear photoresponses are caused by the interplay between interband, intersubband, and intraband transition. This interplay is controlled by the Fermi level position with respect to the Moiré subbands. We show that the photosignals saturate with rising intensity, while contributions from different transitions differ in their respective saturation behavior.

HL 33.4 Thu 15:45 H32

Dielectric function of $CuBr_xI_{1-x}$ thin films — •E. Krüger[1], M. Seifert[2], M. Bar[1], S. Merker[3], P. Bischoff[1], H. Krautscheid[3], S. Botti[2], M. Grundmann[1], and C. Sturm[1] — [1]Universität Leipzig, Felix-Bloch-Institut für Festkörperphysik, Germany — [2]Friedrich-Schiller-Universität Jena, Institut für Festkörpertheorie und -optik, Germany — [3]Universität Leipzig, Institut für Anorganische Chemie, Germany

Copper halides such as CuI and CuBr are promising p-type semiconductors for transparent optoelectronic devices, especially due to the recently proposed hole density tunability [1]. Here, we present the dielectric function of $CuBr_xI_{1-x}$ thin films ($0 \leq x \leq 1$) determined by spectroscopic ellipsometry in the spectral range from 0.7 eV to 6.5 eV at room temperature. The observed features in the dielectric function are attributed to various electronic transitions in the Brillouin zone [2]. Non-monotonic behavior is observed for the band gap energy as a function of alloy composition revealing a quadratic bowing parameter of 0.5 in good agreement with literature [3]. The spin-orbit splitting decreases linearly from 650 meV for CuI to 150 meV for CuBr. The experimental results are compared with DFT-calculated band structures for different alloy compositions. The effects of bond length mismatches, chemical disorder, and different contributions of metal and halogen atoms to the upper valence bands are discussed in detail.

[1] Yamada et al., Adv. Funct. Mater. **30**, 2003096 (2020)
[2] Krüger et al., APL **113**, 172102 (2018)
[3] M. Cardona, Phys. Rev. **113**, 69 (1963)

HL 33.5 Thu 16:00 H32

Neutralisation of detrimental effects on the Rydberg exciton absorption spectrum — •Katharina Brägelmann, Mariam Harati, Binod Panda, Julian Heckötter, and Marc Assmann — Experimentelle Physik II, Technische Universität Dortmund, 44225 Dortmund

We report on the neutralisation of charged impurities by excitation of Rydberg excitons with surprisingly small laser powers. Rydberg excitons are highly excited states in Cu_2O with principal quantum numbers of up to $n = 30$ [1] with extensions in μm range. The well-known theories propose an n^{-3} scaling for both oscillator strengths and linewidths of the excitons. Usually the highest states ($n = 16$ and above) show some deviation from those theories, as oscillator strengths are smaller and linewidths are wider than expected, which leads to an reduced absorption of these states. Those deviation are known to stem from the presence of charged impurities in the material [2]. Here, we show a way to increase the absorption and to minimize the deviations mentioned above. This increase of absorption happens when the system is pumped in an extremly narrow energy region around the band gap (less than 1 meV) with very small powers of only $0.1 - 10\,\mu$W. This effect indicates a 'purification' of the illuminated volume as the naturally charged impurities have less detrimental impact on the high excitonic states. This research contributes to a deeper understanding of impurity - exciton interactions.

[1] M. A. M. Versteegh et al., Phys. Rev. B 104, 245206 (2021).
[2] S. O. Krüger et al., Phys. Rev. B 101 (2020).

15 min. break

Invited Talk HL 33.6 Thu 16:30 H32

Ultrastrong light-matter coupling in materials — •Niclas S. Mueller[1,2], Eduardo B. Barros[3], Florian Schulz[4], Holger Lange[4], and Stephanie Reich[1] — [1]Department of Physics, Freie Universität Berlin, Berlin, Germany — [2]Present address: NanoPhotonics Centre, Cavendish Laboratory, University of Cambridge, United Kingdom — [3]Department of Physics, Universidade Federal do Ceara, Fortaleza, Ceara, Brazil — [4]Department of Physical Chemistry, University of Hamburg, Hamburg, Germany

Driven by the field of cavity quantum electrodynamics there is an ever-growing quest for systems with extreme light-matter coupling. In the regimes of ultra- and deep strong coupling the coupling strength becomes comparable to the bare excitation energy, leading to exotic phenomena like virtual photons in the ground state and the breakdown of the Purcell effect. Here, we discuss how ultrastrong coupling is systematically achieved in materials, without the need for external cavities. We introduce densely packed supercrystals of gold nanoparticles as an artificial material where the coupling strength can be tuned from ultra- to deep strong coupling. Using a unified theory of dipole-active material excitations, we show that light-matter coupling gets maximized in three-dimensional materials, setting an upper limit for the coupling strength in cavities. From a large set of experimental data, we identify phonons in ferroelectrics, excitons in molecular crystals, and plasmons in metallic supercrystals as excitations where light-matter coupling is so strong that it affects the material ground state, eventually leading to phase transitions and changing the mechanical properties.

HL 33.7 Thu 17:00 H32

Optical Characterization of Phase-Pure Wurtzite GaAs/II-VI Core/Shell Nanowires — •Mike Külkens, Marvin Marco Jansen, Detlev Grützmacher, and Alexander Pawlis — Peter-Grünberg-Institut (PGI-9), Forschungszentrum Jülich GmbH, Germany

Self-catalysed III/V semiconductor core/shell nanowires (NWs) grown by molecular beam epitaxy (MBE) provide enormous potential to develop miniaturized electronic and optoelectronic devices. Following our recent demonstration of WZ-phase-pure *GaAs* NW growth we investigated a novel type of hybrid NWs composed of a WZ-type GaAs core with various WZ-type II/VI-semiconductor shells. The shell provides excellent confinement and passivation of the GaAs core due to the large bandgap energy difference between the two materials and allows to tune the optical bandgap of the GaAs core by tensile strain within a range of several 100 meV.

Here we report on the structural and optical properties of WZ-phase-pure grown $GaAs/Zn_{1-x}Mg_xSe$ core/shell NWs. μ-PL investigations reveal the presence of tensile strain in the *GaAs* core induced by the $Zn_{1-x}Mg_xSe$ shell, which can be engineered via the magnesium concentration and the shell thickness. The measured redshift of the near-band emission from the GaAs core was verified by evaluation of the strain and its effect on the *GaAs* bandgap, using a hydrostatic strain model. The results presented here pave the way for applications of WZ-phase-pure *GaAs*/II-VI core/shell NWs for optoelectronic devices with tunable wavelength in the infrared spectral range.

HL 33.8 Thu 17:15 H32

ZnSe-Based Microdisk Resonators in Novel Supported Geometry — •Wilken Seemann[1], Christian Tessarek[1], Siqi Qiao[2], Nils von den Driesch[2], Alexander Pawlis[2], Gordon Callsen[1], and Jürgen Gutowski[1] — [1]Institute of Solid State Physics, University of Bremen, Germany — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich, Germany

Microdisk resonators often suffer from thermal problems due to the limited contact of the underetched structure to the substrate. In order to circumvent this, ZnSe-based microdisks were fabricated in a supported geometry, i.e., in contact to the substrate over their whole bottom facet. This is achieved by growing a ZnSe:Cl quantum well (QW) encapsulated in ZnMgSe barriers on an AlAs underlayer. Oxidation of the underlayer to Al_2O_3 after disk fabrication increases the refractive index difference between the resonator and the substrate.

Scanning electron microscopy reveals a high structural quality of the fabricated microdisks. Micro-photoluminescence measurements show that the resulting resonators support high-Q resonances near the band edge emission of the ZnSe:Cl QW and a large number of whispering gallery modes on the defect emission band. The latter can be reproduced using a plane-wave model. Raman measurements of microdisks, as well as the as-grown ZnSe-based structure on the oxidized and non-oxidized AlAs underlayer, are used to analyze the mechanical properties of the disk and the influence of the oxidation process on the strain in the QW structure.

HL 33.9 Thu 17:30 H32

Enhancing directivity in optical waveguide antennas — •Henna Farheen[1], Lok-Yee Yan[2], Till Leuteritz[2], Siqi Qiao[2], Florian Spreyer[1], Christian Schlickriede[1], Viktor Quiring[1], Christof Eigner[1], Thomas Zentgraf[1], Stefan Linden[2], Viktor Myroshnychenko[1], and Jens Förstner[1] — [1]Paderborn University, Paderborn, Germany — [2]Universität Bonn, Bonn, Germany

We show the numerical and experimental realization of optimized broadband optical traveling-wave antennas made from low-loss dielectric materials. The antennas are composed of a director and reflector placed over a glass substrate and a dipole emitter located in the feed gap between them serves as an internal source of excitation. Our studies reveal that the highly directive nature of our antennas comes from two dominant guided TE modes excited in the waveguide-like director of the antenna, in addition to the leaky modes. Furthermore, our numerical results are in excellent agreement with the experimental measurements of the antennas that were fabricated using a two-step electron beam lithography. Compared to the previously studied plasmonic antennas for photon emission, our all-dielectric approach demonstrates a new class of highly directional, low loss, and broadband optical antennas.

[1]Farheen, Henna, et al. Optimization of optical waveguide antennas for directive emission of light. JOSA B 39.1 (2022): 83-91.

[2]Farheen, Henna, et al. Broadband optical Ta2O5 antennas for directional emission of light. Optics Express 30.11 (2022): 19288-19299.

HL 33.10 Thu 17:45 H32

First-principles study of momentum-forbidden excitons in bulk 2H-MoX2 (X= S, Se) — •Ravi Kaushik[1,2] and Sergey Artyukhin[1] — [1]Italian Institute of Technology, Genova, Italy — [2]University of Genova, Genova, Italy

Coulomb-bound electron-hole pairs (excitons) dominate the optical response of atomically thin transition metal dichalcogenide (TMD) semiconductors. While Mo-based TMDs monolayers have a direct gap, bulk MoS2 and MoSe2 possess an indirect gap, with momentum-forbidden lowest energy excitonic transitions. Here we study how the effects of translational symmetry breaking by thermal phonons and in scanning spectroscopies can lead to a violation of the usual optical selection rules.

