Semiconductor Physics Division
Fachverband Halbleiterphysik (HL)

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Overview of Invited Talks and Sessions

(Lecture halls H1, H3, H4, H5, and H7; Poster P)

Invited Talks

HL 1.1	Mon	10:00–10:30	H4	**Phonon Screening of Excitons in Halide Perovskites and Beyond** — •Marina Filip
HL 1.2	Mon	10:30–11:00	H4	**Anharmonic semiconductors - Lessons Learned from Halide perovskites** — •Omer Yaffe
HL 1.3	Mon	11:00–11:30	H4	**Exciton structure symmetry analysis for quantum-well layered halide perovskites and charge-energy transfer in presence of π-conjugated organic chromophores** — •Claudio Quarti
HL 1.4	Mon	11:45–12:15	H4	**Solid state ionics of hybrid halide perovskites: equilibrium situation and light effects** — •Alessandro Senocrate, Gee Yeong Kim, Tae-Youl Yang, Giuliano Gregori, Michael Grätzel, Joachim Maier
HL 1.5	Mon	12:15–12:45	H4	**Unifying Ultrafast Polarization Responses of Lead Halide Perovskites via Two-Dimensional Optical Kerr Effect** — •Sebastian F. Maehrlein
HL 5.1	Mon	13:30–14:00	H4	**The role of chalcogen vacancies for atomic defect emission in MoS_2** — Elmar Mitterreiter, Bruno Schuler, Daniel Hernangómez-Pérez, Julian Klein, Jonathan Finley, Sivan Refaely-Abramson, Alexander Holleitner, Alexander Weber-Bargioni, •Christoph Kastl
HL 7.1	Tue	10:00–10:30	H4	**Ultrafast Spin-Lasers** — Natalie Jung, Markus Lindemann, Tobias Pusch, Rainer Michalzik, Martin R. Hofmann, •Nils C. Gerhardt
HL 11.1	Tue	13:30–14:00	H4	**Modulation Doping in High-Mobility Alkaline-Earth Stannates** — •Bharat Jalan
HL 11.2	Tue	14:00–14:30	H4	**Ultrathin oxides on InGaN nanowires: Hybrid nanostructure photoelectrodes and optical analysis of chemical processes** — P. Neuderth, J. Schörmann, M. Coll, M. de la Mata, J. Arbiol, R. Marschall, •M. Eickhoff
HL 11.3	Tue	14:30–15:00	H4	**Doping and charge compensation mechanisms in semiconducting oxides** — •Andreas Klein
HL 11.4	Tue	15:00–15:30	H4	**Oxide Memristors for edge computing and secure electronics** — •Heidemarie Schmidt
HL 11.5	Tue	15:30–16:00	H4	**Integration of 33°Y-$LiNbO_3$ films with high-frequency BAW resonators** — Sondes Boujnah, Mihaela Ivan, Vincent Astié, Samuel Margueron, Mario Constanza, Jean-Manuel Decams, •Ausrine Bartasyte
HL 14.1	Wed	10:00–10:30	H4	**Quantum Interference of Identical Photons from Remote Quantum Dots** — •Giang N. Nguyen, Liang Zhai, Clemens Spinnler, Julian Ritzmann, Matthias C. Löbl, Andreas D. Wieck, Arne Ludwig, Alisa Javadi, Richard J. Warburton
HL 15.1	Thu	10:00–10:30	H4	**Quasi-instantaneous switch-off of deep-strong light-matter coupling** — •Christoph Lange, Joshua Mornhinweg, Maike Halbhuber, Viola Zeller, Cristiano Ciuti, Dominique Bougeard, Rupert Huber
HL 15.2	Thu	10:30–11:00	H4	**Lithium niobate nonlinear nanophotonics** — •Frank Setzpfandt
HL 15.3	Thu	11:00–11:30	H4	**Quadratic nanomaterials for integrated photonic devices** — •Rachel Grange

HL 15.4	Thu	11:45–12:15	H4	**Topological plasmonics: Ultrafast vector movies of plasmonic skyrmions on the nanoscale** — •Harald Giessen, Pascal Dreher, David Janoschka, Frank Meyer zu Heringdorf, Tim Davis, Bettina Frank
HL 15.5	Thu	12:15–12:45	H4	**Supercontinuum second-harmonic generation spectroscopy of 2D semiconductors** — •Steffen Michaelis de Vasconcellos
HL 18.1	Thu	13:30–14:00	H4	**Telecom wavelength quantum dot-based single-photon sources for quantum technologies** — •Anna Musial
HL 22.1	Fri	10:00–10:30	H4	**Two-dimensional gain materials for new nanolaser concepts** — •Christopher Gies
HL 22.2	Fri	10:30–11:00	H4	**Room-temperature polariton lattices for quantum simulation** — •Stephane Kena-Cohen
HL 22.3	Fri	11:00–11:30	H4	**Topological nanocavity lasers and topological high-power lasers** — •Yasutomo Ota, Yasuhiko Arakawa, Satoshi Iwamoto
HL 22.4	Fri	11:45–12:15	H4	**Topological Insulator Lasers** — •Miguel A. Bandres, Steffen Wittek, Gal Harari, Mordechai Segev, Demetrios N. Christodoulides, Mercedeh Khajavikhan
HL 22.5	Fri	12:15–12:45	H4	**When polariton condensates have dissipations or have no excitons** — •Hui Deng

Invited talks of the joint symposium SKM Dissertation Prize 2021 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	10:00–10:25	Audimax 2	**Avoided quasiparticle decay from strong quantum interactions** — •Ruben Verresen, Roderich Moessner, Frank Pollmann
SYSD 1.2	Mon	10:25–10:50	Audimax 2	**Co-evaporated Hybrid Metal-Halide Perovskite Thin-Films for Optoelectronic Applications** — •Juliane Borchert
SYSD 1.3	Mon	10:55–11:20	Audimax 2	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYSD 1.4	Mon	11:20–11:45	Audimax 2	**The thermodynamics of stochastic systems with time delay** — •Sarah A.M. Loos
SYSD 1.5	Mon	11:50–12:15	Audimax 2	**First Results on Atomically Resolved Spin-Wave Spectroscopy by TEM** — •Benjamin Zingsem

Invited talks of the joint symposium Potentials for NVs sensing magnetic phases, textures and excitations (SYNV)

See SYNV for the full program of the symposium.

SYNV 1.1	Mon	13:30–14:00	Audimax 2	**Harnessing Nitrogen Vacancy Centers in Diamond for Next-Generation Quantum Science and Technology** — •Chunhui Du
SYNV 1.2	Mon	14:00–14:30	Audimax 2	**Nanoscale imaging of spin textures with single spins in diamond** — •Patrick Maletinsky
SYNV 1.3	Mon	14:30–15:00	Audimax 2	**Spin-based microscopy of 2D magnetic systems** — •Jörg Wrachtrup
SYNV 1.4	Mon	15:15–15:45	Audimax 2	**Exploring antiferromagnetic order at the nanoscale with a single spin microscope** — •Vincent Jacques
SYNV 1.5	Mon	15:45–16:15	Audimax 2	**Nanoscale magnetic resonance spectroscopy with NV-diamond quantum sensors** — •Dominik Bucher

Invited talks of the joint symposium Multidimensional coherent spectroscopy of functional nanostructures (SYCS)

See SYCS for the full program of the symposium.

SYCS 1.1	Tue	10:00–10:30	Audimax 1	**Multidimensional coherent spectroscopy of perovskite nanocrystals** — •Steven Cundiff, Albert Liu, Diogo Almeida, Gabriel Nagamine, Lazaro Padilha
SYCS 1.2	Tue	10:30–11:00	Audimax 1	**Coherent multidimensional techniques for the characterization of nanomaterials** — •Elisabetta Collini

SYCS 1.3	Tue	11:00–11:30	Audimax 1	**Exciton Dynamics revealed by Multidimensional Coherent Spectroscopies applied to Light-Harvesting Systems** — •Thomas L.C. Jansen
SYCS 1.4	Tue	11:45–12:15	Audimax 1	**Revealing couplings with action-based 2D microscopy** — •Tobias Brixner
SYCS 1.5	Tue	12:15–12:45	Audimax 1	**Low-frequency phonons affect charge carrier dynamics in hybrid perovskites** — •Mischa Bonn

Invited talks of the joint symposium Advanced neuromorphic computing hardware: Towards efficient machine learning (SYNC)

See SYNC for the full program of the symposium.

SYNC 1.1	Wed	10:00–10:30	Audimax 1	**Equilibrium Propagation: a Road for Physics-Based Learning** — •Damien Querlioz
SYNC 1.2	Wed	10:30–11:00	Audimax 1	**Machine Learning and Neuromorphic Computing: Why Physics and Complex Systems are Indispensable** — •Ingo Fischer
SYNC 1.3	Wed	11:00–11:30	Audimax 1	**Photonic Tensor Core Processor and Photonic Memristor for Machine Intelligence** — •Volker Sorger
SYNC 1.4	Wed	11:45–12:15	Audimax 1	**Material learning with disordered dopant networks** — •Wilfred van der Wiel
SYNC 1.5	Wed	12:15–12:45	Audimax 1	**In-memory computing with non-volatile analog devices for machine learning applications** — •John Paul Strachan

Prize talks of the joint Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:00	Audimax 1	**Organic semiconductors - materials for today and tomorrow** — •Anna Köhler
SYAW 1.2	Wed	14:00–14:30	Audimax 1	**PbTe/CdTe nanocomposite as an attractive candidate for room-temperature infrared detectors** — •Grzegorz Karczewski
SYAW 1.3	Wed	14:40–15:10	Audimax 1	**Fingerprints of correlation in electronic spectra of materials** — •Lucia Reining
SYAW 1.4	Wed	15:10–15:40	Audimax 1	**Artificial Spin Ice: From Correlations to Computation** — •Naëmi Leo
SYAW 1.5	Wed	15:40–16:10	Audimax 1	**From microwave optomechanics to quantum transport – carbon nanotubes as highly versatile hybrid devices** — •Andreas K. Hüttel
SYAW 1.6	Wed	16:20–16:50	Audimax 1	**Quantum spin dynamics of a spin-1/2 antiferromagnetic Heisenberg-Ising chain** — •Zhe Wang
SYAW 1.7	Wed	16:50–17:20	Audimax 1	**Imaging the effect of electron transfer at the atomic scale** — •Laerte Patera

Invited talks of the joint symposium Spain as Guest of Honor (SYES)

See SYES for the full program of the symposium.

SYES 1.1	Wed	13:30–13:40	Audimax 2	**DFMC-GEFES** — •Julia Herrero-Albillos
SYES 1.2	Wed	13:40–14:10	Audimax 2	**Towards Phononic Circuits based on Optomechanics** — •Clivia M. Sotomayor Torres
SYES 1.3	Wed	14:10–14:40	Audimax 2	**Adding magnetic functionalities to epitaxial graphene** — •Rodolfo Miranda
SYES 1.4	Wed	14:45–15:15	Audimax 2	**Bringing nanophotonics to the atomic scale** — •Javier Aizpurua
SYES 1.5	Wed	15:15–15:45	Audimax 2	**Hydrodynamics of collective cell migration in epithelial tissues** — •Jaume Casademunt
SYES 1.6	Wed	15:45–16:15	Audimax 2	**Understanding the physical variables driving mechanosensing** — •Pere Roca-Cusachs

Invited talks of the joint symposium Attosecond and coherent spins: New frontiers (SYAS)

See SYAS for the full program of the symposium.

SYAS 1.1	Thu	10:00–10:30	Audimax 2	**Ultrafast Coherent Spin-Lattice Interactions in Iron Films** — •Steven Johnson
SYAS 1.2	Thu	10:30–11:00	Audimax 2	**Ultrafast spin, charge and nuclear dynamics: ab-initio description** — •Sangeeta Sharma, John Kay Dewhurst
SYAS 1.3	Thu	11:15–11:45	Audimax 2	**Light-wave driven Spin Dynamics** — •Martin Schultze, Markus Münzenberg, Sangeeta Sharma
SYAS 1.4	Thu	11:45–12:15	Audimax 2	**All-coherent subcycle switching of spins by THz near fields** — •Christoph Lange, Stefan Schlauderer, Sebastian Baierl, Thomas Ebnet, Christoph Schmid, Darren Valovcin, Anatoly Zvezdin, Alexey Kimel, Rostislav Mikhaylovskiy, Rupert Huber
SYAS 1.5	Thu	12:15–12:45	Audimax 2	**Ultrafast optically-induced spin transfer in ferromagnetic alloys** — •Stefan Mathias

Invited talks of the joint symposium Physics of van der Waals 2D heterostructures (SYWH)

See SYWH for the full program of the symposium.

SYWH 1.1	Thu	13:30–14:00	Audimax 2	**Spin interactions in van der Waals topological materials and magnets** — •Saroj Dash
SYWH 1.2	Thu	14:00–14:30	Audimax 2	**Exciton optics, dynamics and transport in atomically thin materials** — •Ermin Malic, Samuel Brem, Raul Perea-Causin, Daniel Erkensten, Roberto Rosati
SYWH 1.3	Thu	14:30–15:00	Audimax 2	**Correlated Electrons in van der Waals Superlattices: Control and Understanding** — •Tim Wehling
SYWH 1.4	Thu	15:15–15:45	Audimax 2	**Exciton manipulation and transport in 2D semiconductor heterostructures** — •Andras Kis
SYWH 1.5	Thu	15:45–16:15	Audimax 2	**Chern Insulators, van Hove singularities and Topological Flatbands in Magic-angle Twisted Bilayer Graphene*** — •Eva Andrei, Shuang Wu, Zhenyuan Zhang

Invited talks of the joint symposium The Rise of Photonic Quantum Technologies – Practical and Fundamental Aspects (SYPQ)

See SYPQ for the full program of the symposium.

SYPQ 1.1	Fri	10:00–10:30	Audimax 2	**Quantum dots operating at telecom wavelengths for photonic quantum technology** — •Simone Luca Portalupi
SYPQ 1.2	Fri	10:30–11:00	Audimax 2	**Photonic graph states for quantum communication and quantum computing** — •Stefanie Barz
SYPQ 1.3	Fri	11:00–11:30	Audimax 2	**Rare-earth ion doped solids at sub-Kelvins: practical and fundamental aspects** — •Pavel Bushev
SYPQ 1.4	Fri	11:45–12:15	Audimax 2	**Quantum Light and Strongly Correlated Electronic States in a Moiré Heterostructure** — •Brian Gerardot
SYPQ 1.5	Fri	12:15–12:45	Audimax 2	**Quantum communication in fibers and free-space** — •Rupert Ursin

Sessions

HL 1.1–1.5	Mon	10:00–12:45	H4	**Focus Session: When theory meets experiment: Hybrid halide perovskites for applications beyond solar**
HL 2.1–2.5	Mon	10:00–12:45	H7	**Focus Session: Exotic Charge Density Wave States of Matter: Correlations and Topology (joint session TT/HL)**
HL 3.1–3.26	Mon	10:00–13:00	P	**Poster Session I**
HL 4.1–4.7	Mon	11:15–13:00	H3	**2D materials and their heterostructures (joint session DS/HL/CPP)**
HL 5.1–5.9	Mon	13:30–16:15	H4	**2D semiconductors and van der Waals heterostructures I (joint session HL/DS)**

HL 6.1–6.8	Mon	13:30–17:00	H5	**Focus Session: Magnon Polarons - Magnon-Phonon Coupling and Spin Transport (joint session MA/HL)**
HL 7.1–7.5	Tue	10:00–11:30	H4	**Semiconductor Lasers**
HL 8.1–8.28	Tue	10:00–13:00	P	**Poster Session II**
HL 9.1–9.3	Tue	11:45–12:30	H4	**Nitride: Preparation, Charakterization and Devices**
HL 10.1–10.5	Tue	13:30–16:15	H3	**Focus Session: Highlights of Materials Science and Applied Physics I (joint session DS/HL)**
HL 11.1–11.7	Tue	13:30–16:30	H4	**Focus Session: Functional Metal Oxides for Novel Applications and Devices**
HL 12.1–12.6	Tue	13:30–16:45	H5	**Focus Session: Spin-Charge Interconversion (joint session MA/HL)**
HL 13.1–13.32	Tue	13:30–16:30	P	**Poster Session III**
HL 14.1–14.9	Wed	10:00–12:45	H4	**Materials and devices for quantum technology (joint session HL/TT)**
HL 15.1–15.5	Thu	10:00–12:45	H4	**Focus Session: Tailored Nonlinear Photonics**
HL 16.1–16.6	Thu	11:15–12:45	H1	**Semiconductors: Optical, Transport and Ultrafast Properties**
HL 17.1–17.5	Thu	13:30–16:15	H1	**Focus Session: Topological Phenomena in Synthetic Matter (joint session DS/HL)**
HL 18.1–18.10	Thu	13:30–16:30	H4	**Quantum Dots and Wires (joint session HL/TT)**
HL 19.1–19.31	Thu	13:30–16:30	P	**Poster Session IV**
HL 20	Thu	18:00–19:00	MVHL	**Annual General Meeting of the Semiconductor Physics Division**
HL 21.1–21.4	Fri	10:00–11:00	H1	**Focus Session: Highlights of Materials Science and Applied Physics II (joint session DS/HL)**
HL 22.1–22.5	Fri	10:00–12:45	H4	**Focus Session: Emerging Semiconductor Laser Concepts**
HL 23.1–23.7	Fri	11:15–13:00	H1	**Focus Session: Highlights of Materials Science and Applied Physics III (joint session DS/HL)**
HL 24.1–24.1	Fri	13:30–15:00	Audimax 2	**Quo Vadis Quantum Technologies? About Promises, Prospects, and Challenges**
HL 25.1–25.5	Fri	13:30–14:45	H4	**2D semiconductors and van der Waals heterostructures II (joint session HL/DS)**

Annual General Meeting of the Semiconductor Physics Division

Thursday 18:00–19:00 MVHL

- Bericht des Vorsitzenden
- Wahl der Leitung des Halbleiterphysik Fachverbandes
- Verschiedenes

HL 1: Focus Session: When theory meets experiment: Hybrid halide perovskites for applications beyond solar

Hybrid halide perovskites are by now well-established solar absorber and emitter materials, with power conversion efficiencies of single-cell devices exceeding 20 percent. We have observed - with notable exceptions - a widening gap between experimental and theoretical efforts in the literature on halide perovskites. Further, a large fraction of the literature focuses on properties relevant for optoelectronic applications, while we envision a much wider scope for these materials, e.g in spintronic and electrochemical applications. The purpose of this focus session is to provide a platform for theorists and experimentalists working in this field, to interact, present state-of-the-art methods, and exchange their ideas on future directions for this technologically relevant class of materials beyond the current focus on optoelectronics.

Organizers: Linn Leppert (University of Twente) and Felix Dreschler (TU München)

Time: Monday 10:00–12:45 Location: H4

Invited Talk HL 1.1 Mon 10:00 H4

Phonon Screening of Excitons in Halide Perovskites and Beyond — •Marina Filip — University of Oxford, Department of Physics

The interaction of photoexcited bound electron-hole pairs (excitons) is screened by both electrons and by polar phonons. For organic-inorganic lead-halide perovskites, theoretical and experimental evidence suggests that ionic vibrations have an important contribution to the dielectric screening [1,2]. However, state of the art GW/BSE methodology for studying electronic and optical excitations does not capture phonon screening effects. In this talk I will present our recently developed framework based on GW/BSE, to include phonon screening effects [3]. I will show that phonon screening contributes to significantly reduce the exciton binding energy, and demonstrate this effect for lead halide perovskites, CsPbX3 (X = Cl, Br, I), as well as other well known semiconductors and insulators. Furthermore, I will show our generalization of the Wannier-Mott model to include phonon screening effects, and discuss general trends for the phonon screening contribution to the exciton binding energy.

[1] Miyata et al, Nat. Phys. 11, 582 (2015) [2] Umari et al, JPCL, 9 , 3 ,620 (2018) [3] Filip, Haber & Neaton, PRL, in press (2021)

This work was supported by the US Department of Energy and the UK EPSRC. Computational resources were provided by the National Energy Research Scientific Computing Center (NERSC) and the Texas Advanced Computing Center (TACC) through the NSF-funded XSEDE program.

Invited Talk HL 1.2 Mon 10:30 H4

Anharmonic semiconductors - Lessons Learned from Halide perovskites — •Omer Yaffe — Weizmann Institute of Science, Rehovot, Israel

In semiconductor physics, the dielectric response, charge carrier mobility and other electronic material properties at finite temperatures, are always treated within the framework of the harmonic approximation. This approach is very successful in capturing the properties of tetrahedrally bonded semiconductors such as silicon and GaAs.

In my talk, I will show that halide perovskites are fundamentally different due to their strongly anharmonic lattice dynamics. Large amplitude, local polar fluctuations induced by lattice anharmonicity localize the electronic states and enhance the screening of electric charge within the material. In other words, in some aspects, halide perovskites behave more like a liquid than a crystalline solid. I will also discuss the implications of these findings on other families of semiconductors such as organic and rock-salt semiconductors.

Invited Talk HL 1.3 Mon 11:00 H4

Exciton structure symmetry analysis for quantum-well layered halide perovskites and charge-energy transfer in presence of π-conjugated organic chromophores — •Claudio Quarti — Laboratory for Chemistry of Novel Materials, University of Mons

2D layered halide perovskites are surging as interesting materials for opto-electronic applications. These systems are characterized by a quantum-well structure, with a semiconducting halide perovskite frame sandwiched between organic insulating spacers, the spatial confinement stabilizing tightly bound excitons. Still, full understanding of the native electronic and excitonic properties of layered halide perovskites is inherently hard to achieve, as many physical mechanisms contribute to complicate the scenario, including dielectric confinement, structural distortions, Spin-Orbit-Coupling (SOC), etc. Here, I review the electronic and excitonic structure of 2D layered halide perovskites, adopting group theory symmetry analysis. This highlights the analogies and differences in the atomic contributions on the single particle band structure, as compared to the 3D case, with SOC inherently included in the analysis. I will then consider the interaction between the organic spacers and the inorganic semiconducting frame in the case of a type II heterointerface, as obtained via incorporation of π-conjugated molecular moieties as organic spacers. With reference to tetrazine-based layered halide perovskite, I discuss several photoexcitation decay channels, with clear distinction between charge, singlet- and triplet-energy transfer.

15 min. break.

Invited Talk HL 1.4 Mon 11:45 H4

Solid state ionics of hybrid halide perovskites: equilibrium situation and light effects — •Alessandro Senocrate[1,2], Gee Yeong Kim[1], Tae-Youl Yang[1], Giuliano Gregori[1], Michael Grätzel[1,2], and Joachim Maier[1] — [1]Max-Planck-Institut für Festkörperforschung, Stuttgart, Germany — [2]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

In recent years, hybrid halide perovskites have been attracting great attention due to their exceptional photo-electrochemical properties. When used as light-harvesters in solar cells, device efficiencies exceeding 25 % can be realized. We showed that a deeper understanding of (i) functionality, (ii) stability, as well as (iii) the possibility to improve the performance require a thorough insight into non-stoichiometry and ion transport. In this contribution, we study the nature of the ionic conductivity in methylammonium lead iodide ($MAPbI_3$), the archetypal halide perovskite, by means of a great number of electrochemical and nuclear magnetic techniques. To aid the experimental investigation, we include detailed defect chemical modelling describing the effects of varying iodine partial pressure (stoichiometry) and dopant content. By extending this study to the situation under illumination, we observe a striking enhancement of ionic conductivity by more than 2 orders of magnitude in $MAPbI_3$, alongside the expected increase in electronic conductivity. Such analyses are then extended to other halide perovskite compositions. While discussing these results, a mechanistic explanation of this astonishing phenomenon arises, which has relevance for photo-stability and photo-demixing processes.

Invited Talk HL 1.5 Mon 12:15 H4

Unifying Ultrafast Polarization Responses of Lead Halide Perovskites via Two-Dimensional Optical Kerr Effect — •Sebastian F. Maehrlein — Columbia University, New York, USA — Fritz Haber Institute of the Max Planck Society, Berlin, Germany

The microscopic mechanism behind the outstanding optoelectronic properties of lead halide perovskites (LHPs) may lead to novel design principles for defect tolerant semiconductors, but is still highly debated. Previous studies, investigating the LHPs' ultrafast polarization response by the optical Kerr effect lead to dynamic screening models, which suggest charge carrier protection by large polarons and/or liquid-like screening.

Here, we finally decode the variety of nonlinear polarization signals by developing two-dimensional optical Kerr effect (2D-OKE) spectroscopy. We unveil a surprisingly unified origin: Both (inorganic and hybrid) LHP responses are governed by nonlinear mixing of anisotropic and highly dispersive light propagation near the optical band gap [1]. Based on the 2D-OKE fingerprint, we quantify dispersion anisotropy, follow phase transitions and trace lattice parameters of hybrid alloyed LHPs; supported by a comprehensive four-wave-mixing model. Moreover, our findings raise the awareness in all types of polarization sensitive pump-probe experiments and their modeling, where oscillatory signals are commonly assigned to coherent low-energy excitations (e.g. phonons, magnons, etc.). The presented works were mainly performed with L. Huber, F. Wang, and P.P. Joshi at X.-Y. Zhu group (Columbia U). [1] S. F. Maehrlein et al., DOI:10.1073/pnas.2022268118

HL 2: Focus Session: Exotic Charge Density Wave States of Matter: Correlations and Topology (joint session TT/HL)

The recent observation of charge density waves (CDW) in a variety of topological materials ranging from two-dimensional dichalcogenides, Weyl semimetals and metallic kagome systems has prompted intensive research on the origin and effects of such states. In these systems charge order forms the basis for correlated and topological states of quantum matter: Mott Hubbard correlations, tentative spin-liquid physics and chiral superconductivity in two-dimensional dichalcogenides, the emergence of axionic CDWs in Weyl semimetals and an interplay of Z2 topology, charge order and superconductivity in kagome metals. At the same time topology and electron correlations feed back on the CDW formation and dynamics. In this Focus Session we bring together theorists and experimentalists working in the field to discuss the interplay of charge order, correlations and topology in representative model systems, to identify major open challenges in our understanding of these systems and ultimately reach out for controlling CDW physics in correlated topological states of matter.

Organizers: Roser Valenti (Frankfurt University), Tim Wehling (Bremen University)

Time: Monday 10:00–12:45 Location: H7

HL 2.1 Mon 10:00 H7

Chiral superconductivity in the alternate stacking compound 4Hb-TaS$_2$ — •Amit Kanigel — Technion. Haifa, Israel

We study 4Hb-TaS$_2$, which naturally realizes an alternating stacking of 1T-TaS$_2$ and 1H-TaS$_2$ structures. The former is a well-known Mott insulator, which has recently been proposed to host a gapless spin-liquid ground state. The latter is a superconductor known to also host a competing charge density wave state. We find a superconductor with a T$_c$ of 2.7 Kelvin and anomalous properties, of which the most notable one is a signature of time-reversal symmetry breaking, abruptly appearing at the superconducting transition. This observation is consistent with a chiral superconducting state.

HL 2.2 Mon 10:30 H7

Non-local electronic correlations in 1*T*-TaS$_2$ out of equilibrium — •Uwe Bovensiepen — University of Duisburg-Essen, Faculty of Physics and Center for Nanointegration (CENIDE), 47048 Duisburg, Germany

Transition metal dichalcogenides with a d^1 transition metal electron configuration exhibit broken symmetry ground states and distorted structures. The formation of charge density wave (CDW) states in conjunction with Mott physics in 1*T*-TaS$_2$ is a well know example. Current efforts aim at microscopic understanding of the intertwined electronic and lattice effects. In this regard experiments in the time domain provide direct insights because the characteristically different timescales of electronic hopping with a time constant $\hbar/J \approx 2$ fs and the CDW amplitude period of 400 fs can be well distinguished. In this talk time-resolved photoelectron spectroscopy results will be presented in connection with theoretical results to discuss electronic excitations and their dynamics. Excitation and relaxation of doubly occupied sites is mediated by intersite hopping and coupling to delocalized electrons [1,2]. Comparison with literature indicates that such electron dynamics can be excited selectively, separate from lattice excitations. First experiments towards bulk sensitive, time-resolved photoelectron spectroscopy [3] will be discussed as well.

Funding by the DFG through SFB 1242 is gratefully acknowledged.

[1] Ligges et al., PRL **120**, 166401 (2018)
[2] Avigo et al., PR Research **2**, 022046(R) (2020)
[3] Beyazit et al., PRL **125**, 076803 (2020)

15 min. break

HL 2.3 Mon 11:15 H7

Axionic charge density wave in the Weyl semimetal (TaSe$_4$)$_2$I — •Johannes Gooth — Max Planck Institut für Chemische Physik fester Stoffe, Dresden, Germany

An axion insulator is a correlated topological phase, which is predicted to arise from the formation of a charge-density wave in a Weyl semimetal that is, a material in which electrons behave as massless chiral fermions. The accompanying sliding mode in the charge-density-wave phase - the phason - is an axion and is expected to cause anomalous magnetoelectric transport effects. However, this axionic charge-density wave has not yet been experimentally detected. Here, we report the observation of a large positive contribution to the magnetoconductance in the sliding mode of the charge-density-wave Weyl semimetal (TaSe$_4$)$_2$I for collinear electric and magnetic fields. The positive contribution to the magnetoconductance originates from the anomalous axionic contribution of the chiral anomaly to the phason current, and is locked to the parallel alignment of the electric and magnetic fields. By rotating the magnetic field, we show that the angular dependence of the magnetoconductance is consistent with the anomalous transport of an axionic charge-density wave. Our results show that it is possible to find experimental evidence for axions in strongly correlated topological condensed matter systems, which have so far been elusive in any other context.

Invited Talk HL 2.4 Mon 11:45 H7

Electronic instabilities of kagomé metals and density waves in the AV$_3$Sb$_5$ materials — •Leon Balents — University of California, Santa Barbara

Recently, a new class of kagomé metals, with chemical formula AV$_3$Sb$_5$, where A = K, Rb, or Cs, have emerged as an exciting realization of quasi-2D correlated metals with hexagonal symmetry. These materials have been shown to display several electronic orders setting in through thermodynamic phase transitions: multi-component (*3Q*) hexagonal charge density wave (CDW) order below a T$_c$ of 90K, and superconductivity with critical temperature of 2.5K or smaller, and some indications of nematicity and one-dimensional charge order in the normal and superconducting states. Other experiments show a strong anomalous Hall effect, suggesting possible topological physics. I will discuss a theory of these phenomena based in part on strong interactions between electrons at saddle points, as well as ideas related to different competing density wave orders.

HL 2.5 Mon 12:15 H7

Charge density waves and superconductivity in kagome metals — •Titus Neupert — Univertity of Zurich, Zurich, Switzerland

Strongly correlated itinerant electron systems exhibit an intertwining of interactions and electronic band fermiology, including flat bands and van Hove points with diverging density of states, nesting patterns, or band degeneracies –for instance of Dirac type or quadratic band touching. The kagome lattice stands out in that it combines all these characteristics, and has thus been subject to many theoretical investigations. However, material realizations of kagome metals with interaction-induced Fermi instabilities have largely been elusive. The recently discovered family of kagome materials AV3Sb5 has filled this gap, displaying charge ordered and superconducting phases with unconventional properties. In my talk, I will discuss the status quo understanding of these instabilities emanating from a critical synopsis of experiments and theoretical studies.

HL 3: Poster Session I

Topics:
- 2D semiconductors and van der Waals heterostructures
- Optical properties
- Quantum transport and quantum Hall effect
- THz and MIR physics in semiconductors

Time: Monday 10:00–13:00 Location: P

HL 3.1 Mon 10:00 P

Biopolymer-templated TiO2 SERS sensors — •QING CHEN[1,2], MARIE BETKER[1,4,5], CONSTANTIN HARDER[1,3], CALVIN BRETT[1,5], MATTHIAS SCHWARTZKOPF[1], NILS ULRICH[7], MARIA EUGENIA TOIMIL MOLARES[7], CHRISTINA TRAUTMANN[7], DANIEL SÖDERBERG[4,5], CHRISTIAN WEINDL[3], VOLKER KÖRSTGENS[3], PETER MÜLLER-BUSCHBAUM[3,6], MINGMING MA[2], and ROTH STEPHAN[1] — [1]DESY, Notkestraße 85, 22607 Hamburg, Germany — [2]USTC, 230026 Hefei, China — [3]TUM, James-Franck Straße 1, 85748 Garching, Germany — [4]KTH, Teknikringen 56-58, 100 44 Stockholm, Sweden — [5]WWSC, Teknikringen 52-56, 100 44 Stockholm, Sweden — [6]MLZ, TUM, Lichtenbergstraße 1, Garching 85748, Germany — [7]GSI Helmholtz Center, Planckstrße 1, Darmstadt 64291, Germany

Titanium dioxide (TiO2) is an excellent candidate for semiconductor metal oxide-based Surface enhanced Raman scattering (SERS) substrate. We report a novel strategy of the cellulose nanofibril (CNF) - assisted assembly of TiO2/CNF thin-films with a hierarchical three-dimensional network and crystallinity as a SERS substrate. TiO2/CNF thin-films are obtained through the combined action of surface templating and thermal annealing. A high enhancement factor in terms of semiconductor SERS substrates for 4-mercaptobenzoic acid of 1.79 * 106 is obtained in the TiO2/CNF thin-films on ITO substrate with a thickness of 10 nm after thermal annealing. Our approach realizes the improvement of SERS sensitivity of semiconductor metal oxide nanomaterials through a cooperative modulation of the biotemplate morphology and the TiO2 crystalline state.

HL 3.2 Mon 10:00 P

Quantum Theory of Exciton-Plasmon Coupling in Two-Dimensional Semiconductors functionalized with Metal Nanoparticles — •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 (TMDCs) exhibit tigthly bound excitons with large optical amplitudes, originating from a reduced screening of the Coulomb interaction due to the reduced dimensionaly of these ultrathin materials. The latter gives also rise to a high sensivity of such excitons to their environment.

Contrary, the optical response of metal nano-particles is dominated by plasmons which are collective electron oscillations. They facilitate an impressive amplification of the electric near-field and allow to manipulate the electric field on dimensions below the diffraction limit.

In the presented work, we consider theoretically exciton-plasmon coupling in a hybrid structure of a TMDC layer supported by a single metal nano-particle or a two-dimensional array. 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 in classical Mie theory.

Our studies reveal new "plexcitonic" eigenstates of the hybrid system. Furthermore, the results confirm that the configuration allows to reach the strong coupling limit which features a Rabi splitting of tens of meV.