HL 34: Focus Session: Perspectives in Cu(In,Ga)Se 2

Time: Thursday 15:00–18:00 Location: H33

Invited Talk HL 34.1 Thu 15:00 H33

Super-high efficiency CIGS devices: current status and pathways forward — •Romain Carron — Laboratory for Thin Films and Photovoltaics, Empa, Duebendorf, Switzerland

In this contribution, we discuss the limitations to the photovoltaic performance of Cu(In,Ga)Se2 (CIGS) devices, and possible pathways to boost cell efficiencies towards 25% and beyond. Starting from a comparison of record CIGS cells to other photovoltaic technologies, we evaluate the potential for improvement of each of the individual parameters Voc, Jsc, and FF towards the Shockley-Queisser limit. Then we walk through the main causes for losses for each of the individual parameters, connect them to the last decade's progress, and suggest pathways for future improvements. The open-circuit voltage is discussed in particular depth, including the prediction of its value, the role of impurities and alkali elements in high-efficiency devices, the impact of other absorber modifications, and of advanced optical management. Finally, we discuss how the layer sequence of a CIGS solar cell differs from its functional structure. On this basis, we describe potentially advantageous modifications to the device architecture and the related challenges.

Invited Talk HL 34.2 Thu 15:30 H33

Highlights from the development of the world record Cd-free CIGSSe 30x30cm2 solar module — •Anastasia Zelenina — AVANCIS GmbH, Otto-Hahn-Ring 6, 81739 Munich, Germany

In this contribution, the R&D process of 30x30 cm2 CIGSSe solar modules will be discussed [1]. One of the main advantages of the process is the application of an environmentally friendly dry Zn(O,S) buffer, which is applied as an alternative to the widely used CdS chemical

bath deposition (CBD) process. Over the past few years, our development of the 30x30 cm2 CIGSSe modules has been focused on the optimization of the absorber properties. An increased absorber thickness has been applied, with the aim to increase absorption and increase the short circuit current density (JSC). The Jsc-improvement was combined with enhancing the absorber quality through the optimization of the elemental absorber depth profile. The enhanced absorber quality lead to better diode parameters and higher JSC*VOC product values. Furthermore, the absorber surface homogeneity was improved for this increased absorber thickness leading to an enhancement of the Fill Factor (FF) values. The improved absorber homogeneity results mostly from tuning the rapid thermal annealing (RTP) process. The combination of these development steps lead to the achievement of a world record efficiency of 19.8% [2]. This new process developments on 30x30cm2 sized modules will also be the basis for the power development on production-sized modules and will be used for further production upgrades.

[1] "Absorber optimization in CIGSSe modules with a sputtered Zn(O,S) buffer layer at 19% Efficiency", M. Stölzel et al., Proceedings of 36th EU PVSEC, Marseille (2019), p. 590-596, DOI: 10.4229/EUPVSEC20192019-3AO.7.1

[2] NREL Champion Photovoltaic Module Efficiency Chart https://www.nrel.gov/pv/module-efficiency.html

HL 34.3 Thu 16:00 H33

Overcoming current limitations of Cu(In,Ga)Se2 photovoltaic devices — •Daniel Abou-Ras — Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Hahn-Meitner-Platz 1, 14109 Berlin, Germany

Recently, a review paper entitled "CIGS photovoltaics: reviewing an evolving paradigm" (Stanbery et al 2022 J. Phys. D: Appl. Phys. 55 173001, doi: 10.1088/1361-6463/ac4363) has provided an overview of various issues to be improved in Cu(In,Ga)Se2 (CIGS) thin-film solar cells to reach power-conversion efficiencies of 25% and beyond. The authors of this contribution highlight the necessity of implementing device concepts already in use for the established Si and GaAs photovoltaic technologies also for CIGS devices. Possible ways of enhancing the collection and reducing nonradiative recombination in CIGS solar cells are described. I intend to give a brief insight into the main aspects of this review paper in the planned Focus Session.

HL 34.4 Thu 16:15 H33

Identification of nonradiative recombination centers in CuInSe2 and CuGaSe2 — •Baoying Dou[1], Stefano Falletta[2], Christoph Freysoldt[1], and Jörg Neugebauer[1] — [1]Max-Planck-Institut für Eisenforschung GmbH — [2]Ecole Polytechnique Fédérale de Lausanne

Cu(In,Ga)Se2 is a promising solar absorber for thin-film solar cell applications. Nonradiative carrier recombination is one of the key processes that limits the device efficiency. To achieve high performance, it is crucial to identify the critical defects and quantify their induced nonradiative recombination rates. Prior first-principle calculations proposed that the antisites InCu and GaCu, are donors with a transition levels in the band gap, so they may act as nonradiative recombination centers. However, the existence of transition levels in the band gap does not necessarily trigger nonradiative recombination. Using first-principles methods, we quantitatively show that internal conversion in the neutral charge state to the distorted DX center configuration plays a crucial role in carrier recombination by opening an efficient hole capture pathway. The positive charge state returns to the antisite configuration without barrier to complete the entire recombination cycle. However, our calculations show that the DX center is only stable in CuGaSe2, not in CuInSe2. We discuss the consequences of these findings for defect engineering in CuInSe2, CuGaSe2, and its alloys.

30 min. break

Invited Talk HL 34.5 Thu 17:00 H33

Digital Twins - a simulation model for Cu(In,Ga)Se2 solar cells of high and moderate efficiency — •Matthias Maiberg[1], Chang-Yun Song[1], Marcin Morawski[1], Felix Neduck[1], Joshua Damm[1], Heiko Kempa[1], Dimitrios Harisko[2], Wolfram Witte[2], and Roland Scheer[1] — [1]Institute of Physics, Martin-Luther-University Halle-Wittenberg, von-Danckelmann-Platz 3, 06120 Halle (Saale), Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-forschung Baden-Württemberg, Meitnerstraße 1, 70563 Stuttgart, Germany

To overcome the current record efficiency of Cu(In,Ga)Se2 (CIGSe) solar cells, loss mechanisms need to be identified through comprehensive device models. The development of such models, however, is hampered by the complex film microstructure of CIGSe as well as its multi-component device structure. In the first part of our talk, we present one-dimensional models for CIGSe solar cells with high efficiency at around 19 % and moderate efficiency at around 16 %. These models have been obtained by a fitting routine for a set of experimental data which calls the simulation tool Synopsys TCAD as the subprogram. As an outcome, we obtain material parameters of CIGSe. The minority carrier lifetime, for example, exhibits values of >15 ns in the highly efficient cells while it is only 3 ns in the moderately efficient device. In the second part of our talk, we use such digital twin in order to identify loss mechanisms in the solar cells. Here, we address the non-radiative recombination as origin of electronic losses as well as the band gap grading and the window layers as origins for optical losses.

HL 34.6 Thu 17:30 H33

Analysis of the diode factor in CIGSe solar cells — •Valentina Serrano Escalante and Thomas Paul Weiss — University of Luxembourg

In previous work [1] we suggest there is a link between metastable defects and the diode factor. Changes in doping density after light soaking are observed when measuring CV profiles. Those changes are caused by metastable transitions, accounted by the shift of the majority fermi level upon illumination, which in turn increases the diode factor. There are several methods to determine this parameter, namely, from an analysis of the current-voltage curves (JV) [2], using the diode equation or from the slope of the Voc dependence with illumination intensity: Jsc-Voc [3]. Within this work, those methods are tested in a set of CIGSe, Cu poor samples, grown with the three-stage process, with good efficiencies (without any post-deposition treatment) in the range from 15% to 17%. For the analysis of the JV curves under dark, the two-diode model [4] is implemented. Using a 1-diode fit always results in a high value (>1.5), indicating dominant recombination in the space charge region. We use a 2-diode fit to obtain information on the diode factor originating from recombination in the quasi-neutral zone, which is affected by the metastable effects. In the case of JV under illumination, the extraction of the diode factor seems to be hampered by the cross-over between light and dark JV characteristics, which in CIGSe cells might be due to a change in an energetic barrier under light [5]. Therefore, the diode factor under illumination is determined more reliably from Jsc-Voc measurements.

HL 34.7 Thu 17:45 H33

Exact determination of Quasi-Fermi Level splitting from absolute photoluminescence and absorptance spectra — •Sevan Gharabeiki, Taowen Wang, Ajay Singh, Alex Redinger, and Susanne Siebentritt — Department of Physics and Materials Science, University of Luxembourg, 4422 Belvaux, Luxembourg

Photoluminescence (PL) is a powerful tool to investigate the Quasi-Fermi level splitting (QFLS) in absorbers and hence the upper limit of the open-circuit voltage (Voc) in a solar cell. Planck's generalized law and external radiative (ERE) method are the two most common ways to determine the QFLS. Planck's generalized law uses a high energy slope of the PL spectrum and assumes the absorptance (A) to be unity for the photons with energy sufficiently higher than the absorber bandgap. However, in CIGSe solar cells, which employ a graded bandgap, and poly-crystalline perovskite solar cells, the assumption A=1 is no more valid. On the other hand, the ERE method makes use of the radiative bandgap. Many studies consider the PL emission peak position to be the radiative bandgap which is not accurate. Herein, we present a combination of PL and absorptance measurements to accurately determine the QFLS in the CIGSe and methylammonium tintriiodide Perovskite (MASI) absorbers. Then, we compare our QFLS values from the Plancks generalized law and the ERE method. We emphasize that the radiative bandgap and PL maximum are not the same, and using the PL maximum as a radiative bandgap can result in errors in QFLS extraction.

HL 35: Acoustic Waves and Nanomechanics

Time: Thursday 15:00–16:00 Location: H34

HL 35.1 Thu 15:00 H34

A hybrid (Al)GaAs-$LiNbO_3$ surface acoustic wave resonator for cavity quantum dot optomechanics — •Emeline Nysten[1], Armando Rastelli[2], and Hubert Krenner[1] — [1]Physikalisches Institut, WWU Münster, Germany — [2]Institute of Semiconductor and Solid-State Physics, Johannes Kepler Universität Linz, Austria

Surface acoustic waves (SAW) are a useful tool to control the emission of quantum dots (QDs). In particular, SAWs enable the modulation of their energy levels through the deformation potential coupling [1]. Here, we explore the possibility to enhance the interaction between the SAW and the QDs by transferring them on a strong piezoelectric $LiNbO_3$ substrate by epitaxial lift-off [2,3]. Additionally, the membrane is transferred inside a SAW resonator confining the acoustic field inside the cavity. High acoustic quality factors of $Q > 4000$ are demonstrated for the SAW resonator for an operation frequency of $f = 300\,\mathrm{MHz}$ and stay high even after the hybridization. The frequency and position dependent optomechanical coupling of single quantum dots with the resonator modes is recorded and quantified. A possible non-linear coupling between the QDs and the resonator modes is also observed [4]. [1] Appl. Phys. Lett. 93, 081115 (2008) [2] Phys. Rev. B 88, 085307 (2013) [3] J. Phys. D: Appl. Phys. 50, 43LT01 (2017) [4] Appl. Phys. Lett. 117, 121106 (2020)

HL 35.2 Thu 15:15 H34

Determining Amplitudes of Standing Surface Acoustic Waves via Atomic Force Microscopy — •Jan Hellemann[1], Filipp Müller[1], Madeleine Msall[2], Paulo V. Santos[1], and Stefan Ludwig[1] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin, Deutschland — [2]Bowdoin College, Maine, USA

Our aim is the realization of strong coupling between cavity phonons and a few electron double quantum dot as an on-chip hybrid system for quantum information applications. For this purpose, we develop radio frequency surface-phonon cavities containing a double quantum dot laterally defined in a GaAs/AlGaAs heterostructure. To characterize a phonon cavity we generate standing surface acoustic waves (SSAW) by driving the cavity defining interdigital transducers and image the SSAW using atomic force microscopy (AFM), which is able to resolve submicron wavelengths of the SSAW at a few GHz. Alternative techniques are discussed in a related contribution by N. Ashurbekov.

Here, we focus on the AFM cantilever deflection, which substantially overestimates the SSAW amplitude because the cantilever with an eigenfrequency in the kHz range is driven by energy transfer from the much faster oscillating surface. We demonstrate a method to nevertheless determine the actual SSAW amplitude by comparing the hystereses of force curve measurements with model predictions based on solving the equation of motion of the driven cantilever [1]. Finally we present our first characterization measurements of a double quantum dot coupled to a phonon cavity.

[1] J. Hellemann et al, PRApplied **17**, 044024 (2022)

HL 35.3 Thu 15:30 H34

Radio Frequency Surface Acoustic Wave Cavities near 6 GHz — •Nazim Ashurbekov[1], Michael Hanke[1], Edoardo Zatterin[2], Madeleine Msall[3], Jan Hellemann[1], Paulo Santos[1], Tobias Schulli[2], and Stefan Ludwig[1] — [1]Paul-Drude-Institut, Berlin, Germany — [2]European Synchrotron, Grenoble, France — [3]Bowdoin College, Maine, USA

Aiming at strong coupling between confined phonons and confined electrons in hybrid quantum circuits, we develop radio frequency (rf) surface-phonon cavities. The cavities are defined by focusing surface gate Bragg mirrors. They also serve as interdigital transducers, which we use to generate standing surface acoustic waves (SSAWs) for characterizing the cavities. At frequencies >3 GHz corresponding to wavelengths <1 μm most methods to measure the SSAWs become increasingly difficult.

Here, we explore two experimental methods with superior resolutions, scanning X-ray diffraction microscopy (SXDM) and atomic force microscopy (AFM). We present AFM measurements of focused rf SSAWs near 6 GHz and compare them with SXDM measurements. While AFM provides a basic characterization of the SSAW, SXDM in addition yields its complete 3D strain field, relevant for the electron-phonon coupling.

Finally, comparing our experimental results with finite elements method simulations allows us to explore design variations for future optimizations of the electron-phonon coupling in quantum devices.

HL 35.4 Thu 15:45 H34

A quantum dot coupled to a mechanical resonator — •Clemens Spinnler[1], Giang Nam Nguyen[1], Liang Zhai[1], Alisa Javadi[1], Andreas D. Wieck[2], Arne Ludwig[2], Ying Wang[3], Peter Lodahl[3], Leonardo Midolo[3], and Richard J. Warburton[1] — [1]Department of Physics, University of Basel — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum — [3]Niels Bohr Institute, University of Copenhagen

Coupling a single-photon emitter to a mechanical resonator is a promising route towards operations involving a single photon and a single phonon. Semiconductor quantum dots (QDs) are bright sources of coherent single-photons, and their optical two-level transition can be coupled to mechanical motion via deformation potential coupling.

Here, we present a membrane-design resonator: a cantilever with a fundamental in-plane mode at 3.1 MHz with a quality factor as high as 22'000. The membrane design hosts a heterostructure diode for stabilising the QD's charge state. This results in narrow optical linewidths and a high mechanical sensitivity. We probe the Brownian motion at low temperature, 4 K, of the mechanical resonator via the resonance fluorescence from a single quantum dot. The mechanical noise imprinted on the QD's photons is extracted via an autocorrelation measurement. A single photon coupling strength of around 100 kHz is estimated. The in-plane mechanical motion probed here, together with the membrane design, allows a translation to higher frequencies using phononic-crystal resonators for which operation in the resolved-sideband regime becomes viable.

HL 36: Materials and Devices for Quantum Technology 2

Time: Thursday 15:00–17:45 Location: H36

HL 36.1 Thu 15:00 H36

Influence of (N,H)-terminated surfaces on stability, hyperfine structure, and zero-field splitting of NV centers in diamond — Wolfgang Körner[1], •Reyhaneh Ghassemizadeh[1], Daniel Urban[1], and Christian Elsässer[1,2] — [1]Fraunhofer Institute for Mechanics of Materials IWM, Wöhlerstr. 11, 79108 Freiburg, Germany — [2]University of Freiburg, Freiburg Materials Research Center (FMF), Stefan-Meier-Straße 21, 79104 Freiburg, Germany

We present a density functional theory analysis of the negatively charged nitrogen-vacancy (NV^-) defect complex in diamond located in the vicinity of (111)- or (100)-oriented surfaces with mixed (N,H)-terminations [1]. We assess the stability and electronic properties of the NV^- center and study their dependence on the H:N ratio of the surface termination. The formation energy, the electronic density of states, the hyperfine structure and zero-field splitting parameters of an NV^- center are analyzed as function of its distance and orientation to the surface. We find stable NV^- centers with bulk-like properties at distances of at least ~ 8 Å from the surface provided that the surface termination consists of at least 25% substitutional nitrogen atoms. The studied surface terminations have a minor effect on the ground state whereas the NV orientation has major effects. Our results show that axial NV centers near a flat 100% N-terminated (111) surface are the optimal choice for NV-based quantum sensing applications as they are the least influenced by the proximity of the surface.

[1] W. Körner, R. Ghassemizadeh, D. F. Urban, and C. Elsässer, arXiv:2109.12557

HL 36.2 Thu 15:15 H36

Quantum optimal control for conveyor-mode single-electron shuttling in Si/SiGe — •Alessandro David[1], Veit Langrock[2], Julian D. Teske[3], Lars R. Schreiber[3], Hendrik Bluhm[3], Tommaso Calarco[1], and Felix Motzoi[1] — [1]Institute of Quantum Control (PGI-8), Forschungszentrum Jülich, Germany — [2]Institute of Theoretical Nanoelectronics (PGI-2), Forschungszentrum Jülich, Germany — [3]JARA-FIT Institute of Quantum Information, Forschungszentrum Jülich and RWTH Aachen, Germany

An electron shuttling device is a promising candidate for the scalability of spin-qubits quantum computers. We consider a gated Si/SiGe quantum well capable of shuttling electrons smoothly by a translating confining potential (conveyor-mode). Dephasing coupling with valley degree of freedom and geometry of the quantum well dictate a maximum shuttling speed to keep the electron state adiabatically in the ground state and avoid excitation of the valley state. In this work we use the position of the electron as a control parameter and we optimise the trajectory of the electron to show how the electron can be shuttled faster and with lower infidelity compared to the adiabatic regime.

HL 36.3 Thu 15:30 H36

Optimizing Diamonds for the Electrical Readout of Nitrogen-Vacancy Centers in Diamond — •Lina Maria Todenhagen, Hamza Ouerfelli, and Martin Stefan Brandt — Walter Schottky Institut, Technische Universität München, Garching

The nitrogen-vacancy (NV) center in diamond is one of the most attractive quantum systems used in practical applications. Owing to its exceptionally stable spin state, it can be easily initialized, manipulated and read out even at room temperature. However, the widely used optical readout (ODMR) of the NV center is not easily miniaturized, since it requires an extensive optical setup. Alternatively, we can directly read out the spins electrically by generating a spin-dependent photocurrent (EDMR). However, compared to the traditional optical readout, EDMR of NV centers has been investigated in much less detail up to now.

The present work addresses the optimization of the diamond host material for the electrical readout and compares the results to the optical analogue. The investigated substrates cover type IIa CVD diamonds as well as type Ib HPHT diamonds, both in their as-grown state and after different post-treatments, including electron irradiation and annealing. We focus on the effects of other defects such as substitutional nitrogen present in the samples on the spin-dependent photocurrent and the achievable contrast. Our results indicate that the choice of diamond material is a lot more critical for EDMR than for ODMR and may serve as a guideline for the further development of highly integrated NV sensors based on electrical readout.

HL 36.4 Thu 15:45 H36

Superconducting single-photon detectors made of NbTiN using a novel method to characterize the timing jitter — •Lucio Zugliani[1], Rasmus Flaschmann[1], Stefan Strohauer[2], Christian Schmid[1], Fabian Wietschorke[1], Stefanie Grotowski[2], Sven Ernst[2], Simone Spedicato[2], Mirco Metz[1], Björn Jonas[1], Jonathan Finley[2], and Kai Müller[1] — [1]Walter Schottky Institute and Department for Electrical and Computer Engineering, Technical University of Munich, Germany — [2]Walter Schottky Institute and Physics Department, Technical University of Munich, Germany

In recent years, superconducting single-photon detectors (SSPDs) have raised tremendous attention as a key technology for optical quantum processing and faint light detection. With their unparalleled performances to detect single photons, further investigation of these detectors is of high interest [1, 2].