HL 3.3 Mon 10:00 P

Near-field terahertz spectroscopy of flakes of 2D materials — •AHMAD-REZA ETEMADI, SEBASTIAN MATSCHY, AHANA BHATTACHARYA, and MARTIN MITTENDORFF — Department of physics, University of Duisburg-Essen, 47057 Duisburg, Germany

THz spectroscopy is a powerful tool to investigate the carrier dynamics in many materials. Unfortunately, gaining access to the THz conductivities of small samples, e.g. flakes of 2D materials, is rather difficult, as the THz spot size is much larger than the structure of interest. Direct detection in the near-field improves the spatial resolution and can be done by placing the sample directly on top of an electro-optic crystal. A near-infrared (NIR) beam is exploited to probe the THz field in the vicinity of the flake. The spatial resolution of the experiment is mostly determined by the NIR beam size in the electro-optic crystal and the diffraction of the THz beam by the sample. Here we analyze the potential performance of such a THz near-field microscope and present the current stage of our instrument.

HL 3.4 Mon 10:00 P

Optical properties of various crystalline phases of WO_3 — •FELIX BERNHARDT and SIMONE SANNA — Institut für Theoretische Physik and Center for Materials Research, Justus- Liebig-Universität Gießen, 35392 Gießen, Germany

Tungsten trioxide (WO_3) is a semiconductor suitable for a wide variety of applications. Due to multiple, temperature-driven phase transitions and an electronic band gap within the optical spectrum [1], it is employed in a multitude of devices, ranging from smart windows [3] to gas sensors [5]. In this work, we investigate the monoclinic (stable at room temperature), the triclinic and orthorhombic phases of WO3 from first principles. Furthermore, we compare them with a hypothetical, simpler cubic configuration, which is often employed to approximate the real structures in theoretical studies.

Ground state properties such as lattice parameters and electronic structures are calculated within density functional theory (DFT). The optical response is modeled within the Bethe-Salpeter equation and time-dependent DFT using a long-range corrected kernel. Our results are in excellent agreement with previous theoretical investigations [1,4] as well as experiments [2,6]. The cubic phase fails to correctly reproduce the dielectric function of the real crystals.

[1] M Mansouri et al, Turk. Journal of Phys. 41(238) (2017) [2] B Loopstra et al, Acta Cryst. 25(1420) (1968) [3] L Liang et al, Sci. Rep. 3(1936) (2013) [4] F Wang et al, Journal Of Phys. Chem. 115(8345) (2011) [5] N. Yamazoe et al, Catalysis Surveys from Asia 7(63-75) (2003) [6] M Vargas et al, Journal of Applied Phys. 115(2014)

HL 3.5 Mon 10:00 P

Theoretical investigations of (non linear) optical properties of [RSi(CH2SnPh)3E3] molecules and molecular crystals on the path to understanding white light generation using molecules containing adamantane-like cores. — •FERDINAND ZIESE[1], IRÁN ROJAS-LEÓN[2], CHRISTOF DUES[1], STEFANIE DEHNEN[2], and SIMONE SANNA[1] — [1]Solid State Spectroscopy, Institut für Theoretische Physik Heinrich-Buff-Ring 16, 35392 Gießen — [2]The Dehnen Group, Hans-Meerwein-Straße 4, 35032 Marburg

Recent studies have demonstrated white light generation from molecular clusters with adamantane-like cores and different ligands [1,2]. The mechanism leading to the white light emission is currently under discussion. In order to understand the intertwinement between atomic and electronic structure and optical response, we have modeled the structural, electronic, and (nonlinear) optical properties from first principles. Isolated molecules and molecular crystals with formula unit [RSi(CH2SnPh)3E3], where R=Ph, Tol, and E=S, Se, Te. Both the chemistry of the ligands and of the cluster core have an heavy impact on the optical response of the material. The investigations presented append current and past investigations on the path towards understanding white light generation using molecules containing adamantane-like cores.

[1] N. W. Rosemann, J. P. Eußner, A. Beyer, S. W. Koch, K. Volz, S. Dehnen, S. Chatterjee, Science 2016, 352, 301

[2] N. W. Rosemann, J. P. Eußner, E. Dornsiepen, S. Chatterjee, S. Dehnen, J. Am. Chem. Soc. 2016, 138, 16224.

HL 3.6 Mon 10:00 P

How to Trace Structural Dynamics in Lead Halide Perovskites Using THz Kerr Effect Spectroscopy — •Maximilian Frenzel[1], Marie Cherasse[1,2], Leona Nest[1], Martin Wolf[1], and Sebastian F. Maehrlein[1] — [1]Fritz Haber Institute of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany — [2]LSI, CEA/DRF/IRAMIS, CNRS, Ecole polytechnique, Institut Polytechnique de Paris, 91120 Palaiseau, France

The origin of the surprising optoelectronic performance of lead halide perovskite (LHP) semiconductors is still debated. It has been suggested that their highly polar and anharmonic lattice might beneficially govern their optoelectronic properties in the form of dynamic charge carrier screening. To study the LHP's ultrafast lattice polarization when subjected to a transient electric field we employ THz Kerr Effect (TKE) spectroscopy. In particular, we investigate the responses in the organic-inorganic hybrid semiconductor $MAPbBr_3$ and its fully inorganic counterpart $CsPbBr_3$. By comparing our obtained signals to four-wave mixing simulations, we find that it is crucial to account for dispersion and optical anisotropy, as certain features may be misidentified for molecular relaxation dynamics or quasi-particle oscillations. Finally, we show that strong THz fields nonlinearly excite Raman active phonons in both materials, corresponding to distortions of the inorganic lattice. We hope that these findings lead to a more complete understanding of the ultrafast lattice response to transient local fields and its contributions to charge carrier screening.

HL 3.7 Mon 10:00 P

single-photon emission and coherence properties of quantum emitters in WSe_2 monolayers — Martin von Helversen[1], •Bárbara Rosa[1], Chirag Palekar[1], Carlos Antón-Solanas[2], Christian Schneider[3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Institute of Physics,Carl von Ossietzky University, Oldenburg, Germany — [3]Institute of Physics, University of Oldenburg, Oldenburg, Germany

Two-dimensional van der Waals monolayers have arisen as a new platform for exploring optical, electronic, and structural properties of semiconducting materials. Among several unique features of transition-metal dichalcogenides, the ability of manipulating one or few atomiclayers play an important role in providing a potential two-level single photon emitters (SPEs) by engineering of strain [1,2] or defects [2]. In this work, we explore the quantum properties of SPEs in strained WSe2monolayers [1]. By conducting off- and quasi-resonant optical excitation at cryogenic temperatures, we identify emitters with linewidth sas low as 70 /*mu*eV. Furthermore, throughout second order autocorrelation measurements we observe a multi-photon suppression by achieving $g^{(2)}(0) = 0.05(5)$. Lastly, we investigate the first order of coherence in SPEs WSe_2 when performing scanning Michelson interferometer experiments.

[1] L. N. Tripathi, et al.ACS Photonics8, 5, 1919-1926 (2018).

[2] K. Parto et al.Nat Commun.12, 3585 (2021).

HL 3.8 Mon 10:00 P

Magnetotunneling Spectroscopy of Double Quantum Wells in GaAs/AlGaAs Heterostructures — •Maximilian Mischke[1], Gunnar Schneider[1], Werner Dietsche[2], and Rolf Johann Haug[1] — [1]Leibniz Universität Hannover, Institut für Festkörperphysik — [2]Max-Planck-Institut für Festkörperfoschung, Stuttgart

In order to investigate the influence of a parallel magnetic field on bilayer phenomena, we performed magnetotunneling measurements on GaAs/AlGaAs double quantum wells. Therefore, the tunneling current between the two quantum wells is measured dependent on applied bias voltage, electron densities in the individual wells and a magnetic field oriented parallel to the 2D layers. We observe a systematic dependence of the tunneling resonance on the energetic difference of the two wells due to imbalanced densities. The applied bias compensates the mismatch. The parallel magnetic field introduces an additional term to the wave vector of the electrons, leading to a shift of the Fermi circles of the two quantum wells against each other [1]. This shift has an influence on the tunneling resonance since 2D-2D-tunneling requires not only energy conservation but also conservation of momentum [2]. The results of the measurements allow for a mapping of the Fermi contours of the two quantum wells [3,4].

[1] G.S. Boebinger et al, Phys. Rev. B 43, 12673 (1991)

[2] J.P. Eisenstein et al, Appl. Phys. Lett. 58, 1497 (1991)

[3] J.P. Eisenstein et al, Phys. Rev. B 44, 6511 (1991)

[4] T. Ihn et al, Phys. Rev. B 54, R2315 (1996)

HL 3.9 Mon 10:00 P

Back Focal Plane Imaging of Interlayer Excitons in WSe_2/$MoSe_2$ Heterostructures — •Lukas Sigl[1], Mirco Troue[1], Mauro Brotons-Gisbert[2], Brian Gerardot[2], Ursula Wurstbauer[3], and Alexander Holleitner[1] — [1]TU Munich, Germany — [2]Heriot-Watt University, United Kingdom — [3]University of Münster, Germany

Transition metal dichalcogenide monolayers exhibit strong light-matter interactions, which promotes them as ideal candidates for novel 2D optoelectronic applications. A vertical stacking into van der Waals heterostacks leads to the formation of long-lived interlayer excitons in adjacent layers.

We experimentally determine the transition dipole orientation of interlayer excitons in WSe_2/$MoSe_2$ heterobilayers at a base temperature of 1.7 K. The far-field photoluminescence is observed in the back focal plane of a microscope objective, such that the angular emission pattern can be resolved. An analytical model, based on source terms and transfer matrices, provides an accurate description of the dipole radiation from the heterobilayers. The obtained dipole orientation gives insight into the nature of interlayer exciton transitions and coincides with theoretical calculations for the ground state configurations in R- and H-type heterobilayers.

HL 3.10 Mon 10:00 P

Terahertz spectroscopy on nanograined Bismuth Telluride pellets — •Ahana Bhattacharya[1], Jeongwoo Han[1], Sepideh Izadi[3,4], Sarah Salloum[2], Stephan Schulz[2], Gabi Schierning[3], and Martin Mittendorff[1] — [1]Department of Physics, University of Duisburg-Essen,47057, Duisburg, Germany — [2]Department of Chemistry, University of Duisburg-Essen, 45141, Essen, Germany — [3]Department of Physics, Experimental Physics, Bielefeld University, 33615, Bielefeld, Germany — [4]Leibniz IFW Dresden, Institute for Metallic Materials, 01069, Dresden, Germany

Topological insulators (TI) host surface carriers with a very high mobility. However, the transport properties of extended crystals are dominated by bulk carriers which outnumber the surface carriers by orders of magnitude. One way to overcome the domination of bulk carriers is to use compacted TI nanoparticles. Bismuth Telluride nanoparticles which are compacted by hot pressing to nanograined bulk samples with a high surface to volume ratio are studied and analyzed.

THz time-domain spectroscopy is used as a tool to elucidate the contribution of surface and bulk carriers to the transport properties. While this is not possible with dc measurements, this can be achieved by measuring the reflection as a function of the frequency. Charge carriers with a high mobility lead to a pronounced frequency dependence of the conductivity, and thus the reflection, while low mobility carriers lead to a rather flat response. Analyzing the experimental results at various temperatures allows us to understand the role of surface and bulk carriers

HL 3.11 Mon 10:00 P

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

In recent years, 2D materials have garnered a lot of attention. Particularly graphene and transition metal dichalcogenides have been researched extensively [1]. However, there is a continuous interest in different groups of 2D materials because of their potential for new physics. Among these, the transition metal trichalcogenides (TMTC) include a lot of materials showing extraordinary properties [2].

We want to present our research on the TMTC zirconium triselenide

($ZrSe_3$) which we synthesized by a chemical transport method, exfoliated into thin flakes and then contacted by using e-beam lithography. It was possible to determine characteristics similar to that of the bulk material, even in thin layers down to 9 nm. Temperature dependent measurements give a value of about 0.6 eV for the band gap. Looking at the case of infinite thickness by comparing samples with different thicknesses a mean free path for the bulk material was determined. Thin flakes showed a degradation behavior under ambient condition which was investigated in more detail, showing a growth over several weeks. Furthermore, thin-film transistors show n-type doping when operated with a gate voltage.

[1] A. K. Geim, I. V. Grigorieva, Nature, 499, 419-425 (2013).
[2] J. O. Island et al., 2D Materials, 4, 0220033 (2017).

HL 3.12 Mon 10:00 P

Polarization resolved photoluminescence study of interlayer excitons in a twisted van-der-Waals heterostructure — •Johannes Michl[1], Sergey Tarasenko[2], Frederik Lohof[3], Christopher Gies[3], Martin von Helversen[4], Renee Sailus[5], Sefaattin Tongay[5], Takashi Taniguchi[6], Kenji Watanabe[6], Tobias Heindel[4], Stephan Reitzenstein[3], Tatiana Shubina[2], Sven Höfling[1], Carlos Anton-Solanas[1,7], and Christian Schneider[7] — [1]Technische Physik, Universität Würzburg — [2]Ioffe Institute, St. Petersburg — [3]Institute for Theoretical Physics, University of Bremen — [4]Institute of Solid-State Physics, Technische Universität Berlin — [5]Arizona State University — [6]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan — [7]Institute of Physics, Carl von Ossietzky University Oldenburg

Two-dimensional monolayers of transition metal dichalcogenides (TMDCs) offer a wide range of possibilities for investigation due to their unique optical properties, resulting from the exotic valley physics and the strong Coulomb interaction. By stacking two different TMDCs with a twist angle, a van der Waals heterostructure is formed that exhibits a spatially periodical Moiré potentials.

We discuss polarization resolved photoluminescence experiments performed on interlayer excitons in a slightly twisted MoSe2/WSe2 heterobilayer. In detail, we focus on the polarization properties of our sample: Our results highlight the observation of a significant degree of circular polarization of excitons, which can be manipulated with an externally applied magnetic field.

HL 3.13 Mon 10:00 P

Magnetotransport Measurements on Folded Twisted Bilayer Graphene-Hexagonal Boron Nitride Heterostructure — •Bei Zheng[1], Lina Bockhorn[1], Christopher Belke[1], Sung Ju Hong[2], 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 transport properties of bilayer graphene are strongly depended on rotational mismatch between the two graphene sheets, owing to the energy band modulation from the corresponding Moiré superlattice [1,2]. Here, we focused on the magnetotransport characteristics of folded twisted bilayer graphene (fTBG) which was obtained by mechanical exfoliation and it's heterostructure stacking with hexagonal boron nitride (hBN). The typical Landau fan diagrams from our hBN/fTBG/hBN sample were observed and the corresponding quantum Hall effect was investigated. Additional to the charge neutrality point (CNP), a local resistance peak which is independent of the perpendicular applied magnetic field was also distinguished. This could be attributed to the folded edge [1] that induces strong gauge fields [3] and exhibits different charge carrier densities.

[1] H. Schmidt et al., Nat. Commun. 5, 5742 (2014)
[2] J. C. Rode et al., 2D Mater. 3, 035005 (2016)
[3] D. Rainis et al., Phys. Rev. B 83, 265404 (2011).

HL 3.14 Mon 10:00 P

An ultra-sensitive cavity absorption microscope for hyperspectral imaging of 2D materials — Manuel Nutz[1], •Ines Amersdorffer[1], Florian Sigger[1], Theodor Hänsch[2], Alexander Högele[2], Christoph Kastl[3], and Thomas Hümmer[1] — [1]Qlibri project, Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [3]Walter Schottky Institute and Physics Department, TU Munich, Garching, Germany

We use a tunable high-finesse optical micro-cavity as a versatile and powerful tool to measure absorption in transition metal dichalcogenides (TMDs) down to the parts-per-million level. Our scanning-cavity imaging technique [1,2], where a microscopic mirror is scanned across a larger mirror that hosts the sample, allows to collect absorption images of 2D materials with unprecedented sensitivity, spatially resolved with 2*m resolution and in real time. Our approach can be extended to allow for spectrally resolved measurements and reveals polarization-dependent absorption, implanted defects, crystal foldings, and bubbles. Furthermore, we present our progress to extend this absorption measurements to cryogenic temperatures. [1] Mader et al., Nat Commun 6, 7249 (2015) [2] Hümmer et al., Nat Commun 7, 12155 (2016)

HL 3.15 Mon 10:00 P

Detection of correlated noise in quantum rings — C. Riha[1], S. S. Buchholz[1], O. Chiatti[1], A. D. Wieck[2], D. Reuter[3], and •S. 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

Cross-correlated noise measurements in equilibrium at a bath temperature of $T_{bath} = 4.2$ K are performed in etched AlxGa1-xAs/GaAs-based quantum rings [1], which are of interest to the study of mode control and heat flow at the nanoscale and in quantum systems [2]. The measured white noise exceeds the thermal noise expected from the measured electron temperature T_e and the electrical resistance R. This excess noise is neither observed if one arm of a quantum ring is depleted of electrons nor in 1D-constrictions that have a length and width comparable to the quantum rings. Also, it decreases as T_{bath} increases and vanishes for $T_{bath} > 12$ K. A model is presented that suggests that the excess noise originates from the correlation of noise sources, mediated by phase-coherent propagation of electrons. The noise measurements at $T_{bath} = 4.2$ K allow the estimation of a correlation coefficient from the excess noise.

[1] C. Riha *et al.*, Appl. Phys. Lett. **117**, 063102 (2020)
[2] S. S. Buchholz *et al.*, Phys. Rev. B **85**, 235301 (2012); C. Kreisbeck *et al.*, Phys. Rev. B **82**, 165329 (2010); C. Riha *et al.*, Appl. Phys. Lett. **106**, 083102 (2015)

HL 3.16 Mon 10:00 P

Improving the Visibility of Graphene on III-V semiconductors — •Timo Kruck, A.D. Wieck, and Arne Ludwig — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

In a first step towards working with graphene on III-V semiconductors the visibility of graphene will be analyzed and improved with an optical microscope in the NIR range.

Each layer of graphene absorbs a certain fraction of light in a wide spectral range from visible to infrared. This fraction is $\pi\alpha \sim 2.3\%$, where α is the fine-structure constant. This absorption can be enhanced by superimposing it on certain photonic structures. For this purpose, a DBR based on GaAs and AlAs with an antireflection layer was grown on a GaAs substrate with MBE and according reflectance spectra are measured. Graphene has been exfoliated on this structure and is observed with an optical microscope illuminated by a NIR VCSEL. The resulting contrast produced by a different number of layers is analyzed and compared with simulations based on the transfer matrix method (TMM). The TMM simulations are supported by reflectometry to account for deviations of the as-grown structure from the intended structure.

HL 3.17 Mon 10:00 P

Temperature and magnetic field dependent noise measurements in 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

Phase-coherent transport of electrons and resulting interference effects offer a way to characterize systems. Noise measurements can be used to determine system properties, such as the electron temperature T_e. White noise exceeding the expected thermal noise has been reported in quantum ring structures [1]. The presented model suggests that the excess noise is caused by a correlation of noise sources in quantum rings, because said excess noise can only be observed when two interfering electron pathes exist. 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 12 K and magnetic fields ranging from -50 mT to 50 mT. The aim is to quantify the relationship between the phase coherence length of the electrons and the excess noise in the quantum ring structures.

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

HL 3.18 Mon 10:00 P

Charge transfer in TMDC-graphene heterobilayers with defects — •Daniel Hernangómez-Pérez and Sivan Refaely-Abramson — Weizmann Institute of Science, Rehovot, Israel

Recent experimental and theoretical studies of charge transport in van der Waals heterostructures have revealed a rich arena of electronic and optical phenomena, that span from tunneling spectroscopy [1] to ultrafast interfacial charge transfer after photoexcitation [2, 3]. We focus here on a theoretical study of charge transfer processes occurring at the interface of XS_2-graphene heterobilayers with isolated chalcogen vacancies (X = Mo, W). We analyze the low-energy subgap features of the defect states in the presence of graphene and propose a perturbation-based theory to describe electronic transport between the defect states mediated by the graphene layer.

[1] N. Papadopoulos, P. Gehring, K. Watanabe et al. Phys. Rev. B 101, 165303 (2020). [2] L. Yuan, T.-F. Chung, A. Kuc et al. Science Advances 4 (2), 10.1126/sciadv.1700324 (2018). [3] S. Aeschlimann, A. Rossi, M. Chávez-Cervantes et al. Science Advances 6 (20), 10.1126/sciadv.aay0761 (2020).

HL 3.19 Mon 10:00 P

A field-effect-transistor based on the carbon allotropes diamond and graphene — •Vasilis Dergianlis, Martin Geller, Dennis Oing, Nicolas Wöhrl, and Axel Lorke — Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany

Graphene is the two-dimensional carbon allotrope that exhibits exceptional mechanical strength and electron mobility. Due to its high conductivity, it is considered as one of the best conductors and can also be used as gate electrode in transistor-type devices. A second important carbon allotrope is diamond, which is a wide-bandgap semiconductor in its bulk form, where by hydrogen termination and exposure to ambient atmosphere, a two dimensional hole gas (2DHG) is formed on its surface.

In this work, we have combined the two aforementioned 2D carbon allotropes together with a thin layer of hexagonal Boron Nitride (h-BN) to a diamond-based FET. The sample consists of chemical vapor deposition-grown diamond, where a hydrogen termination induces a 2DHG on the surface as a conductive layer [1]. Graphene and hBN flakes were exfoliated and, using a dry-transfer method, placed onto the functionalized diamond surface. In this transistor-like structure, the h-BN serves as the gate-dielectric. As graphene is an ambipolar two-dimensional semiconductor itself, it can serve as both the gate electrode and tunable conductive channel. We show FET characterization of the graphene-gated structure with a mobility of $5\,cm^2/V\cdot s$ and carrier density of $p = 3.7\cdot 10^{12}cm^{-2}$ at a gate voltage of $V_g = -9V$

[1] Oing, D., et al. Diamond and Related Materials **97**, 107450 (2019).

HL 3.20 Mon 10:00 P

Proximity control of interlayer exciton-phonon hybridization in van der Waals heterostructures — •Marlene Liebich[1], Philipp Merkl[1], Chaw-Keong Yong[1], Isabella Hofmeister[1], Gunnar Berghaeuser[2,3], Ermin Malic[2,3], and Rupert Huber[1] — [1]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Department of Physics, Philipps-Universitaet Marburg, 35037 Marburg, Germany — [3]Department of Physics, Chalmers University of Technology, 412 96 Gothenburg, Sweden

Van der Waals stacking has provided unprecedented flexibility in shaping many-body interactions by controlling electronic quantum confinement, orbital overlap and electron-phonon coupling. We introduce proximity-controlled strong-coupling between Coulomb correlations and lattice dynamics in neighbouring van der Waals materials, creating new electrically neutral hybrid eigenmodes, called excitonic Lyman polarons. Specifically, we explore how the internal orbital $1s$–$2p$ transition of Coulomb-bound electron-hole pairs in monolayer tungsten diselenide resonantly hybridizes with lattice vibrations of a polar capping layer of gypsum. Tuning orbital exciton resonances across the vibrational resonances, we observe distinct anticrossing and polarons with adjustable exciton and phonon compositions. Such proximity-induced hybridization can be further tailored by shaping the spatial wavefunction overlap of excitons and phonons, providing a promising new route towards engineering novel ground states of two-dimensional systems.

HL 3.21 Mon 10:00 P

Implementation of the Bethe-Salpeter Equation in the Spex Code — •Jörn Stöhler[1,2], Dmitrii Nabok[1], Christoph Friedrich[1], and Stefan Blügel[1] — [1]Forschungszentrum Jülich and JARA, 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. In recent developments the BSE has been applied to compute the exciton band dispersion and exciton effective masses, inelastic electron scattering, and many more.

We have implemented the BSE in the SPEX code, a full-potential linearized augmented planewave (FLAPW) code that supports a range of Green function based methods including the GW approximation, optical spectra in the random phase approximation, and more. The BSE is run on top of a one-shot G_0W_0 calculation with SPEX, or directly on top of the underlying density functional theory (DFT) calculations from FLEUR.

Our code has been tested for various bulk, layered and monolayer semiconductors, among them LiF and MoS2, and includes spin-orbit coupling. The results agree with the literature. We also use the crystal symmetries to achieve a significant computational speedup, and maintain good scalability of the code for parallel computing.

HL 3.22 Mon 10:00 P

Excitation-induced quenching and optical amplification in a CDW-phase of a two dimensional material — •Stephan Michael and Hans Christian Schneider — Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, P.O. Box 3049, 67653 Kaiserslautern, Germany

The optical excitation of two dimensional materials like transition metal dichalcogenides (TMDs) in connection with their rich electronic phase diagrams offer new ways to manipulate material properties on ultrafast timescales [1,2]. We study theoretically the appearance and the quenching of a CDW phase in a model system of a two dimensional material due to optical excitation with time-dependent interaction matrix elements and screening effects. We describe the excitonic and coherent-phonon effects in the band-dynamics by electron-hole and electron-phonon coupling. The non-equilibrium carrier dynamics includes the optical excitation, the carrier-carrier scattering as well as the carrier-phonon scattering. We discuss how interaction processes affect anomalous expectation values and use projection techniques to illustrate the time-dependent appearance of additional bands. We propose an optical amplification effect in the mid-infrared up to infrared regime with a potential for high-frequency modulation.

[1] S. Mathias et. al., Nat. Commun. **7**, 12902 (2016).
[2] S. Michael and H. C. Schneider, Phys. Rev. B **100**, 035431 (2019).

HL 3.23 Mon 10:00 P

Electric field manipulation of the Zeeman splitting in van der Waals heterostructures — •Paulo E. Faria Junior and Jaroslav Fabian — University of Regensburg, Regensburg, Germany

Under external magnetic fields, the interplay of spin and orbital angular momenta drives the Zeeman splitting, often encoded by the effective g-factors. Here, we explore the electric field control of g-factors in transition metal dichalcogenides (TMDCs) van der Waals heterostructures (vdWHs) of $MoSe_2$ and WSe_2. Using a full ab initio approach for the electronic structure and g-factors, we show that external electric fields introduce strong interlayer hybridization with robust signatures in the g-factors of interlayer and intralayer excitons. Furthermore, different interlayer exciton species can be identified by their characteristic dependence with respect to the electric field, an important information to disentangle the optical spectra observed in experiments. In summary, our study provides fundamental insight on the electric field manipulation of g-factors in TMDC-based vdWHs, benchmarking the relevant physics that must be included to investigate moiré excitons. Supported by SFB 1277 and SPP 2244.

HL 3.24 Mon 10:00 P

InGaAs Based Resonant Tunnelling Diodes By GSMBE — •Begum Yavas Aydin, Sven Höfling, Fauzia Jabeen, and Lukas Worschech — Technische Physik, University of Würzburg, Am Hubland, D-97074 Würzburg, Germany

Resonant Tunneling Diodes (RTD) are promising devices for various applications such as GHz to THz oscillators and high sensitivity photon detectors due to their ultra-high frequency, ultra-high-speed, and low power. High current density (JP) and high peak-to-valley current ratio (PVCR) are required for high-speed RTDs. To obtain high current densities and PVCR, structural parameter's dependence on barrier thickness, the spacer thickness of emitter and collector play key role.

InGaAs-based RTDs are grown by gas sources molecular beam epitaxy (GSMBE). High current density can be achieved by a thin barrier with a high electron transmission [1]. Peak current density reached 75 kA/cm2 with 1.5 nm thin AlAs barriers. Three RTD samples differing in In0.53Ga0.47As collector spacer thickness of 5, 10, and 25 nm are grown. The highest JP of 500 kA/cm2 with PVCR 5.7 is achieved at room temperature for a 1.5 nm thin AlAs barrier and an asymmetric spacer layer.

[1] Moise, T. S., et al. J. of Appl. Phys. 78.10 (1995)

[2] Kanaya, H., et al. J. of Infrared, Millimeter, Terahertz Waves 35.5 (2014)

HL 3.25 Mon 10:00 P

Nonlinear THz spectroscopy at TeraFERMI — •Johannes Schmidt, Paola Di Pietro, and Andrea Perucchi — Elettra - Sincrotrone Trieste S.C.p.A., S.S. 14 km - 163,5 in Area Science Park, I-34149 Basovizza, Trieste, Italy

TeraFERMI is a THz beamline at the Free-electron laser (FEL) FERMI. After passing the undulator of the FEL the electron bunches are refocused on a thin slab and generate coherent transition radiation (CTR) as THz pulses with a spectral range of typically 0.1 to 6 THz. TeraFERMI provides strong single-cycle pulses with MV/cm electric peak fields or magnetic peak fields up to 1 T, which is in combination with the low repetition rate of 50 Hz an ideal source for nonlinear spectroscopy in many sciences from biology to physics. The short ps THz-pulses are phase-envelope stable with a low temporal jitter of about 66 fs (rms) and is therefore perfect for THz-pump probe experiments with different probe colors. Up to now, we focused on THz-pump NIR-probe and fluence-dependent THz spectroscopy. Thereby is the radial polarization of the beam a specialty of the CTR THz-beam and allows for longitudinal spectroscopy. Here, we report about the latest technological advances of TeraFERMI as well as first pilot experiments.

HL 3.26 Mon 10:00 P

Quantum anomalous Hall effect in Bernal-stacked bilayer graphene — Fabian Geisenhof[1], Felix Winterer[1], Anna Seiler[2], Jakob Lenz[1], Tianyi Xu[3], Fan Zhang[3] und •Thomas Weitz[2] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Germany — [2]Department of Physics, University of Texas at Dallas, USA — [3]1st Physical Institute, University of Göttingen, Germany

The anomalous quantum Hall effect is a peculiar state of matter that has been observed in only very few materials systems including artificially engineered Moiré heterostructures [1]. However, the special bandstructure of naturally occurring bilayer graphene, has also been predicted to host an interaction-driven quantum anomalous Hall insulating phase at zero magnetic field [2], which has escaped previous experimental observation. Here, based on advanced sample design of near-field imaging, suspension and dual-gating, we show clear signatures of this quantum anomalous Hall insulating phase in ultra-clean bilayer graphene [3]. Besides the simplicity, diversity, and robustness of the system, the quantum anomalous Hall phase is also distinct from previously observed ones, since it is the first phase that does not only exhibit quantized charge Hall conductance at zero magnetic field, but also spin, valley and spin-valley anomalous quantum Hall effects as well as out-of-plane ferroelectricity.

[1] A.L. Sharpe, et al. Science 365, 605 (2019); M. Serlin, et al. Science 367, 900 (2020),

[2] F. Zhang Synthetic Metals 210, 9 (2015)

[3] F. R. Geisenhof, et al. arXiv:2107.06915 (2021)

HL 4: 2D materials and their heterostructures (joint session DS/HL/CPP)

Time: Monday 11:15–13:00 Location: H3

HL 4.1 Mon 11:15 H3

Tunable phases of Moire excitons in van der Waals heterostructures — •Samuel Brem[1], Christopher Linderälv[2], Paul Erhart[2], and Ermin Malic[1,2] — [1]Philipps University, Marburg, Germany — [2]Chalmers University of Technology, Göteborg, Sweden

Two monolayers of Transition Metal Dichalogenides can be vertically stacked to form a type-II heterostructure, hosting spatially indirect interlayer excitons. Recent studies have shown that moire superlattices can be created by stacking monolayers with a finite twist-angle, giving rise to a tunable modification of exciton features in optical spectra. The moire patterns lead to a spatially varying band gap and consequently, excitons experience a periodic potential modifying their transport properties.

We have combined first-principles calculations with the excitonic density matrix formalism to develop an exciton model for small-angle twisted MoSe2/WSe2 heterostructures. Based on a microscopic approach, we calculate the band structure and wave functions of intra- and interlayer excitons within a twist-tunable moire lattice as well as the resulting optical response. For a range of small twist-angles, we predict completely flat exciton bands corresponding to moire trapped, localized quantum emitters. However, we reveal that this moire exciton phase quickly changes with increasing twist-angle, and at 3°, there are only delocalized excitons. We find the emergence of multiple moire exciton peaks in the absorption, whose spectral shifts with varying twist-angle are characteristic for the trapped or delocalized phase.

HL 4.2 Mon 11:30 H3

Electrical control of spin-orbit coupling-induced spin precession and spin-to-charge conversion in graphene proximitized by WSe2 — •Franz Herling[1], Josep Ingla-Aynes[1], C. K. Safeer[1], Nerea Ontoso[1], Jaroslav Fabian[2], Luis E. Hueso[1,3], and Felix Casanova[1,3] — [1]CIC nanoGUNE BRTA, Spain — [2]University of Regensburg, Germany — [3]IKERBASQUE, Basque Foundation for Science, Spain

When combined with WSe2, a large spin-orbit coupling gets imprinted by proximity effect into graphene. Here, we use this effect to achieve the strong SOC regime in bilayer graphene. Together with the long, gate tunable spin diffusion, this provides unique control knobs to manipulate coherent spin precession in the absence of an external magnetic field. Remarkably, we observe in these devices that the sign of the precessing spin polarization can be tuned electrically by a back gate voltage and by a drift current. This realization of a spin field-effect transistor at room temperature in a diffusive system, a long-awaited goal of spintronics, could be a cornerstone for the implementation of energy efficient spin-based logic.

In accordance with the large proximity-induced SOC, we also observe spin Hall effect in similar heterostructures with an unprecedented spin-to-charge conversion length of up to 41 nm. Such highly efficient conversion up to room temperature will play a crucial role for the future integration of spintronic devices into existing electronic infrastructure.

HL 4.3 Mon 11:45 H3

Gate-Switchable Arrays of Quantum Light Emitters in Contacted Monolayer MoS_2 van der Waals Heterodevices — •Alexander Högter[1,2], Julian Klein[1,2,3,4], Katja Barthelmi[1,3], Lukas Sigl[1,2], Samuel Gyger[5], Takashi Taniguchi[6], Kenji Watanabe[6], Val Zwiller[5], Klaus D. Jöns[5], Ursula Wurstbauer[2,7], Jonathan Finley[1,2,3], and Alexander Holleitner[1,2,3] — [1]Walter Schottky Institut, TU Munich — [2]Exzellenzcluster e-conversion — [3]Munich Center for Quantum Science and Technology — [4]Massachusetts Institute of Technology, Cambridge — [5]KTH Royal Institute of Technology, Dept. of Applied Physics — [6]National Institute for Materials Science, Tsukuba — [7]Institute of Physics, Westfälische Wilhelms-Universität Münster

Controlling single-photon emission on a few nanometers plays an important role for the scalability of future quantum photonic circuits.

Moreover, it is highly relevant to facilitate a gate-switchable emission for quantum information schemes. By irradiating MoS_2 with helium ions, we generate single-photon sources at ~1.75 eV with a lateral position accuracy of only a few nanometers. [1] Second-order correlation measurements unambiguously proof the nature of single-photon emission. Charge doping of the monolayer MoS_2 can be used for switching the quantum emission on and off. [2] This deterministic control of light emission in spatial and temporal means paves the way for new integrated quantum photonic technologies.

[1] J. Klein, L. Sigl et al., ACS Photonics 8, 2 (2021).
[2] A. Hötger et al., Nano Lett. 21, 2 (2021).