Here, we present our recent progress on NbTiN SSPDs measured at 4.5K. We discuss our approaches to improve the most important figures of merit (dark count rate, dead time, timing jitter, efficiency) including an optimization of the quality of the superconducting NbTiN films and the integration of the detector in a broad-band cavity.

In particular, we focus on the impact of the substrate material on the resulting parameters such as the detected voltage pulse. We investigate the characteristic of pulse height, rise time and timing jitter, finding a relation between the timing jitter and the pulse properties.

[1]*C. Natarajan et al., Sup. Sci. and Tech. 25, 063001 (2012)
[2]*I. Zadeh, Appl. Phys. Lett. 118, 190502 (2021)

HL 36.5 Thu 16:00 H36

Focused ion beam implantation and luminescence of erbium ions in semiconductor nanostructures — •Christian Düputell[1], Patrick Lindner[2], Varvara Foteinou[3], Yujiao Li[4], Jörg Debus[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum — [2]Experimentelle Physik 2, TU Dortmund — [3]RUBION, Ruhr-Universität Bochum — [4]ZGH, Ruhr-Universität Bochum

We report on focused ion beam (FIB) implantation of erbium ions in semiconductor nanostructures. Semiconductor nanostructures have attracted a lot of attention due to their unique optical, electrical and mechanical properties. Focused ion beam is an elegant method to tune these specific properties. This contribution lines out the implantation processes and the methods used to characterize the samples after implantation. Erbium is implanted in various semiconductor nanostructures in its 3+ state using an alloy liquid metal ion source. Furthermore, a sputter cathode source is used to implant erbium(III) oxide. Implantation is done at room temperature as well as at elevated temperatures to reduce radiation damage. The implanted ion distribution is simulated by SRIM and measured by atom probe tomography. After the implantation, the samples are annealed under nitrogen gas using a rapid thermal annealing technique. Photoluminescence measurements on erbium luminescence are carried out at cryogenic temperatures (10 K) as a function of the annealing and implantation parameters. The quality of the samples is then rated according to emission intensity of the important telecom-C-band wavelength of 1.54 μm.

15 min. break

HL 36.6 Thu 16:30 H36

Searching for signatures of magnetism and induced superconductivity in magnetic topological insulator-superconductor hybrid devices — •Max Vassen-Carl, Michael Schleenvoigt, Benedikt Frohn, Detlev Grützmacher, and Peter Schüffelgen — Peter Grünberg Institute 9, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

Topological materials harbor great possibilities for the future of quantum computation. In theory, when quasi-1D topological isolators (TIs) are coupled to superconductors localized Majorana zero modes (MZM) arise at the end of the quasi-1D hybrid structure. However, quasi-1D TIs require a certain in-plane magnetic field, which depends on the cross-section area of the TI, to retrieve the topological properties lost by confinement. Deviations of said TI cross-section change the penetrating flux and can lead to additional opening and closing of the topological gap, creating unwanted MZMs. One possible solution is to integrate magnetism directly into the TI, creating so-called magnetic topological insulators (MTIs), which retain their topological properties even when confined. In this work Chromium is used to magnetically dope (BixSb1-x)2Te3, by means of MBE. First, ex-situ fabricated MTI-Nb Josephson Junctions (JJ) showed no supercurrent, but instead an increase of resistance for low bias voltages. To gain further insights on the interplay between SC and MTI a new sample layout was designed which allows for Josephson and Hall bar measurements in one device. In order to obtain highest S-MTI interface quality those hybrid devices are fully fabricated under UHV conditions.

HL 36.7 Thu 16:45 H36

Coherent interactions between confined fluids of light and GHz-phonons — •Alexander Kuznetsov, Klaus Biermann, and Paulo Santos — Paul-Drude-Institut für Festkörperelektronik in Forschungsverbund Berlin, e. V., Berlin, Germany

Microcavity exciton-polaritons are at the heart of an emerging field of polaromechanics, which studies coupling between polariton and mechanical degrees of freedom and promises unit quantum cooperativity. One challenge is to reach the regime of coherent interactions, when the polariton decoherence rate is smaller than mechanical frequency.

We reached this milestone by coupling polariton fluids of light (macroscopic quantum state) to GHz phonons. High-resolution optical spectroscopy revealed ns-long coherence time reaching $\tau = 2ns$. Monochromatic $\Omega_M = 7GHz$ phonons were injected into a trap using acoustic transducers. Since $1/\tau < \Omega_M$, the interaction resulted in the appearance of well-resolved phonon sidebands in the emission – an optical frequency comb. We demonstrated tuning of the sidebands by the phonon amplitude, which was controlled by the radio-frequency power applied to the transducer.

The demonstrated coherent polaromechanical device is a building block for a bi-directional interface between microwave and optical domains, atomic clocks, and is useful to study rich physics of sideband cooling and amplification.

HL 36.8 Thu 17:00 H36

A solid-state source of single and entangled photons at diamond SiV-center transitions operating at 80 K — •Eddy P. Rugeramigabo[1], Xin Cao[1], Jingzhong Yang[1], Tom Fandrich[1], Yiteng Zhang[1], Benedikt Brechtken[1], Rolf J. Haug[1,2], Michael Zopf[1], and Fei Ding[1,2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Laboratorium für Nano- und Quantenengineering, Leibniz Universität Hannover, Germany

Epitaxially grown quantum dots (QDs) hold great potential for the generation of 'flying' qubits. Coupling these emitters to quantum memories with long coherence times enables the development of hybrid nanophotonic devices incorporating the advantages of both systems. GaAs/AlGaAs QDs based on droplet etching and nanohole infilling exhibit tunable, well-defined optical properties, with emission typically reported at around 780nm. Silicon-vacancy (SiV) centers in diamond show long coherence times and strong interactions with single photons via their zero phonon line (ZPL) at around 737 nm. Here we report the first quantum dot containing material emitting nonclassical light that matches the SiV ZPL. Careful adjustments of the GaAs thickness in the QDs lead to a narrow wavelength distribution (736.2 ± 1.7 nm) and small exciton fine structures (7.0 ± 4.6 eV). Polarization entangled photons are generated via the biexciton-exciton cascade decay with a fidelity of 0.727 ± 0.092. High single photon purity is maintained from 4 K ($g^{(2)}(0)$= 0.07 ± 0.02) up to 80 K ($g^{(2)}(0)$= 0.11 ± 0.01), therefore, paving the way towards cost-efficient applications in quantum repeaters and quantum memories.

HL 36.9 Thu 17:15 H36

Electric field-induced exciton darkening and fine structure vanishing in GaAs/AlGaAs coneshell quantum structures — •Geoffrey Pirard[1] and Gabriel Bester[1,2] — [1]Physical Chemistry and Physics Departments, University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee, 149, D-22761 Hamburg, Germany

Electronic and optical properties of coneshell quantum structures (CSQS) are investigated via a combination of the empirical pseudopotential and the configuration interaction methods. It is found that the application of a vertical electric field onto CSQS can provoke a darkening of the exciton bright doublet accompanied by the suppression ot its fine structure. The existence of such a four-fold degenerate exciton state finds its origins in the carriers' localization: one type of carrier is strongly confined at the bottom of the nanostructure whereas its counterpart is pulled apart in such a way that its probability density acquires a delocalized ring-like nature. The separation between carriers' wave functions leads to a vanishing exchange interaction and reduces the values of the direct Coulomb integrals, giving rise to a tunable long-lived degenerate dark exciton. These properties make the CSQS promising candidates to construct the building blocks of quantum memories.

HL 36.10 Thu 17:30 H36

Bright InAs quantum dot based single-photon sources at telecom wavelengths — •Monica Pengerla[1], Alkaales Mohanad[2], Ranbir Kaur[2], Jan Donges[1], Lucas Bremer[1], Johannes Schall[1], Sven Rodt[1], Mohamed Benyoucef[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623 — [2]Institute of Nanostructure Technologies and Analytics (INA), Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany

Quantum dot (QD) based single-photon sources are key elements of photonic quantum networks. Most interesting are sources emitting at telecom wavelengths to enable long distance quantum communication. Here, we report on deterministically fabricated single-photon sources based on InAs QDs grown on InP substrate. Numerical simulations of such QD heterostructures with backside distributed Bragg reflector and reveal photon extraction efficiency exceeding 50% when integration the QD into mesa or circular Bragg grating structures. The numerical designs are implemented by deterministic device processing using machine learning enhanced in-situ electron beam lithography. Microphotoluminescence studies reveal the excellent optical and quantum optical properties of the fabricated quantum devices.

HL 37: Thermal Properties

Time: Thursday 16:30–17:15 Location: H34

HL 37.1 Thu 16:30 H34

Thermal characterization of semiconductor membranes by Raman thermometry — •Isabell Hüllen[1], Mahmoud Elhajhasan[1], Wilken Seemann[1], Markus R. Wagner[2], and Gordon J. Callsen[1] — [1]Institut für Festkörperphysik, Universität Bremen, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Germany

Photonic structures like nanolasers are often based on freestanding semiconductor membranes comprising hole lattices. As a result, a high number of interfaces limits the thermal conductivity and consequently the overall device performance under high injection conditions. Thus, it remains an open task to correlate the thermal and optical characterization of photonic membranes often based on III-V semiconductors. In this contribution we follow a careful step-by-step approach to attest the suitability of Raman thermometry (RT) for a precise determination of the thermal conductivity κ. First, we analyse a well-studied bulk material like Ge to not only extract κ, but also to assess underlying errors and experimental limitations. Consequently, the RT technique is applied to Ge membranes, in preparation of the subsequent thermal characterization of photonic membranes. Here, we characterize a 250-nm-thick c-plane GaN membrane, which forms the basis for state-of-the-art nanobeam lasers. RT reveals that κ is reduced by up to one order of magnitude in comparison to bulk values. The pronounced Photoluminescence signal of our GaN membrane directly enables an alternative optical and thermal characterization, which we link to RT, aiming to bridge optical and thermal material characterization.

HL 37.2 Thu 16:45 H34

Can group IV alloys compete in thermoelectrics? — •Oliver Krause[1], Ada Chimenti[2], Omar Concepción[1], Thorsten Brazda[1], Stefano Roddaro[2], Detlev Grützmacher[1], and Dan Buca[1] — [1]Peter-Grünberg-Institute 9 (PGI-9), Forschungszentrum Jülich, 52428 Jülich, Germany — [2]Dipartimento di Fisica "E. Fermi", Università di Pisa, Largo Bruno Pontecorvo 3, 56127 Pisa, Italy

The thermoelectric effect allows the conversion of heat into electricity. A material suited for efficient thermoelectric power generation using small temperature differences with a base at room temperature is of outmost interest. The figure of merit in thermoelectrics is ZT, indicating how suited a material is for thermoelectric applications. It can be optimized by reducing the thermal conductivity k and increasing the electrical conductivity σ of a material with a large Seebeck coefficient α. Here, we investigate the potential of group-IV alloys GeSn and SiGeSn, a material system compatible to standard Si technology.

We present a study of k of crystalline GeSn alloys deposited by chemical vapor deposition. The differential 3ω technique was used to determine k electrically. Our preliminary data shows that k strongly decreases with increasing the Sn content, reaching values as low as 5 $\frac{\mathrm{W}}{\mathrm{m \cdot K}}$ at room temperature. The data are compared with previous reports of the same material using Raman thermometry. Using data of the electrical conductivity and modelling of Seeback coefficient, ZT values for both p and n type GeSn layers are calculated.

HL 37.3 Thu 17:00 H34

Anisotropy in the c-plane thermal conductivity of Gallium Nitride — •Mahmoud Elhajhasan[1], Isabell Hüllen[1], Wilken Seemann[1], Ian Rousseau[2], Nicolas Grandjean[2], and Gordon Callsen[1] — [1]Institute of Solid State Physics, University of Bremen, Germany — [2]Institute of Solid State Physics, École Polytechnique Fédérale de Lausanne (EPFL), Switzerland

The thermal characterization of modern semiconductor membranes commonly employed for photonic devices like nanobeam lasers (1D) or photonic crystals (2D), often lacks spatial resolution and appropriate quantification. However exactly these two points are relevant for the detection of e.g., thermal anisotropies, heat spots, and interfaces providing thermal resitance.

In this contribution, Raman thermometry employing one laser beam (1LRT) is used to quantify the thermal conductivity κ of 250-nm-thick state-of-the-art, c-plane GaN membranes. The same membranes are then probed by two laser Raman thermometry (2LRT) to map the temperature distribution caused by a heating laser via a second probe laser. As a result, κ is determined for all in-plane crystal directions. A particular thermal anisotropy is revealed in c-plane GaN via this direct thermal imaging technique with sub-μm spatial resolution, which compares well to ab-initio calculations.

Consequently, we outline first potential routes towards thermal optimizations of photonic nanostructures.

HL 38: Members' Assembly

Themen unter anderem:

- Bericht
- Informationen zu Dresden 2023
- Verschiedenes

Time: Thursday 18:00–19:00 Location: H34

All members of the Semiconductor Physics Division are invited to participate.

HL 39: Quantum Dots and Wires 6: II-VI and related

Time: Friday 9:30–10:45 Location: H32

HL 39.1 Fri 9:30 H32

Raman and X-ray photoemission study of thin films of binary and ternary semiconductor quantum dots — •Oleksandr Selyshchev[1,2], Volodymyr Dzhagan[3,4], and Dietrich R.T. Zahn[1,2] — [1]Semiconductor Physics, TU Chemnitz, Germany — [2]Center for Materials, Architectures, and Integration of Nanomembranes (MAIN), TU Chemnitz, Germany — [3]Institute of Semiconductors Physics, NAS of Ukraine, Kyiv, Ukraine — [4]Taras Shevchenko National University of Kyiv, Ukraine

Quantum dots (QDs) of ternary semiconductor chalcogenides MInS2 (M = Cu, Ag) attract attention as environment friendly alternatives to toxic cadmium and lead chalcogenides. Even though both ternary and binary QDs exhibit size dependent absorption and photoluminescence spectra, the properties of ternary compounds additionally depend on composition, variety of crystalline phases, and defects. Here, we present a comparative Raman and X-ray photoemission spectroscopic (XPS) study of thin films of binary CdS and ternary MInS2 QDs to examine their structural and electronic properties. Raman results show that MInS2 QDs co-exist in chalcopyrite and Cu-Au type phases. XPS study revealed indium-rich surface deviating from ideal stoichiometry. Auger parameters confirm metal ions in the expected oxidation states, while the boundary states of sulfur indicate surface passivation through the thiolate group of thioglycolate ligands. The ionization potentials of binary and ternary QDs are found to be the same as those for the bulk indicating that the bandgap increase is due to quantum confinement of electrons in the conduction band.

HL 39.2 Fri 9:45 H32

Collective Properties of CdSe-CdS giant-shell Quantum Dots — •Yannic Stächelin[1], Artur Feld[1], Agnes Weimer[1], Michael Deffner[2,3], Sonja Krohn[4], Jan Steffen Niehaus[4], and Holger Lange[1,3] — [1]Institut für Physikalische Chemie, Universität Hamburg, Hamburg, Germany — [2]Institut für Anorganische und Angewandte Chemie, Universität Hamburg, Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany — [4]Fraunhofer IAP-CAN, Hamburg, Germany

CdSe-CdS core-giant-shell QDs are nowadays available with near-unity quantum yields, which makes them interesting candidates for lasing or display applications. Bright, high-PLQY QDs might also contribute to photonic quantum technologies as building blocks. QDs can realize deterministic photon-emitters and enable key quantum photonic resources and functionalities. Interaction of densely packed QDs can lead to collective phenomena like excitonic and photonic coupling, superfluorescence and enhanced quantum coherence. Incoherent dephasing processes may deteriorate the inherent quantum properties of QDs. We investigate dependencies of exciton formation in CdSe-CdS giant-shell QDs and interaction in dense ensembles of QDs via ultrafast THz and transient absorption spectroscopy. Polymer-micelles are used to produce dense ensembles containing a variable amount of QDs. In dense ensembles, we observe the onset of a collective dynamic depending on the excitation conditions, which are thus a means of controlling the dynamics.

HL 39.3 Fri 10:00 H32

Excitonic fine structure of epitaxial Cd(Se,Te) on ZnTe type-II quantum dots — •Petr Klenovsky[1,2], Piotr Baranowski[3], and Piotr Wojnar[3] — [1]Department of Condensed Matter Physics, Faculty of Science, Masaryk University, Kotlářská 267/2, 61137 Brno, Czech Republic — [2]Czech Metrology Institute, Okružní 31, 63800 Brno, Czech Republic — [3]Institute of Physics, Polish Academy of Sciences, Al Lotników 32/46, PL-02-668 Warsaw, Poland

The structure of the ground state exciton of Cd(Se,Te) quantum dots embedded in ZnTe matrix is studied experimentally using photoluminescence spectroscopy and theoretically using $\mathbf{k} \cdot \mathbf{p}$ and configuration interaction methods. The experiments reveal a considerable reduction of fine-structure splitting energy of the exciton with increase of Se content in the dots. That effect is interpreted by theoretical calculations to originate due to the transition from spatially direct (type-I) to indirect (type-II) transition between electrons and holes in the dot induced by increase of Se. The trends predicted by the theory match those of the experimental results very well.

The theory identifies that the main mechanism causing elevated fine-structure energy in particular in type-I dots is due to the multipole expansion of the exchange interaction. Moreover, the theory reveals that for Se contents in the dot > 0.3, there exist also a peculiar type of confinement showing signatures of both type I and type II and which exhibits extraordinary properties, such as almost purely light hole character of exciton and toroidal shape of hole states.

HL 39.4 Fri 10:15 H32

Polarized emission with sub-meV linewidth from single, two-dimensional PbS nanoplatelets — •Pengji Li[1], Lars Klepzig[2,3], Jingzhong Yang[1], Michael Zopf[1], Jannika Lauth[2,3,4], and Fei Ding[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Institute of Physical Chemistry and Electrochemistry, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Cluster of Excellence PhoenixD, Welfengarten 1A, D-30167 Hannover, Germany — [4]Universität Tübingen, Institute of Physical and Theoretical Chemistry, Auf der Morgenstelle 18, D-72076 Tübingen, Germany

In the past few decades, the tunability and strong light-matter coupling in nanometer-sized colloidal systems promotes their potential use in novel applications such as quantum metrology, quantum imaging or quantum communication. Two-dimensional (2D) nanoplatelets (NPLs) have recently moved into focus due to their controllable photoluminescence properties. In this work, the optical properties of single colloidal 2D PbS NPLs are explored at cryogenic temperature (T=4

K). Stable and narrow-band excitonic emission of single PbS NPL near 1.8 eV is observed with linewidths down to 0.6 meV.The prominent exciton-phonon interaction are detected. The emission features a strongly polarized emission with a degree of polarization up to 77%. These findings denote the first observation of narrow-band polarized photoluminescence (PL) from 2D PbS nanoplatelets, which were believed to suffer from broad PL due to complex band-edge exciton states evolving from the 64-fold degeneracy in PbS.

HL 39.5 Fri 10:30 H32

Exciton recombination dynamics and polarization properties in CsPbI3 perovskite nanocrystals — •Gang Qiang[1], Dmitri R. Yakovlev[1,2], Elena V. Shornikova[1], Danil O. Tolmachev[1], Mikhail A. Prosnikov[3], Elena V. Kolobkova[4], Peter C. M. Christianen[3], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, D-44221 Dortmund, Germany — [2]St. Petersburg, Russia — [3]High Field Magnet Laboratory (HFML-EMFL), Radboud University, 6525 ED Nijmegen, The Netherlands — [4]St. Petersburg, Russia

We synthesized CsPbI3 NCs in fluorophosphate glass matrix and investigated the optical properties at various temperatures down to 4.2 K and in external magnetic fields up to 30 T. Recombination dynamics demonstrate clearly two-exponential decay characteristic for exciton emission with the dark exciton as a ground state. An anomalous polarization properties is observed at low temperature (e.g. 4.2 K), i.e. with the increasing of magnetic field, the degree of circular polarization (DCP) increases smoothly, while at ~21 T a 'hump' shows up. Higher temperature blurs this behavior, and it can not be clearly observed at 20 K. Moreover, for the spin dynamics, at low temperature (4.2 K) and high magnetic field (> 8 T), after reaching the maximum, the time resolved DCP tends to decreases and slowly relaxes to at a constant level, which is quite different from the observations in III-V and II-VI NCs.