HL 4.4 Mon 12:00 H3

Tunnelling transport in bilayer graphene nanostructures with quantum dots — •Angelika Knothe[1], Vladimir Fal'ko[1], and Leonid Glazman[2] — [1]National Graphene Institute, University of Manchester, Manchester M13 9PL, United Kingdom — [2]Department of Physics, Yale University, New Haven, CT 06520, USA

Quantum nanostructures, e.g., quantum wires and quantum dots, are needed for applications in quantum information processing devices, e.g., transistors or qubits. In gapped bilayer graphene (BLG), one can confine charge carriers electrostatically, inducing smooth confinement potentials while allowing gate-defined control of the confined structure. I will discuss charge transport in BLG nanostructures with electrostatically confined quantum dots. We investigate both theoretically and in collaboration with experiments how the BLG dots' highly degenerate single- and two-electron spin and valley multiplets, which depend on, e.g., the displacement field and the electron-electron interactions, manifest in tunnelling transport. This way, we shed light on BLG material parameters while opening the field for using the dots' rich spin and valley multiplets for quantum information.

1) Theory of tunneling spectra for a few-electron bilayer graphene quantum dot, A. Knothe, L. Glazman, V. Fal'ko, arXiv:2104.03399 2) Probing two-electron multiplets in bilayer graphene quantum dots, S. Möller, L. Banszerus, A. Knothe, L. Glazman, V. Fal'ko, C. Stampfer, et. al, arXiv:2106.08405 3) Quartet states in two-electron quantum dots in bilayer graphene, A. Knothe, V. Fal'ko, PRB 101, 235423 (2020)

HL 4.5 Mon 12:15 H3

Unconventional Superconductivity in Magic-Angle Twisted Trilayer Graphene — •Ammon Fischer — Institute for Theory of Statistical Physics, RWTH Aachen University

Magic-angle twisted trilayer graphene (MATTG) recently emerged as a highly tunable platform for studying correlated phases of matter, such as correlated insulators and superconductivity. Superconductivity occurs in a range of doping levels that is bounded by van Hove singularities which stimulates the debate of the origin and nature of superconductivity in this material. In this work, we discuss the role of spin-fluctuations arising from atomic-scale correlations in MATTG for the superconducting state. We show that in a phase diagram as function of doping (ν) and temperature, nematic superconducting regions are surrounded by ferromagnetic states and that a superconducting dome with $T_c \approx 2$ K appears between the integer fillings $\nu = -2$ and $\nu = -3$. Applying a perpendicular electric field enhances superconductivity on the electron-doped side which we relate to changes in the spin-fluctuation spectrum. We show that the nematic unconventional superconductivity leads to pronounced signatures in the local density of states detectable by scanning tunneling spectroscopy measurements.

HL 4.6 Mon 12:30 H3

Twist angle dependent proximity induced spin-orbit coupling in graphene/transition-metal dichalcogenide heterostructures — •Thomas Naimer[1], Klaus Zollner[1], Martin Gmitra[2], and Jaroslav Fabian[1] — [1]Institute for Theoretical Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Institute of Physics, P. J. Šafárik University in Košice, 04001 Košice, Slovakia

We investigate proximity-induced spin-orbit coupling (SOC) in graphene on the four transition-metal dichalcogenides (TMDCs) MoS_2, WS_2, $MoSe_2$ and WSe_2 from first principles. By using different supercells of graphene/TMDC heterostructures we provide systematic insight on the effect of twist angles on the low energy Dirac spectrum. We find that the exact position of the Dirac cone within the TMDC band gap depends linearly on the biaxial strain applied to the graphene. From this relation we extrapolate the zero-strain band offset and correct the band offsets of all calculations by employing a transverse electric field across the heterostructure. The corrected results reveal massive twist angle tunability of both the magnitude and flavor of proximity induced SOC: We observe a peak in SOC at approximately 19° twist angle and vanishing SOC at 30°. This work was supported by ENB "Topologische Isolatoren" and SFB 1277.

HL 4.7 Mon 12:45 H3

Predicting the adsorption of alkali metals on 2D materials — Maofeng Dou and •Maria Fyta — Institute for Computational Physics, University of Stuttgart, Stuttgart, Germany

The adsorption of alkali metal atoms on two-dimensional transition metal dichalcogenides (2D TMDCs) is investigated using quantum-mechanical calculations. Specifically, we evaluate the adsorption characteristics of Li on 2D TMDCs through the respective adsorption energies. We decompose these energies into separate components in order to fundamentally understand the adsorption process. The adsorption energies of lithium on 2D TMDCs were found to strongly and linearly correlate with the energy of the lowest unoccupied states of the materials. Accordingly, we propose and demonstrate the use of this energy as a descriptor for predicting adsorption energies. We further proceed with additional 2D TMDCs and adsorbed alkali atoms in order to generate a database that allows us to learn and make predictions. Our results strongly support the use of the energy of the lowest unoccupied states as a novel efficient descriptor for a data-driven design of materials with pre-selected properties and functions for target applications.

HL 5: 2D semiconductors and van der Waals heterostructures I (joint session HL/DS)

Time: Monday 13:30–16:15 Location: H4

Invited Talk HL 5.1 Mon 13:30 H4

The role of chalcogen vacancies for atomic defect emission in MoS_2 — Elmar Mitterreiter[1], Bruno Schuler[2], Daniel Hernangómez-Pérez[3], Julian Klein[4], Jonathan Finley[1], Sivan Refaely-Abramson[3], Alexander Holleitner[1], Alexander Weber-Bargioni[5], and •Christoph Kastl[1] — [1]Walter Schottky Institute, TU Munich — [2]nanotech@surfaces Laboratory, Empa — [3]Department of Molecular Chemistry and Materials Science, Weizmann Institute of Science — [4]Massachusetts Institute of Technology — [5]Molecular Foundry, Lawrence Berkeley National Laboratory

The microscopic understanding of defect-related modifications in 2D materials requires correlation between atomic structure and resulting macroscopic electronic, optical or excitonic properties. Combing controlled defect engineering with optical spectroscopy as well as atomic imaging and ab-initio theory, we identify the optical signature of pristine chalcogen vacancies in single layer MoS_2. [1] Vacancies introduce a narrow optical emission, markedly different from previously observed broad luminescence bands. Comparing annealed vs. He-ion treated MoS_2, we establish that the recently discovered single-photon emitters in He-ion irradiated MoS_2 originate from chalcogen vacancies. Using focused ion beam irradiation, the latter can be created site-selectively [2] with a spatial precision better than 10 nm [3], which is important for a prospective integration of defect-based single photon emitters into quantum photonic circuits. [1] E. Mitterreiter et al., Nat. Commun. 12, 3822 (2021). [2] J. Klein et al. ACS Photonics 8, 669-677 (2021). [3] E. Mitterreiter et al., Nano Lett. 20, 4437 (2020).

HL 5.2 Mon 14:00 H4

Coherent light emission of exciton-polaritons in an atomically thin crystal at room temperature — •Hangyong Shan[1], Lukas Lackner[1], Bo Han[1], Evgeny Sedov[2], Falk Eilenberger[4], Sebastian Klembt[3], Sven Höfling[3], Alexey V. Kavokin[2], Christian Schneider[1], and Carlos Anton-Solanas[1] — [1]Institute of Physics, Carl von Ossietzky University, 26129 Oldenburg, Germany. — [2]School of Science, Westlake University, 310024 Hangzhou, People's Republic of China. — [3]Technische Physik, Universität Würzburg, D-97074 Würzburg, Am Hubland, Germany. — [4]Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University, 07745 Jena, Germany.

We experimentally study the coherence of exciton-polaritons in a Fabry-Perot microcavity loaded with an atomically thin WSe2 layer. Via Michelson interferometry, we capture clear evidence of increased spatial and temporal coherence of the emitted light from the spatially confined system ground-state. The coherence build-up is accompanied by a threshold-like behaviour of the emitted light intensity, which is a fingerprint of a polariton condensation effect. Valley-physics is manifested in the presence of an external magnetic field, which allows us to manipulate K and K* polaritons via the Valley-Zeeman-effect. Our findings are of high application relevance, as they confirm the possibility to use atomically thin crystals as simple and versatile components of coherent light-sources, and in valleytronic applications at room temperature.

HL 5.3 Mon 14:15 H4

Bosonic condensation of exciton-polaritons in an atomically thin crystal — •Carlos Anton-Solanas[1,2], Maximilian Waldherr[1], Martin Klaas[1], Holger Suchomel[1], Tristan H. Harder[1], Hui Cai[3], Evgeny Sedov[4], Sebastian Klembt[1], Alexey V. Kavokin[4], Sefaattin Tongay[5], Kenji Watanabe[6], Takashi Taniguchi[6], Sven Hoefling[1], and Christian Schneider[2] — [1]Univ. Wuerzburg, Germany — [2]Univ. Oldenburg, Germany — [3]Univ. California, USA — [4]Westlake Univ., China — [5]Arizona State Univ., USA — [6]Nat. Institute for Materials Science, Japan

Semiconducting monolayer crystals have emerged as a new platform for studies of tightly bound excitons and many-body excitations in ultimately thin materials. Their giant dipole coupling to optical fields makes them very appealing for (nano-) photonic devices, and for fundamental investigations in the framework of cavity quantum electrodynamics.

Our experiments demonstrate the strong light-matter coupling and, for the first time, the bosonic condensation of exciton-polaritons in an atomically thin layer of $MoSe_2$ coupled to a hybrid micro-cavity [1].

We demonstrate the emergence of long-range first-order spatial coherence, via interferometric $g^{(1)}(\tau)$ measures, and we have investigated the Zeeman splitting effects of condensed polaritons under strong magnetic fields.

[1] Anton-Solanas, C., Waldherr, M., Klaas, M. et al. Bosonic condensation of exciton polaritons in an atomically thin crystal. Nat. Mater. (2021).

HL 5.4 Mon 14:30 H4

Hybridization between monolayer transition-metal dichalcogenides and conjugated molecular adsorbants — •Jannis Krumland[1] and Caterina Cocchi[1,2] — [1]Humboldt-Universität zu Berlin — [2]Carl von Ossietzky Universität Oldenburg

We present a first-principles study on electronic hybridization in inorganic-oraganic interfaces composed of monolayer transition-metal dichalcogenides (TMDCs; molybdenum and tungsten disulfide and diselenide) and exemplary carbon-conjugated molecules such as pyrene and perylene. By means of band-structure unfolding techniques applied to hybrid density-functional theory calculations including spin-orbit coupling, we achieve an intuitive and clear description of electronic interaction between the inorganic and organic components of the heterostructures. From atom-projected band structures, we are able to rationalize the strong mixing between the valence states of the TMDC and the molecular orbitals. We additionally clarify why the highest occupied orbital couples with the TMDC bands only very weakly, regardless of the composition of the interface. The proposed analysis based on band structure unfolding lends itself for computationally efficient and yet reliable predictions of electronic interactions in more complex hybrid interfaces including larger molecules harvesting visible radiation.

HL 5.5 Mon 14:45 H4

Tunable Polymer/Air Bragg Optical Microcavity Configurations for Light-Matter Coupling with Transition-Metal Dichalcogenides and their Heterostructures — •Chirag Palekar[1,2], Stephan Reitzenstein[1], and Arash Rahimi-Iman[2] — [1]Present address: Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany — [2]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, 35032 Marburg, Germany

Light-matter interactions (LMI) in semiconducting materials is being studied extensively with the help of optical microcavities. Specifically, tunable microcavities provide a versatile platform to control the LMI between the material excitation and cavity photons. Here, we explore a new resonator approach which can be employed to achieve microscopic photonic Fabry-Pérot (FP) cavities with mechanically- tunable resonator modes and polymer/air Bragg mirrors [1], directly on a chip or device substrate in combination with active materials. Moreover, our simulations based on the transfer matrix method show, compression-induced mode control of the air-Bragg cavities enables tuning between the weak and strong coupling regime. Using this unique cavity configurations, LMI experiments with 2D semiconductors such as transitionmetal dichalcogenides (TMDC) are very attractive. Additionally, incorporation of TMDC heterostructures in FP cavities will provide a platform to understand the new regimes of Dicke superradiance as well as Bose-Einstein condensation of Moiré exciton-polaritons. Ref.: [1] Phys. Status Solidi RRL 2021, 15, 2100182

15 min. break

HL 5.6 Mon 15:15 H4

Phonon-assisted exciton dissociation in transition metal dichalcogenides — •Raul Perea-Causin[1], Samuel Brem[1], and Ermin Malic[1,2] — [1]Chalmers University of Technology, Gothenburg, Sweden — [2]Philipps-Universität, Marburg, Germany

Monolayers of transition metal dichalcogenides (TMDs) have been established in the last years as promising materials for novel optoelectronic devices. However, the performance of such devices is often limited by the dissociation of tightly bound excitons into free electrons and holes. While previous studies have investigated tunneling at large electric fields, we focus in this work on phonon-assisted exciton dissociation that is expected to be the dominant mechanism at small fields.

We present a microscopic model based on the density matrix formalism providing access to time- and momentum-resolved exciton dynamics including phonon-assisted dissociation [1]. We track the pathway of excitons from optical excitation via thermalization to dissociation, identifying the main transitions and dissociation channels. Furthermore, we find intrinsic limits for the quantum efficiency and response time of a TMD-based photodetector and investigate their tunability with externally accessible knobs, such as excitation energy, substrate screening, temperature and strain.

Our work provides microscopic insights in fundamental mechanisms behind exciton dissociation and can serve as a guide for the optimization of TMD-based optoelectronic devices.

[1] R. Perea-Causin et al., Nanoscale 13, 1884 (2021)

HL 5.7 Mon 15:30 H4

Lattice Configurations of Self-Assembled Folded Graphene — •Lina Bockhorn, Johannes C. Rode, Lucas Gnörich, Pengfei Zuo, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, 30167 Hannover, Germany

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. Therefore, it is highly desirable to gather insight into the mechanical formation of these structures on the nano-scale.

Here, we focus on the evolution of self-assembled folded graphene generated via atomic force microscopy technique, which could give a deep insight into its underlying growth energy [1, 2, 3]. The self-assembly process involves the folding-over of the graphene layer and the subsequent growth of a twisted graphene bilayer. We conclude, that these self-assembled structures move not only forward during the growth process but also appear to rotate and lock in at specific commensurate twist angles.

[1] J. C. Rode et al., Ann. Phys. 529, 1700025 (2017).
[2] J. C. Rode et al., 2D Mater. 6, 015021 (2018).
[3] L. Bockhorn et al., Appl. Phys. Lett. 118, 173101 (2021).

HL 5.8 Mon 15:45 H4

All-optical polarization and amplitude modulation of second harmonic generation in atomically thin semiconductors — •Sebastian Klimmer — Institute of Solid State Physics, Friedrich Schiller University Jena, Jena, Germany

Nonlinear optics is of paramount importance in several fields of science and technology. This is particularly true in the case of second harmonic generation (SHG), which is commonly used for frequency conversion, self-referencing of frequency combs, crystal characterization, sensing, and ultra-short pulse characterization. Large efforts have been devoted in the last years to realizing electrical and all-optical modulation of SHG in atomically thin materials, which are easy to integrate on photonic platforms and thus ideal for novel nano-photonic devices. Here, we propose a new approach to broadband all-optical modulation of SHG in 2D materials. Our concept is based only on symmetry considerations and thus is applicable to any material of the D3h symmetry group and with deep sub-wavelength thickness, such as all monolayer transition metal dichalcogenides. With this approach we demonstrate a 90° rotation of the polarization of the emitted SH on a time-scale limited only by the fundamental pulse duration. In addition, this ultrafast polarization switch can be immediately applied to realize all-optical SH amplitude modulation with depth of 100 %. Our results outperform any previous work on all-optical SHG modulation [1,2] in terms of modulation speed, modulation depth and SHG bandwidth.

[1] Taghinejad M. *et al.*, Small **16**, 1906347 (2020)
[2] Cheng Y. *et al.*, Nano Lett. **20**, 11 (2020) 8053-8058

HL 5.9 Mon 16:00 H4

Microscopic Theory of Exciton-Exciton Annihilation in Two-Dimensional Semiconductors — •Alexander Steinhoff, Matthias Florian, and Frank Jahnke — Institute for Theoretical Physics, University of Bremen, Bremen, Germany

Auger-like exciton-exciton annihilation (EEA) is considered the key fundamental limitation to quantum yield in devices based on excitons in two-dimensional (2d) materials. Since it is challenging to experimentally disentangle EEA from competing processes, guidance of a quantitative theory is highly desirable. The very nature of EEA requires a material-realistic description that is not available to date.

We present a many-body theory of EEA based on first-principle band structures and Coulomb interaction matrix elements that goes beyond an effective bosonic picture. Applying our theory to monolayer MoS_2 encapsulated in hexagonal BN, we obtain an EEA coefficient in the order of 10^{-3} cm^2s^{-1} at room temperature, suggesting that carrier losses are often dominated by other processes, such as defect-assisted scattering.

Our studies open a perspective to quantify the efficiency of intrinsic EEA processes in various 2d materials in the focus of modern materials research.

HL 6: Focus Session: Magnon Polarons - Magnon-Phonon Coupling and Spin Transport (joint session MA/HL)

The coupling of spin waves and atomic lattice vibrations in solid magnetic states, so-called magnon polarons (MPs), can have large impact on spin transport properties as recently explored for spin Seebeck effect, spin pumping and nonlocal spin transport. This resonant enhancement can be reached when the magnon dispersion is shifted by a magnetic field and crosses the phonon dispersion with sufficient overlap. While initially observed at low temperatures and large magnetic fields, further material and device developments have led to MPs at room temperature and moderate magnetic fields. Thus, MPs become important for the manipulation and amplification of spin currents in spintronic and spin caloritronic devices, e.g. by carrying the spins much further than using uncoupled magnons. This focus session highlights the main important research outcomes for MPs, state-of-the-art techniques to detect MPs, such as Brillouin light scattering, and to study MP transport, e.g. by spin Seebeck effect and nonlocal spin transport, as well as the investigation of MPs in different material classes such as garnets, ferrites and antiferromagnets. In addition, the excessive theoretical work on MPs performed recently is addressed in this focus session.

Organizer: Timo Kuschel (Bielefeld University)

Time: Monday 13:30–17:00 Location: H5

Invited Talk HL 6.1 Mon 13:30 H5

Magnon-polarons in magnetic insulators — •Benedetta Flebus — Boston College, Chestnull Hill, USA

We theoretically study the effects of strong magneto-elastic coupling on the transport properties of magnetic insulators. We develop a Boltzmann transport theory for the mixed magnon-phonon modes, i.e., magnon-polarons, and determine transport coefficients of the composite quasi-particles. Magnon-polaron formation causes anomalous features in the magnetic field and temperature dependence of the spin Seebeck effect when the disorder scattering in the magnetic and elastic subsystems is sufficiently different. We discuss how experimental data by Kikkawa et al. [PRL 117, 207203 (2016)] on yttrium iron garnet films can be explained by an acoustic quality that is much better than the magnetic quality of the material.

Invited Talk HL 6.2 Mon 14:00 H5

Spin-phonon coupling in non-local spin transport through magnetic insulators — •Rembert Duine — Institute for Theoretical Physics, Utrecht University, The Netherlands

Long-range spin transport through ferromagnetic and antiferromagnetic insulators has recently been demonstrated. In this talk I will discuss how spin-phonon interactions influence this transport. In the first part of the talk I will discuss how bulk spin-phonon interactions lead to magnon-polaron formation and how this composite boson influences the non-local transport. In the second part, I will discuss how spin-phonon interactions across an interface give rise to long-distance spin transport that is carried purely by phonons.

Invited Talk HL 6.3 Mon 14:30 H5

Double accumulation and anisotropic transport of magneto-elastic bosons in yttrium iron garnet films — •Alexander A. Serga — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Kaisersalutern, Germany

Interaction between quasiparticles of a different nature, such as magnons and phonons, leads to mixing their properties and forming hybrid states in the areas of intersection of individual spectral branches. In garnet ferrite films, such hybridization results in a resonant increase in the efficiency of the spin Seebeck effect and the spontaneous bottleneck accumulation of hybrid magnetoelastic bosons—magnon polarons.

Similar to the Bose-Einstein magnon condensation (BEC), the latter phenomenon occurs in a yttrium iron garnet film exposed to microwaves. However, unlike the BEC, which is a consequence of the equilibrium Bose statistics, the bottleneck accumulation is determined by changing interparticle interactions. Studying the transport properties of accumulated quasiparticles, we found that such accumulation occurs in two frequency-distant groups: quasiphonons and quasimagnons. These quasiparticles propagate in the film plane as spatially localized beams with different group velocities. The developed theoretical model qualitatively describes the double accumulation effect, and the analysis of the two-dimensional quasiparticle spectrum makes it possible to determine the wavevectors and frequencies of each group.

Funded by the ERC Advanced Grant 694709 SuperMagnonics and by the DFG within TRR 173 – 268565370 (project B04).

HL 6.4 Mon 15:00 H5

enhancement of the spin seebeck effect by magnon-phonon resonance in a partially compensated magnet — •R. Ramos[1,2], T. Hioki[3,4], Y. Hashimoto[1], T. Kikkawa[1,3,4], P. Frey[5], A.J.E. Kreil[5], V.I. Vasyuchka[5], A.A. Serga[5], B. Hillebrands[5], and E.

Saitoh[1,3,4] — [1]WPI AIMR, Tohoku University, Japan — [2]CIQUS, Departamento de Química-Física, Universidade de Santiago de Compostela, Spain — [3]Department of Applied Physics, The University of Tokyo, Japan. — [4]IMR, Tohoku University, Japan — [5]Fachbereich Physik and Landesforshungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

The spin Seebeck effect (SSE) refers to the generation of a spin current in magnetic materials by the application of a thermal gradient. Recently, the effect of magnon-phonon hybridization, resulting from the crossing of the magnon and phonon dispersions, has been detected in the SSE and named magnon-polaron SSE. This is experimentally observed as spikes of the SSE-voltage at the magnetic field values for which the hybridization between the magnon and phonon dispersions is maximized over k-space. In this talk, we will report the detection of magnon-polaron SSE in a nonmagnetic-ion-substituted garnet system at room temperature and low magnetic fields [1]. The effect is 8 times larger than that observed in a YIG film. We show that the magnon dispersion can be strongly affected by the nonmagnetic-ion substitutions, thus resulting in a clear modification of the magnetic field condition for the observation of magnon-polarons. [1] R. Ramos et al. Nature Comm. 10, 5162 (2019).

Invited Talk HL 6.5 Mon 15:15 H5

Magnon polarons and the low-temperature spin-Seebeck effect — •Piet Brouwer and Rico Schmidt — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany

Using a simplified microscopic model of coupled spin and lattice excitations in a ferromagnetic insulator we evaluate the magnetic-field dependence of the longitudinal spin Seebeck effect at low temperatures. We find that at low temperatures, large magnetic fields, and for not-too-large system sizes the spin Seebeck effect is almost completely mediated by magnon polarons, superpositions of magnon and phonon excitations, with frequency close to the crossing points of magnon and phonon dispersions. We find an enhancement of the spin-Seebeck effect for “critical” values of the magnetic field, for which magnon and phonon dispersions touch. Such an enhancement of the longitudinal spin-Seebeck effect was observed experimentally by Kikkawa et al. [Phys. Rev. Lett. 117, 207203 (2016)]. We find that the existence of this enhancement is independent of the relative strength of magnon-impurity and phonon-impurity scattering.

Invited Talk HL 6.6 Mon 15:45 H5

Magnon-Polarons in different flavors: (anti)ferromagnetic to topological — •Akashdeep Kamra — Condensed Matter Physics Center (IFIMAC) and Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

Due to magnetoelastic coupling, magnons and phonons in a magnet can combine to form hybrid quasiparticles, inheriting properties from both, called magnon-polarons. We will begin by examining and clarifying the essential requirements for their hybridization in terms of the spin conservation laws and the nature of the magnetoelastic coupling. This will allow us to deduce the properties, such as spin, of the magnon-polarons thus formed and provide guidance on how to engineer magnon-polarons. In carrying out this general discussion, we will analyze the cases of magnon-polarons in ferromagnets as examples. Then, we will apply the general principles developed to the cases of antiferromagnets and topological magnonic insulators thereby demonstrating magnon-polarons with novel, tunable, and chiral properties. We will conclude our discussion with recent experiments suggesting spin-phonon coupling to underlie collective quantum phenomena in the high-Tc superconductor YBCO.

References: [1] A. Kamra, H. Keshtgar, P. Yan, and G. E. W. Bauer. Phys. Rev. B 91, 104409 (2015). [2] H. T. Simensen, R. E. Troncoso, A. Kamra, and A. Brataas. Phys. Rev. B 99, 064421 (2019). [3] E. Thingstad, A. Kamra, A. Brataas, and A. Sudbø. Phys. Rev. Lett. 122, 107201 (2019).

Invited Talk HL 6.7 Mon 16:15 H5

Magnon polarons in antiferromagnetic insulator Cr2O3 — •Jing Shi — Department of Physics & Astronomy, University of California, Riverside, USA

While magnon polarons in ferrimagnetic materials have been experimentally investigated by various meanings including the spin Seebeck effect, nonlocal transport, inelastic neutron scattering, spin pumping, etc., similar hybridized excitations in antiferromagnets have not been well explored. For typical antiferromagnets, the magnon dispersion lies well above the acoustic phonon dispersion, which prevents the formation of magnon polarons under accessible magnetic fields. In this talk, I will first review the main magnon polaron results in yttrium iron garnet [1], a ferrimagnetic insulator. My focus will be on a special antiferromagnetic insulator: Cr2O3. In this uniaxial antiferromagnet, the left-handed magnon branch can be effectively lowered to zero at ~6 T, the spin-flop transition, allowing for thermodynamic measurements. In our study of Cr2O3 spin Seebeck effect [2], We observe magnon polaron anomalies right below the spin flop transition. where the left-handed magnon dispersion intersect both longitudinal and transverse acoustic phonon dispersions. I will present our experimental data and analysis in my talk.

[1] H.R. Man et al., Direct observation of magnon-phonon coupling in yttrium iron garnet. Phys. Rev B 96, 100406(R) (2017). [2] J.X. Li et al., Observation of magnon-polarons in a uniaxial antiferromagnetic insulator Cr2O3. Phys. Rev. Lett. 125, 217201(2020).

HL 6.8 Mon 16:45 H5

Revealing thermally driven distortion of magnon dispersion by spin Seebeck effect in Gd3Fe5O12 — •Bin Yang[1], Si Yu Xia[1], Hui Zhao[1], Gan Liu[1], Jun Du[1], Ka Shen[2], Zhiyong Qiu[3], and Di Wu[1] — [1]National Laboratory of Solid State Microstructures, Jiangsu Provincial Key Laboratory for Nanotechnology, Collaborative Innovation Center of Advanced Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China — [2]Center for Advanced Quantum Studies and Department of Physics, Beijing Normal University, Beijing 100875, China — [3]School of Materials Science and Engineering, Dalian University of Technology, Dalian 116024, China

We report a systematic study of the temperature and field dependences of the spin Seebeck effect (SSE) in a bilayer of Pt/Gd3Fe5O12. An anomalous structure is observed in the magnetic field dependent measurements at temperatures between ~60 and ~210 K.We attribute these anomalies to the contribution from the quasiparticles hybridized between the Gd moment dominated spin wave (α mode) and the transversal acoustic phonon, known as the magnon polarons, and explain these rich phenomena by an increase of the group velocity of the α-mode magnon with increasing temperature and the nonparabolic magnon dispersion of Gd3Fe5O12. Our results demonstrate that the magnon polaron induced SSE is helpful for the investigation of the magnon dispersion evolution with a simple transport approach.

HL 7: Semiconductor Lasers

Time: Tuesday 10:00–11:30 Location: H4

Invited Talk HL 7.1 Tue 10:00 H4

Ultrafast Spin-Lasers — Natalie Jung[1], Markus Lindemann[1], Tobias Pusch[2], Rainer Michalzik[2], Martin R. Hofmann[1], and •Nils C. Gerhardt[1] — [1]Photonics and Terahertz Technology, Ruhr-University Bochum, 44780 Bochum, Germany — [2]Institute of Functional Nanosystems, Ulm University, 89081 Ulm, Germany

Current-driven intensity-modulated semiconductor lasers are key optical sources for short-distance data transmission, but their modulation bandwidth is usually limited to values below 50 GHz. By exploiting the coupling between carrier spin and light polarization in semiconductor spin-lasers, the modulation frequencies can be increased to values above 200 GHz [1]. These high frequencies are achievable by increasing the resonance frequency of the coupled spin-photon system using strong birefringence in the laser cavity. Birefringent spin-lasers are capable to provide polarization modulation bandwidths and digital data transmission rates of more than 240 GHz and 240 Gbit/s respectively [1]. In contrast to intensity modulation in conventional lasers, polarization modulation in spin-lasers is largely independent of the pumping level and less sensitive to temperature increase [2]. This makes spin-lasers perfect candidates for future ultrafast communication systems as well as for many other emerging applications such as radio-over-fiber [3], neuromorphic computing [4] or THz generation [5].

[1] M. Lindemann et al., Nature 568, 212 (2019). [2] M. Lindemann et al., AIP Adv. 10, 035211 (2020). [3] N. Yokota et al., IEEE Photon. Technol. Lett. 33, 297 (2021). [4] K. Harkhoe et al., Appl. Sci. 11, 4232 (2021). [5] M. Drong et al., Phys. Rev. Appl. 15, 014041 (2021).

HL 7.2 Tue 10:30 H4

Extraction of silver permittivity at cryogenic temperatures through the optical characterization of Ag-coated plasmonic nanolasers — •Georgios Sinatkas[1,2], Aris Koulas-Simos[2], Jianxing Zhang[3], Jia-Lu Xu[3], Cun-Zheng Ning[3,4], and Stephan Reitzenstein[2] — [1]School of Physics, Aristotle University of Thessaloniki, 54124, Greece — [2]Institut für Festköperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany — [3]Department of Electronic Engineering, Tsinghua University, Beijing, 100084, China — [4]School of Electrical, Computer and Energy Engineering, Arizona State University, Tempe, AZ 85287, USA

Plasmonic nanolasers hold great promise for compact, low threshold opto-electronic devices [1, 2]. For the development and design of such lasers, often operating at cryogenic temperatures, it is important to know the temperature dependence of the involved materials with high accuracy. Here, we report the extraction of silver permittivity in the range 10 K–230 K by performing temperature-dependent μPL measurements in conjunction with numeric simulations on silver-coated nanolasers in the near-infrared regime. By mapping the changes in Q-factor, measured at transparency, into silver-loss variations, we extract the imaginary part of silver permittivity, estimating an order of magnitude shift in the examined temperature range. This data is missing from the literature and it could be useful for theoretically validating experimental observations and evaluating thermal effects.

[1] S. I. Azzam et al., *Light: Science & Applications* **9**(1) (2020).
[2] S. Kreinberg et al., *Laser Photonics Rev.* **14**(12), 2000065 (2020).

HL 7.3 Tue 10:45 H4

Linewidth transition at the laser threshold of quantum-well nanolasers — •J. Buchgeister[1], M. L. Drechsler[1], F. Lohof[1], C. Gies[1], F. Jahnke[1], A. Koulas-Simos[2], K. Laiho[2], G. Sinatkas[2], S. Reitzenstein[2], T. Zhang[4], J. Xu[4], C.-Z. Ning[3,4], and W. W. Chow[5] — [1]Universität Bremen, Germany — [2]Technische Universität Berlin, Germany — [3]Arizona State University, USA — [4]Tsinghua University, China — [5]Sandia National Laboratories, USA

Semiconductor nanolasers as small-scale sources of coherent light have become increasingly important for applications in the data and medical 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 input-output characteristics. The research presented here focuses on a quantum-optical study of a silver-coated InGaAsP nanolaser, accompanied by a full quantum-mechanical semiconductor laser theory; this gives access to the time-resolved single-photon and zero-time-delay two-photon correlation function that holds information about the photon statistics, allowing 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 that holds not just in a stationary regime, but also when focusing on the temporal dynamics for the investigation of the coherence time. This procedure 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 7.4 Tue 11:00 H4

Electro-optical switching of a topological polariton laser — •Philipp Gagel[1], Tristan H. Harder[1], Simon Betzold[1], Oleg A. Egorov[2], Johannes Beierlein[1], Holger Suchomel[1], Monika Emmerling[1], Adriana Wolf[1], Ulf Peschel[2], Sven Höfling[1], Christian Schneider[3], and Sebastian Klembt[1] — [1]Technische Physik, Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Institute of Condensed Matter Theory and Solid State Optics, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, D-07743, Germany — [3]Institute of Physics, University of Oldenburg, D-26129 Oldenburg, Germany

Here we implement a topological domain boundary defect in an orbital Su-Schrieffer-Heeger geometry by etching coupled pillars into an AlGaAs based microcavity. We show exciton-polariton lasing from the topologically non-trivial domain boundary defect in the bandgap of the P-bands under optical excitation. A gold back and top contact is used to apply a reverse bias to the structure allowing to tune the exciton-polariton detuning due to a shift in the energetic position of the exciton based on the quantum confined Stark effect. This way, we demonstrate control of the energetic position polariton condensation and lasing takes place. Furthermore, we show that this effect can be used to switch the polariton lasing from the topological defect on and off. These findings are an important step towards the realization of an electrically driven, topological polariton laser.

HL 7.5 Tue 11:15 H4

Investigation of the bimodal behavior of microlasers with a two-channel photon number-resolving transition edge sensor system — •Marco Schmidt[1,2], Isa Hedda Grothe[3], Sergej Neumeier[3], Lucas Bremer[1], Martin von Helversen[1], Wenera Zent[1], Boris Melcher[3], Jörn Beyer[2], Christian Schneider[4,5], Sven Höfling[4], Jan Wiersig[3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin — [2]Physikalisch-Technische Bundesanstalt, Abbestraße 2-12, 10587 Berlin — [3]Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Universitätsplatz 2, 39106 Magdeburg — [4]Technische Physik, Universität Würzburg, Am Hubland, 97074 Würzburg — [5]Universität Oldenburg, 26129 Oldenburg

A two-channel photon-number-resolving (PNR) transition-edge sensor (TES) is used to measure the photon-number distribution of a bimodal quantum-dot micropillar laser [1]. The TES system simultaneously detect light emission of two orthogonal components of the fundamental emission mode of the bimodal microlaser. The applied cross-correlation scheme provides an unprecedented access to the joint PNR and allows an insight into the photon statistics and dynamics of the coupled mode components. Especially, the measurements reveal an optical bi-stability of the anti-correlated mode components, which can be interpreted as a temporal hopping between emission with coherent and thermal-like emission statistics. Our studies clearly demonstrate the great advantage of investigating nanophotonic devices via TESs.