HL 40: THz and MIR Physics in Semiconductors

Time: Friday 9:30–11:45 Location: H33

HL 40.1 Fri 9:30 H33

Generation of intense sub-half-cycle terahertz pulses from spatially indirect interband transitions — •Christian Meineke[1], Michael Prager[1], Johannes Hayes[1], Qiannan Wen[2], Lukas Kastner[1], Dieter Schuh[1], Kilian Fritsch[3], Oleg Pronin[3], Markus Stein[4], Sangam Chatterjee[4], Mackillo Kira[2], Rupert Huber[1], and Dominique Bougeard[1] — [1]University of Regensburg, 93040 Regensburg — [2]University of Michigan, Ann Arbor, Mi 48109 — [3]Helmut Schmidt University, 22043 Hamburg — [4]Justus Liebig University, 35392 Giessen

Ultimately short phase-stable terahertz (THz) pulses form the bedrock of THz lightwave electronics, where the carrier field creates a transient bias to control electrons on sub-cycle time scales. Here, we introduce a fully scalable high-repetition-rate THz source generating intense phase-locked and strongly asymmetric sub-cycle field transients. The key idea is to engineer electronic wavefunctions in type-II aligned semiconductor quantum wells such that resonant interband photoexcitation induces an ultrafast charge separation over several nanometers even without any bias. Our detailed quantum mechanical analysis reveals that local charging dynamics lifts the spatial separation of electrons and holes, leading to an abrupt decrease of the dipole moment, generating one single pronounced positive field peak. The THz bandwidth is scalable up to the mid-infrared by reducing the pump pulse duration. The versatility of our emitter allows adjusting waveforms, spectra, and field strengths to many applications, such as ultrabroadband spectroscopy and femtosecond nanoscopy.

HL 40.2 Fri 9:45 H33

Exploring mid-infrared transient gain in graphene — •Kalliopi Mavridou[1,2], Angelika Seidl[1,2], Rakesh Rana[1], Alexej Pashkin[1], Manfred Helm[1,2], and Stephan Winnerl[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, Dresden 01328, Germany — [2]Faculty of Physics and Center for Advancing Electronics Dresden, Technische Universität Dresden, Dresden 01062, Germany

In our study we employ a powerful method, namely a three-pulse pump-probe technique, that was first suggested by Kim *et al.*[1], to explore the possibility to achieve transient gain photon energies below the optical phonon energy (∼ 200 meV) in graphene. Intriguingly, this technique is not widely established and to our knowledge has never been used in the mid- or far-infrared spectral range. The principle behind this method relies on the effect of a strong pre-pump pulse of 1.55 eV photons, which can cause a transient population inversion at lower energies. This population inversion is evidenced by a sign flip of the mid-infrared (86 meV photon energy) pump-probe signal that is related to either absorption or stimulated emission of mid-infrared photons of the pump beam. We present the results on multilayer graphene obtained under various experimental configurations. Our findings shed light into the completion of rapid thermalization via Coulomb scattering and carrier cooling via optical phonons.

1. Kim, K.; Urayama, J.; Norris, T.; Singh, J.; Phillips, J.; Bhattacharya, P. *Appl. Phys. Lett.*, **2002**, *81*, 670-672.

HL 40.3 Fri 10:00 H33

Elastic and inelastic exciton scattering in InGaAs multi-quantum wells — •Daniel Anders, Markus Stein, and Sangam Chatterjee — Institute of Experimental Physics I and Center for Materials Research (LAMA), Justus-Liebig-University Giessen, Heinrich-Buff-Ring 16, D-35392 Giessen, Germany

The interaction of optically injected excitons amongst each other as well as with electrons is one of the most fundamental questions in semiconductor physics. In the past, scattering processes in semiconductors between charge carriers and excitons have been studied intensively using a wide variety of experimental methods, e.g., four-wave-mixing spectroscopy, time-resolved photoluminescence spectroscopy, or optical pump - optical probe spectroscopy. In contrast to the aforementioned methods optical pump - terahertz probe spectroscopy allows to distinguish between elastic and the destructive inelastic scattering processes of excitons. While the linewidth of the intraexcitonic resonance provides a measure for the total scattering rate of all scattering processes, the change of the intraexcitonic oscillator strength is only sensitive to inelastic scattering processes. In this work, we compare exciton-electron and exciton-exciton scattering and determine the respective contributions of elastic and inelastic scattering processes.

HL 40.4 Fri 10:15 H33

Highly superlinear terahertz photoconductance in GaAs quantum point contacts in the deep tunneling regime — •Maximilian Otteneder[1], Marcel Hild[1], Ze-Don Kvon[2,3], Ekaterina E. Rodyakina[2,3], Mikhail M. Glazov[4], and Sergey D. Ganichev[1,5] — [1]Terahertz Center, University of Regensburg, Regensburg, Germany — [2]Novosibirsk, Russia — [3]Novosibirsk, Russia — [4]St. Petersburg, Russia — [5]CENTERA, Institute of High Pressure Physics, Warsaw, Poland

A highly superlinear in radiation intensity photoconductance induced by continuous wave terahertz laser radiation with low intensities has been observed in quantum point contacts made of GaAs quantum wells operating in the deep tunneling regime. For very low values of the dark conductance $G_{\rm dark}/G_0 \approx 10^{-6}$, with the conductance quantum $G_0 = 2e^2/h$, the photoconductance scales exponentially with radiation intensity and increases by almost four orders of magnitude at already 100 mW/cm^2. This effect is observed for a radiation electric field oriented along the source drain direction. We provide model considerations of the effect and attribute it to the variation of the tunneling barrier height by the radiation field due to local diffraction effects. We also demonstrate that cyclotron resonance due to an external magnetic field manifests itself in the photoconductance, completely suppressing the photoresponse.

15 min. break

Invited Talk HL 40.5 Fri 10:45 H33

Ultrafast subcycle dynamics of deep-strong light-matter coupling — •Joshua Mornhinweg[1], Maike Halbhuber[1], Laura Diebel[1], Viola Zeller[1], Josef Riepl[1], Cristiano Ciuti[2], Do-

minique Bougeard[1], Rupert Huber[2], and Christoph Lange[3] — [1]Universität Regensburg, Germany — [2]Université de Paris, France — [3]TU Dortmund, Germany

Subcycle interactions of strong light fields and electric charges lead to multi-octave spanning dynamics such as high-harmonic generation. In optical microcavities, even vacuum field fluctuations can drive non-perturbative light-matter coupling. Once the rate of energy exchange between the cavity and the matter mode becomes of the order of the carrier frequency of light, ultrastrong coupling (USC) emerges, and the profound modification of the vacuum ground state gives rise to novel phenomena such as cavity-mediated superconductivity. Here, we explore intriguing subcycle effects of USC including non-adiabatic dynamics occurring during quasi-instantaneous switch-off of the coupling, for which we observe sub-polariton-cycle polarization oscillations. Additionally, we drive USC with strong coherent THz fields to reveal nonlinear interactions between the polariton states, breaking the normal-mode approximation. Finally, we present deep-strong coupling (DSC) of multiple light and matter modes, creating a spectrum of Landau magneto-polaritons which covers 6 optical octaves, a coupling strength of $\Omega_R/\omega_c \approx 3.0$, and a record virtual ground state population exceeding 1 photon. Our results open up new avenues for dynamically tailoring of USC and DSC on strongly subcycle timescales.

HL 40.6 Fri 11:15 H33

Probing Free Electrons in InSb with Terahertz Shockwave Spectroscopy — •Peter Fischer, Gabriel Fitzky, Davide Bossini, Alfred Leitenstorfer, and Ron Tenne — Department of Physics and Center for Applied Photonics, University of Konstanz, D-78457 Konstanz, Germany

The Auger process, a non-radiative three-particle recombination, is critical especially in narrow-band semiconductors where it sets a fundamental efficiency limit for optoelectronic applications. Since their characteristic response frequencies fall within a broadband interval in the terahertz and mid-infrared range, quantitative studies of the electron dynamics in these materials remain challenging. Here, we demonstrate a new pump-probe technique able to monitor the free carrier plasma by observing its signature in the transient terahertz reflectivity spectrum. A broadband terahertz source, providing at the same time maximum temporal resolution, emerges from slicing the electric-field transient on a subcycle time scale, effectively generating a shockwave. Applying this transient to InSb after interband excitation, we find that the Auger-recombination coefficient increases by a factor of two from room temperature to 4.2 K. Furthermore, the importance of electron trapping to accurately model carrier dynamics is illustrated. Our approach exclusively targets the response of free charge carriers, disentangled from other contributions by e.g. bound excitons. Therefore, it offers a tool complementary to established time-resolved techniques.

HL 40.7 Fri 11:30 H33

Nonlinear photocurrents induced by terahertz radiation in twisted bilayer graphene — •Stefan Hubmann[1], Philipp Soul[1], Giorgio di Battista[2], Marcel Hild[1], Kenji Watanabe[3], Takashi Taniguchi[3], Dmitri Efetov[2], and Sergey Ganichev[1] — [1]Terahertz Center, University of Regensburg, 93040 Regensburg, Germany — [2]ICFO, Castelldefels, Barcelona 08860, Spain — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

We report on the observation of nonlinear photocurrent and photoconductivity in twisted bilayer graphene (tBLG) with twist angles below 1°. We show that excitation of the tBLG bulk causes a photocurrent, whose sign and magnitude are controlled by the orientation of the radiation electric field and the photon helicity. The developed theory shows that the current is formed by asymmetric scattering in gyrotropic tBLG. For the observed photocurrents, we demonstrate the emergence of pronounced oscillations upon variation of the gate voltage, which correlate with the oscillations of the sample resistance. These photocurrent oscillations originate in interband transitions between a multitude of subbands in tBLG. Furthermore, at higher radiation intensities, we detected a nonlinear intensity dependence of bulk photogalvanic current and photoconductivity. These nonlinear photoresponses are caused by the interplay between interband, intersubband, and intraband transition. This interplay is controlled by the Fermi level position with respect to the Moiré subbands. We show that the photosignals saturate with rising intensity, while contributions from different transitions differ in their respective saturation behavior.