[1] M. Schmidt et al, Phys. Rev. Res. 3, 013263 (2021)

HL 8: Poster Session II

Topics:
- Functional semiconductors for renewable energy solutions
- Heterostructures, interfaces and surfaces
- Nitrides: Preparation and characterization
- Organic semiconductors
- Oxide semiconductors
- Perovskite and photovoltaics
- When theory meets experiment: Hybrid halide perovskites for applications beyond solar

Time: Tuesday 10:00–13:00 Location: P

HL 8.1 Tue 10:00 P

Design optimization for bright electrically-driven quantum dot single-photon sources emitting in telecom O-band — Sergey Blokhin[1], Mikhail Bobrov[1], Nikolai Maleev[1], •Jan Donges[2], Lukas Bremer[2], Alexey Blokhin[3], Alexey Vasil'ev[3], Alexander Kuzmenkov[3], Evgenii Kolodeznyi[4], Vitaly Shchukin[2,5], Nikolay Ledentsov[5], Stephan Reitzenstein[2], and Victor Ustinov[3] — [1]Ioffe Institute, Politekhnicheskaya 26, St. Petersburg 194021, Russia — [2]Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [3]Research and Engineering Center for Submicron Heterostructures for Microelectronics, Politekhnicheskaya 26, St. Petersburg 194021, Russia — [4]ITMO University, Kronverksky pr. 49, St. Petersburg 197101, Russia — [5]VI Systems GmbH, Hardenbergstr. 7, 10623 Berlin, Germany

To enable long distance quantum communication, electrically-driven single-photon sources with almost ideal optical properties are desired. Through 3D finite-difference time-domain modelling, we present a design based on self-assembled quantum dots which delivers promising results in the telecom O-band by employing a broadband bottom distributed Bragg reflector (DBR) and a top DBR formed in a dielectric micropillar with an additional circular Bragg grating in the lateral plane. The design provides broadband emission enhancement (8-10nm) with an overall photon-extraction efficiency of 83% into the upper hemisphere, while photon coupling into single-mode fibers reaches efficiencies up to 40% for a HNA fiber (NA = 0.42). Blokhin et al., Opt. Express 29, 6582-6598 (2021)

HL 8.2 Tue 10:00 P

Examination of time-energy-entanglement on the biexciton-exciton-system under resonant two-photon driving via Franson interferometry — •Marcel Hohn, Matthias Kunz, Samir Bounouar, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin, Germany

We investigate the degree of time-energy entanglement from the XX-X-system under resonant two-photon driving. The dressing of this "three-level ladder" system leads to new eigenstates and previous experiments showed correlated emission of paired photons with manipulatable time ordering of the cascade [1]. In addition, a recent theoretical treatment indicated possibilities and limitations for the visibility of two-photon interference using Franson interferometry [2]. We measured the degree of time-energy-entanglement of the emitted pairs by Franson interferometry and observed a strong dependence of the visibility on excitation power and detuning. In particular, our measurements show that the degraded energy time entanglement of the XX-X-system under off-resonant excitation can be enhanced via strictly resonant two-photon-excitation.

[1] S. Bounouar et al., Physical Review Letters 118 (2017).
[2] K. Barkemeyer et al., Physical Review A 103 (2021).

HL 8.3 Tue 10:00 P

Focused ion beam implantation of rare-earth ions in semiconductor nanostructures — •Christian Düputell, Arne Ludwig, and Andreas D. Wieck — Chair of Applied Solid State Physics, Ruhr University, Bochum

We report on focused ion beam (FIB) implantation of rare-earth ions in semiconductor nanostructures. Semiconductor nanostructures have attracted a lot of attention due to their unique optical, electrical and mechanical properties. To use nanostructures for a certain purpose, often very specific properties have to be achieved. An elegant method to tune the electrical and optical properties of semiconductor nanostructures is focused ion beam implantation. Using ion beams offers high-resolution lateral engineering, local band gap modulation due to ion-induced intermixing as well as local doping applications and even isotopic resolution. To carry out implantation of rare-earth ions in semiconductor nanostructures, we especially focus on the incorporation of erbium ions into GaAs. Erbium shows two unique properties. First, it has a huge magnetic moment, which could lead to a rich spectrum of possible spin coupling processes in the host material. And second, the optical transitions of erbium should lead to an emission of electromagnetic radiation at the important telecom-C-band wavelength of 1.54 μm, which has minimal absorption in glass fibres. We are presenting the current status of our studies on both of these properties as a function of the implantation pattern, the ion fluence and the used annealing parameters. We also report on the preparation and composition of the corresponding liquid metal alloy sources for FIB.

HL 8.4 Tue 10:00 P

Using a novel scanning probe technique to strongly couple a single quantum dot to a tunable plasmonic nanogap antenna at room temperature — •Michael A. Becker[1], Hsuan-Wei Liu[1], Korenobu Matsuzaki[1], Randhir Kumar[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light — [2]Friedrich Alexander University of Erlangen-Nürnberg

Scanning probe techniques are indispensable methods for optical investigations of structures smaller than the diffraction limit. Moreover, techniques like atomic force microscopy and scanning near-field optical microscopy can be utilized to measure electrical and thermal conductance and probe near-field light-matter interactions. However, these types of experiments typically require sensitive and expensive state-of-the-art equipment. Here, we report on a novel and simple press-roll scanning probe technique (PRoScan) capable of performing optical near-field measurements with remarkable stability, even in the absence of any stabilization mechanism. We demonstrate its performance by a precise coupling of an individual quantum dot to a gold nanoparticle, where we can control the Purcell enhancement with nanometer-resolution. Next, we utilize the technique to create an open and tunable nanogap antenna. By tuning the resonance of the nanogap antenna and controlling the position of the single quantum dot, we can drive the system from the weak to the strong light-matter coupling regime, evidenced by a vacuum Rabi splitting and a characteristic anticrossing behaviour.

HL 8.5 Tue 10:00 P

Capacitance-voltage spectroscopy on quantum dots without electronic wetting layer states — •Ismail Bölükbasi, Sven Scholz, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, D-44780 Bochum, Germany

Quantum dots have interesting physical properties and allow research in zero dimensional systems. They are used in modern displays and may become important for the progress of semiconductor and information technology in the form of qubits in quantum computers and quantum memories or sources of high-fidelity single photons in quantum communication applications.

Quantum dots are created by molecular-beam-epitaxy (MBE) in the so-called Stranski-Krastanov growth mode. InAs arranges epitaxially on GaAs in a strained layer of up to 1.5 monolayers without relaxation before nucleation of coherently strained islands takes place. This layer remains between the islands and is called the wetting layer.

We find that a monolayer of AlAs deposited after the growth of the quantum dots can suppress certain states in this wetting layer [1], allowing to purify their photoluminescence spectra from electronic contributions such as for example a two-dimensional-electron gas would induce. Capacitance-voltage and photoluminescence measurements are carried out to investigate the effects of this monolayer of AlAs on the physical properties of the quantum dots and the modified charging behaviour around flat band conditions.

[1] Löbl, M. C. et al. Excitons in InGaAs quantum dots without electron wetting layer states. Commun. Phys. 2, 93 (2019).

HL 8.6 Tue 10:00 P

Surface Morphology of Self-Assembled InAs/GaAs Quantum Dots and Pattern Definition Layers grown by Molecular Beam Epitaxy — •Peter Zajac, Nikolai Bart, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum

The nucleation of self-assembled InAs/GaAs Quantum Dots (QDs), grown by molecular beam epitaxy, can be locally influenced by growing them on gradient pattern definition layers. Macro Photoluminescence Spectroscopy (PL) mapping reveals a modulation of QD density in a striped pattern along the gradient direction. Automated Atomic Force Microscopy (AFM) was employed to study the morphology of pattern definition layers over several millimeters, revealing a sinusoidal behavior of the monolayer step density. Local PL contrast is used to locate areas of highest QD density modulation. It is proposed that the periodic variation of roughness locally modifies the QD nucleation condition leading to the observed pattern [1].

[1] Bart et al., arXiv:2011.10632 (2020).

HL 8.7 Tue 10:00 P

Wafer Scale Density Modulation of Self-Assembled Quantum Dots by Epitaxial Surface Roughness Control — •Nikolai Bart, Nikolai Spitzer, Peter Zajac, Marcel Schmidt, Andreas D. Wieck, and Arne Ludwig — Ruhr-Universität Bochum, Lehrstuhl für Angewandte Festkörperphysik, Universitätsstraße 150, 44801 Bochum, Germany

The effect of nanoscale roughness of GaAs surfaces on the nucleation of self-assembled InAs quantum dots (QD) is investigated with photoluminescence (PL) spectroscopy. We control the roughness in-situ by simple epitaxial layer-by-layer growth: Depositing integer (fractional) values of GaAs monolayer thicknesses yields a smooth (rough) surface. We report significant differences in both PL intensity and QD surface density at the critical threshold of nucleation. By growing GaAs thickness gradients, we create and control various density modulation patterns on whole 3-inch wafers. Moreover, we investigate the influence of surface annealing time and temperature on the modulation and demonstrate how to utilize this mechanism for density control of high quality single QD photonic device wafers.

HL 8.8 Tue 10:00 P

Semiconductor nanophotonic light sources with site- and number- controlled quantum dots for the investigation of collective effects — •Ching-Wen Shih, Jan Grosse, Imad Limame, Chirag Palekar, Yuhui Yang, Lasse Kosiol, Sebastian Krüger, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany

Sub- and superradiance are intriguing collective radiative emission processes which occur when coherence is built up among the emitters spontaneously via exchange of photons. Semiconductor quantum dots (QDs) are attractive candidates to study these collective emission processes. However, a systematic study of the collective effects in these semiconductor nanostructures requires a control over the position, number, and emission energy of the quantum dot emitters. We report on the development of nanophotonic light sources via a buried-stressor approach, which enables a precise position control of the InGaAs QDs by tailoring the strain induced by an oxidation aperture. Furthermore, the number of such site-controlled QDs is successfully varied from 0 to 20 across each device via a careful balance between the aperture size and the MOCVD growth condition. Finally, electron beam lithography is implemented to pattern micro-mesa cavity structures, which enhance the photon extraction efficiency of the QDs to facilitate the observation of sub- and superradiance.

HL 8.9 Tue 10:00 P

A Master Equation centered foundation for an open-source project for quantitative simulation of the transition dynamics in finite state quantum systems. — •Arn Baudzus, Andreas Wieck, and Arne Ludwig — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

We present a novel approach and status on the implementation of a program to quantitatively simulate the electronic, photonic and phononic behaviour of a quantum dot that is embedded in a semiconductor device. Our main aim is to start an open-source project, everyone can expand and contribute to.

We outline a theoretical framework that is developed to break this complex system down into modules that can be treated one at a time.

The framework is centered around the generation and solution of master equations with constant or time dependent coeffitients. The coeffitients in the master equation and the information of the relevant states can be calculated by different programs, each governing another kind of interaction.

We use a graph data structure to manage the system states and interface with the other program parts in an intuitive way. A C++ implementation for this structure has been developed.

At the moment we are mainly focusing on the simulation of electron tunneling dynamics between a single quantum dot and a two dimensional electron gas. We illustrate how the tunnel dynamics can be simulated using our framework.

HL 8.10 Tue 10:00 P

Spatially resolved multi-probe electrical characterization of GaAs-based nanowire structures — •Juliane Koch[1], Lisa Liborius[2], Peter Kleinschmidt[1], Werner Prost[2], and Thomas Hannappel[1] — [1]Fundamentels of energy materials, Ilmenau University of Technology, Germany — [2]Components for High Frequency Electronics (BHE), University of Duisburg-Essen, Germany

To achieve high performance optoelectronic devices with III-V semiconductor nanowire (NW) heterostructures sophisticated junctions with controlled properties are required. In order to study microscopic details of the NW structure and its composition, we investigated upright standing p-GaAs/i-GaInP/n-GaInP core-shell-shell NWs on the growth substrates. Cores of the NWs were grown via the vapor-liquid-solid mode followed by epitaxial shell growth in a low-pressure horizontal metalorganic vapor-phase epitaxy reactor. We employ a combination of material-selective wet chemical etching of as-grown coaxial NWs and a multi-tip scanning tunnelling microscope operated as a four-point nano-prober to obtain spatially resolved I-V analysis. These revealed a leakage mechanism causing degraded core-shell pn-junction performance, which is localized at the NW base where a buried contact of the n-GaInP shell to the p-GaAs substrate is formed. Furthermore, the combination of SEM with EDX and XRD measurements reveal the contrast of NW shell and planar layer growth. Our high-end characterization methods enable a direct relation between the NW structures and the electronic properties of as-grown coaxial NWs, which provides precise advice for future NW core-shell pn-junction optimization.

HL 8.11 Tue 10:00 P

Examination of self-assembled quantum dots in a density-modulated pattern with capacitance-voltage and photolulminescence spectroscopy — •Nikolai Spitzer, Nikolai Bart, Arne Ludwig, and Andreas Wieck — Ruhr-Universität Bochum

Self-assembled InAs quantum dots (QDs) on GaAs with a QD density modulation upright to the growth direction were grown by molecular beam epitaxy. The QDs can be arranged in stripe patterns whose properties can be changed by a gradient in the GaAs sublayer beneath the QDs. We suspect that the formation of QDs is favoured by atomic rough areas as opposed to flat areas during molecular epitaxial growth. The differences in the sublayer are due to the profile of the molecular beam. Capacitance-voltage spectroscopy and photoluminescence spectroscopy are used to investigate the properties of the quantum dots arranged in this way at different densities.

HL 8.12 Tue 10:00 P

Design and fabrication of waveguide-based nanobeam cavity for on-chip single photon source — •Yuhui Yang[1], Uğur Meriç Gür[1,2], Johannes Schall[1], Ronny Schmidt[1], Arsenty Kaganskiy[1], Michael Mattes[2], Samel Arslanagić[2], Stephen Reitzenstein[1], and Niels Gregersen[3] — [1]Institut für Festkörperphysik, TU Berlin, Germany — [2]Department of Electrical Engineering, Technical University of Denmark, Denmark — [3]Department of Photonics Engineering, Technical University of Denmark , Denmark

In quantum technology, the two-photon interference acts as an important role related to the indistinguishability of single-photon. One approach to improve the indistinguishability of single-photon is to enhance the spontaneous emission into cavity mode by Purcell effect. In this regard, nanobeam cavities, are promising candidates because they can easily be integrated with other on-chip components. In this contribution, we optimize the geometrics of nanobeam cavities. A numerically optimized nanobeam cavity design yields a high directional spontaneous emission β factor of 0.73 with broadband enhancement of 9 nm. The nanobeam cavity containing embedded InGaAs/GaAs quantum dots fabricated structures demonstrates the cavity effect. By micro-photoluminescence (μPL) characterization, three distinct Fabry-Pérot resonance peaks as well as cavity effects are observed. Due to the Purcell enhancement from the cavity, the spontaneous emission rate of a resonance (non-resonance) peak is (1.59 * 0.09) ns^{-1} [(1.14 * 0.14) ns^{-1}], indicating the potential of nanobeam cavity for full on-chip single-photon source.

HL 8.13 Tue 10:00 P

Frequency Shift of Electronic Resonances in Self Assembled InAs Quantum Dots — •Ibrahim Azad Engin, Ismail Bölükbaşi, Sven Scholz, Andreas D. Wieck, and Arne Ludwig — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-UniversitätBochum, D-44780 Bochum, Germany

Self-assembled InAs quantum dots (SAQD) proved promising semiconductor structures as single-photon sources and provide possibilities for quantum memories. Therefore understanding the physical properties is important and in progress. We investigate electronic resonances in InAs SAQDs by using C(V)-spectroscopy.

The thermal shift of the s-states has been reported and described with a master equation [1], which has been improved further to model excitonic and non-equilibrium states in such SAQD [2]. The model shows contrarily shifting in dependence of frequency and temperature.

Here we investigate both s- and p-states in dependence of temperature and frequency to measure the shifting characteristics of p-peaks and observe the dominancy of the frequency shift for s-states. The superposition of thermal and frequency shift are being analyzed. Adjustments to the master equation model are needed.

[1] Brinks, F. et al., "Thermal shift of the resonance between an electron gas and quantum dots: what is the origin?" New J. Phys. 18, 123019 (2016).

[2] Valentin, S. et al., "Illumination-induced nonequilibrium charge states in self-assembled quantum dots", Phys. Rev. B 97, 045416 (2018).

HL 8.14 Tue 10:00 P

Metamorphic buffer layer based single-photon sources for application in quantum telecommunications — •Piotr Andrzej Wronski, Sven Höfling, and Fauzia Jabeen — 1Technische Physik, University of Würzburg and Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, Am Hubland, D-97074 Würzburg, Germany

Obtaining single-photon sources requires them not only to characterize by low FSS, low g(2)(0), and high emission rate, it is also essential for them to be built-in telecommunication network. Ideally, obtained sources should emit at spectral range aligned with the lowest attenuation window (C-band) for silicon fibers. So far, such emitters are reported only on InP, but the low refractive contrast of lattice-matched materials makes it difficult to obtain complete photonic structures with efficient outcoupling.

Metamorphic buffer layer on GaAs substrate as a base for InAs QDs leads to strain relaxation and induces required emission shift. Past attempts in this matter lacked low surface roughness required for development of top DBRs and fabricating micropillars

By implementing our approach of introducing a stepwise increase of "In" composition inside a digitally alloyed superlattice, we can observe a shift of emission wavelength, improvement of surface quality, and observation of single-photon emission in 1550 nm spectral range from InAs QDs grown on GaAs (001) substrate, confirmed by autocorrelation experiments. The incorporation of AlAs/GaAs DBRs improved the emission intensity.

HL 8.15 Tue 10:00 P

Purcell-enhanced single-photon emission from a strain-tunable quantum dot in a cavity-waveguide device — •Florian Hornung[1], Stefan Hepp[1], Stephanie Bauer[1], Erik Hesselmeier[1], Xueyong Yuan[2,3], Michael Jetter[1], Simone Luca Portalupi[1], Armando Rastelli[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, 70569 Stuttgart, Germany — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University Linz, 4040 Linz, Austria — [3]School of Physics, Southeast University, Nanjing, 211189, China

The miniaturization of optical elements to chip-size in so-called photonic integrated circuits has attracted a lot of attention in recent years. Due to its great scalability, the approach seems highly promising for the efficient realization of photon-based quantum technologies.

In this study, we show the coupling of an In(Ga)As quantum dot (QD) to a waveguide-integrated cavity. The chip is bonded to a piezoelectric actuator, enabling the strain-tuning of both the emission energy of the QD and the cavity mode. As the QD is more sensitive to the applied strain, a differential tuning factor of four is obtained, allowing to compensate the initial energy mismatch of the QD and the cavity. A clear Purcell-enhancement as well as the single-photon emission of the device are demonstrated. This combination of a strain-tunable quantum emitter and a waveguide-integrated cavity represents an important building block for large scale quantum photonic circuits.

HL 8.16 Tue 10:00 P

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

Local droplet etched GaAs quantum dots (LDE-QDs) are a promising candidate for excellent single and entangled photon sources. Taking further steps towards application, this requires structures of increasing complexity, engineering the electronic and photonic environments of the QDs. Therefore, it is important to get perfectly matched QDs for the required photonic structures. In this submission, we show a way to compensate for non-perfectly adjusted growth conditions and to accelerate required parameter studies.

We induce certain flux gradients by stopping sample rotation and using the parallax of the effusion-cells. This results in a gradual change of deposited material and cell flux, as well as an induced surface roughness modulation. By this we can vary properties of the QDs like density and emission wavelength over the hole wafer range. Additionally, we induce a stripe patterned density modulation, which was shown before with Stranski-Krastanov QDs. As an example, the widest achieved wavelength shift of the ground state emission energy at 100 K, measured by photoluminescence spectroscopy, extends over the range of 795 nm to 737 nm. The change in surface roughness leads to an additional periodical modulation of the ground state of approximately 3 nm on a mm scale.

HL 8.17 Tue 10:00 P

Changes of transport properties in individual carbon nanotubes due to MOF growth — •Marvin J. Dzinnik[1], Benedikt Brechtken[1], Hendrik A. Schulze[2], Adrian Hannebauer[2], Enes Akmaz[1], Peter Behrens[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [2]Institut für Anorganische Chemie, Leibniz Universität Hannover, Callinstrasse 9, 30167 Hannover, Germany

Metal-organic frameworks (MOF) are porous structures with tunable pore size and adsorption sites but mostly non-conducting. In combination with carbon nanotubes (CNTs) these hybrid structures preserve porosity of the MOFs while gaining conductivity through the CNTs [1,2]. The mechanism of MOF growth on CNTs is accountable to the functionalization of the carbon nanotubes [1]. To study the interaction between MOF and CNTs and the influence of the synthesis, we prepared samples of contacted multi-walled CNTs. We drop-casted CNTs from ethanol solution on a silicon dioxide surface and contacted them with Cr and Au by electron beam lithography and lift-off. DC transport measurements were performed. In a second step, the sample with the contacted CNT was given into a UiO-66 MOF synthesis. Later transport measurements show drastically increased two-terminal resistance.

[1] H. A. Schulze et al., ChemNanoMat, 5, 1159-1169, (2019).

[2] M.-Q. Wang et al., Electrochimica Acta, 190, 365-370, (2016).

HL 8.18 Tue 10:00 P

Optimal Bandwidth in Quantum Event Measurements Using Post-Processing — •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

The realization of novel applications, such as quantum computing or quantum sensing, is largely limited by the time resolution and accuracy with which individual quantum events can be measured. For the measurement of single electron tunneling, radio-frequency single-electron transistors and quantum point contacts have been the most successful detection methods. A promising alternative to this is to exploit an optical transition. For this purpose, resonance fluorescence of the excitonic transition is detected at 4.2 K from a self-assembled quantum dot embedded in a tailored diode structure.

In this work, we use single photon signal post-processing to identify the optimal time resolution for the analysis of our data. We show how the bandwidth affects both the determination of the tunneling rates and the statistical evaluation by full counting statistics, and demonstrate that we can evaluate our data with sampling rates up to 340 kHz. Using a simple model, we discuss the limiting factors for reaching the highest time resolution and propose how a time resolution of more than 1 MHz could be achieved.

HL 8.19 Tue 10:00 P

Topological superconductivity in (3D) topological insulator-based hybrid devices — •Dennis Heffels[1], Declan Burke[2], Malcolm R. Connolly[2], Peter Schüffelgen[1], Kristof Moors[1], and Detlev Grützmacher[1] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich — [2]Imperial College London

Topological insulator (TI) nanostructures have been proposed as a host system for one-dimensional topological superconductivity. This is made possible by the special properties of the TI surface states in combination with an external magnetic field and proximity-induced superconductivity. Recently, however, it was shown that specific conditions are required to realize fully gapped topological superconductivity. In this talk, I will report on tight-binding simulations with Kwant that allow for a detailed investigation of the formation of a topological band gap in experimentally realizable hybrid devices. We model the TI hybrid device in full three-dimensional detail which allows us to compare different device layouts and proximitization schemes. In general, we find that a topological gap can be opened by breaking the transverse symmetry of the system. One possibility for such a symmetry breaking is the consideration of a ribbon which is only proximitized via the top surface. Our simulation approach also allows us to optimize the device layout in order to maximize the size of the gap. I will also comment on related experimental activities on TI nanostructure-based hybrid devices and tunnel junctions as well as magnetic TI-based hybrid devices.

HL 8.20 Tue 10:00 P

Deterministically fabricated GaAs quantum dot based single-photon sources with emission at Cs wavelengths — •Monica Pengerla[1], Lucas Bremer[1], Jin Dong Song[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Center for Opto-Electronic Materials and Devices, Korea Institute of Science and Technology, Seoul 02792, Republic of Korea

In this work, we investigate GaAs based quantum dot (QD) single photon sources at 894 nm. The goal is to control the emission of single photon sources time delay with Cs vapor. To increase the photon extraction efficiency, the device design includes a gold mirror on back side. Numerical simulations reveal a photon extraction efficiency of approximately 52% with numerical aperture NA = 0.4. The flip chip gold bonding process results in a thin QD membrane, which includes wet etching of AlGaAs and GaAs layers. The preliminary low temperature micro photoluminescence and cathodoluminescence results of Au bonded samples are fair enough to pursue further device fabrication steps. With In-situ electron-beam lithography (EBL), QDs at target wavelength, based on their intensity can be selected prior to the structure patterning. We are planning to deterministically integrate quantum dots at 894 nm into mesa and one ring structure with in-situ electron beam lithography. Later, the emitted single photon properties of fabricated structures will be studied with photon autocorrelation measurements.

HL 8.21 Tue 10:00 P

Structural and Optical Properties of Hexagonal Pyramids Containing GaInN Quantum dots Formed by Wet Etching of GaInN/GaN Quantum Wells — •Samar Hagag, Sidikejiang Shawutijiang, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Technische Universität Braunschweig, Institut f. Angewandte Physik, 38106 Braunschweig,Germany

We present first results from our studies of the structural and optical properties of hexagonal pyramids containing GaInN Quantum Dot(QD)-like structures located close to the tip of pyramids with a smooth side facets of the type (1-10-1) and very sharp tips obtained through the wet chemical etching of GaInN/GaN Quantum Well(QW)structures grown on N-face GaN. The photoluminescence spectrum of the QD's shows the intuitive additional quantum confinement manifested by a blue shift of the photoluminescence peak and narrow emission lines have been observed in the microphotoluminescence spectra. A comparison between the peak energy separation observed in the microphotoluminescence spectrum of pyramidal structures containing several quantum disks and calculations of the quantization energy of the quantum disks shows that the top most QD has a diameter of 18.5nm. In a further attempt to control the position and size of the hexagonal pyramids a Focused Ion Beam-deposited etch mask was used and regular array of pyramidal structures were formed. While the QD thickness and indium contents are given by the QW structure,an optimization of the etching process to control the pyramid size is required to enable the control of the QD lateral extension.

HL 8.22 Tue 10:00 P

Kondo effect in a few-electron quantum dot — •Olfa Dani[1], Johannes C. Bayer[1], Timo Wagner[1], Gertrud Zwicknagl[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Institut für Mathematische Physik, Technische 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 however exactly calculated for models adopting simplifying assumptions concerning the electronic structure of the quantum dot.

The investigated quantum dot device is based on a flat two-dimensional electron gas (2DEG) formed in a GaAs/AlGaAs heterostructure. A single quantum dot is formed in this 2DEG using top-gates and a quantum point contact (QPC) is operated as sensitive charge detector, allowing the real-time detection of electrons tunneling through the system [1].

The Kondo effect dominates at a strong coupling between dot and leads. It gives rise to a finite conductance in the otherwise Coulomb-blockaded regime, and has a characteristic temperature dependence. Here we study the Kondo effect as a function of the tunnel coupling and its symmetry. For small number of electrons, we see that the shell structure[2] of the electronic states in the quantum dot influence the Kondo effect.

[1] T. Wagner, et. al., Nat. Nanotech. 12, 218-222 (2017).
[2] L. P. Kouwenhoven, Rep. Prog. Phys. 64, 701-736 (2001).

HL 8.23 Tue 10:00 P

Theoretical description of higher excited quantum dot states in an external magnetic field — •Jan Kaspari, Matthias Holtkemper, Tilmann Kuhn, and Doris Reiter — Institut für Festkörpertheorie, WWU Münster, Wilhelm-Klemm-Straße 10, 48149 Münster, Germany

The influence of a magnetic field on the quantum dot states is usually reduced to the interaction of the external magnetic field with the spins of electrons and holes. Based on the envelope function approximation and minimal coupling we derive additional interaction terms of the magnetic field with the envelope functions and treat the magnetic field interaction, direct and short-range exchange Coulomb interactions as well as the four-band Luttinger theory within a configuration interaction approach. The quantum dot confinement is approximated by an anisotropic harmonic potential. We show that the magnetic field interaction with the envelope functions crucially depends both on the geometry of the quantum dot as well as on the orientation of the magnetic field. In the case of a magnetic field in the growth direction of a cylindrically symmetric quantum dot we find that the interaction with the envelopes results in the mixing of states of the same type which leads to a partial splitting of higher excited energy levels, while for a broken cylindrical symmetry an additional mixing with other orbital states and further energy shifts can be noted. We discuss in detail the observed dependencies on geometric parameters and analyze whether the common approximation to describe the interaction of the external magnetic field solely with spins is applicable for higher excited states.

HL 8.24 Tue 10:00 P

Ultra-high quality factor Ta2O5-on-insulator microring res-

onators with cryogenic temperature stability — •Julian Rasmus Bankwitz, Martin A. Wolff, Adrian Abazi, Alexander Eich, and Carsten Schuck — Institute of Physics University of Münster, Germany

Tantalum pentoxide (Ta2O5) on insulator is an emerging nanophotonic material system that benefits applications in nonlinear and quantum technology due to its outstanding optical properties [1]. As many implementations of quantum technology require cryogenic environments a need for low loss photonic integrated circuits with high temperature stability has arisen. Here we demonstrate ultra-high quality factor Ta2O5-on-insulator microring resonators with minimal temperature-dependent wavelength shift (TDWS). Through careful tuning of design and nanofabrication parameters, we achieve critically coupled devices with loaded quality factors of up to 1.8 Mio., observed over the entire range from room to cryogenic temperatures. The TDWS of ring resonances is as low as 237 pm from 1.74 K to 286 K and, remarkably, vanishes in the 110 K to 140 K range as it changes sign. Our Ta2O5-on-SiO2 devices will thus enable athermal operation of ultra-stable resonators as desired for wavelength division multiplexing, on-chip frequency stabilization and low-noise optical frequency combs.

[1] G. Moody et al. "Roadmap on Integrated Quantum Photonics," arXiv preprint arXiv:2102.03323, 2021.

HL 8.25 Tue 10:00 P

Magnetic Field Dependence of the Auger Recombination Rate in a Self-Assembled Quantum Dot — •Fabio Rimek[1], Hendrik Mannel[1], Marcel Ney[1], Arne Ludwig[2], Andreas D. Wieck[2], Martin Geller[1], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University Duisburg-Essen, Germany — [2]Chair of Applied Solid State Physics, Ruhr-University Bochum, Germany

A 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 third charge carrier that leaves the dot or is excited to an higher energy level. Therefore the Auger effect destroys the radiative trion transition - an effect, which should be minimized for future applications of QDs using the spin states as stationary qubit that should be transferred to a photon via this trion transition.
In this work, we investigate how the Auger rate is affected by an external magnetic field, applied along the growth direction of the sample. In the magnetic field, the trion state of a QD is no longer spin degenerate and splits up. We use two-color, time-resolved resonance fluorescence spectroscopy to investigate the quenching of the trion recombination by the Auger effect. Two-color excitation allows us to symmetrically excite both trion resonances and thus neglect spin relaxation as well as spin-flip Raman scattering. We observe a suppression of the Auger recombination by almost a factor of three, when increasing the field up to B = 10T. **[1] A. Kurzmann et al., Nano Lett. **16, 3367-3372 (2016)

HL 8.26 Tue 10:00 P

Halogen vacancy migration at a surface of CsPbBr3: Insights from Density Functional Theory — •Raisa-Ioana Biega[1] and Linn Leppert[1,2] — [1]Institute of Physics, University of Bayreuth, Bayreuth 95440, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, 7500 AE Enschede, The Netherlands

Migration of mobile halogen ions is ubiquitous in lead-halide perovskites, and has been studied in detail experimentally and with computational modelling techniques. However, the question whether and how surfaces affect ion migration in these materials is still debated. Here we contribute to this debate by using density functional theory to compute bromine vacancy migration in the bulk and at the (001) surface of cubic CsPbBr3. We find that the migration barrier at the surface is approximately half of that in the bulk due to larger structural distortions at the surface. The targeted choice of an alkali-halide passivation layer can suppress this undesirable effect and leads to an increase of migration barrier to almost the bulk value.

HL 8.27 Tue 10:00 P

Polarons and Dynamic Disorder in Halide Perovskites: a Tight Binding Approach — •Maximilian. J. Schilcher[1], Matthew. Z. Mayers[2], Paul. J. Robinson[2], David. J. Abramovitch[3], Liang. Z. Tan[4], Andrew. M. Rappe[5], David. R. Reichman[2], and David. A. Egger[1] — [1]Technical University of Munich, Germany — [2]Columbia University, USA — [3]University of California Berkeley, USA — [4]Lawrence Berkeley National Laboratory, USA — [5]University of Pennsylvania, USA

Unusual experimental observations of halide perovskites (HaPs) are often explained by polaronic effects. However, the standard polaron picture in its simplest form cannot properly rationalize some of the key carrier-transport features of HaPs. We propose to augment it by a complementary concept based on dynamic disorder [1], taking into account the slow, anharmonic lattice dynamics and incoherent nature of carrier relaxation in HaPs. This approach can be tackled computationally in the framework of a tight-binding (TB) model [2], allowing for modeling large-scale system sizes and temperature-dependent optoelectronic properties. We demonstrate that in this way, we can, e.g., elucidate on the influence of dynamic disorder around room temperature on the band gaps in a variety of HaPs.

[1] M. J. Schilcher et al., ACS Energy Lett. 6, 2162-2173 (2021).
[2] M. Z. Mayers et al., Nano Lett. 18, 8041-8046 (2018).

HL 8.28 Tue 10:00 P

Disorder in halide perovskites: anharmonicity and dynamically shortened correlations — •Christian Gehrmann and David A. Egger — Technical University Munich, Germany

Small Urbach energies, important for an effective collection of sunlight in photovoltaic devices, imply a short range correlated disorder potential [1]. Halide perovskites (HaPs), however, are discussed to show a long-range bonding mechanism, anharmonic nuclear dynamics, disorder, and small Urbach energies all at the same time. We show that correlations in the disorder potential for electronic states, calculated using density functional theory (DFT) and DFT-based molecular dynamics simulations, are dynamically shortened in HaPs [2]. This dynamic shortening of the disorder correlation, which we attribute to the motion of A-site and, in particular, X-site ions, results in narrow band-edge energy distributions as we show explicitly. Our findings about correlations in the disorder potential due to nuclear motion is complemented by data showing considerable anharmonicity in the lattice dynamics of $CsPbBr_3$. With this, we conclude that besides showing complex nuclear dynamics, a mechanism of dynamic shortening of the disorder potential promotes a sharp optical absorption edge in HaPs.

[1] C. W. Greeff & H. R. Glyde, Phys. Rev. B 51, 1778-1783 (1995).
[2] C. Gehrmann & D. A. Egger, Nat. Commun. 10, 3141 (2019).

HL 9: Nitride: Preparation, Charakterization and Devices

Time: Tuesday 11:45–12:30 Location: H4

HL 9.1 Tue 11:45 H4

AlPN on GaN: A new barrier material for HEMTs — •Markus Pristovsek and Yuto Ando — IMaSS, Nagoya University, Japan

We report on the ternary alloy wurzite AlP_yN_{1-y} on (0001) GaN, grown by metal-organic vapor phase epitaxy. AlPN is lattice matched to GaN at about 11% P content, while having a larger bandgap than AlInN. Furthermore, AlPN is grown in H_2 at similar temperatures as GaN, avoiding long growth interruptions and temperature ramping. Unlike AlInN, Ga carry over is not an isssue. Finally, there is tertiary-butylphosphine (tBP), a proven metal-organic precursor with a high vapor pressure which is not available for AlScN. Therefore, AlPN looks like a promising material to replace AlGaN as barrier layer in high electron mobility transistors (HEMT) especially for high frequency applications. First results confirmed high sheet carrier densities, and highlighted the crucial influence of strain to avoid point defects. As with any new material there are new challenges, most notably the growth transitions between the binary GaN and the group V alloy AlPN and avoiding detrimental effects on growth and background doping from residual P in GaN.

HL 9.2 Tue 12:00 H4

Low-temperature internal quantum efficiency of GaInN/GaN quantum wells under steady state conditions — •Shawutijiang Sidikejiang[1], Philipp Henning[1,2], Philipp Horenburg[1], Heiko Bremers[1,2], Uwe Rossow[1], Dirk Menzel[3], and Andreas Hangleiter[1,2] — [1]Institut für Angewandte Physik, Technische Universität Braunschweig — [2]Laboratory for Emerging Nanometrology, Technische Universität Braunschweig — [3]Institut für Physik der Kondensierten Materie, Technische Universität Braunschweig

In this work, we compared the low-temperature PL intensities of a range of QW samples under identical conditions, mounting the samples side by side. Normalizing the measured intensity to the absorbed power density in the QWs, we find that the PL efficiencies of several samples, which the 100% internal quantum efficiency (IQE) can be confirmed by the temperature-dependent lifetime measurements from time-resolved PL (TRPL), are identical under steady-state PL excitation. On the other hand, for samples with a reduced low-temperature IQE observed in TRPL, the PL efficiencies saturate at significantly lower values. The experimental results confirm a unity IQE at low temperature for those efficient samples, but also allow to estimate the absolute IQE of samples with a lower efficiency by a direct comparison. The latter case is investigated by studying the influence of point defects due to Ar implantation on the low-temperature PL efficiency of the QWs.

HL 9.3 Tue 12:15 H4

Structural analysis of novel orientations of AlN grown on *m*-plane sapphire — •Jochen Bruckbauer[1], Gergely Ferenczi[1], Humberto Foronda[2], Sarina Graupeter[2], Ben Hourahine[1], Aimo Winkelmann[1,3], Zhi Li[4], Ling Jiu[4], Jie Bai[4], Tao Wang[4], Tim Wernicke[2], Michael Kneissl[2], and Carol Trager-Cowan[1] — [1]University of Strathclyde, UK — [2]Technische Universität Berlin, Germany — [3]AGH University of Science and Technology, Poland — [4]University of Sheffield, UK

Heteroepitaxial III-nitrides can be grown with a wide range of orientations on a range of substrates. Determination of the epitaxial orientation relationship of the nitride film with its substrate is often necessary. Here, we report on the determination and observation of novel orientations in AlN grown on *m*- or $(1\bar{1}00)$ plane sapphire using electron backscatter diffraction (EBSD). An electron backscatter diffraction pattern is recorded for each spatial point in an EBSD map from which crystal structure, orientation and misorientation can be determined with a spatial resolution of around 50 nm and a relative angular precision of around 0.1°. The AlN thin film exhibits twinned regions where the normal to a $\{1\bar{2}13\}$ plane for each twin is within 9° of the $[1\bar{1}00]$ sapphire direction. The twins share a common $\{1\bar{1}00\}$ plane. Furthermore for each twin, the normal to a $\{11\bar{2}2\}$ AlN plane is within 3.5° of the $[11\bar{2}0]$ sapphire direction and a $\langle\bar{4}312\rangle$ AlN direction is within 2° of the [0001] sapphire direction. These orientations, together with the usually observed $(1\bar{1}00)$ and $(11\bar{2}2)$ cases, form a family of related growth directions for nitride thin films.

HL 10: Focus Session: Highlights of Materials Science and Applied Physics I (joint session DS/HL)

Jointly organized on the occasion of the 60th anniversary of the *physica status solidi* journals (*pss*, http://www.pss-journals.com), this Focus Session features several invited presentations, talks and posters from key contributors on core condensed matter and applied physics topics. Highlights comprise the latest results on diamond, nitride semiconductors, organic materials, two-dimensional and quantum systems, oxides, magnetic materials, solar cells, thermoelectrics and more.

physica status solidi was launched by Akademie-Verlag Berlin in July 1961 and is published by Wiley-VCH Berlin and Weinheim today, supported by Wiley colleagues in China and the US. While in its first three decades it served as an East-West forum for solid state physics, since 1990 it has evolved into a family of journals with international author- and readership in a globalized scientific world. Its professional editorial services include topical curation, peer review organization, technical editing, special issue and hybrid open access publication.

The Focus session celebrates the numerous close collaborations and the steady support which the journals receive from their Advisory Board members, authors, reviewers and guest editors, including many members of the DPG and the condensed matter physics community in Germany.

(More information on '60 years of *pss*' is available at http://bit.ly/60_years_pss)

Organizers: Stefan Hildebrandt (Editor-in-Chief, pss), Norbert Esser (TU Berlin, ISAS) and Stephan Reitzenstein (TU Berlin)

Time: Tuesday 13:30–16:15 Location: H3

Topical Talk HL 10.1 Tue 13:30 H3

Single crystal diamond grown by CVD: state of the art, current challenges and applications — •Jean-Charles Arnault[1], Samuel Saada[2], and Victor Ralchenko[3,4] — [1]NIMBE, UMR CEA-CNRS 3685, Université Paris-Saclay, F-91191 Gif sur Yvette, France — [2]CEA, LIST, DM2I, F-91191 Gif-sur-Yvette, France — [3]Prokhorov General Physics Institute of Russian Academy of Sciences, Vavilov str. 38, Moscow 119991, Russia — [4]Harbin Institute of Technology, Harbin 150080, P.R. China

Single crystal diamond is the material of choice for future power electronics. Its electrical and thermal properties outperform those of other wide band gap semiconductors like 4H-SiC, GaN or Ga2O3. In addition, diamond can host a wide range of color centers (NV, SiV, GeV,...) that bring optical and spin properties suitable for quantum applications. This explains the ultrafast development of quantum applications based on diamond materials within the last years. For both application fields, diamond films of excellent crystalline quality are required and an accurate tuning of dopants is needed. This talk will draw the state of art of single crystal diamond grown by CVD either starting with diamond substrate (homoepitaxy) or controlling diamond epitaxial nucleation on a foreign substrate (heteroepitaxy). Progresses on substrates, growth mechanisms and reduction of structural defects, doping, upscaling and applications will be reviewed. In light of last progresses, future challenges and the respective roles of homoepitaxial and heteroepitaxial materials in the applications roadmap will be discussed.

Topical Talk HL 10.2 Tue 14:00 H3
Tuning Semiconductor Mode-Locked Laser Frequency Combs by Gain and Cavity Design — Stefan Meinecke and •Kathy Lüdge — Institute of Theoretical Physics, Technische Univ. Berlin

Passively mode-locked semiconductor lasers produce sequences of short optical pulses at high repetition rates without the need for an external driving frequency. They find applications in optical data communication and metrology and are promising candidates for comb generation in all-optical integration schemes [1].

The gain material as well as the cavity design play a crucial role for their performance and can be designed easily via epitaxial growth. We explore the pulse performance optimization of a three-section tapered quantum-dot laser by means of a numerical model that assumes both the microscopic charge-carrier scattering processes as well as the light-propagation along the device. Motivated by an experimentally characterized device [2], we utilize pulse peak power, pulse width and long-term timing jitter to characterize the performance. The results predict optimal configurations for both the angle of the tapered gain section and the position of the saturable absorber section. These findings can be interpreted and understood in terms of the gain and absorption recovery processes within the active regions of the laser and thus explain why the nano-structured quantum-dot gain medium is especially suited for optimizing the pulse performance.

[1] R. Guzmán et al., Opt. Lett. 42, 2318 (2017).
[2] S. Meinecke et al., Sci. Rep. 9, 1783 (2019).

Topical Talk HL 10.3 Tue 14:30 H3
Monolayer-thick GaN/AlN heterostructures for UVB & UVC ranges: technology, design and properties — Valentin Jmerik, Alexey Toropov, Valery Davydov, and •Sergey Ivanov — Ioffe Institute, Polytekhnicheskaya 26, Saint Petersburg, 194921, Russia

The development of monolayer (ML)-thick GaN/AlN multilayer heterostructures for deep ultraviolet (UV) optoelectronics is discussed. Analysis of plasma-assisted molecular beam epitaxy and metal-organic vapor phase epitaxy show that extreme interface sharpness and sub-ML accuracy in controlling the layer thickness are the main advantages of the former, while the lowest density of threading dislocations and wide possibilities for the implementation of various two-dimensional growth mechanisms are the attractive features of the latter. The structural properties of ML GaN/AlN heterostructures are evaluated comparatively by X-ray diffraction, scanning transmission electron microscopy and Raman spectroscopy. Studies of the optical properties of ML-thick GaN/AlN quantum wells (QWs) reveal that quenching of the Stark effect, suppression of polarization switching, as well as a true excitonic nature of the UV-emission in ultra-thin (1-2ML) QWs ensure a high internal quantum yield of 75% in such structures emitting at 235 nm. High optical quality of 100-nm-thick layers of ML-GaN/AlN digital alloys is confirmed by the optically pumped stimulated emissions in the range 262-290 nm with a minimum threshold of 700kW/cm2. The possibilities of using ML-GaN/AlN MQWs to fabricate powerful (Watt-range) electron-beam pumped UVC-emitters in the spectral range 240-260 nm are demonstrated.

15 minutes break

Topical Talk HL 10.4 Tue 15:15 H3
Optical and vibrational properties of layered 2D materials — •Janina Maultzsch — Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

Atomically thin layered crystals have received great attention due to their fascinating physical properties. By deterministic stacking and twisting of these two-dimensional (2D) materials, an almost unlimited variety of material's combinations and resulting physical properties can be achieved. The properties can be further modified by chemical functionalization of the surface. In this talk I will present theoretical predictions on novel 2D antimony oxide structures which show tunable electronic properties depending on the oxygen content. Second, based on recent experiments on chemically functionalized MoS_2 layers, we present transitions from the 2H to the 1T' phase along with the characteristic phonon modes of the 1T' phase of MoS_2.

Topical Talk HL 10.5 Tue 15:45 H3
Organic/inorganic low dimensional material systems: Fundamental aspects and device applications — •Emil List-Kratochvil — Institut für Physik, Institut für Chemie & IRIS Adlershof, Humboldt-Universität zu Berlin, Zum Großen Windkanal 2, 12489 Berlin, Germany — Helmholtz-Zentrum für Materialien und Energie GmbH, HySPRINT Helmholtz Innovation Lab, Hahn-Meitner-Platz 1, 14109 Berlin, Germany

The ability to form heterostructures from different materials, yet from the same material class, has revolutionized electronic and optical technologies during the past decades. To explore novel electronic and optoelectronic functionalities based on heterostructures in a natural next step we have turned to systematically explore hybrid inorganic/organic materials systems (HIOS) in heterostructures combining materials from dissimilar material classes. Among different aspects in this HIOS research endeavour, it was found that an in-depth understanding and control over the energy level alignment in HIOS is the key to attain novel electronic and optoelectronic functionalities. In this contribution, we report on fundamental aspects of the self-assembled monolayer formation on different metal oxide and 2D semiconductors such as transition metal dichalcogenides, observations of switching processes and successful implementations in diode, light emitting diode, electrolyte gated field effect transistor and neuromorphic plasmonic device structures.

HL 11: Focus Session: Functional Metal Oxides for Novel Applications and Devices

Metal oxides exhibit a myriad of fascinating physical properties that enable a large variety of potential applications such as sensors and detectors, solar energy harvesting, transparent and potentially bendable electronics, power electronics, high-electron-mobility transisitors, memristors, topological quantum computation and so on. These functionalities typically require homo- or heteroepitaxial layers of high crystallinity with bendable amorphous semiconducting oxides as an exception. This session sets a focus on growth of bulk and thin films, experimental and theoretical investigation of their physical properties as well as fabrication and characterization of demonstrator devices.

Organizers: Oliver Bierwagen (Paul-Drude-Institut für Festkörperelektronik, Berlin), Holger Eisele (TU Berlin), Jutta Schwarzkopf (Leibniz-Institut für Kristallzüchtung, Berlin) and Holger von Wenckstern (Universität Leipzig).

Time: Tuesday 13:30–16:30 Location: H4

Invited Talk HL 11.1 Tue 13:30 H4

Modulation Doping in High-Mobility Alkaline-Earth Stannates — •Bharat Jalan — University of Minnesota, Twin Cities, USA

The vast majority of work concerning a conducting oxide interface focus on the LaAlO3/SrTiO3 (LAO/STO) interfaces including some on Al2O3/STO and ReTiO3/STO (Re refers to the rare-earth elements) interfaces among others. Amazingly, all these heterostructures involve the use of STO as an active layer where electron transport occurs. Attempts to synthesize non-STO based modulation-doped heterostructure have been unsuccessful so far despite theoretical predictions. Nor has any appreciable level of control been gained over the electron density at the interface, which is critical to device applications. In this talk, we will report the first demonstration of true modulation doping in a wider bandgap perovskite oxides without the use of STO. We show that the La-doped SrSnO3/BaSnO3 system precisely fulfills the theoretical criteria for electron doping in BaSnO3 using electrons from La-doped SrSnO3, and we demonstrate how rearrangement of electrons can be used to control the insulator-to-metal transition in these heterostructure. We further show the use of angle-resolved HAXPES as a non-destructive approach to not only determine the location of electrons at the interface but also to quantify the width of electron distribution in BaSnO3. The transport results are in good agreement with the results of self-consistent solution to one-dimensional Poisson and Schrödinger equations.

Invited Talk HL 11.2 Tue 14:00 H4

Ultrathin oxides on InGaN nanowires: Hybrid nanostructure photoelectrodes and optical analysis of chemical processes — P. Neuderth[2], J. Schörmann[2], M. Coll[3], M. de la Mata[4], J. Arbiol[4], R. Marschall[5,6], and •M. Eickhoff[1,2] — [1]Inst. of Solid State Physics, Univ. of Bremen, Germany — [2]Inst. of Exp. Phys. I, JLU Giessen, Germany — [3]Inst. de Ciencia de Materials de Barcelona, Spain — [4]ICN2, Barcelona, CAT, Spain — [5]Inst. of Phys. Chem., JLU Giessen, Germany — [6]Phys. Chem. III, Univ. of Bayreuth, Germany

We demonstrate an experimental strategy for systematically assessing the influence of surface passivation layers on the photocatalytic properties of nanowire (NW) photoanodes by combining photocurrent analysis, photoluminescence spectroscopy and high resolution transmission electron microscopy. We apply this approach to separate the influence of different mechanisms on recombination and transport processes of photogenerated carriers and to compare the effect of TiO2, CeO2 and Al2O3 coatings deposited by atomic layer deposition (ALD). Due to efficient charge transfer from the InGaN NW core a stable TiO2-covered photoanode with visible light excitation is realized. As further applications we demonstrate the quantitative optical analysis of oxygen diffusion in ultrathin CeO2 and of the Li intercalation in TiO2 using hybrid nanostructures. In both cases the optical properties of the InGaN NWs are used as a probe for chemical processes in the ultrathin oxide layer that was deposited by ALD. Further potential applications of advanced hybrid nanostructures are discussed.

Invited Talk HL 11.3 Tue 14:30 H4

Doping and charge compensation mechanisms in semiconducting oxides — •Andreas Klein — Technical University of Darmstadt

Different charge compensation mechanisms are known for ionic solids. Among them are the formation of compensating defects such as electronic or ionic defects, the valence changes of atoms and the segregation of dopants. In principle, the introduction of positive charges by donor doping or reduction results either in the compensation by electrons, negatively charged intrinsic acceptors as metal vacancies, the reduction of a one of the species in the compound, or in the segregation of the dopant species. The situation is reversed for the addition of negative charges. While the different mechanisms are well-documented for different materials, predicting the prevailing compensation mechanism in a material is hardly possible. It is well known that the Fermi energy is determined by the defect concentrations but it is equivalent to describe the concentration of defects as a function of the Fermi energy. This enables a direct comparison of the different compensation mechanisms. The challenges in discriminating the different compensation mechanisms are discussed using the example of Sn-doped indium oxide.

Invited Talk HL 11.4 Tue 15:00 H4

Oxide Memristors for edge computing and secure electronics — •Heidemarie Schmidt — Leibniz-IPHT, Jena, Germany — Friedrich-Schiller-Universität Jena, Jena, Germany — Fraunhofer ENAS, Chemnitz, Germany

In the future, new hardware components will determine the power and strength of artificial intelligence and manchine learning. These components are called memristors [1]. The first memristor with unified analog data storage and information processing is the BiFeO3 (BFO) memristor. BFO is an electroforming-free, bipolar memristor and its potential has been shown in in-memory information processing [2], edge computing [3], and hardware cryptography. Another electroforming-free memristor is the unipolar memristor YMnO3 (YMO) [4]. In order to develop memristor technology and applications further, it is more than ever necessary to understand the underlying resistive switching mechanisms when a write voltage is applied. We discuss results from quasi-static test measurements on BFO [5] and from temperature dependent transport measurements on YMO [6]. [1] Leon Chua, IEEE Transactions on Circuit Theory 18, 507, 1971 [2] T. You et al., Adv. Funct. Mat. 24, 3357-3365, 2014. [3] N. Du et al., Front. Neurosci. 15, 660894, 2021. [4] H. Schmidt, 118, 140502, 2021. [5] N. Du et al., Phys. Rev. Applied 10, 054025, 2018. [6] V.R. Rayapati et al., J. Appl. Phys. 126, 074102, 2019.

Invited Talk HL 11.5 Tue 15:30 H4

Integration of 33°Y-LiNbO$_3$ films with high-frequency BAW resonators — Sondes Boujnah[1], Mihaela Ivan[2], Vincent Astié[3], Samuel Margueron[1], Mario Constanza[1], Jean-Manuel Decams[3], and •Ausrine Bartasyte[1] — [1]FEMTO-ST Institute, University of Bourgogne Franche-Comté Besançon, France — [2]SATT-Sayence, Dijon, France — [3]Annealsys, Montpellier, France

The next generation telecommunications require RF filters operating at frequencies of 6-9 GHz. LiNbO$_3$ (LN) films were identified as one of the materials with sufficient electromechanical coupling, K^2, for these applications. To attain 6-9 GHz frequencies in bulk acoustic wave (BAW) devices, LN film thickness has to be below 200 nm, which makes challenging their fabrication by popular smart-cut process. This motivates further development of integration of deposited highly-coupled LN films with BAW resonators. Several challenges have to be overcome in the case of LN direct growth on electrodes/mirrors/sacrificial layers used in BAW devices: (i) heterostructure has to be stable chemically/structurally at LN growth temperature/atmosphere, (ii) eliminate interaction between Li_2O and SiO_2, (iii) bottom electrode with good conductivity.

The aim of this work is to optimize SMR and HBAR structures adapted to high-deposition temperatures, and chemically not interacting with LN thin films. The Bragg mirror with a reflection coefficient of 0.98 and a stopband width of 3.1 GHz, centered at 6 GHz, for the longitudinal mode was designed. Deposition parameters were optimized to fabricate the Bragg reflectors with small roughness, without defaults and good stability and Pt bottom electrode with low resistivity ($4\mu\Omega\cdot$cm). The SMR resonator based on 125 nm thick 33°Y-LN film allows attain pure longitudinal mode with K^2 as high as 14.5 % at 5.9 GHz. 33°Y-LN films grown on seed layer/Pt bottom electrode presented single orientation, and dielectric constant close to bulk LN. After electrical poling, the pyroelectric coefficient increased from 11 $\mu C\cdot m^{-2}\cdot K^{-1}$ to the value of bulk 33°Y-LN indicating single domain state of the film. The acoustical performance of BAW devices will be presented, as well.

HL 11.6 Tue 16:00 H4

Observation and control of improper ferroelectric nanodomains in Gd2(MoO4)3 — •Ivan Ushakov[1], Theodor Holstad[1], Didier Perrodin[2], Edith Bourret[2], and Dennis Meier[1] — [1]NTNU Norwegian University of Science and Technology, Norway — [2]Materials Science Division, Lawrence Berkeley National Laboratory, USA

Gd2(MoO4)3 is a classical example of an improper ferroelectric material and has been extensively studied with respect to its ferroic properties and ferroelectric/ferroelastic domains. Here, we revisit the ferroelectric domain structure and expand previous optical investigations to the nanoscale. By using Piezoresponse Force Microscopy (PFM), we resolve the established pattern of ferroelectric and anti-phase domains in Gd2(MoO4)3. In addition, we discover stripe-like nano-domains with a periodicity of about 50 nm. The response of the ordered nanodomains to locally applied electric fields, pressure, and temperature is presented. Our findings provide new insight into the physics of Gd2(MoO4)3 at the level of the domains and introduce novel opportunities for property engineering at the local scale.

HL 11.7 Tue 16:15 H4

Electronic Raman scattering study of Ir4+ ions in beta-Ga2O3 — •Palvan Seyidov[1], Manfred Ramsteiner[2], Zbigniew Galazka[1], and Klaus Irmscher[1] — [1]Leibniz-Institut für Kristallzüchtung, Max- Born-Str. 2, 12489 Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Leibniz-Institut im Forschungsverbund Berlin e.V., Hausvogteiplatz 5-7, 10117 Berlin, Germany

Currently, beta-Ga2O3 is in the research focus as a material for power electronic devices because of its anticipated high electric break down field (~8MV/cm). For such applications, unintentional impurities in bulk crystals can lead to detrimental effects in device performance. Here we study electronic Raman scattering (ERS) of Ir4+ ions in bulk crystals grown by the Czochralski method. The optical excitation energy was varied between 1.95eV to 3.81eV by using Ar+ ion and HeCd lasers. Conventionally, Raman scattering is used to investigate vibrational modes of molecules and crystals. In contrast, inelastic light scattering due to electronic transitions can be studied by ERS. We observed an ERS feature at 5152 cm-1 (1.94 um, 0.639 eV) in room-temperature spectra from bulk beta-Ga2O3. The observed spectral feature is attributed to Ir4+ ions incorporated on Ga sites and assigned to an intra-center d-d transition within the t2g orbitals. The ERS efficiency is found to strongly depend on the photon energy used for optical excitation. The observed maximum at 2.8 eV can be explained by a resonance enhancement involving an electron transfer from Ir3+ to the conduction band at ~2.2 eV and an Ir4+ intra-center transition at ~0.6 eV.

HL 12: Focus Session: Spin-Charge Interconversion (joint session MA/HL)

While classical spintronics has traditionally relied on ferromagnetic metals as spin generators and spin detectors, a new approach called spin-orbitronics exploits the interplay between charge and spin currents enabled by the spin-orbit coupling (SOC) in non-magnetic systems. Efficient spin-charge interconversion can be realized through the direct and inverse Edelstein effects at interfaces where broken inversion symmetry induces a Rashba SOC. Although the simple Rashba picture of split parabolic bands is usually used to interpret such experiments, it fails to explain the largest conversion effects and their relation to the actual electronic structure.

Organizer: Ingrid Mertig (University Halle-Wittenberg)

Time: Tuesday 13:30–16:45 Location: H5

Invited Talk HL 12.1 Tue 13:30 H5

Spin-charge interconversion with oxide 2-dimensional electron gases — •Manuel Bibes — Unité Mixte de Physique CNRS/Thales

Oxide 2-dimensional electron gases (2DEGs) display a wide range of functionalities including Rashba spin-orbit coupling (SOC), which offers exciting opportunities for spintronics. In this talk, I will show that the 2DEG that forms at the interface of SrTiO3 (STO) with LaAlO3[1] or reactive metals such as Al[2,3] may be exploited to efficiently interconvert spin and charge currents. By applying a gate voltage, we tune the position of the Fermi level in the complex multi-orbital structure of STO, which results in a strong variation of the conversion amplitude[4]. This can be related to the band structure through ARPES experiment and tight-binding calculations. I will present results from both spin-charge conversion where spins are injected by spin pumping in a FMR cavity and detected as a transverse voltage[5], and from charge-spin conversion probed through the bilinear magnetoresistance (BMR). Using a semi-classical model, the analysis of the BMR amplitude yields a good estimate of the Rashba coefficient[6]. In a second part, I will present gate-controlled, all-electrical spin current generation and detection in planar nanodevices only based on a STO 2DEGs[7].

[1] Ohtomo et al, Nature 2004, 427, 423. [2] Rödel et al, Adv. Mater. 2016, 28, 1976. [3] Vicente-Arche et al, PR Mater. 2021, 5, 064005. [4] Lesne et al, Nat. Mater 2016, 15, 1261. [5] Vaz et al, Nat. Mater. 2019, 18, 1187. [6] Vaz et al, PR Mater. 2020, 4, 071001. [7] Trier et al, Nano Lett. 2020, 20, 395.

Invited Talk HL 12.2 Tue 14:00 H5

Spin-to-charge current conversion for logic devices — •Felix Casanova — CIC nanoGUNE, San Sebastian, Basque Country, Spain

The integration of logic and memory in spin-based devices, such as the recent MESO proposal by Intel [1], could represent a post-CMOS paradigm. A key player is the spin Hall effect (SHE), which allows to electrically create or detect pure spin currents without using ferromagnets (FM). Understanding the different mechanisms giving rise to SHE allows to optimize spin-to-charge conversion (SCC) in heavy metals. With this knowledge, we developed a novel and simple FM/Pt nanodevice to readout the in-plane magnetic state of the FM electrode using SHE [2]. The spin-orbit based detection allows us to independently enhance the output voltage (needed to read the in-plane magnetization) and the output current (needed for cascading circuit elements) with downscaling of different device dimensions, which are necessary conditions for implementing the MESO logic [1].

Finally, I will present a radically different approach to further enhance SCC. By engineering a van der Waals heterostructure which combines graphene with a transition metal dichalcogenide, we first demonstrated SHE in graphene due to spin-orbit proximity [3]. The combination of long-distance spin transport and SHE in the same material gives rise to an unprecedented SCC efficiency, making graphene-based systems excellent candidates for MESO logic [1,2].

[1] Manipatruni et al., Nature 565, 35 (2019); [2] Pham et al., Nature Electron. 3, 309 (2020); [3] Safeer et al., Nano Lett. 19, 1074 (2019); Herling et al., APL Mater. 8, 071103 (2020).

Invited Talk HL 12.3 Tue 14:30 H5

Electrical and thermal generation of spin currents by magnetic graphene — •B.J van Wees[1], T.S. Ghiasi[1], A.A. Kaverzin[1], D.K. de Wal[1], A.H. Dismukes[2], and Bart Wees[2] — [1]Zernike Institute for Advanced Materials, Groningen, The Netherlands — [2]Department of Chemistry, Colombia University, New York, NY, USA

I will introduce proximity effects in Van der Waals heterostructures of graphene and materials with strong spin orbit interaction or magnetic 2D materials. Then I will discuss recent experiments [1] where we demonstrate with (non)local spin transport experiments that the proximity of the antiferromagnet CrSBr introduces a strong spin dependent conductivity (with a polarization of about 24%) in (bilayer) graphene. The strength of the exchange field is estimated to be about 170T, implying that the graphene has become magnetic by proximity. This also resulted in the observation of a spin-dependent Seebeck effect. These results were recently confirmed using non-magnetic injector/detector electrodes [2] Fimally I will indicate some new (device) functionalities made possible by this strong proximity inducedspin-charge coupling in graphene [1] T.S. Ghiasi et al., Nature Nanotech. 16, 788, Vol 18, 2021 [2] A.A. kaverzin et al., in preparation

15 min. break.

Invited Talk HL 12.4 Tue 15:15 H5

Ferroelectric switching of spin-to-charge conversion in GeTe — •Christian Rinaldi — Dipartimento di Fisica, Politecnico di Milano, 20133 Milano, Italy

Scalable and energy efficient magneto-electric spin-orbit (MESO) logic has been recently proposed by Intel as technologically suitable computing alternative to CMOS devices, towards attojoule electronics [1]. The MESO device comprises a magnetoelectric unit to drive a magnetic memory, while the read-out is perfomed exploiting spin-to-charge conversion in materials with large spin-orbit coupling.

Here we show that the ferroelectric Rashba semiconductor germanium telluride offers memory as well as spin-orbit read-out in a single material compatible with silicon, thus offering the opportunity for a great simplification of the MESO structure. Here we first demonstrate the robust control of ferroelectricity through gating. Then, by spin pumping measurements in Fe/GeTe, we reveal the ferroelectric control of its sizeable spin-to-charge conversion. These results pave the way to low power spin-orbit logic devices beyond-CMOS. [1] S. Manipatruni, Nature 565, 35 (2019); [2] S. Varotto et al., arXiv preprint, arXiv:2103.07646 (2021).

Invited Talk HL 12.5 Tue 15:45 H5

Theory of spin and orbital Edelstein effects in a topological oxide two-dimensional electron gas — •Annika Johansson[1], Börge Göbel[1,2], Jürgen Henk[1], Manuel Bibes[3], and Ingrid Mertig[1] — [1]Martin Luther University Halle-Wittenberg, Halle, Germany — [2]Max Planck Institute of Microstructure Physics, Halle, Germany — [3]Unité Mixte de Physique CNRS/Thales, Université Paris-Sud, Université Paris-Saclay, Palaiseau, France

$SrTiO_3$ (STO)-based two-dimensional electron gases (2DEGs) provide a highly efficient spin-to-charge conversion [1], also known as inverse Edelstein effect [2,3]. Recently, an extremely large spin-to-charge conversion efficiency was demonstrated in the 2DEG at the interface between STO and Al [4]. The application of a gate voltage leads to a strong variation and even sign changes of the spin-to-charge conversion.

We explain this unconventional gate dependence of the (inverse) spin Edelstein effect from a theoretical perspective by Boltzmann transport calculations within a multiorbital tight-binding model. Further, we report on the electrically induced magnetization originating from the orbital moments, known as orbital Edelstein effect [5]. At STO interfaces the orbital Edelstein effect exceeds the spin Edelstein effect by more than one order of magnitude.

[1] E. Lesne *et al.*, Nat. Mater. **15**, 1261 (2016)
[2] V. M. Edelstein, Solid State Commun., **73**, 233 (1990)
[3] K. Shen *et al.*, Phys. Rev. Lett. **112**, 096601 (2014)
[4] D. Vaz *et al.*, Nature Materials **18**, 1187 (2019)
[5] A. Johansson *et al.*, Phys. Rev. Research **3**, 013275 (2021)

Invited Talk HL 12.6 Tue 16:15 H5

Nonlinear magnetoresistance and Hall effect from spin-momentum locking — •Giovanni Vignale — University of Missouri

Surface states of topological insulators exhibit the phenomenon of spin-momentum locking, whereby the orientation of an electron spin is determined by its momentum. Recently a link has been discovered between the spin texture of these states and a new type of nonlinear magnetoresistance, which depends on the relative orientation of the current with respect to the magnetic field as well as the crystallographic axes, and scales linearly with both the applied electric and magnetic fields. The nonlinear magnetoresistance originates from the conversion of a non-equilibrium spin current into a charge current under the application of an external magnetic field. Additionally, it has been found that the nonlinear planar Hall effect, manifested as a transverse component of the nonlinear current, exhibits a Pi/2 phase shift with respect to the nonlinear longitudinal current, in marked contrast to the usual Pi/4 phase difference that exists between the linear planar Hall current and the linear longitudinal current in typical topological insulators and transition metal ferromagnets. In this talk I review the development of the theory vis-a-vis experiments done on the surface of topological insulator Bi_2Se_3 films and other materials.

HL 13: Poster Session III

Topics:
- Materials and devices for quantum technology
- Quantum dots and wires
- Functional Metal Oxides for Novel Applications and Devices
- Advanced neuromorphic computing hardware: Towards efficient machine learning

Time: Tuesday 13:30–16:30 Location: P

HL 13.1 Tue 13:30 P

Universal short-time response and formation of correlations after quantum quenches — •Klaus Morawetz — Münster University of Applied Sciences, Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil

The short-time evolutions of two distinct systems, the pump and probe experiments with a semiconductor and the sudden quench of cold atoms in an optical lattice, are found to be described by the same universal response function. This analytic formula at short time scales is derived from the quantum kinetic-theory approach observing that correlations need time to form. The demand of density conservation leads to a reduction of the relaxation time by a factor of 4 in quench setups. The influence of the finite-trapping potential is derived and discussed along with Singwi-Sjølander local-field corrections including the proof of sum rules. The quantum kinetic equation allows to understand how two-particle correlations are formed and how the screening and collective modes are build up.

Phys. Rev. B 90 (2014) 075303, Phys. Rev. E 66 (2002) 022103, Phys. Rev. E 63 (2001) 20102, Phys. Lett. A 246 (1998) 311

HL 13.2 Tue 13:30 P

Synchronization Properties in Coupled Mode-Locked Lasers — •Clara Rodríguez Roca-Sastre, Stefan Meinecke, and Kathy Lüdge — Institut für Theoretische Physik, Technische Universität, Berlin, Deutschland

Passively mode-locked semiconductor lasers (PMLLs) are simple and compact sources of high-frequency ultrashort light pulses. These devices can be used in novel secure communication schemes and for optical clock synchronization. However, due to the lack of an external reference clock, this class of MLLs exhibits higher timing jitter than their active counterparts [1]. To overcome this detrimental effect, mutual all-optical coupling can be introduced to reduce the timing jitter [2]. This technique also allows access to different synchronization regimes of the laser outputs. To better understand the synchronization regime, we numerically model a coupled system using delay differential equations [1]. Two coupled identical lasers pumped differently can operate with a high degree of in-phase and localized synchronization if one of them is driven in stable FML operation and the detuning between the devices is not too pronounced. Otherwise, the ML output collapses and complex dynamics such as multi-pulse dynamics may arise. The lasers then exhibit mode-locked pulses with a finite number of different intensities. In addition, regions of anti-phase dynamics appear at delay times around fractional integers of the laser resonance round-trip time.

[1] Otto et al., New J. Phys. 14, 113033 (2012).
[2] Simos et al., IEEE JQE 54, 2001106 (2018).

HL 13.3 Tue 13:30 P

Off-resonant excitation swing up of a quantum emitter — •Thomas Bracht[1], Michael Cosacchi[2], Tim Seidelmann[2], Moritz Cygorek[3], Alexei Vagov[2,4], Martin Axt[2], Tobias Heindel[5], and Doris Reiter[1] — [1]Institut für Festköpertheorie, Universität Münster,Germany — [2]Theoretische Physik III, Universität Bayreuth, Germany — [3]Heriot-Watt University, Edinburgh, United Kingdom — [4]ITMO University, St. Petersburg, Russia — [5]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany

Controlled preparation of a quantum emitter is key for many of its applications, for example as a single photon source. Here, we present a scheme which uses pulses detuned significantly below the excited-state energy that lead to a swing up of the quantum emitter occupation. We show that a two-color excitation leads to high final excited-state occupation and discuss the conditions under which the scheme works. Applied to semiconductor quantum dots, the proposed swing-up scheme results in the emission of high-quality single photons. The main advantage of our scheme compared to Rabi rotations is that no filtering is needed in order to separate the resulting signal from the laser source. Another advantage is that in contrast to off-resonant schemes relying on phonon-assisted transitions, our scheme does not depend on any auxiliary quasi-particles. In summary, we are proposing an experimentally feasible swing-up scheme to excite a quantum emitter yielding high-quality photon emission for quantum technology.