HL 41: Organic Semiconductors 2

Time: Friday 9:30–10:45 Location: H34

HL 41.1 Fri 9:30 H34

Understanding structure-to-property relationships for phonons and thermal transport in hydrogen-bonded organic semiconductors. — •Lukas Legenstein, Lukas Reicht, Tomas Kamencek, Sandro Wieser, and Egbert Zojer — Institute of Solid State Physics, Graz University of Technology, Graz, Austria

Research on organic semiconductors (OSC) has primarily focused on their (opto-)electronic properties. The understanding of phonons in these materials is, however, still rather poorly developed, despite their crucial role for charge and heat transport processes. Of central importance in this context are lattice phonons dominated by translations and rotations of entire molecules, which are coupled through non-covalent interactions. To elucidate how non-covalent bonding types such as H-bonding and π-π interactions affect phonons in otherwise vdW-stacked OSCs, we simulate the phonon bands of crystalline quinacridone (QA), as a prototypical H-bonded OSC. Notably, QA forms polymorphs with fundamentally different crystal structures, which strongly impact the observed phonons. The obtained phonon bands show complex dispersions with avoided crossings and mode hybridisations due to a mixing of inter- and intra-molecular vibrations. The phonons are simulated combing the phonopy package with density-functional theory employing the FHI-aims and VASP codes. The calculated phonon band structures are also used for benchmarking on-the-fly trained machine learning force fields calculated with VASP, which are then employed for modelling thermal transport within the Green-Kubo formalism.

HL 41.2 Fri 9:45 H34

Regiochemistry of Donor-Dendrons Controls the Performance of TADF Dendrimer based OLEDs — •Rishabh Saxena[1], Dianming Sun[2], Stavros Athanasopoulos[1], Eli Zysman-Colman[2], and Anna Köhler[1] — [1]University of Bayreuth, Germany — [2]University of St. Andrews, UK

The potential of dendrimers exhibiting thermally activated delayed fluorescence (TADF) as emitters in solution-processed organic light-emitting diodes (OLEDs) has to date not yet been realized. This in part is due to a poor understanding of the structure-property relationships in dendrimers where reports of detailed photophysical characterization and mechanism studies are lacking. In this study, we investigated dendrimers with multiple dendritic electron-donating moieties connected to a central electron-accepting core via a para- or a meta-phenylene bridge. Characterization of host-free OLEDs revealed the superiority of meta-dendrimers as compared to the already reported para-analogue. Photophysical investigations in the films showed that, although all the dendrimers possess similar singlet-triplet energy gap, normally implying similar reverse intersystem crossing (RISC) rate, better TADF properties are obtained for meta-dendrimers when compared to para-dendrimers. In this regard, what this study reveals is that the reorganization energy can play an important role in enhancing RISC rate and that this can be modulated as a function of the regiochemistry of donor dendron about the acceptor. This is a heretofore unexploited strategy and can be used as a general chemical design principle, especially in the case of bulky dendrimers.

HL 41.3 Fri 10:00 H34

Optical Vortices in Hemispherical Organic Microcavities — •Johannes Düreth[1], Simon Betzold[1], Marco Dusel[1], Monika Emmerling[1], Jürgen Ohmer[2], Utz Fischer[2], Christian Schneider[3], Sven Höfling[1], and Sebastian Klembt[1] — [1]Technische Physik, RCCM and Würzburg-Dresden Cluster of Excellence ct.qmat, University of Würzburg, Germany — [2]Department of Biochemistry, University of Würzburg, Germany — [3]Institute of Physics, University of Oldenburg, Germany

Light can carry two different kinds of angular momentum: spin angular momentum (SAM), which is associated with polarization, and orbital

angular momentum (OAM), which occurs in light with spiral phase fronts. In recent years, it has been shown that rotational symmetry of a microcavity systems leads to an effective spin-orbit coupling of the SAM and the OAM of photons, resulting in new polariton eigenstates.

Here, we study helical Laguerre-Gaussian modes $LG_{0\pm1}^{\sigma\pm}$ formed in such systems. For a total angular momentum of $J = 0$, both eigenstates are radially and azimuthally polarized, respectively. Due to the spatial dependence of the linear polarization, we measure spin vortices for these modes. In contrast, the energetically degenerate modes with $J = 2$ exhibit opposite circular polarization and carry an optical OAM with opposite chirality. Accordingly, phase vortices with opposite sign were measured by polarization-dependent interference measurements.

Moreover, we show that the preservation of pump polarization allows selection of the optical OAM of ±1.

HL 41.4 Fri 10:15 H34

Experimental and theoretical studies of the occupied density of states distribution of charge carriers at low temperatures in disordered organic semiconductors — •Andrei Stankevych, Rishabh Saxena, Heinz Bässler, Andrey Kadashchuk, and Anna Köhler — Soft Matter Optoelectronics and Bavarian Polymer Institute (BPS), Universitätsstrasse 30, 95448 Bayreuth, Germany

The thermally-stimulated luminescence (TSL) technique has been applied to determine the width of density of state (DOS) distribution σ_{DOS} in pristine amorphous films of 18 common OLED materials. The high-temperature wing of the TSL curve in amorphous materials is an exact replica of the deeper portion of the DOS distribution and yields the effective DOS width. In addition, we measured the width of the TSL curves σ_{TSL} and found that it scales linearly with σ_{DOS} parameter, suggesting an existence of a universal ratio σ_{TSL} / $\sigma_{DOS} \approx 2/3$ observed for a large set of organic materials. The low-temperature energy relaxation of photogenerated carriers within a Gaussian DOS implies a significant narrowing of the ODOS distribution. In order to gain a deeper insight into this effect, we performed extensive Monte-Carlo simulations of charge-carrier energetic relaxation process and found that such "spectral narrowing" effect is a genuine property of the hopping carrier relaxation at low temperature within a Gaussian DOS. Moreover, we found that spatial energy correlation effects, which are indeed present in organic media, must be considered for the quantitative description of experimental observations.

HL 41.5 Fri 10:30 H34

Exploring the interplay of oriented molecules and device performance by post-annealing studies of organic light-emitting diodes — •Dinara Samigullina, Christian Hänisch, Karl Sebastian Schellhammer, and Sebastian Reineke — Dresden Integrated Center for Applied Physics and Photonic Materials (IAPP) and Institute of Applied Physics, Technische Universität Dresden, Germany

Organic light-emitting diodes (OLEDs) have been widely investigated in the last decades exploring strategies to enhance their performance. Nevertheless, a thorough understanding of the microscopic processes during the thin-film formation and morphology evolution is quite challenging and under debate in many facets. In this work, we present a comprehensive study of the influence of post-annealing on the optoelectronic performance of OLEDs. In addition to standard characterisation techniques such as spectroscopy and electrical measurements, we use impedance spectroscopy in order to probe the change in polarisation of organic thin films depending on the annealing temperature. We show, how the orientation of permanent dipole moments (PDMs) in thin films can be manipulated by post-annealing and connect this to improved electrical performance. Moreover, angle-resolved emission spectra reveal the influence of heating on the orientation of the transition dipole moment (TDM) of emitting molecules. In such manner, the correlation between annealing temperature and orientation of PDMs and TDMs is studied while taking into consideration the optoelectronic properties of OLEDs.

HL 42: 2D Materials 6 (joint session HL/CPP/DS)

Time: Friday 9:30–12:00 Location: H36

HL 42.1 Fri 9:30 H36

THz conductivity of nanograined Bi2Te3 pellets with varying Te doping — •Ahana Bhattacharya[1], JeongWoo Han[1], Sepideh Izadi[2], Sarah Salloum[3], Stephan Schulz[3], Gabi Schierning[2], and Martin Mittendorff[1] — [1]Universität Duisburg-Essen, Fakultät für Physik, 47057 Duisburg, Germany — [2]Universität Bielefeld, Fakultät für Physik, 33615 Bielefeld, Germany — [3]Universität Duisburg-Essen, Fakultät für Chemie, 45141 Essen, Germany

The topological insulator Bi2Te3 hosts surface states with a high carrier mobility as back scattering of charge carriers is suppressed due to the spin-momentum locking. While in large crystals the electronic properties are dominated by the bulk states, hot-pressed pellets of nanograined Bi2Te3 offer a high surface-to-volume ratio, which provides a platform to exploit the surface carriers even in extended samples. Here we employ THz time-domain spectroscopy to disentangle the contribution of surface and bulk carriers to the transport properties. Even at room temperature the THz reflection is determined by characteristic features of the high-mobility surface carriers, i.e. Drude conductivity but also plasmonic contributions. The latter are caused by confinement of the surface carriers due to the mechanical structure of the sample. Variations of the Te content allows to shift the Fermi energy and thus strongly influences the resulting THz spectra.

HL 42.2 Fri 9:45 H36

Direct growth of monolayer MoS2 on nanostructured silicon waveguides — •A Kuppadakkath[1], E Najafidehaghani[2], Z Gan[2], A Tuniz[3], G Ngo[1], H Knopf[1], F Löchner[1], F Abtahi[1], T Bucher[1,5], S Shradha[1], T Käsebier[1], S Palomba[3], N Felde[4], P Paul[1], T Ullsperger[1], S Schröder[4], A Szeghalmi[1,4], T Pertsch[1,4], I Staude[1,5], U Zeitner[1,4], A George[2], A Turchanin[2], and F Eilenberger[1] — [1]Institute of Applied Physics (FSU), Jena, Germany — [2]Institute of Physical Chemistry (FSU), Jena, Germany — [3]Sydney Nano, Camperdown, Australia — [4]Fraunhofer IOF, Jena, Germany — [5]Institute of Solid State Physics (FSU), Jena, Germany

We report for the first time the direct growth of Molybdenum disulfide (MoS2) monolayers on nanostructured silicon-on-insulator waveguides. Our results indicate the possibility of utilizing the Chemical Vapour Deposition (CVD) on nanostructured photonic devices in a scalable process. Direct growth of 2D material on nanostructures rectifies many drawbacks of the transfer-based approaches. We show that the van der Waals materials grow conformally across the curves, edges, and the silicon-SiO2 interface of the waveguide structure. Here, the waveguide structure used as a growth substrate is complex not just in terms of its geometry but also due to the two materials (Si and SiO2) involved. A transfer-free method like this yields a novel approach for functionalizing nanostructured, integrated optical architectures with an optically active direct semiconductor.

HL 42.3 Fri 10:00 H36

Atomic layer deposition of ternary $MoWS_2$ — •Christian Tessarek, Tim Grieb, Andreas Rosenauer, and Martin Eickhoff — Institut für Festkörperphysik, Universität Bremen

Two-dimensional (2D) monolayers of binary molybdenum disulfide (MoS_2) and tungsten disulfide (WS_2) belong to the transition metal dichalcogenide (TMDC) material family and are direct band gap semiconductors. The optical band gap of monolayer MoS_2 and WS_2 is ∼1.9 and 2.0 eV, respectively. Ternary $Mo_xW_{1-x}S_2$ enables tuning of excitonic transition energy dependent on the concentration x.

Atomic layer deposition (ALD) is used to deposit $MoWS_2$ in the whole composition range between pure MoS_2 and WS_2. The concentration x is determined by the frequency position of the A_{1g} Raman mode. The distribution of W and Mo atoms in the crystal lattice of $MoWS_2$ is studied by high resolution scanning transmission electron microscopy. Additional annealing is performed to improve structural and optical properties. Photoluminescence spectroscopy measurements show concentration dependent spectral position of A and B excitonic emission.

HL 42.4 Fri 10:15 H36

Epitaxial growth of post transition metal chalcogenides:

From standard approaches to new capabilities — •Eugenio Zallo[1,2], Michele Bissolo[1], Marco Dembecki[1], Gregor Koblmüller[1], and Jonathan J. Finley[1] — [1]Walter-Schottky-Institut and Physik Department, Technische Universität München, Am Coulombwall 4, 85748, Garching, Germany — [2]Paul-Drude-Institut für Festkoerperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, 10117, Berlin, Germany

Van der Waals (vdW) materials grown epitaxially are an urgent challenge for the development of scalable and high-crystalline-quality semiconductor films that can be exploited for novel device technologies. 2D materials "beyond graphene" have sparked immense interest in recent years, due to their excellent physical properties. Among them, post transition metal chalcogenides (PTMC, M={In,Ga} and C={S,Se,Te}) are vdW semiconductor materials with extraordinary photoresponsivity, a quasi-direct gap with a Mexican hat valence band and promising thermoelectric properties but they suffer from fast layer oxidation. In this presentation, the molecular beam epitaxy (MBE) growth of large-area PTMC is demonstrated on 3D and 2D bonded substrates by means of encapsulation strategies and careful microscopic and spectroscopic characterizations supported by density functional theory calculations. In order to study the pristine information of air sensitive materials, we present a cutting edge UHV cluster tool for the synthesis of ultrapure 2D-PTMCs and their heterostructures. The potential directions will be described.

HL 42.5 Fri 10:30 H36

Fabrication of Dielectric Mirrors and Microcavity Configurations for Light-Matter Coupling with Transition-Metal Dichalcogenides Heterostructures — •Chirag Palekar[1], Manan Shah[2], Fynn Kunze[2], Peter Klar[2], Stephan Reitzenstein[1], and Arash Rahimi-Iman[2] — [1]Institute of Solid State Physics, Technische Universität Berlin, D-10623, Germany. — [2]I. Physikalisches Institut und Zentrum für Materialwissenschaften, Justus-Liebig Universität Gießen, D-35392, Germany

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15 min. break

HL 42.6 Fri 11:00 H36

Selective area growth of MoS_2 via CVD on patterned GaN-AlO_x substrates — •Simon Wörle, Theresa Grünleitner, Alex Henning, and Ian Sharp — Walter Schottky Institute and Physics Department, Technical University of Munich, Garching, Germany

Two-dimensional (2D) transition metal dichalcogenides have attracted considerable attention due to their unique optoelectronic properties. For the application of 2D materials in semiconductor devices, the controlled and scalable synthesis of high-quality 2D materials is critical.

Here, we demonstrate the selective area growth of MoS_2 by chemical vapor deposition (CVD) on GaN substrates that were patterned with ultrathin aluminum oxide coatings created by low-temperature atomic layer deposition. Optical and scanning electron microscopy images show that mono- and few-layer MoS_2 flakes preferentially nucleate and grow directly on the (uncoated) GaN. Atomic force microscopy and Raman measurements further reveal the formation of triangular and star-like shaped multilayer MoS_2 crystals at the interfaces between GaN and AlO_x. Moreover, the observed fixed orientation of the triangular MoS_2 flakes with respect to the GaN substrate lattice indicates van der Waals epitaxy. By altering the CVD growth conditions, the density of deposited MoS_2 flakes can be tuned, resulting in the growth of either isolated MoS_2 nanosheets or continuous films, in the latter of which the individual flakes have coalesced.

The presented results mark an important step towards integrated MoS_2 based heterostructures for semiconductor device applications.

HL 42.7 Fri 11:15 H36

Patterned growth of transition metal dichalcogenides monolayers and multilayers for electronic and optoelectronic device application — •Seung Heon Han[1], Ziyang Gan[1], Emad Najafidehaghani[1], Fatemeh Abtahi[2], Christof Neumann[1], Julian Picker[1], Tobias Vogel[2], Uwe Hübner[3], Falk Eilenberger[2], Antony George[1], and Andrey Turchanin[1] — [1]Institute of Physical Chemistry, Friedrich Schiller University Jena, Jena, Germany — [2]Institute of Applied Physics, Friedrich Schiller University Jena, Jena, Germany — [3]Leibniz Institute of Photonic Technology (IPHT), Jena, Germany

We present a simple, large area, cost effective soft lithographic method for growth of high-quality two-dimensional transition metal dichalcogenides (TMDs). Initially, a liquid precursor (Na2MoO4 in aqueous solution) is patterned on the growth substrate using micro-molding in capillaries (MIMIC) technique. Subsequently, a chemical vapor deposition (CVD) step is employed to convert the precursor patterns to monolayer, few layers, or bulk TMDs, depending on the precursor concentration. The grown patterns were characterized using optical microscopy, atomic force microscopy, Raman spectroscopy, X-ray photoelectron spectroscopy, scanning electron microscopy, and photoluminescence spectroscopy to reveal their morphological, chemical, and optical characteristics. The applicability of the grown patterned TMDs were tested for application such as field effect transistors, photodetectors, and memtransistor devices.

HL 42.8 Fri 11:30 H36

Conductive 2D MOFs in van-der-Waals heterostructures — •Jonas Pöhls[1], Zhiyong Wang[2], Renhao Dong[2], and Thomas Weitz[1] — [1]I. Physical Institute University of Göttingen, Göttingen, Germany — [2]Technical University of Dresden, Dresden, Germany

In conventional three-dimentional (3D) Metal-Organic Frameworks (MOFs) the electric conductivity is limited by the large separation of the metal centers by the organic ligands. Recent advantages in the synthesis of layered two-dimensional conjugated MOFs (2D c-MOFs) lead to a large improvement of the electronic properties, these materials allow a charge transfer along both interlayer (π-π-stacking) and intralayer (basal plane) directions [1]. In order to elucidate the underlying charge transport mechanisms in the 2D c-MOFs, we perform electronic characterizations of the films implemented in field-effect transistors under varying conditions. In addition to the improved properties of the 2D c-MOFs themselves, their 2D nature make them also a promising candidate for the fabrication of van-der-Waals heterostructures with other 2D materials like graphene, which could give access to a variety of interaction-driven effects. We present first results on the charge transport of 2D c-MOFs down to the size of single crystals as well as implemented in van-der-Waals heterostructures.

[1] Z. Wang et al. "Interfacial Synthesis of Layer-Oriented 2D Conjugated Metal*Organic Framework Films toward Directional Charge Transport", J. Am. Chem. Soc. (2021)

HL 42.9 Fri 11:45 H36

Controlled Encapsulation of Monolayer MoS2 with Ultrathin Aluminium Oxide for Tunnel Contacts — •Sergej Levashov, Chenjiang Qian, Theresa Grünleitner, Jon J. Finley, Alex Henning, and Ian D. Sharp — Walter Shottky Institut, TUM, München, Deutschland

Two-dimensional (2D) semiconductors have unique optoelectronic properties that provide the opportunity to overcome current scaling and performance limits of semiconductor devices. To harness the full of potential of 2D materials, requires their seamless integration with bulk materials. In particular, contacting mono- and few-layer 2D semiconductors with metals is challenging since the deposition process may introduce defects impeding interfacial charge transport. Here we use low-temperature atomic layer deposition to encapsulate monolayer MoS_2 with a van der Waals bonded and ultrathin aluminium oxide (AlO_x) layer. The 18 Å thin AlO_x coating introduces additional charge carriers ($\sim 5 \cdot 10^{12}$ cm^{-2}), while it also protects monolayer MoS_2 from defect creation during metallization. Microscratching of the AlO_x adlayer by contact mode atomic force microscopy and subsequent spectroscopic analysis demonstrate the reversibility of the charge transfer doping effect, indicating weak interaction. Importantly, current voltage measurements yielded a two-fold reduction in the contact resistance for MoS_2 field-effect transistors contacted with AlO_x interlayer. Overall, this work demonstrates the beneficial effect of the AlO_x adlayer for improving 2D device contacts and provides a scalable route to the damage-free integration of 2D semiconductors.