HL 13.4 Tue 13:30 P

On the Advantage of Sub-Poissonian Single Photon Sources in Quantum Communication — •Daniel Vajner, Timm Gao, and Tobias Heindel — Institute of Solid State Physics, Technical University Berlin, 10623 Berlin

Quantum Communication in principle enables a provably secure transmission of information. While the original protocols envisioned single photons as the quantum information carrier [1], nowadays implementations and commercial realizations make use of attenuated laser pulses. There are, however, a number of advantages of using single photon sources. They are not limited by the Poisson statistics and suffer less under finite-key length corrections [2]. In addition, the second order interference visibility of true single photons can exceed the classical value of 50% which will be benefitial for all quantum information processing schemes, as well as measurment device independent QKD schemes, that rely on Bell state measurements of photons from different sources [3]. Given recent advances in the development of engineered semiconductor QD-based light sources, harnessing these advantages is within reach. We present an overview of different scenarios in which employing single photon sources improves the communication rate and distance.

[1] Bennett et al. *Proceedings of the IEEE International Conference on Computers, Systems and Signal Processing* (1984)
[2] Cai et al. *New Journal of Physics* 11.4 (2009): 045024
[3] Mandel, L. *Physical Review A* 28.2 (1983): 929

HL 13.5 Tue 13:30 P

Diameter dependent whispering gallery mode lasing effects in quantum dot micropillar cavities — •Imad Limame, Ching-Wen Shih, Johannes Pietsch, Aris Koulas-Simos, Leo Roche, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, D-10623 Berlin

Whispering-gallery modes (WGMs) were first theorized by Lord Rayleigh in 1878 at the St. Paul cathedral. WGMs with lateral emission characteristics occur also in micropillar cavities which is of great interest for integrated quantum nanophotonics. In this work, we present an in depth study of WGM emission in micropillars ranging between 2 and 20 μm in diameter. The samples were grown by mean of metal organic chemical vapor deposition and include multi layers of InGaAs quantum dots as active region. The pillars were processed using electron beam lithography, using a Ni hard mask. This hard mask is only partially removed to create a highly obsorbant surface on the top of the pillar, which suppresses emission through standard vertically emitting micropillar modes. The optical properties were studied by means of micro-photoluminescence spectroscopy (μPL). Investigating the input-output characteristics, the free spectral range, the Q-factor and the beta-factor as function of the pillar diameter provides deep insight into the underlying physics and paves the way for the applicaiton of the developed WGM microlasers as coherent excitation sources in integrated quantum photonic circuits.

HL 13.6 Tue 13:30 P

Continuum of quantized bound quasinormal modes — •Robert Fuchs, Sebastian Franke, Andreas Knorr, and Marten Richter — Technische Universität Berlin, Berlin, Germany

Quasinormal modes (QNMs) have proven to be a useful and intuitive way to define modes for open cavities. They have been calculated for a variety of problems both in classical electrodynamics, and recently used in a fully quantized description for three dimensional geometries.

However, so far, a quantized description of multi-cavity-structures using QNMs with substantial propagation delays is missing. We show that an extension of the QNM quantization is possible if the cavities are far away from each other so that retardation effects are important.

The related 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 multi-time correlation functions we are able to construct a systematic formulation to describe the inter-cavity transfer determined by QNM parameters.

HL 13.7 Tue 13:30 P

Fiber-pigtailing quantum-dot cavity-enhanced light emitting diodes — Lucas Rickert[1], •Frederik Schröder[1], Timm Gao[1], Christian Schneider[2,3], Sven Höfling[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Technische Physik, Physikalisches Institut, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Würzburg, Germany — [3]Institut für Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany

Semiconductor quantum dots embedded in engineered microcavities are considered key building blocks for photonic quantum technologies [1]. The direct fiber-coupling of respective devices would thereby offer many advantages for practical applications [2]. Here, we present a method for the direct and permanent coupling of electrically operated quantum-dot micropillar-cavities to single-mode fibers [3]. The fiber-coupling technique is based on a robust four-step process fully carried out at room temperature, which allows for the deterministic coupling of a selected target device. Using the cavity mode electroluminescence as feedback parameter, precise fiber-to-pillar alignment is maintained during the whole process. Permanent coupling is achieved in the last process step using UV curing of optical adhesive. Our results are an important step towards the realization of plug-and-play benchtop electrically-driven single-photon sources.

[1] T. Heindel et al., Appl. Phys. Lett. 96, 011107 (2010)
[2] T. Kupko et al., arXiv.2105.03473 (2021)
[3] L. Rickert et al., arXiv.2102.12836 (2021)

HL 13.8 Tue 13:30 P

Hyperspectral imaging for deterministic quantum dot microcavities — •Quirin Buchinger[1], Magdalena Moczała-Dusanowska[1], Łukasz Dusanowski[2], Tobias Huber[1], and Sven Höfling[1] — [1]Technische Physik, Universität Würzburg, 97074 Würzburg, Germany — [2]Department of Electrical and Computer Engineering, Princeton University, 08544 Princeton (NJ), USA

For many photonic quantum communication schemes, including quantum networks, indistinguishable single photons or entangled photon pairs are required. Semiconductor quantum dots (QDs) in microcavities are a promising source due to their high quantum efficiency [1], photon indistinguishability [2], and outcoupling efficiency. As a disadvantage these self-assembled QDs are randomly distributed over the sample and have inhomogeneosly distributed emission wavelengths.

Here, we present an approach using hyperspectral imaging to locate self-assembled QDs and to integrate them deterministically into microcavities. We image InGaAs-QDs in a GaAs-Membrane and perform subsequent processing of Circular-Bragg-grating cavities. We show possibilities and solutions to improve the spatial accuracy through marker design, data acquisition and image processing. Further, we discuss the combination of imaging and acquisition of single spectrums at thereby identified QDs to reduce the needed time compared to hyperspectral imaging without a trade-off on spectral and spatial information.

[1]Michler et al. Science, 290, 2282-2285 (2020)
[2]Santorio et al. Nature, 419, 594-597 (2002)

HL 13.9 Tue 13:30 P

Mobility spectrum analysis on three-dimensional topological insulator $BiSbTeSe_2$ — •Jimin Wang[1], Alexander Kurzendorfer[1], Lin Chen[1], Zhiwei Wang[2], Yoichi Ando[2], Yang Xu[3], Ireneusz Miotkowski[3], Yong P. Chen[3], and Dieter Weiss[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, German — [2]Physics Institute II, University of Cologne, Zülpicher Str. 77, 50937 Köln, Germany — [3]Department of Physics and Astronomy, Purdue University, West Lafayette, Indiana 47907, USA

We conducted mobility spectrum analysis on a high quality 3D topological insulator film of $BiSbTeSe_2$ to extract mobility μ, and carrier density n. Top and bottom gates were applied to tune the carrier density on top and bottom surfaces independently. At 1.5 K, when conduction is entirely dominated by the Dirac surface states, we always find two dominant conduction channels (top and bottom surfaces), with $\mu = 500 - 3000\,\mathrm{cm^2/(Vs)}$, and n on the order of $10^{12}\,\mathrm{cm^{-2}}$. However, at sufficiently high temperature ($T = 85\,\mathrm{K}$), when the bulk contributes, a third channel with maximum mobility $\mu \sim 400\ \mathrm{cm^2/(Vs)}$, and n on the order of $10^{11} - 10^{13}\,\mathrm{cm^{-2}}$ opens. Our data show the feasibility of the method to analyze the different conduction channels in a topological insulator, being also promising for other similar material systems.

HL 13.10 Tue 13:30 P

Feedback-induced chaotic emission from a GaAs-QW high-contrast grating microcavity structure — •Aris Koulas-Simos[1], Melanie Hoeschele[1], Jiaqi Hu[2], Hui Deng[2,3], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Applied Physics Program, University of Michigan, Ann Arbor, Michigan 48109, USA — [3]Department of Physics, University of Michigan, Ann Arbor, Michigan 48109, USA

We investigate the optical and quantum optical properties of a high-contrast grating microcavity structure based on GaAs multiple quantum wells subject to optical feedback. Power-dependent microphotoluminescence (μPL) studies reveal the typical s-shaped form in the I/O curve with a pronounced kink signifying the lasing onset, accompanied by an abrupt linewidth narrowing. The effect of the optical feedback is visible in the shift of the threshold to lower excitation powers. Additional angle-resolved PL measurements show a condensation to lower k-states and spectrally narrower emission. In power-dependent photon-autocorrelation, enhanced bunching and revival peaks with a period equal to the round-trip time of the external cavity are pronounced, indicating chaotic emission as a result of the optical feedback [1]. This is again verified by calculating the photon-autocorrelation function $g^{(2)}(\tau)$ through single-shot intensity trace measurements with a streak camera.

[1] F. Albert et al., *Nat. Comm.* **2**, p. 1-5 (2011)

HL 13.11 Tue 13:30 P

Spectral manipulation of coherent acoustic phonons in a graphite nanofilm observed by ultrafast electron diffraction — •Arne Ungeheuer, Ahmed Hassanien, Mashood Mir, Arne Senftleben, and Thomas Baumert — University of Kassel, Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

Femtosecond-laser-excited nanomechanical strain-waves in thinfilm-structures allow for a series of quantized resonant modes with amplitudes that depend on the photoinduced spatiotemporal strain-distribution in the material [1]. We investigate the possibilities to amplify specific higher harmonic modes in a graphite nanofilm, employing a NIR femtosecond-laser double pulse excitation-scheme. We present results from ultrafast electron diffraction studies for different relative pulse-delays within the double-pulse sequence, yielding constructive or destructive interference for selected coherent acoustic phonon harmonics.

[1] F. Hudert et al.: Phys. Rev. B 79, 2009.

HL 13.12 Tue 13:30 P

Laser controlled charge-carrier dynamics in pyrene-doped $MoSe_2$ monolayer — •Matheus Jacobs[1], Jannis Krumland[1], and Caterina Cocchi[1,2] — [1]Institut für Physik und IRIS Adlershof, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Institute of Physics, Carl von Ossietzky Universität Oldenburg,26129 Oldenburg, Germany

In the last years, the interest in transition metal dichalcogenide monolayers have grown enormously due to their unique electronic structure and light-matter coupling properties. Combining these materials with carbon conjugated molecules can give rise to new materials with enhanced opto-electronic performance, specially when excited by coherent radiation. In the framework of real-time time-dependent density functional theory, we investigate the ultrafast charge-carrier dynamics at the interface formed by pyrene molecules physisorbed on a $MoSe_2$ monolayer. By monitoring the effect of the incident pulse intensity on the energy and the electron transfer on the hybrid heterostructure, we identify a striking nonlinear response of the system, which in turn impacts the charge-carrier dynamics and the nature of cahrge transfer from the inorganic to the organic components.

HL 13.13 Tue 13:30 P

Validity of the Siegert relation in partially-coherent regimes — •Monty Drechsler, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Bremen, Germany

With increasing miniaturization of coherent light sources to the diffraction limit and below, their emission properties change and new effects appear. Therefore, a description in the context of quantum optics is required. An objective in studying such nano light sources is their classification. In this context, the investigation of the statistical nature of photon correlations plays a major role. We are able to access information about photon correlations quantified by $g^{(1)}(\tau)$ and $g^{(2)}(\tau)$ using a master-equation or a cluster-expansion approach. We discuss the temporal behavior of these correlation functions in different device regimes from the quantum limit of a single emitter to larger systems. When combining the theoretical prediction with experiments we are confronted with the limited time resolution of detectors used in the measurement of correlations function. To treat this issue, a generalized Siegert relation has been used previously [1][2]. Here, we quantify when such an approach is justified.

[1] Kreinberg et al., Light Sci Appl 6, e17030 (2017)
[2] Kreinberg et al., Laser & Photonics Reviews 14, Nr. 12, 2000065 (2020)

HL 13.14 Tue 13:30 P

Top-down fabrication of silicon nanophotonic structures for hosting single-photon emitters — •Nagesh S. Jagtap[1,2], Michael Hollenbach[1,2], Ciaran Fowley[1], Woo Lee[3], Manfred Helm[1,2], Georgy V. Astakhov[1], Artur Erbe[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]Korea Research Institute of Standards and Science (KRISS), Yuseong, 305-340 Daejeon, Republic of Korea

Silicon, the ubiquitous material for computer chips, has recently been shown to be instrumental for hosting sources of single-photons emitting in the strategic optical telecommunication O-band (1260-1360 nm)[1], the so-called G center. To increase the brightness and the photon extraction efficiency of single G center, the coupling of these centers into photonic structures is strong.

This work presents a top-down approach avoiding the use of ion beam-based etching methods for fabricating high-quality defect-free photonic structures such as silicon nanopillars, which can host single-photon emitters. This method builds upon a wet-chemical process known as metal-assisted chemical etching. We report the successful fabrication of two-dimensional arrays of vertically-directed waveguiding silicon nanopillars. We also show the etch chemistry dependence on the Si wafer resistivity along with its effect on the etch rate and the sidewall roughness of pillars for a variety of pillar diameters.

References:[1] M. Hollenbach, et al. Opt. Express 28,26111-26121

HL 13.15 Tue 13:30 P

Sensitivity to high energy Proton irradiation of 670 nm VCSELs in emitter and receiver mode — •Heinz-Christoph Neitzert — Salerno University - DIIn, Fisciano (SA), Italy

Vertical Cavity Surface Emitting Lasers (VCSELs) have recently found increasing interest also for space applications, for example for ultra-compact atomic clocks and intra-satellite data-links. Besides their application as efficient emitters also their application as resonant-cavity type photo-receiver has been demonstrated. The radiation stability of commercial VCSELs emitting at 670nm bas been tested with the exposition to 68 MeV protons with different fluence values up to 10^13 protons/cm^2. Besides the conventional electrical and electro-optical characterization under forward bias conditions, also the reverse bias characteristics up to device breakdown and the receiver characteristics under white light LED illumination have been investigated. Even for the highest proton fluence value only a very small change of the laser threshold current and slope efficiency values has been observed, confirming that these VCSELs can be operated successfully in space or in a high energy physics environment. Regarding their optical receiver properties up to 10^12 protons/cm^2, only a minor decrease of the primary photocurrent was observed. Only for the highest proton fluence a more substantial decrease in open circuit voltage and primary photocurrent and also a increase of the reverse bias current due to defect related tunnelling, before the inset of avalanche breakdown, has been found.

HL 13.16 Tue 13:30 P

Carrier dynamics and modulation properties in tunnel- injection based quantum-dot structures — •Michael Lorke[1], Igor Khanonkin[2], Stephan Michael[1], Gadi Eisenstein[2], and Frank Jahnke[1] — [1]Institute for Theoretical Physics, University of Bremen, Germany — [2]Andrew and Erna Viterbi Department of Electrical Engineering, Technion, Haifa, Israel

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

HL 13.17 Tue 13:30 P

Wave Digital Emulation of Hydra's Neuronal Activity — •Sebastian Jenderny[1], Karlheinz Ochs[1], Christoph Giez[2], Alexander Klimovich[2], and Thomas Bosch[2] — [1]Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany — [2]Christian-Albrechts University Kiel, Zoological Institute, Kiel, Germany

Modeling real neuronal networks by electrical circuits is especially interesting as it can reveal novel design principles. A promising model organism for this purpose is Hydra, a freshwater polyp with rich behavioral patterns despite its neuronal network only consisting of roughly 3000 neurons. Modeling Hydra's nerve net by an electrical circuit is, however, challenging as only calcium imaging measurements instead of electrophysiology are available. The neuronal activity associated to these calcium imaging measurements are difficult to mimic by electrical circuits as they are based on fluorescence traces instead of voltage and current measurements. In this work, we present a circuit-based approach to mimic these fluorescence traces utilizing the fact that the latter can be used to determine the intracellular calcium concentration. For this purpose, we make use of the Morris-Lecar model already accounting for calcium currents and hence allowing to calculate a calcium concentration comparable to the one inferred from the fluorescence traces. A wave digital emulation of our circuit approach shows the successful mimicking of exemplary neuronal activity of Hydra.

HL 13.18 Tue 13:30 P

Light-sensitive Resonant Tunneling Diodes for single photon detection — •Sebastian Krüger[1], Andreas Pfenning[2], Fabian Hartmann[1], Fauzia Jabeen[1], and Sven Höfling[1] — [1]Technische Physik, Julius-Maximilians Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Stewart Blusson Quantum Matter Institute, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4

Double barrier resonant tunneling diodes (RTDs) are versatile optoelectronic devices with a multitude of possible applications. The focus of interest is the application for terahertz oscillation and the detection of single photons. Especially the downtime-free photodetection has an advantage compared to the state-of-the-art techniques, which are using avalanche multiplication. The capability of single-photon detection has been demonstrated in [1]. The low efficiency of around 10% is limiting. We present our work on RTD photodetectors based on AlGaAs/GaAs DBQW with GaAsSb quantum well (QW) close to the double barrier structure [2]. The strained ternary alloy, GaAsSb, is grown on GaAs. The type II band alignment leads to better *hole* confinement compared to InGaAs-QW or quantum dots (QD). The photodetection based on minority charge carrier accumulation at the DBS in RTDs, is sensed by the influence of their electrostatic potential. It leads to an additional voltage drop over the DBS and shifts the I(V) characteristics towards lower voltages [2]. [1] J. C. Blakesley, et al., Physical Review Letters 94, 067401 (2005). [2] A.Pfenning, et al., Applied Physics Letters 107, 081104 (2015).

HL 13.19 Tue 13:30 P

Towards Scalable Reconfigurable Electronics: Fabrication of Schottky Barrier Field-Effect Transistors using Flash Lamp Annealing — •Muhammad Bilal Khan, Sayantan Ghosh, Slawomir Prucnal, Rene Hübner, Artur Erbe, and Yordan M. Georgiev — Institute of Ion Beam Physics And Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden

To complement the scaling down of complementary metal-oxide-semiconductor (CMOS), new device concepts have been introduced. One such concept is the reconfigurable field-effect transistor (RFET). In the most general case, an RFET is a silicon nanowire (SiNW) based device. The SiNW is silicided at both ends, which results in silicide-Si-silicide Schottky junctions. Typically, two distinct gate electrodes are placed on silicide-Si junctions. By controlling the electrostatic potential on the gate electrodes, the RFET is programmed to the *p*- or *n*-polarity. We report on the fabrication and electrical characterization of top-down fabricated SiNW based RFETs. Flash lamp annealing based silicidation process is developed, which enables control over the silicidation process. Uni-polar transfer characteristics are obtained using two top-gates. The effect of implementing various gate dielectric materials (SiO_2, Al_2O_3 and hBN) is studied to enhance device electrostatics.

HL 13.20 Tue 13:30 P

Space-charge effects in high-coherence electron pulses — •Alexander Schröder, Christopher Rathje, Niklas Müller, Jonathan Weber, Nora Bach, and Sascha Schäfer — Institute of Physics, University of Oldenburg, Germany

Ultrafast transmission electron microscopy (UTEM) enables the imaging of ultrafast nanoscale dynamics, utilizing an optical-pump/electron-probe approach within a high-resolution transmission electron microscope [1]. The spatio-temporal resolution in this technique sensitively depends on the phase-space structure of the employed ultrashort electron pulses. Whereas needle-shaped photoemitters were demonstrated to deliver high-coherence electron pulses in the single-electron regime, at larger bunch charges significant Coulomb interactions within the pulse need to be considered [2].

Using the newly constructed Oldenburg UTEM, we investigate the impact of Coulomb interactions on the longitudinal phase-space structure of electron pulses. Depending on the illumination intensity on the photoemitter, we observe a fluence-dependent shift and broadening of the electron energy distribution which is compared to a multi-particle simulation taking into account the expanding electron pulse close to the emitter tip. The impact of the initial electron energy after photoemission, the acceleration field and the bunch charge on the spatio-temporal electron pulse structure at the sample are discussed.

[1] A. Feist et al., Ultramicroscopy, 176, 63 (2017)
[2] N. Bach et al., Structural Dynamics 6, 014301 (2019)

HL 13.21 Tue 13:30 P

Solving the Vertex Cover Problem with a Wave Digital Model of an Ising Machine — •Bakr Al Beattie and Karlheinz Ochs — Ruhr University Bochum, Bochum, Germany

The efficient solution of NP-problems is an unresolved computational challenge with many real-world applications. Ising machines are promising for solving these types of problems. The idea is to map a problem onto the Ising Hamiltonian and let an Ising machine find the ground state, which corresponds to the solution of the problem. These machines are designed so they have the natural tendency to converge to the ground state of the Hamiltonian. Multidimensional wave digital algorithms are known to be massively parallel, and they are additionally robust for emulating large electrical networks, like the coupled oscillator network of an Ising machine. In this work, a wave digital model mimicking the phase dynamics of an ideal Ising machine is derived and generalized to support solving Ising problems containing the Zeeman term. To prove usefulness and quality of this wave digital Ising machine, we solve a vertex cover problem.

HL 13.22 Tue 13:30 P

Decision-Making Processes by a Kuramoto Model with Hebbian Learning: Circuit Synthesis and Wave Digital Emulation — •Sebastian Jenderny, Dennis Michaelis, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Decision-making processes are an interesting topic often studied in synchronizing oscillatory networks. Here, synchronization is, on an abstract level, related to learning. In this context, the Hebbian learning rule can be interpreted as the increasing and decreasing coupling strength between oscillators with a small and a large phase difference, respectively. This can for example be implemented by the Kuramoto model, being a simple and well-studied model for oscillatory networks. Our aim is to synthesize an electrical circuit of the Kuramoto model with Hebbian learning with which decision-making processes can be mimicked. For this purpose, we derive a memristor model accounting for the Hebbian learning rule. We then develop a corresponding wave digital model and utilize it to mimic the decision-making process associated with the observation of optical illusions.

HL 13.23 Tue 13:30 P

A Memristive Circuit for a Delay-Based Supervised Classi-

fier — Dennis Michaelis, •Sebastian Jenderny, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Supervised learning based on artificial neural networks is a major principle for many pattern recognition tasks. Corresponding circuit implementations are often based on implementing synaptic weight changes. In this work, we propose a different approach based on learning delays instead of synaptic weights. For this purpose, we synthesize an electrical circuit for a dynamic axon model. The resulting circuit is based on memristive Jaumann structures in combination with delay elements. We utilize this circuit to design a neural network for the supervised learning of gait patterns. Here, the learning is based on the circuit selecting delay lengths in a self-organized way, which further introduces an additional degree of freedom compared to the synaptic weight approach. A wave digital emulation verifies our approach by showing that the axonal delays associated with the trained gait patterns are successfully learned, leading to correct classification results.

HL 13.24 Tue 13:30 P

Mimicking Delay-Based Self-Sustaining Gait Pattern Generators — Dennis Michaelis, •Sebastian Jenderny, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Hardware implementations of gait pattern generators are an active field of research especially in robotics, where recent approaches are based on neural networks. Most of the latter implementations, however, only consider synaptic weight changes. In contrast to this, we design a gait pattern generator being able to learn and generate self-sustaining gait patterns based on a neural network adjusting its axonal delays. For this purpose, we synthesize a memristive circuit of a dynamic axon model serving as the basis for the neural network. Here, the circuit realization of the axon is based on Jaumann structures with memristors. A wave digital emulation of the resulting complete circuit verifies our approach by showing the successful learning and generation of self-sustained gait patterns of a dog.

HL 13.25 Tue 13:30 P

Towards an Improved Anticipation Circuit with Self-Organized Resonance-Frequency-Adaption — Karlheinz Ochs and •Sebastian Jenderny — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

Inspired by the ability of an amoeba to anticipate environmental changes, an RLC circuit with a memristor in parallel has been proposed as an anticipation circuit. Here, the memristor enables a self-organized Q-factor adaption. Since this circuit's functionality is limited to an excitation with its resonance frequency, further research has been done to achieve an additional self-organized resonance-frequency adaption. Existing approaches are based on utilizing memcapacitors instead linear capacitors, where the memcapacitor models are very sophisticated. In contrast to this, in this work we develop a physically more meaningful memcapacitor to use it for an improved anticipation circuit. A wave digital emulation of the resulting circuit shows a self-organized resonance-frequency adaption, supporting the Q-factor adaption of the memristor.

HL 13.26 Tue 13:30 P

Optimal Topology Formation of Memristive Neuronal Networks — Dennis Michaelis, •Sebastian Jenderny, and Karlheinz Ochs — Ruhr University Bochum, Chair of Digital Communication Systems, Bochum, Germany

The topology formation of neuronal networks during their ontogenesis is of great importance since it lays the foundation for the neuronal networks being well adapted for future tasks. While the synapse formation is the most popular part of this aspect, it is also important to take axon growth into account. This is because the latter can be assumed to play a key role in the emergence of optimal communication paths of neuronal networks in terms of delays. In this work, we synthesize an electrical circuit abstractly mimicking the topology formation of neuronal networks with respect to delays by making use of memristors. The resulting circuit can be used to find the optimal communication paths of a neuronal network by finding its minimal spanning tree, which is verified by LTspice simulations.

HL 13.27 Tue 13:30 P

CMOS back-end compatible Metal-$Hf_{0.5}Zr_{0.5}O_2$-Al_2O_3-Metal ferroelectric tunnel junction devices for neuromorphic applications — •Keerthana Nair[1,2], Marco Holzer[1,2], Sourish Banerjee[1], Catherine Dudourdieu[1,2], and Veeresh Deshpande[1] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, 14109 Berlin, Germany — [2]Freie Universität Berlin, Physical Chemistry, Arnimallee 22, 14195 Berlin, Germany

$Hf_{0.5}Zr_{0.5}O_2$ (HZO) ferroelectric layer provides an opportunity for CMOS back-end-of-line integrable devices owing to low crystallization temperature (around 400°C). Ferroelectric tunnel junction (FTJ) memory devices based on HZO feature ultra-low power consumption and have potential for multiple resistance states necessary for neuromorphic applications. FTJ architecture based on the Metal-Ferroelectric-Dielectric-Metal stack allows high ON/OFF ratio with thicker ferroelectric layer (10-12nm). In this work, we demonstrate 400°C-crystallized Metal-HZO-Al_2O_3-Metal FTJ architecture with TiN and W metals. Utilizing the coercive field distribution of the domains, we demonstrate multiple resistance states through partial switching operations and switching pulse-width modulations. The influence of cycling waveform on the ON/OFF ratio (which directly impacts achievable multiple resistance states) will be discussed. The intermediate resistance state stability will also be discussed. Our study also investigates the role of the process conditions, dielectric thickness and metal placement on attaining high ON/OFF ratio back-end compatible FTJ devices.

HL 13.28 Tue 13:30 P

Epitaxial BaSnO3 thin films without extended defects on lattice matched LaInO3 substrates — •Daniel Pfützenreuter, Zbigniew Galazka, Robert Schewski, Klaus Irmscher, Martin Albrecht, and Jutta Schwarzkopf — Leibniz-Institut für Kristallzüchtung, Max-Born-Str. 2, 12489 Berlin, Germany

BaSnO3 is a semiconducting perovskite material offering an electron mobility of 320 cm2/Vs at a carrier density of 8E19 cm-3 at room temperature in a bulk crystal. Epitaxial thin films however, always have a much lower electron mobility, which is ascribed to a high density of threading dislocations emerging in the films as a consequence of a large lattice mismatch between substrate and film.

LaInO3 crystals with (110) surface orientations were applied as a novel orthorhombic substrate for the epitaxial growth of BaSnO3 thin films due to its negligible lattice mismatch. We revealed by means of reflection high energy electron diffraction, energy dispersive x-ray analysis and atomic force microscopy that a slight Ba-doping in the LaInO3 substrates helps to stabilize the substrate surface at elevated temperatures and under reducing atmosphere, which are the typically used pulsed laser deposition conditions for the growth of BaSnO3 thin films. Transmission electron microscopy measurements confirm the growth of fully strained BaSnO3 thin films without extended defects on LaInO3:Ba substrates. Temperature dependent Hall-effect measurements of a BaSnO3 film doped with 0.5 % La exhibit a Hall-mobility of 69 cm2/Vs at room temperature and 99 cm2/Vs at 20 K at a constant charge carrier density of 3.8E19 cm-3.

HL 13.29 Tue 13:30 P

β-Ga2O3 material for vertical power devices: challenges to the epitaxy process — •Ta-Shun Chou, Saud Bin Anooz, Raimund Grüneberg, Vi Tran Thi Thuy, Zbigniew Galazka, Klaus Irmscher, Palvan Seyidov, Martin Albrecht, and Andreas Popp — Leibniz-Institut für Kristallzüchtung, Berlin, Germany

β-Ga2O3 is a promising ultra-wide bandgap (~4.8 eV) semiconductor material. A breakdown field strength up to 8 MV/cm is expected from theoretical calculation, which makes it attractive for power electronic applications and a competitor to SiC and GaN. Especially a vertical architecture for β-Ga2O3-based transistors can exploit the high potential of this material and will benefit from a low on-resistance at a given breakdown voltage in combination with less power losses within a transistor switching operation. To fulfill the requirements of the vertical device, extremely low doped homoepitaxial thin films with thicknesses of several um and high crystallinity are necessary.

In this contribution, we present the growth development to achieve step-flow β-Ga2O3 grown layer by MOVPE on Mg-doped β-Ga2O3 (100) substrates with a thickness above 1 um by applying a high growth rate. This improvement can be related to the possible formation of a Ga adlayer which is widely reported already for the GaN system. In addition low, Si doping concentrations down to and below 1E17 cm^-3 were demonstrated while maintaining mobilities comparably high as previous results based on low growth rate and low thickness layers. The developed epitaxy process is a key enabler for the growth of (100) β-Ga2O3 material for vertical power device applications.

HL 13.30 Tue 13:30 P

Influence of group III dopants on the properties of SnO(001) films grown via plasma-assisted molecular beam epitaxy — •Kingsley Egbo, Georg Hoffmann, Andrea Ardenghi, Alexandra Papadogianni, Jonas Laehnemann, and Oliver Bierwagen — Paul-Drude-Institut für Festkörperelektronik, 10117 Berlin, Germany

Most metal oxides show a propensity for n-type conductivity, few oxides show p-type character. Metastable tin monoxide (SnO) is among the few p-type oxide semiconductors and its unintentional p-type conductivity is believed to be controlled by Sn-vacancies. Few studies have also suggested the possibility for bipolar doping in SnO. In this study, the growth of SnO(001) doped with the group III La, In and Ga on YSZ(100) substrates by plasma-assisted MBE is investigated. Structural properties of the doped SnO(001) films were studied by x-ray diffraction, Raman spectroscopy and scanning electron microscope. Detailed electrical properties of the doped films are obtained from Hall Effect measurements. Hole concentration, p of ~0.8-2.0 x 1019 cm-3 and resistivity, ρ of 0.15-0.30 Ω-cm respectively is obtained from room temperature hall measurement of unintentionally doped SnO (001). We find that p increases to ~ 4.0-5.0 x 1019 cm-3 and ρ decreased to 0.04-0.063 Ω-cm for Ga doped films. In contrast, thin films doped with In and La show reduction in p and remarkable increase in ρ with increasing dopant concentration. Our results reveal that p-type conductivity in SnO can be improved by Ga acceptors while La and In likely acts as compensating donors in SnO. These results offer an opportunity for exploring bipolar doping in SnO.

HL 13.31 Tue 13:30 P

The role of Sr deficiency in SrTiO3 thin films grown by metal-organic vapor phase epitaxy — •Aykut Baki, Julian Stöver, Tobias Schulz, Houari Amari, Carsten Richter, Jens Martin, Klaus Irmscher, Martin Albrecht, and Jutta Schwarzkopf — Leibniz-Institut für Kristallzüchtung, Max-Born-Str. 2 in 12489 Berlin

SrTiO3 is widely studied due to interesting physical properties such as its high permittivity at room temperature, resistive switching and strain induced ferroelectricity. However, the underlying physical origin of these effects is not fully understood. In order to investigate the influence of structural defects on the physical properties, we performed the growth of SrTiO3 films by liquid-delivery spin metal-organic vapor phase epitaxy, which takes place nearby the thermodynamic equilibrium and at high oxygen partial pressures ensuring growth of films with high quality and negligible amount of oxygen vacancies. In this study, homoepitaxial SrTiO3 thin films were grown on 0.5 wt.% niobium doped SrTiO3 (100) substrates with varying Sr/Ti ratio in the gas phase. This provides single-phase stoichiometric and deliberately off-stoichiometric thin films with an intentionally incorporated Sr deficiency. Even films with Sr deficiency of up to 20 % were grown without the formation of any extended defects or foreign phase. In-situ high-resolution x-ray diffraction and transmission electron microcopy measurements verified a negligible amount of oxygen vacancies in the films and the absence of conductive oxygen filaments at typically applied switching voltages in a metal-oxide-semiconductor structure. The observed physical properties are Sr-deficiency related.

HL 13.32 Tue 13:30 P

Doping of β-Ga2O3 in a plasma assisted MBE using a SiO source. — •Andrea Ardenghi[1], Georg Hoffmann[1], Oliver Bierwagen[1], Piero Mazzolini[2], Andreas Falkenstein[3], and Manfred Martin[3] — [1]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — [2]Department of Mathematical, Physical and Computer Sciences, Parma University, Italy — [3]Institute of Physical Chemistry, RWTH Aachen University, Aachen, Germany

β-Ga2O3 is the most likely candidate for the next generation of power electronic devices but, achieve high quality doped sample is still challenging. To obtain n-doping for Ga2O3 the main candidate are Sn, Ge and Si. Between them Si-doped samples showed the higher mobility, making Si the most interesting doping source. Using a silicon source as dopant in PAMBE can be difficult since, due to the oxygen plasma, the source will be oxidized. In Kalarickal work[1], the flux from the Si source were highly influenced by the oxygen pressure, due to the formation and desorption of SiO. In order to avoid this problem a study similar to the one reported by Hoffmann et al[2]. was carried on a SiO source. Another advantage of the SiO source is the low cell temperature in comparison with Si and SiO2. From our results temperatures between 600-800°C should give us doping concentration in the range of 10e17 to 10e20 cm-3. The SiO source will be used for the growth of Si-doped Ga2O3 layers by PAMBE and the results will be reported.

[1]Kalarickal, Nidhin Kurian, et al. Applied Physics Letters 115.15 (2019).

[2]Hoffmann, Georg, et al. APL Materials 8.3 (2020).

HL 14: Materials and devices for quantum technology (joint session HL/TT)

Time: Wednesday 10:00–12:45 Location: H4

Invited Talk HL 14.1 Wed 10:00 H4

Quantum Interference of Identical Photons from Remote Quantum Dots — •Giang N. Nguyen[1], Liang Zhai[1], Clemens Spinnler[1], Julian Ritzmann[2], Matthias 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, Switzerland — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr- Universität Bochum, Germany

Photonic quantum technology provides a viable route to quantum communication, quantum simulation, and quantum information processing. Scaling the complexity requires photonic architectures containing a large number of single photons, multiple photon-sources and photon-counters. Semiconductor quantum dots are bright and fast sources of coherent single-photons. For applications, a significant roadblock is the poor quantum coherence upon interfering single photons created by independent quantum dots.

Here, we present two-photon interference with near-unity visibility using photons from remote quantum dots. We show a Hong-Ou-Mandel visibility of 93% between photons from quantum dots separated in two cryostats. Exploiting the quantum interference, we demonstrate a photonic controlled-not circuit and a high-fidelity entanglement between photons of different origins. These results provide a long-awaited solution to the challenge of creating coherent single photons in a scalable way.

HL 14.2 Wed 10:30 H4

Natural heavy-hole flopping mode qubit in germanium — •Philipp M. Mutter and Guido Burkard — University of Konstanz, Konstanz, Germany

Flopping mode qubits in double quantum dots allow for coherent spin-photon hybridization and fast qubit gates when coupled to either an alternating external or a quantized cavity electric field. To achieve this, however, electronic systems rely on synthetic spin-orbit interaction by means of a magnetic field gradient as a coupling mechanism. Here we theoretically show that this challenging experimental setup can be avoided in heavy-hole systems in germanium by utilizing the sizable cubic Rashba spin-orbit interaction. We argue that the resulting natural flopping mode qubit possesses highly tunable spin coupling strengths that allow for qubit gate times in the nanosecond range when the system is designed to function in an optimal operation mode which we quantify.

HL 14.3 Wed 10:45 H4

On-chip Stark tuning of deterministically fabricated quantum dot waveguide systems — Peter Schnauber, Jan Grosse, Arsenty Kaganskiy, Maximilian Ott, Pavel Anikin, Ronny Schmidt, •Sven Rodt, and Stephan Reitzenstein — Institute of Solid State Physics, Technische Universit́at Berlin, Hardenbergstraße 36, D-10623 Berlin, Germany

On-chip quantum photonic circuits based on monolithic waveguides structures provide a compact and robust solution for setting up quantum logics and processors. The required structuring has already reached a very high level in different material systems but the monolithic integration of a number of single-photon emitters with identical emission wavelength is still a crux of the matter. We tackle this issue by deterministically integrating single InGaAs/GaAs quantum dots (QDs) into pin-doped GaAs/AlGaAs waveguides by in-situ electron-beam lithography (iEBL) [1]. This approach promises the integration of QDs with quasi-identical emission wavelength in combination with a fine-tuning mechanism via the quantum confined Stark effect. The wavelength accuracy in the pre-selection step of iEBL was about 0.2 nm which is nicely covered by tuning-range of about 0.4 nm when applying a bias voltage of up to 1.2 V. This paves the way for the fabrication of scalable quantum photonic circuits that rely on photon interference from multi emitters.

[1] P. Schnauber et al., APL Photonics 6, 050801 (2021)

HL 14.4 Wed 11:00 H4

Integration of NV-centers in nanodiamond in 1D photonic crystal cavities — •Jan Olthaus[1], Philip P.J. Schrinner[2], Carsten Schuck[2], and Doris E. Reiter[1] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]Institute of Physics, Center for NanoTechnology - CeNTech and Center for Soft Nanoscience - SoN, University of Münster, Germany

The scalable integration of single-photon emitters with photonic circuits remains a major hurdle for the realisation of quantum information technologies. Efficient integration requires an interface, combining low losses and high coupling strength between these components. Here, we show results for the coupling of nitrogen vacancy centers in nanodiamond to 1D on-substrate photonic crystal cavities. In the first step, we use 3D FDTD simulations to optimise the geometry of a on-substrate photonic crystal cavity based on tantalum pentoxide waveguides. Based on the optimised structures, we then analyse the coupling conditions, if a nanodiamond cluster of varying sizes is placed in different positions around the cavity center. We find that for a deterministic air-mode design, optimal coupling is achieved when placing the nanodiamond at the air-waveguide interface within the central air-hole. Then, we validate our results experimentally by placing nanodiamonds close to the determined optimal position. We measure antibunching of the integrated photoluminescence signal proving single-photon emission. The scalability of our approach is demonstrated by simultaneous readout of the electron-spin of two neighbouring devices in a optical detected magnetic resonance measurement.

HL 14.5 Wed 11:15 H4

Optoelectronic sampling of ultrafast electric transients with single quantum dots — •Sebastian Krehs[1], Alex Widhalm[1,2], Dustin Siebert[2], Nand Lal Sharma[1,3], Timo Langer[1], Björn Jonas[1], Dirk Reuter[1], Andreas Thiede[2], Jens Förstner[2], and Artur Zrenner[1] — [1]Paderborn University, Physics Department, Warburger Straße 100, 33098 Paderborn, Germany — [2]Paderborn University, Electrical Engineering Department, Warburger Straße 100, 33098 Paderborn, Germany — [3]Institute for Integrative Nanosciences, Leibniz IFW Dresden, Helmholtzstraße 20, 01069 Dresden, Germany

The use of quantum systems as sensors promises high sensitivity, high precision and access to nanoscale applications. In our work, we have pioneered optoelectronic sampling of ultrafast electric signals with low capacitance single quantum dots photodiodes as sensor devices [1]. Our concept exploits the Stark effect to convert a time-dependent electric signal into a time-dependent shift of the QD transition energy. Time resolved measurements of the shift can be measured by resonant ps laser spectroscopy with spectrally tunable photocurrent detection. With our method we are able to sample the laser synchronous output pulse of an ultrafast CMOS circuit at cryogenic temperatures. We demonstrate an impressive sub-20 ps time resolution and an amplitude resolution in the mV-range. Theoretical calculations show that the accuracy of our method is not affected or limited by a moderate timing jitter or the optical pulse width.

[1] http://arxiv.org/abs/2106.00994

15 min. break.

HL 14.6 Wed 11:45 H4

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 14.7 Wed 12:00 H4

Photon-number entanglement generated by sequential excitation of a two-level atom — Stephen C. Wein[1], Juan C. Loredo[2], Maria Maffei[3], Paul Hilaire[2], Abdou Harouri[2], Niccolo Somaschi[4], Aristide Lemaitre[2], Isabelle Sagnes[2], Loic Lanco[2,5], Olivier Krebs[2], Alexia Auffeves[3], Christoph Simon[1], Pascale Senellart[2], and •Carlos Anton-Solanas[2,6] — [1]Univ. of Calgary, Canada — [2]C2N-CNRS, France — [3]Inst. Neel-CNRS, France — [4]Quandela SAS, France — [5]Univ. Paris-Diderot, France — [6]Carl von Ossietzky Univ., Germany

During the spontaneous emission of light from an excited two-level atom, the atom briefly becomes entangled with the photonic field, producing the entangled state $\alpha|e,0\rangle + \beta|g,1\rangle$, where g and e are the ground and excited states of the atom, and 0 and 1 are the vacuum and single photon states [1].

We experimentally show that the spontaneous emission can be used to deliver on demand photon-number entanglement encoded in time [2]. By exciting a charged quantum dot (an artificial two-level atom) with two sequential π pulses, we generate a photon-number Bell state $\alpha|00\rangle + \beta|11\rangle$. We characterize the quantum properties of this state using time-resolved photon correlation measurements. We theoretically show that applying longer sequences of π pulses to a two-level atom can produce multipartite time-entangled states with properties linked to the Fibonacci sequence.

[1] V. Weisskopf, E. Wigner, Zeitschrift für Physik 63, 54 (1930). [2] S. C. Wein, et al., arXiv:2106.02049 (2021).

HL 14.8 Wed 12:15 H4

Evaluating Atomically Thin Quantum Emitters for Quantum Key Distribution — •Timm Gao[1], Martin v. Helversen[1], Carlos Anton-Solanas[2], Christian Schneider[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

Single photon sources are considered key building blocks for future quantum communication networks. In recent years, atomic monolayers of transition metal dichalcogenides (TMDCs) emerged as a promising material platform for the development of compact quantum light sources. In this work, we evaluate for the first time the performance of a single photon source based on a strain-engineered WSe_2 monolayer [1] for quantum key distribution (QKD). Employed in a QKD-testbed emulating the BB84 protocol, we analyze the single-photon purity in terms of $g^{(2)}(0)$ and secret key rates as well as quantum bit error rates to be expected in full implementations of QKD. Furthermore, we exploit routines for the performance optimization previously applied to quantum dot based single-photon sources [2]. Our work represents a major step towards the application of TMDC-based devices in quantum technologies.

[1] L. Tripathi et al., ACS Photonics 5, 1919-1926 (2018)
[2] T. Kupko et al., npj Quantum Inform. 6, 29 (2020)

HL 14.9 Wed 12:30 H4

Single Photon Emission from a topological cavity — •Jonathan Jurkat[1], Sebastian Klembt[1], Tristan H. Harder[1], Johannes Beierlein[1], Monika Emmerling[1], Tobias Huber[1], Christian Schneider[2], and Sven Höfling[1] — [1]Technische Physik, Wilhelm-Conrad-Röntgen-Research Center for Complex Material Systems, and Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Am Hubland, D-97074 Würzburg, Germany — [2]Institute of Physics, University of Oldenburg, 26129 Oldenburg, Germany

We measured the emission enhancement as well as single photon emission of a In(Ga)As quantum in spectral resonance with a topological defect mode. The emission was measured in a micro-photoluminescence setup under quasi resonant pumping with a pulsed laser. Spectral resonance was achieved by means of temperature tuning. The photonics lattice and topologically protected defect mode was implemented in an orbital Su-Schrieffer-Heeger chain. This zigzag chain of coupled micropillar devices was fabricated using molecular beam epitaxy in combination with an etch and overgrowth technique. These coupled resonators offer the exciting opportunity to combine a complex band structure formation with the emission of single localized quantum emitters.

HL 15: Focus Session: Tailored Nonlinear Photonics

The research field of nonlinear photonics is driven by the tailoring and control of nonlinear light-matter interactions and by the application of nonlinear concepts for advanced light management. Current research activities are driven by concepts from quantum optics, coherent optics, and solid-state physics. The progress in the field strongly benefits from advanced solid-state materials, nanostructures, and photonic structures, as well as from extremely intense and efficient ps and fs laser sources. The application of new concepts paves technically viable routes towards advanced nonlinear photonic devices, which are indispensable for the implementation of efficient frequency conversion, conditional photonic functionalities, and photonic quantum technologies.

Organizers: Artur Zrenner (Universität Paderborn), Thomas Zentgraf (Universität Paderborn) and Manfred Bayer (TU Dortmund)

Time: Thursday 10:00–12:45 Location: H4

Invited Talk HL 15.1 Thu 10:00 H4

Quasi-instantaneous switch-off of deep-strong light-matter coupling — •Christoph Lange[1], Joshua Mornhinweg[2], Maike Halbhuber[2], Viola Zeller[2], Cristiano Ciuti[3], Dominique Bougeard[2], and Rupert Huber[2] — [1]Department of Physics, TU Dortmund University, 44227 Dortmund, Germany — [2]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [3]Université de Paris, laboratoire Matériaux et Phénomènes Quantiques, CNRS, F-75013 Paris, France

Optical microresonators facilitate custom-tailored quantum states of matter by dressing electronic excitations with virtual cavity photons. Once the rate of energy exchange between light and matter modes exceeds the carrier frequency of light, "deep-strong coupling" emerges, which profoundly modifies the vacuum ground state and gives rise to novel phenomena including cavity-mediated superconductivity and other phase transitions. While the exploration of the equilibrium properties of deep-strong coupling has just started, yet more unusual effects are expected on subcycle scales. Here, we explore the dynamics that arises when deep-strong coupling is switched off abruptly. The experiments employ cyclotron resonances of two-dimensional electron gases coupled to light modes of custom-cut THz nanoresonators, which can be switched off by femtosecond photoexcitation. The polariton states are extinguished more than an order of magnitude faster than the polariton cycle duration, leading to sub-polariton-cycle oscillations as confirmed by a quantum model. Our experiments introduce time as a new control parameter for deep-strong light-matter coupling.

Invited Talk HL 15.2 Thu 10:30 H4

Lithium niobate nonlinear nanophotonics — •Frank Setzpfandt — Institute of Applied Physics, Abbe Center of Photonics, Friedrich Schiller University Jena

Lithium niobate is one of the most interesting optical materials, owing to its high transparency in a wide spectral range, high second-order nonlinearity, and the ability for quasi-phase matching. These enticing properties have been utilized many times in nonlinear optics, in particular for nonlinear parametric frequency conversion. However, lithium niobate is also a material that is challenging to structure on the nanoscale, which is only done regularly since a short time.

In this talk, I will discuss our recent progress in the implementation of nanoscale structures in lithium niobate and their application for the generation of classical and quantum light by parametric frequency conversion. In particular, I will focus on our realization of lithium niobate metasurfaces and their use in experimental demonstrations of second-harmonic and photon-pair generation .

Invited Talk HL 15.3 Thu 11:00 H4

Quadratic nanomaterials for integrated photonic devices — •Rachel Grange — ETH Zurich, Switzerland

Nonlinear and electro-optic devices are present in our daily life with many applications: light sources for microsurgery, green laser pointers, or modulators for telecommunication. Most of them use bulk materials such as glass fibres or high-quality crystals, hardly integrable or scalable due to low signal and difficult fabrication. Generating nonlinear or electro-optic effects from materials at the nanoscale can expand the applications to biology and optoelectronics. However, the efficiency of nanostructures is low due to their small volumes. Here I will show several strategies to enhance optical signals by engineering metal-oxides at the nanoscale with the goal of developing nonlinear and electro-optic photonics devices for a broad spectral range. We use metal-oxides such as barium titanate (BTO) and lithium niobate (LNO) as an alternative platform for nanoscale nonlinear photonics. BTO and LNO are non-centrosymmetric materials with high refractive index and high energy band gaps. We already demonstrated linear Mie resonances in BTO and LNO nanostructures, such as nanospheres or nanocubes. Recently, we focused on bottom-up assemblies of BTO nanoparticles to obtain electro-optic metasurfaces and quasi phase matching effects. We measured an electro-optic response in assembled nanostructures as strong as certain other perfect crystalline structure. The field of metal-oxides at the nanoscale has a huge potential of applications in nanophotonics, integrated optics and telecommunication.

15 min. break.

Invited Talk HL 15.4 Thu 11:45 H4

Topological plasmonics: Ultrafast vector movies of plasmonic skyrmions on the nanoscale — •Harald Giessen[1], Pascal Dreher[2], David Janoschka[2], Frank Meyer zu Heringdorf[2], Tim Davis[1,3], and Bettina Frank[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]CENIDE, University of Duisburg-Essen, Duisburg, Germany — [3]University of Melbourne, Melbourne, Australia

Plasmonic skyrmions are topological defects in the electromagnetic near-field on thin metal films, recently observed using scanning near-field optical microscopy. However, only one spatial component of the electric field was measured and one of the most intriguing features of skyrmions, namely their dynamics, was not assessed.

Two-photon photoemission electron microscopy was previously able to image the local plasmon fields with femtosecond time resolution. Still, the vector information about the local electric fields was missing. Here we introduce a new technique, time-resolved vector microscopy, that enables us to compose entire movies on a sub-femtosecond time scale and a 10 nm spatial scale of the electric field vectors of surface plasmon polaritons [1]. Specifically, we image complete time sequences of propagating surface plasmons that demonstrates their spin-momentum-locking as well as plasmonic skyrmions on atomically flat single crystalline gold films that have been patterned using gold ion beam lithography.

[1] T. Davis et al., Science 367, eaba6415 (2020).

Invited Talk HL 15.5 Thu 12:15 H4

Supercontinuum second-harmonic generation spectroscopy of 2D semiconductors — •Steffen Michaelis de Vasconcellos — Institute of Physics and Center for Nanotechnology, University of Münster, Germany

The emergence of 2D materials has opened up a wealth of new research topics for a wide variety of applications. The intensive research efforts on 2D materials were initially ignited by the groundbreaking work on graphene. Since then, the family of 2D crystals and their heterostructures has been expanding rapidly. The research has been focusing not only on their unique electrical properties, but also on their fascinating optical, mechanical, thermal, and chemical properties. Several of the materials are particularly suited for establishing nonlinear light-matter interactions. The strong optical nonlinearity, broadband and tunable optical absorption, and ultrafast response of these materials have been successfully employed in all-optical modulators, saturable absorbers used in passive mode locking and Q-switching, wavelength converters, and optical limiters.

A powerful tool to gain insight into nanoscale materials is the prototypical nonlinear process second-harmonic generation (SHG) due to its dependence on crystal symmetry and electronic structures. We developed a new method to perform ultra-broadband SHG spectroscopy, which provides access to the frequency-dependent nonlinear susceptibility $\chi^{(2)}$ of atomically thin materials and allows for the identification of the prominent excitonic resonances.

HL 16: Semiconductors: Optical, Transport and Ultrafast Properties

Time: Thursday 11:15–12:45 Location: H1

HL 16.1 Thu 11:15 H1

A Koopman's compliant exchange correlation potential for semiconductors — •Michael Lorke, Peter Deak, and Thomas Frauenheim — Universität Bremen

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, on the example of defects in semiconductors, it respects the required linearity condition of the total energy with the fractional occupation number, as expressed by the generalized Koopman's theorem. It is shown, that alloys can be treated with a common choice of the functional. 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 16.2 Thu 11:30 H1

Kerr and Faraday rotations of two-dimensional topological flat bands — Alireza Habibi, Johan Ekström, Thomas Schmidt, and •Eddwi Hasdeo — Department of Physics and Materials Science, University of Luxembourg, Luxembourg, Luxembourg

Flat-band systems are one of main subjects of research in condensed-matter physics especially after the discovery of a strongly correlated phase in twisted bilayer graphene. Flat bands can be observed directly via angle-resolved photo-emission spectroscopy. However, due to the band flatness and the close proximity to the Fermi energy, a flat band is usually difficult to characterize. Here, we propose an alternative characterization method for topological flat bands using photon absorption. In topological bands, the anomalous Hall conductivity can rotate the incident light polarization, resulting in a rotated polarization of the transmitted light (Faraday effect) and the reflected light (Kerr effect). In this work, we employ a model featuring nearly flat bands, for which the bandwidth is much smaller than the band gap. We investigate the dynamical (ac) conductivities of the model in the presence of an external electric field. We contrast how flat bands and dispersive bands can be detected sensitively via Kerr and Faraday rotations. These results can serve as a simple characterization tool to determine the bandwidth or band flatness of topological materials.

HL 16.3 Thu 11:45 H1

Benchmarking the accuracy of screened range-separated hybrids for bulk properties of semiconductors — •Stefan A. Seidl, Bernhard Kretz, Christian Gehrmann, and David A. Egger — Technical University of Munich

A recently developed class of functionals, the so called screened range-separated hybrid (SRSH) functionals, only use one empirical parameter to fit the band gap to the accurately calculated band gap from the GW approach. After the tuning procedure of the range-separation parameter, SRSH functionals have been shown to provide accurate electronic-structure and optical properties of semiconductors [1]. This is an advantage over conventional semilocal and hybrid functionals in density functional theory (DFT), where it is known that they predict the structural properties well, but fail in the accurate description of electronic and optical properties. Here, we assess the accuracy of the SRSH functional to compute static and dynamic bulk properties (lattice constants, bulk moduli, atomization energies as well as phonon dispersion relations) of inorganic semiconductors [2]. We find that for these quantities, SRSH is similarly accurate as the two well-established functionals PBE and HSE. This demonstrates that the superior performance of SRSH for electronic-structure and optical calculations does not come at a cost of reduced accuracy for calculations of bulk properties.

[1] D. Wing et al, Phys. Rev. Materials 3, 064603 (2019)
[2] S. A. Seidl et al, Phys. Rev. Materials 5, 034602 (2021)

HL 16.4 Thu 12:00 H1

Hydrogen-Bonding Ability of the GaAs (001) Surface — •MARSEL KARMO and ERICH RUNGE — Weimarer Str.32

Thin films of direct-band gap III-V-semiconductors are widely used in optoelectronic devices such as lasers or solar cells. Their production via MOVPE/MOCVD involves hydrogen, which may or may not bind to the semiconductor surface. We study the hydrogen-bonding ability of the paradigmatic GaAs (001) surface via DFT using the VASP code. From the calculated thermodynamic potentials, we derive the phase diagram for the surface reconstructions as function of the availability of hydrogen and arsenic. Furthermore, we calculate the potential surface energy (PES) for a single adsorbed hydrogen which gives information about potential hydrogen bonding sites. For a wide range of the surface chemical potentials the (2x2)-surface with one hydrogen adsorbed to each As-dimer is energetically favored.

HL 16.5 Thu 12:15 H1

Size-dependent electrical characteristics of highly doped Germanium nanowires — •ahmad echresh, slawomir prucnal, yordan georgiev, and lars rebohle — Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Germanium (Ge) is the most compatible material with silicon (Si)-based complementary metal-oxide-semiconductor processes. Ge has a higher electron and hole mobility compared to Si, leading to improved device performance. Moreover, Ge nanowires (GeNWs) are promising nanostructures for future nano- and optoelectronics due to their unique properties. In this work, ion beam implantation and flash lamp annealing (FLA) were used to dope phosphorous into the top Ge layer of Ge-on-insulator (GeOI) substrates, achieving a highly n-type doped semiconductor. Raman spectroscopy and Rutherford backscattering spectrometry were performed to characterize the crystallinity of the Ge layers after ion beam implantation and FLA. Subsequently, doped GeNWs were fabricated using electron beam lithography and inductively coupled plasma reactive ion etching. Electrical characterization of the GeNWs was conducted using an innovative Hall bar configuration. The effect of nanowire width on transport parameters such as resistivity and carrier mobility was investigated. Moreover, a nickel germanide layer was made using Ni deposition, followed by FLA to create ohmic contacts on n-type GeNWs.

HL 16.6 Thu 12:30 H1

Extreme ultraviolet laser source for time resolved experiments including a terahertz driver laser — Torsten Golz, Gregor Indorf, Mihail Petev, Jan-Heye Buss, Michael Schulz, and •Robert Riedel — Class 5 Photonics GmbH, Luruper Hauptstraße 1, 22547 Hamburg

The investigation of ultrafast dynamics in condensed matter and interfaces requires high repetition rates and multiple wavelength laser sources, together with femtosecond resolution. To meet these needs, we have therefore designed an extreme-ultraviolet laser source with output within the range of 21.7 to 50 eV (total flux of 3×10^{12} photons/sec), together with a tunable output from 750 - 950 nm with 10 μJ pulse energy and a pulse duration of <40 fs, as well as, a third output for terahertz generation (2 mJ, <600 fs at 1030 nm). All three outputs are optically synchronized and can be used, for example, in time- and angle-resolved photoemission spectroscopy (trARPES) experiments.

HL 17: Focus Session: Topological Phenomena in Synthetic Matter (joint session DS/HL)

Topological insulators are a striking example of materials in which topological invariants are manifested in robustness against perturbations. Topology has emerged as an abstract, yet surprisingly powerful, new paradigm for controlling the flow of an excitation, e.g. the flow of electrons or light. This interdisciplinary Focus Session aims at discussing the latest experimental and theoretical results in the fast developing field of topological phenomena in synthetic matter. The recent merging of topology and cold atoms, photonics, mechanics and many more fields promises a considerable impact on these disciplines. We bring together leading theoretical and experimental experts from the fields of topological phenomena in synthetic matter to discuss recent progress and interdisciplinary synergy emerging at the interface of these fields. Furthermore, we give an overview to young scientists of exciting possibilities of interdisciplinary research in these fields with the special focus on the practical applications of fundamental science.

Organizer: Sebastian Klembt (Julius-Maximilians-Universität Würzburg)

Time: Thursday 13:30–16:15 Location: H1

Topical Talk HL 17.1 Thu 13:30 H1

Exceptional Topology of Non-Hermitian Systems: from Theoretical Foundations to Novel Quantum Sensors — •Jan Carl Budich — Institute of Theoretical Physics, TU Dresden, Dresden, Germany

In a broad variety of physical settings ranging from classical metamaterials to open quantum systems, non-Hermitian (NH) Hamiltonians have proven to be a powerful and conceptually simple tool for effectively describing dissipation. Motivated by recent experimental discoveries, investigating the topological properties of such NH systems has become a major focus of current research. In this talk, I give a brief introduction to this rapidly growing field, and present our latest results. Specifically, we discuss the occurrence of novel topological phases unique to NH systems. There, the role of spectral degeneracies familiar from Hermitian systems such as Weyl semimetals is played by exceptional points at which the effective NH Hamiltonian becomes non-diagonalizable. Furthermore, we show how guiding principles of topological matter such as the bulk boundary correspondence are qualitatively changed in the NH realm. Finally, we demonstrate that the sensitivity of NH systems to small changes in the boundary conditions may be harnessed to devise novel high-precision sensors.

Topical Talk HL 17.2 Thu 14:00 H1

In situ fabrication of (Bi,Sb)-based topological insulator - superconductor hybrid devices — •Peter Schüffelgen — Forschungszentrum Jülich

With their experimental verification in 2007, topological insulators render a new and fascinating material class. A band inversion in the bulk of a 3D topological insulator creates a 2D metallic Dirac system at the physical surface of those 3D crystals. The surface Dirac states are topologically protected and have their spin locked to their momentum. This intrinsic quantum spin texture promises to enable fundamentally new, yet elusive quantum technologies, such as Majorana quantum bits. In this talk, I will introduce the material class of (Bi,Sb)-based topological insulators and discuss experimental challenges. I will present an in situ process that makes it possible to construct hybrid devices comprised of topological and superconductive nanostructures fully under ultra-high vacuum conditions via molecular beam epitaxy. A combination of stencil lithography and selective area growth allows for the realization of a variety of superconductor-topological insulator hybrid devices and solves the associated fabrication challenges.

Topical Talk HL 17.3 Thu 14:30 H1

Atomic monolayers as two-dimensional topological insulators — •Ralph Claessen — Physikalisches Institut und Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, Germany

Two-dimensional topological insulators (2D-TIs) are characterized by hosting spin-polarized conducting band states at their one-dimensional (1D) edges, giving rise to the quantum spin Hall (QSH) effect. As pointed out in the seminal work of Kane and Mele, graphene would constitute the most simple realization of a QSH insulator if it were not for its almost negligible spin-orbit interaction. It has been suggested that going to heavier group IV monolayers (such as the Sn-derived "stanene") could remedy this problem, but a convincing demonstration of such 2D TIs is still lacking. Recently we discovered that the neighboring groups III and V in the Periodic Table provide a promising alternative. Here I will discuss rational design, epitaxial synthesis, as well as ARPES and STM studies of two such synthetic QSH insulators, namely Bi (bismuthene) and In (indenene) monolayers grown on SiC(0001) substrates.

15 minutes break

Topical Talk HL 17.4 Thu 15:15 H1

Topological Insulator Lasers — •Mordechai Segev — Technion - Israel Institute of Technology

Topological Insulator Lasers are semiconductor emitters fabricated on a potential landscape designed to harness the features of topological insulators to force injection-locking of the emitters, making them act as a single coherent laser. The concepts underlying topological insulator lasers will be reviewed along with the recent progress.

Topical Talk HL 17.5 Thu 15:45 H1

TBA — •Morais Smith — TBA

TBA

HL 18: Quantum Dots and Wires (joint session HL/TT)

Time: Thursday 13:30–16:30 Location: H4

Invited Talk HL 18.1 Thu 13:30 H4

Telecom wavelength quantum dot-based single-photon sources for quantum technologies — •Anna Musial — Department of Experimental Physics, Faculty of Fundamental Problems of Technology, Wroclaw University of Science and Technology, Wybrzeze Wyspianskiego 27, 50-370 Wroclaw, Poland

Important building blocks for quantum technology applications are non-classical light sources, in particular those emitting single photons on demand. Among pursued approaches to realize them semiconductor epitaxial quantum dots (QDs) stand out in terms of single-photon purity, compatibility with semiconductor technology including deterministic fabrication of photonic structures, integration into photonic circuits and fiber infrastructure as well as unprecedented possibilities of engineering their electronic structure and optical properties. The current status, recent developments and future prospects of the single-photon sources based on single GaAs-based and InP-based epitaxial QDs emitting in the telecommunication spectral range will be given. Reviewed aspects include thermal stability of emission, energies for efficient quasi-resonant excitation, optimization of photon extraction efficiency, approaches to maximize coupling to a single mode telecom fiber, single-photon emission purity as well as tests of a fully operational plug&play fiber-based single-photon source.

HL 18.2 Thu 14:00 H4

Electric-field induced tuning of electronic correlation in weakly confining quantum dots — Huiying Huang[1], Diana Csontosová[2,3], Santanu Manna[1], Yongheng Huo[4], Rinaldo Trotta[5], Armando Rastelli[1], and •Petr Klenovský[2,3] — [1]Johannes Kepler University Linz, Linz, Austria — [2]Masaryk University, Brno, Czech Republic — [3]Czech Metrology Institute, Brno, Czech Republic — [4]University of Science and Technology of China, Hefei, Anhui, China — [5]Sapienza University of Rome, Rome, Italy

We conduct a combined experimental and theoretical study of the quantum confined Stark effect in GaAs/AlGaAs quantum dots obtained with the local droplet etching method. In the experiment, we probe the permanent electric dipole and polarizability of neutral and positively charged excitons weakly confined in GaAs quantum dots by measuring their light emission under the influence of a variable electric field applied along the growth direction. Calculations based on the configuration-interaction method show excellent quantitative agreement with the experiment and allow us to elucidate the role of Coulomb interactions among the confined particles and – even more importantly – of electronic correlation effects on the Stark shifts. Moreover, we show how the electric field alters properties such as built-in dipole, binding energy, and heavy-light hole mixing of multiparticle complexes in weakly confining systems, underlining the deficiencies of commonly used models for the quantum confined Stark effect.

HL 18.3 Thu 14:15 H4

Towards deterministic generation of time-bin entangled photons from GaAs quantum dots — •Florian Kappe[1], Yusuf Karli[1], Vikas Remesh[1], Santanu Manna[2], Armando Rastelli[2], and Gregor Weihs[1] — [1]Institute for Experimental Physics, University of Innsbruck, Austria — [2]Institute of Semiconductor and Solid State Physics, Johannes Kepler University of Linz, Austria

Semiconductor quantum dots are bright, on-demand single photon sources to realise quantum communication devices. We present our progress towards the deterministic generation of time-bin entangled photon states utilizing single GaAs/AlGaAs quantum dota as photon sources. Our scheme relies on the use of highly chirped picosecond laser pulses and an optically dark exciton state acting as a metastable state. The fidelity of the state preparation is supported by numerical simulations on the quantum dot dynamics. To demonstrate the effect of chirped excitation pulses on the quantum dot, we present an adiabatic-rapid-passage acting on a two-photon resonant transition to the neutral biexciton state. This scheme allows the implementation of a deterministic two-photon source insensitive to power fluctuations of the pump laser.

HL 18.4 Thu 14:30 H4

Quantum Efficiency and Oscillator Strength of InGaAs Quantum Dots for Single-Photon Sources emitting in the Telecommunication O-Band — •Jan Grosse[1], Paweł Mrowiński[1,2], Nicole Srocka[1], and Stephan Reitzenstein[1] — [1]Technische Universität Berlin, Institute for Solid State Physics, Hardenbergstraße 36, 10623 Berlin, Germany — [2]Laboratory for Optical Spectroscopy of Nanostructures, Wrocław University of Technology, Wybrzeze Wyspiańskiego 27, Wrocław, Poland

We demonstrate experimental results based on time-resolved photoluminescence spectroscopy to determine the oscillator strength and the internal quantum efficiency (IQE) of InGaAs quantum dots (QDs) capped by a strain-reducing layer [1] which have been used in single-photon sources (SPS) emitting in the telecom O-Band [2]. The oscillator strength and IQE are evaluated by determining the radiative and non-radiative decay rate under variation of the optical density of states at the position of the QD [3]. We measure a QD sample with different thicknesses of the capping layer realized by a controlled wet-chemical etching process. From numeric modelling the radiative and nonradiative decay rates dependence on the capping layer thickness, we determine an oscillator strength of 24.6 * 3.2 and a high IQE of about (85 * 10)% for the long-wavelength InGaAs QDs [4].

[1] J. Bloch et al., Appl. Phys. Lett. 75, 2199 (1999). [2] A. Musiał et al., Adv. Quantum Technol. 3, 2000018 (2020). [3] J. Johansen et al., Phys. Rev. B 77, 073303 (2008). [4] J. Große et al, arXiv:2106.05351 (2021).

HL 18.5 Thu 14:45 H4

Resonance fluorescence of single In(Ga)As quantum dots emitting in the telecom C-band — •Julius Fischer, Cornelius Nawrath, Hüseyin Vural, Richard Schaber, 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, Germany

Quantum dots represent a rapidly developing platform as sources of non-classical states of light for tackling quantum communication and computation tasks. Especially quantum dots emitting in the telecom C-band (1530nm-1565nm) are promising candidates due to the low absorption losses in the existent telecommunication fiber network.

In this study, we investigate In(Ga)As quantum dots emitting in the telecom C-band under resonant excitation to examine coherence properties and to investigate their single-photon purity as well as photon indistinguishability. Under strong resonant cw excitation, high-resolution fluorescence spectra, namely the Mollow triplet, of a single quantum dot are investigated. These spectra, in combination with a comprehensive fitting procedure, are used as a method to quantitatively attribute decoherence processes and thus presenting an excellent method to provide important insights for future sample optimizations. In addition, under pulsed resonant excitation, the capability of emitting highly pure single photons ($g^{(2)}(0) = 0.023 \pm 0.019$) with a non-postselected indistinguishability of subsequently emitted photons of $V_{\mathrm{TPI}} = 0.144 \pm 0.015$ is demonstrated.

15 min. break

HL 18.6 Thu 15:15 H4

Evaluating a Plug&Play Telecom-Wavelength Single-Photon Source for Quantum Key Distribution — Timm Gao[1], •Lucas Rickert[1], Felix Urban[1], Jan Grosse[1], Nicole Srocka[1], Sven Rodt[1], Anna Musiał[2], Kinga Żołnacz[3], Paweł Mergo[4], Kamil Dybka[5], Wacław Urbańczyk[3], Grzegorz Sęk[2], Sven Burger[6], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institute of Solid State Physics, Technical University Berlin, 10623 Berlin, Germany — [2]Department of Experimental Physics, Wrocław University of Science and Technology, 50-370 Wroclaw, Poland — [3]Department of Optics and Photonics, Wroclaw University of Science and Technology, 50-370 Wrocław, Poland — [4]Institute of Chemical Sciences, Maria Curie Sklodowska University, 20-031 Lublin, Poland — [5]Fibrain Sp. z o.o., 36-062 Zaczernie, Poland — [6]Zuse Institute Berlin, 14195 Berlin, Germany

We report on quantum key distribution (QKD) tests using a 19-inch benchtop single-photon source at 1321 nm based on a fiber-pigtailed quantum dot (QD) integrated into a Stirling cryocooler. Emulating the polarization-encoded BB84 protocol, we achieve an antibunching of $g^{(2)}(0) = 0.10 \pm 0.01$, a raw key rate of up to 4.72 ± 0.13 kHz, and a maximum tolerable loss of 23.19 dB exploiting optimized temporal filters in the asymptotic limit [1]. Our study represents an important step forward in the development of fiber-based quantum-secured communication networks exploiting sub-Poissonian quantum light sources.

[1] T. Kupko et al., arXiv.2105.03473 (2021)

HL 18.7 Thu 15:30 H4

Emission and absorption of a radiative Auger transition — •Clemens Spinnler[1], Liang Zhai[1], Giang N. Nguyen[1], Julian Ritzmann[2], Andreas D. Wieck[2], Arne Ludwig[2], Alisa Javadi[1], Doris E. Reiter[4], Paweł Machnikowski[3], Richard J. Warburton[1], and Matthias C. Löbl[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany — [3]Department of Theoretical Physics, Wrocław University of Science and Technology, Poland — [4]Institut für Festkörpertheorie, Universität Münster, Germany

In multi-electron systems, such as charged semiconductor quantum dots (QD), several electron-hole recombination processes can take place. Besides the well-known resonance fluorescence, Coulomb interactions can lead to radiative Auger processes (shake-up) where part of the recombination energy is transferred to another electron. This Auger electron is left in an excited state and the emitted photon is correspondingly red-shifted.

We report the observation of emission and absorption of a radiative Auger transition from a negatively charged QD. By applying quantum optics techniques to the Auger emission we get insight into single-electron dynamics. We show photon absorption via the radiative Auger transition by driving the QD in a Λ-configuration: while monitoring the resonance fluorescence a second laser is tuned in resonance with the radiative Auger transition. A fluorescence reduction of up to 70% is observed - proving optical driving of the radiative Auger transition.

HL 18.8 Thu 15:45 H4

Interfacing colloidal quantum dots with nanophotonic circuits for integrated single photon sources — •Tobias Spiekermann, Alexander Eich, Helge Gehring, Lisa Sommer, Julian Bankwitz, Wolfram Pernice, and Carsten Schuck — Institute of Physics, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Single photon sources are a key element for the realization of quantum communication, sensing and computing. While there exist several promising quantum emitter candidate systems, integration with nanophotonic networks in large numbers for wafer-scale quantum technologies has remained elusive. Here we show a lithographic technique that allows for interfacing nanophotonic waveguides with individual Colloidal Quantum Dots (CQD) from a solution applied across an entire chip [1]. We record the second order autocorrelation function to confirm single photon emission from CQDs into tantalum pentoxide (Ta_2O_5) waveguides that feature low intrinsic material fluorescence. Moreover, we demonstrate how iterative processing can be used to increase the yield of single CQDs with our technique. We further improve the photostability of CQDs positioned on a chip by subsequent site-passivation via atomic layer deposition of alumina (Al_2O_3). Our work paves the way for scalable integration of colloidal quantum dot single photon sources with photonic integrated circuits.

[1] Cherie R. Kagan, et al., Colloidal Quantum Dots as Platforms for Quantum Information Science, Chemical Reviews 121 (5), 3186-3233 (2021)

HL 18.9 Thu 16:00 H4

Electrical Characterisation of Te-doped InAs Nanowires grown by VS Molecular Beam Epitaxy — •Anton Faustmann, Pujitha Perla, Detlev Grützmacher, Mihail Lepsa und Thomas Schäpers — Peter-Grünberg-Institut PGI-9, FZ-Jülich, Jülich, Deutschland

InAs features high electron mobility and absence of a Schottky barrier at metal interfaces enabling ohmic contacts. In combination with large g-factor and high Rashba spin-orbit coupling this makes InAs nanowires a promising candidate for research of quantum effects. InAs nanowires with Te doping grown by molecular beam epitaxy were investigated in terms of their electrical transport properties at both room and cryogenic temperatures. The nanowires were grown in a catalyst-free vapour-solid process without using Au droplets. In contrast to Si, which shows amphoteric behaviour, Te acts as n-type dopant. It furthermore offers the possibility of an increased overall doping level. The Te doping concentration was found to affect both the morphology of the nanowires as well as electrical properties. The shape of the nanowires depends on Te uptake. Their intrinsic as well as contact resistances decrease considerably at increased doping level. Field-effect measurements using a global back gate show effect on the conductance, depending on the doping concentration. For higher doping no complete pinch-off was observable with conductance saturating at high negative gate voltages. Resistances were found to be only slightly increased at cryogenic temperatures.

HL 18.10 Thu 16:15 H4

Emission Time Statistics of a driven Single-Electron Transistor — •Johannes C. Bayer[1], Fredrik Brange[2], Adrian Schmidt[1], Timo Wagner[1], Christian Flindt[2], and Rolf J. Haug[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Department of Applied Physics, Aalto University, Finland

Precisely controllable single particle sources are an essential part of different quantum technologies operating at fixed clock cycles. A high level of accuracy in the time domain thereby requires detailed understanding of the interplay between an external drive and the response of the single particle source [1,2]. We here present the influence of periodically modulated tunneling rates on the emission time statistics of electrons emitted from a single-electron transistor (SET) [3]. A highly sensitive charge detector allows to detect tunneling events in real-time. By ramping up the driving frequency from slower to faster than the electron tunneling rate, the response of the SET undergoes a transition from adiabatic to non-adiabatic dynamics. This transition is accompanied by significant changes in the emission time statistics, which can be visualized in the waiting time distribution and is well described by our detailed theory.

[1] T. Wagner, et. al., Nat. Phys. 15, 330-334 (2019).
[2] R. Hussein, et. al., Phys. Rev. Lett. 125, 206801 (2020).
[3] F. Brange, et. al., Sci. Adv. 7, eabe0793 (2021).

HL 19: Poster Session IV

Topics:
- Semiconductor lasers
- Semiconductors for quantum technologies
- Ultra-fast phenomena
- Oxide semiconductors
- Tailored Nonlinear Photonics

Time: Thursday 13:30–16:30 Location: P

HL 19.1 Thu 13:30 P

Bandgap and Secondary Phase Analysis of (A)CIGS Solar Cell Absorber and Buffer Layers Using Electroreflectance Spectroscopy — •Michael Dao[1], Jonas Grutke[1], Wolfram Witte[2], Dimitrios Hariskos[2], Heinz Kalt[1], and Michael Hetterich[1,3] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany — [3]Light Technology Institute, KIT, 76131 Karlsruhe, Germany

Thin-film solar cells based on $Cu(In,Ga)Se_2$ (CIGS) absorbers have established themselves as highly efficient photovoltaic devices. To further optimize their properties, the incorporation of silver (Ag) into the absorber layer (ACIGS) is currently investigated by many groups. In this contribution, the effect of Ag on the absorber bandgap energy as well as the corresponding inhomogeneous broadening is investigated by electroreflectance spectroscopy (ER) which allows a destruction-free analysis of full device structures. Additionally, angle-resolved ER (ARER) is applied to study the impact of Ag on the formation of secondary phases as well as possible interdiffusion effects at the absorber-buffer interface. Using this technique, the bandgap energies of both the buffer layer as well as secondary phases can be determined despite interference effects in the multi-layered device structure and the small thickness < 60 nm of the buffer layer.

HL 19.2 Thu 13:30 P

Electroreflectance as a Powerful Tool to Investigate Internal Device Parameters in CIGS Solar Cells — •Lennart Meyer[1], Jonas Grutke[1], Wolfram Witte[2], Dimitrios Hariskos[2], Heinz Kalt[1], and Michael Hetterich[1,3] — [1]Institute of Applied Physics, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Zentrum für Sonnenenergie- und Wasserstoff-Forschung Baden-Württemberg (ZSW), 70563 Stuttgart, Germany — [3]Light Technology Institute, KIT, 76131 Karlsruhe, Germany

Recently, our group has developed and successfully utilized various advanced electroreflectance (ER) spectroscopy techniques for the destruction-free analysis of $Cu(In,Ga)Se_2$ (CIGS) solar cell absorber and buffer layers in full devices, including investigations into interdiffusion phenomena and secondary phase formation. In this contribution, we present first steps towards a novel ER approach that shall enable the determination of internal device parameters such as the built-in potential drop at the absorber-buffer interface, the carrier concentration in the absorber, or the width of the space charge region. To this end, the variation of the CIGS bandgap resonance amplitude in the ER spectra is analysed as a function of the simultaneously applied AC and DC reverse biases, respectively. The cell parameters can then be obtained via theoretical modelling of the experimental data. First examples and applications of this method will be discussed.

HL 19.3 Thu 13:30 P

Atomic and electronic structure of the GaP/Si(001) heterointerface studied by HAXPES — •Agnieszka Paszuk[1], Oleksandr Romanyuk[2], Igor Bartoš[2], Regan G. Wilks[3], Manali Nandy[1], Jakob Bombsch[3], Claudia Hartmann[3], Raül Garcia-Diez[3], Shigenori Ueda[4], Ivan Gordeev[2], Jana Houdkova[2], Peter Kleinschmidt[1], Marcus Bär[3], Peter Jiříček[2], and Thomas Hannappel[1] — [1]Institute of Physics, University of Technology, Ilmenau, German — [2]Institute of Physics, Prague, Czech Republic — [3]Department Interface Design, Helmholtz-Zentrum Berlin, Germany — [4]SPring-8, National Institute for Materials Science, Japan

For highly efficient III-V-on-Si optoelectronic devices it is crucial to prepare defect-free heterointerfaces with defined electronic properties. Commonly a thin, pseudomorphic GaP epilayer is deposited on Si prior to further III-V buffer growth, due to its close lattice matching to Si. Here, the atomic and electronic structures of buried GaP/Si(001) heterointerfaces prepared by MOCVD were investigated by hard X-ray photoelectron spectroscopy combined with theoretical modelling. 4 - 50 nm thick GaP films with a different density of antiphase domain boundaries were grown on Si(001) H-terminated surfaces, as controlled by optical *in situ* spectroscopy. We found that the core-level positions and width change with GaP film thickness and Si substrate type. These observations were related to charge replacement and band bending effects at the interface. In consequence, an inter-diffused layer interface structure model based on the formation of Si-P bonds at the heterointerface and P-doping of the Si substrate is suggested.

HL 19.4 Thu 13:30 P

Electric-field-driven evolution of anti-Frenkel defects in ErMnO3 — •Jiali He[1], Ursula Ludacka[1], Donald Evans[1], Theodor Holstad[1], Erik Roede[1], Kasper Hunnestad[1], Konstantin Shapovalov[2], Zewu Yan[3,4], Edith Bourret[4], Antonius Van Helvoort[1], and Dennis Meier[1] — [1]Norwegian University of Science and Technology(NTNU), Trondheim, Norway. — [2]Institute of Materials Science of Barcelona, Bellaterra, Spain — [3]ETH Zurich, Zürich, Switzerland. — [4]Lawrence Berkeley National Laboratory, Berkeley, USA.

The electronic properties of complex oxides can readily be tuned via oxygen defects, offering intriguing opportunities for precisely controlling the conductivity of materials. Recently, anti-Frenkel defects moved into focus for minimally invasive property engineering. Anti-Frenkel defects are charge-neutral interstitial-vacancy pairs, and their injection makes it possible to adjust the transport behavior in oxides without causing long-range ionic migration or changes in stoichiometry. Here, we present a detailed analysis of the electric-field-driven formation and response of anti-Frenkel defects in hexagonal ErMnO3. The defects are generated via an electrically biased nano-sized probe tip and imaged by cAFM and SEM. We investigate the spatio-temporal evolution of the written defects for different drive voltages, complemented by numerical simulations, which reveal a non-trivial evolution, allowing to separate the initially paired vacancies and interstitials. The results provide new insight into the local electronic properties of ErMnO3 and the nanoscale defect physics of functional oxides in in general.

HL 19.5 Thu 13:30 P

Modification of epitaxial La0.6Sr0.3CoO3-δ thin films by ion irradiation — •Yunxia Zhou[1,2], Lei Cao[1], Andreas Herklotz[3], Diana Rata[3], Suqin He[4], Felix Gunkel[4], Ulrich Kentsch[1], Manfred Helm[1], and Shengqiang Zhou[1] — [1]Helmholtz-Zentrum-Dresden-Rossendorf, Institute of Ion Beam Physics and Materials Research, Bautzner Landstrasse 400, D-01328 Dresden, Germany — [2]University of Electronic Science and Technology of China, State Key Laboratory of Electronic Thin Films and Integrated Device, Xiyuan Ave 2006, 611731 Chengdu, China — [3]Institute of Physics, Martin Luther University Halle-Wittenberg, Halle, 06120, Germany — [4]Peter Grünberg Institut (PGI-7), JARA-FIT, Forschungszentrum Jülich GmbH, Jülich, 52425, Germany

Perovskite oxides exhibits rich physics related to ionic defects. In particular, defect concentration and distribution alter the lattice parameters and affect the competitive interplay between strongly correlated electrons, enabling numerous applications, including sensors, catalysts, and memristive devices. In this work, helium-implantation is demonstrated as a fast, low temperature tool to modulate the vacancy profiles in epitaxial La0.6Sr0.4CoO3-δ thin films. Not only a significant lattice expansion solely along the out-of-plane direction is observed, but also a distinct change in physical properties is evidenced. By proper tuning of the implantation parameters, an enhanced resistivity up to several orders of magnitude is achieved at room temperature. These results offer a new playground for the optimization of oxide-based spintronic and electronic devices.

HL 19.6 Thu 13:30 P

Electric-field-driven evolution of anti-Frenkel defects in ErMnO3 — •Jiali He[1], Ursula Ludacka[1], Donald Evans[1], Theodor Holstad[1], Erik Roede[1], Kasper Hunnestad[1], Konstantin Shapovalov[2], Zewu Yan[3,4], Edith Bourret[4], Antonius Van Helvoort[1], and Dennis Meier[1] — [1]Norwegian University of Science and Technology(NTNU), Trondheim, Norway. — [2]Institute of Materials Science of Barcelona, Bellaterra, Spain — [3]ETH Zurich, Zürich, Switzerland. — [4]Lawrence Berkeley National Laboratory, Berkeley, USA.

The electronic properties of complex oxides can readily be tuned via oxygen defects, offering intriguing opportunities for precisely controlling the conductivity of the materials. Recently, anti-Frenkel defects moved into focus for minimally invasive property engineering. Anti-Frenkel defects are charge-neutral interstitial-vacancy pairs, and their injection makes it possible to adjust the transport behavior in oxides without causing long-range ionic migration or changes in stoichiometry. Here, we present a detailed analysis of the electric-field-driven formation and response of anti-Frenkel defects in hexagonal ErMnO3. The defects are generated via an electrically biased nano-sized probe tip and imaged by cAFM and SEM. We investigate the spatio-temporal evolution of the written defects for different drive voltages, complemented by numerical simulations, which reveal a non-trivial evolution, allowing to separate the initially paired vacancies and interstitials. The results provide new insight into the local electronic properties of ErMnO3 and the nanoscale defect physics of functional oxides in general.

HL 19.7 Thu 13:30 P

Ammonia and Acetone Gas Sensor Based on Nanocomposites of Indium Oxide and Multiwalled Carbon Nanotubes — •Nipin Kohli — Technical University Berlin

This work reports the effect of introducing carbon nanotubes in indium oxide on structural, morphological, optical and ammonia sensing properties. Various characterization techniques such as X-ray diffraction, transmission electron microscopy, BET, Fourier transform infrared, UV-visible and Raman spectroscopy were employed to understand the structural, morphological and optical properties of the synthesized samples. The gas sensors were fabricated out of the synthesized samples to test their response towards ammonia and acetone at different operating temperatures and at different concentrations. The nanocomposite exhibits enhanced sensing performance and is capable of detecting concentration of acetone and ammonia as low as 10 ppm at optimum operable temperature of 300°C and 200°C, respectively.

HL 19.8 Thu 13:30 P

Förster-Type Energy Transfer Between Molecules and Atomically Thin Semiconductors — •Manuel Katzer[1], Malte Selig[1], Sviatoslav Kovalchuk[2], Kyrylo Greben[2], Kirill Bolotin[2], and Andreas Knorr[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Department of Physics, Quantum Nanoelectronics of 2D Materials, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

Interfaces of dye molecules and two-dimensional transition metal dichalcogenides (TMDCs) are promising candidates for optoelectronic applications since they combine the large molecular optical amplitudes and spectral range with high carrier mobilities in the semiconductor [1]. In such interfaces, Förster energy transfer is a key mechanism due to the large dipole moments, and has many intriguing technical applications [2].

In a joint theory-experiment study, we report microscopic calculations of the Förster induced transition rate from dye molecules to a TMDC layer and provide the corresponding optical signatures, with excellent agreement to the experimental data. The theoretic approach is based on microscopic Bloch equations which are solved self-consistently together with Maxwells equations [3], incorporating the sample geometry within the Rytova-Keldysh framework.

[1] Jariwala et al. Nat. Mater. **16**, 170 (2017)
[2] Dagher et al. Nat. Nanotech. **13**, 925-932 (2018)
[3] Selig et al. Phys. Rev. B **99**, 035420 (2019)

HL 19.9 Thu 13:30 P

Atomic Structure of Antiphase Domains on GaP/Si(100):As — Dominik Bratek[1], •Peter Kleinschmidt[1], Manali Nandy[1], Oliver Supplie[1,2], Agnieszka Paszuk[1], and Thomas Hannappel[1] — [1]Institut für Physik, Grundlagen von Energiematerialien, Technische Universität Ilmenau, 98693 Ilmenau, Deutschland — [2]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Deutschland

We have investigated the atomic structure of antiphase domains on GaP(100) on As-terminated Si(100) by scanning tunneling microscopy (STM). Thin GaP layers of 5 nm and 10 nm thickness were deposited on predominately double atomic layer stepped, As-terminated Si(100)-substrates by metalorganic vapor phase epitaxy. Small residuals of the intermediate steps on the substrate lead to the formation of minority antiphase domains in the epitaxial GaP. We show that these antiphase domains extend parallel to the step edges of the substrate. In numerous locations, small residual antiphase domains are embedded in trenches parallel to these step edges, and in other locations only the trenches remain, suggesting that these trenches are residuals of overgrown antiphase domains. Our STM measurements reveal the atomic structure of the antiphase boundaries, which varies substantially: some of these boundaries are just characterized by a half bi-layer step, whereas deep trenches are also frequently observed.

HL 19.10 Thu 13:30 P

Ultrafast energy transfer triggers ionization energy offset dependent quantum yields in low-bandgap NFA solar cells — •Julien F. Gorenflot[1], Safakath Karuthedath[1], Yuliar Firdaus[1], Catherine S. De Castro[1], George Harrison[1], Anastasia Markina[2], Neha Chaturvedi[1], Jafar Khan[1], Ahmed H. Balawi[1], Sri H. K. Paleti[1], Thomas Anthopoulos[1], Derya Baran[1], Denis Andrienko[2], and Frédéric Laquai[1] — [1]KAUST Solar Center (KSC), Material Science and Engineering program (MSE), Physical Science and Engineering division (PSE), King Abdullah University of Science and Technology, Thuwal, Saudi Arabia. — [2]Max Planck Institute for Polymer Research, Mainz, Germany.

Organic solar cells associate an electron donor and an electron acceptor to drive exciton-to-charge conversion where the strong EA acceptor attracts electrons from donor excitons, and the low IE donor attracts holes from acceptor excitons. Recent studies however, claim efficient photocurrent generation in recent non-fullerene acceptor (NFA) based systems with close-to-zero IE or EA offsets. Here, we confirm that sizeable IE offsets are required to drive hole transfer from acceptor exciton. Further charge separation from the interface is however barrierless. Due to fast, Förster Resonant Energy Transfer to the low bandgap acceptor, charge transfer always occurs from the acceptor, making the EA offset unimportant. We model the IE offset dependence of hole transfer and find that two physical parameters are sufficient to describe it. Our model also explains barrierless charge separation and the high charge transfer states energies reported in NFA-based systems.

HL 19.11 Thu 13:30 P

Electronic properties of MoS_2 monolayer doped by donor, acceptor, and aromatic molecules — •Juan Pablo Guerrero[1,2], Ana M. Valencia[2,3], Jannis Krumland[2], and Caterina Cocchi[2,3] — [1]Department of Physics, Freie Universität Berlin (Germany) — [2]Department of Physics and IRIS Adlershof, Humboldt-Universität zu Berlin (Germany) — [3]Institute of Physics, Carl von Ossietzky Universität Oldenburg (Germany)

The electronic properties of hybrid inorganic-organic interfaces are critically influenced by the level alignment across the heterostructure and by possible hybridization effects that occur therein. In turn, these properties are determined by the nature of the molecular dopants and by their arrangements. In the framework of (hybrid) density functional theory, we investigate the electronic structure of a single sheet of MoS_2 covered by monolayers of planar molecules such as pyrene, tetrathiafulvalene, and bithiophene, which are known to act as donors, as well as with the acceptors 7,7,8,8-tetracyanoquinodimethane and its tetrafluorinated counterpart. Our results show that all considered heterostructures exhibit a type II level alignment with negligible charge transfer at the interface. However, in the electronic structure of the systems, the signatures of electron or hole doping to the MoS_2 can be identified.

HL 19.12 Thu 13:30 P

Coulomb Blockade at room temperature of self-assembled GaN quantum dot ensembles, measured via Capacitance-Voltage spectroscopy — •Carlo Alberto Sgroi[1], Julien Brault[2], Jean-Yves Duboz[2], Philippe Vennéguès[2], Sébastien Chenot[2], Arne Ludwig[1], and Andreas D. Wieck[1] — [1]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, D-44780 Bochum, Germany — [2]CNRS - CRHEA, Rue Bernard Grégory, 06560 Valbonne, France

We present capacitance voltage (C(V)) measurements at room temperature of charge-tunable self-assembled wurtzite GaN quantum dots (QDs) in an $Al_xGa_{1-x}N$ matrix grown by MBE. GaN and its alloys have excellent properties such as their thermal stability, high thermal conductivity and wide bandgap energies which make them an ideal candidate for next-generation GaN-based power devices at elevated temperatures. Single-photon sources operating at up to 350 K are already possible1. Due to polarization and strain effects in wurtzite $GaN/Al_xGa_{1-x}N$ heterostructure layers, the band structure is different for the cross section with the GaN QDs and the GaN Wetting Layer (WL) on which the QDs are formed. Large electric fields and defect-assisted electron hopping promote charge transfer through the WL. Performing C(V) spectroscopy at 300 K on an AlGaN-Schottky diode structure with embedded GaN QDs, single-electron discharging in the C(V) spectrum and a Coulomb blockade energy of about 70 meV are measured.

[1] Holmes, M. J., et al. ACS Photonics **3**, 543-546 (2016).

HL 19.13 Thu 13:30 P

Exploration of the electrochemical Interface of InP under applied potentials with Reflection Anisotropy Spectroscopy — •Margot Guidat, Mario Löw, Vibhav Yadav, Jongmin Kim, and Matthias M. May — Universität Ulm, Institute of Theoretical Chemistry, Ulm, Germany

A possible way to achieve a low-carbon energy leads through hydrogen, which can be produced via photoelectrochemical water splitting, in which III-V semiconductors play an important role [1]. However, surface corrosion results in limited performance of photoelectrochemical solar cells.

Some studies have reported that surface functionalization is a way to protect the surface, achieved by etching processes. However, this faces fundamental challenges, especially in electrochemical environments [2]. In this work, we investigate photoelectrochemical etching of Indium Phosphide (100) in contact with hydrochloric acid controlled by Reflection Anisotropy Spectroscopy: an in situ optical probe of electrochemical interfaces with very high interface sensitivity.

The RA spectra show a reversible build-up of an optical anisotropy in cathodic potential ranges, which might account for the reduction of InP into phosphine and metallic In. The latter would further react with HCl to form InCl interfacial film.

[1] Wang, T. and Gong, J. Angew. Chem. Int. Ed. 54, 10718-10732 (2015).

[2] B. L. Pearce, S. J. Wilkins, T. Paskova, A. Ivanisevic. Journal of Materials Research 2015, 30, 2859-2870.

HL 19.14 Thu 13:30 P

Carrier effective masses in 2D halide perovskites from a first-principles approach — •Xiangzhou Zhu[1], Mateusz Dyksik[2,3], Jonas D. Ziegler[5], Matan Menahem[4], Jonas Zipfel[5], Barbara Meisinger[5], Michal Baranowski[3], Omer Yaffe[4], Alexey Chernikov[5,6], Paulina Plochocka[2,3], and David A. Egger[1] — [1]Technical University of Munich, Germany — [2]LNCMI CNRS, France — [3]Wroclaw University of Science and Technology, Poland — [4]Weizmann Institute of Science, Israel — [5]University of Regensburg, Germany — [6]Dresden University of Technology, Germany

Two-dimensional halide perovskites (2D HaPs) are attracting significant attention as promising optoelectronic materials. Effective masses of charge carriers are crucial parameters for device performance and exciton behavior. Here, we report first-principles calculations based on density functional theory (DFT) to investigate magnitudes, microscopic origins and consequences of carrier effective masses in 2D HaPs. We demonstrate that distortions due to organic spacers as well as orbital hybridization effects due to metal cations lead to a wide tunability of effectives mass in 2D HaPs[1]. Furthermore, it is shown that the knowledge of the DFT-computed electron and hole masses is key to capture efficient exciton diffusion, as measured by spatially-resolved optical spectroscopy[2].

[1] Dyksik, M, et al. ACS Energy Lett. 5, 3609 (2020)

[2] Ziegler, J. D., et al. Nano Lett. 20, 6674 (2020)

HL 19.15 Thu 13:30 P

The interfacial (electronic) structure of InP(001) in contact with electrolytes from computational spectroscopy — Vibhav Yadav, Margot Guidat, Mario Löw, •Jongmin Kim, and Matthias M. May — Institute of Theoretical Chemistry, Universität Ulm, Ulm, Germany

The relevance of controlling the electrochemical interface of InP derived materials for energy-conversion has already been established [1]. A tandem structure with the ternary compound, AlInP, in contact with the electrolyte showed 19%, solar-to-hydrogen efficiency [2]. In practical applications under operating conditions, a surface in contact with water oxidizes by insertion or substitution. This leads to surface polymerisation: formation of PO_x and In_2O_3. These species improve the stability of the surface and reduce surface charge-carrier recombination. Therefore, an investigation of the interfacial properties is crucial. In this computational work, we model the electrochemical interface, using first-principles calculations, in accordance with previous experimental studies. Using this model, we will probe the electrochemical double layer region to take into account the electric field fluctuations during a molecular dynamics simulation: simulating open circuit conditions. We develop a methodology, enabling the understanding of surface processes, by means of computational reflection anisotropy spectroscopy (RAS) results. Finally, we compare our results with experiments to derive a comprehensive understanding.

[1] O. Khaselev, et al. Science **280**, 425 (1998).

[2] M. M. May, et al. Nat. Commun. **6**, 8286 (2015).

HL 19.16 Thu 13:30 P

Reduction of crystal defects in GaP buffer layers grown on Si(100) by MOCVD — •Manali Nandy[1], Agnieszka Paszuk[1], Markus Feifel[2], Christian Koppka[1], Peter Kleinschmidt[1], Frank Dimroth[2], and Thomas Hannappel[1] — [1]TU Ilmenau, Gustav-Kirchhoff-Straße 5, 98693, Ilmenau — [2]Fraunhofer Institute for Solar Energy Systems ISE, Freiburg 79110, Germany

The performance of III-V-on-Si multijunction solar cells is still limited by a high density of defects at the GaP/Si heterointerface and in the III-V buffer layers. Here, in order to improve the crystal quality of the GaP(100) buffer layer, we modified the GaP pulse nucleation by substituting the first five TEGa pulses with TMAl. The influence of Al on the defect density in the GaP buffer layers is investigated by electron channeling contrast imaging. 60 nm thick GaP(100) buffer layers grown on GaP nucleation exhibit short misfit dislocations (MDs) and therefore, a high density of threading dislocations (TDs). In contrast, GaP(100) buffer layers grown on GaP/AlP nucleation exhibit less, but longer MDs, which result in a lower density of TDs. In addition, the density of stacking faults and stacking faults pyramids in the GaP layer grown on the AlGaP nucleation is significantly reduced. The surface morphology at the initial growth stage of GaP buffer layers grown on AlGaP nucleation, is smoother compared to buffer layer grown on the GaP nucleation. The application of Al in the GaP nucleation process provides a two-dimensional, smooth layer on which subsequent, high-quality GaP films could be grown, and therefore, shows a promising pathway for improving the performance of III-V-on-Si devices.

HL 19.17 Thu 13:30 P

Understanding surface properties of CsK_2Sb from first principles — •Richard Schier[1], Holger-Dietrich Sassnick[2], and Caterina Cocchi[2] — [1]Humboldt-Universität zu Berlin, Physics Department and IRIS Adlershof, 12489 Berlin — [2]Carl von Ossietzky Universität Oldenburg, Institute of Physics, 26129 Oldenburg

Among the most promising compounds for next-generation photocathodes in particle accelerators, CsK_2Sb is regarded with particular interest. While first-principles calculations have recently contributed to gain insight into the bulk characteristics of this system [1], for most physical processes related to photoemission, surface properties are essential. To fill this gap, we use density functional theory to simulate and analyze the stability and the electronic properties of the low-Miller-index surfaces of CsK_2Sb. After assessing the formation energies, we calculate ionization potential (IP), band structure, and projected density of states (PDOS). Depending on the surface, we find IPs ranging from 2.2 eV to 3.4 eV. The computed band structures reveal that CsK_2Sb surfaces can exhibit either direct and indirect bandgaps, and in some specific cases they can even become metallic. The calculated PDOS offers insight into the atomic contributions to the bands around the Fermi energy.

[1] C. Cocchi et al., J. Phys: Condens. Matter 31, 014002 (2019)

HL 19.18 Thu 13:30 P

Copper iodide thin films: Multistack AFM studies of local electrical properties — •Tillmann Stralka, Holger von Wenckstern, and Marius Grundmann — Solid State Physics, Leipzig, Germany

The search for high-performance p-type transparent 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 strive to understand and differentiate the contribution of grains and grain boundaries (GBs) to transport mechanisms. Topographic features as GBs lead to a depletion of majority charge carriers and even a localised inversion (two dimensional electron gas) within GBs [4]. To acquire morphological and electrical properties with a high spatial resolution we employ atomic force microscopy, which additionally offers current probe mode to characterise electrical properties. These measurements will be conducted and evaluated with a novel approach that offers voltage spectroscopy and localisation of nm sized objects at the same time furthermore correlate topographic features with electrical properties.

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

HL 19.19 Thu 13:30 P

Pump-probe measurements to detect ultra-fast carrier dynamics and carrier density saturation in GaN-based quantum wells — •Malte Schrader, Philipp Henning, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik & Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, 38106 Braunschweig, Germany

The aim of our study is to understand the carrier dynamics in GaN-based quantum wells at high carrier densities. An accurate estimation of the excited charge carrier density in pulsed laser experiments by indirect fluence-to-charge-density conversion is flawed, because the available states for the excited electrons in the conduction band might already be completely filled by the high fluence laser pulse.

We therefore show in this contribution a direct approach by using two pulsed laser beams in quick succession in a pump-probe setup: a pump beam excites the carriers and a probe beam measures the transmission shortly thereafter, and therefore the occupation of the states above the band edge. A laser pulse duration of 35 fs at 5 kHz repetition rate is used in a degenerate setup, meaning pump and probe beam have the same wavelength. The decay of the excited carrier states is encoded in the transmitted probe beam as a function of the delay between pump and probe beam. To detect a saturation limit the fluence of the pump beam is increased. Besides two distinct decay times of around 10 ps and several 100 ps respectively, the ultra-fast intraband relaxation in the fs domain is of special interest.

HL 19.20 Thu 13:30 P

Tuning the electrochemical properties of multifunctional catalyst layers by plasma-enhanced atomic layer deposition — •Matthias Kuhl, Alex Henning, Lukas Haller, Laura Wagner, Chang-Ming Jiang, Verena Streibel, Ian D. Sharp, and Johanna Eichhorn — Walter Schottky Institut, Technische Universität München

Major challenges in photoelectrochemical (PEC) energy conversion systems are the poor efficiency and material instability of semiconductor photoelectrodes under the harsh operating conditions. Recently, it was demonstrated that plasma-enhanced atomic layer deposition (PE-ALD) can be used to fabricate conformal, biphasic Co_3O_4/Co(OH)$_2$ catalyst layers on semiconductor photoelectrodes, which are simultaneously robust and electrochemically active. The nanocrystalline Co_3O_4 layer forms a durable interface to the substrate and the disordered Co(OH)$_2$ surface layer significantly improves the electrocatalytic oxygen evolution reaction (OER) activity.

Here, we leverage the precise control of PE-ALD to further tailor the thickness ratio of the surface and interface layers of the Co_3O_4/Co(OH)$_2$ bilayer by tuning the plasma exposure time during growth. Short pulses lead to the formation of porous, unstable, catalytically active Co(OH)$_2$ layers due to an incomplete precursor decomposition, while long pulses result in denser films and form stable, inactive Co_3O_4 layers. More generally, this work highlights the power of PE-ALD for engineering catalyst/semiconductor interfaces simultaneously exhibiting multiple functionalities.

HL 19.21 Thu 13:30 P

Effect of hydrogen in low temperature GaN underlayer on the effective carrier lifetime in GaInN/GaN single quantum wells — •Rodrigo De Vasconcellos Lourenço[1,2], Philipp Henning[1,2], Samar Hagag[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

The luminescence efficiency of GaInN single quantum well (SQW) structures is affected by the growth conditions of all the layers grown before it and especially those ones directly before the quantum well - the so-called underlayer (UL). Usually, nitrogen is used as carrier gas during low temperature UL growth in low-pressure MOVPE. In this work, molecular hydrogen was added to the carrier gas during pure GaN UL growth and its supply was closed well before the QW is grown. Time-resolved photoluminescence measurements of SQWs with UL containing hydrogen and intentional Si doping suggest that they have better internal quantum efficiency at low temperature compared to the reference sample. Additionally, those showed longer radiative lifetime and longer emission wavelengths at low temperature compared to SQWs with doped UL and without hydrogen. This may indicate that hydrogen reduces the free carriers density by partly compensating the Si doping. Comparing SQWs with UL not intentionally doped, the one containing hydrogen showed shorter effective lifetime at low temperature, which could suggest that hydrogen acts as a donor or that hydrogen induces non-radiative centers.

HL 19.22 Thu 13:30 P

Transient Dielectric Function of Ge, Si, and InP from Femtosecond Pump-Probe Ellipsometry — •Carola Emminger[1,2], Shirly Espinoza[3], Steffen Richter[3,4], Oliver Herrfurth[5,6], Mateusz Rebarz[3], Martin Zahradník[3], Rüdiger Schmidt-Grund[6,7], Jakob Andreasson[3], and Stefan Zollner[1] — [1]New Mexico State University — [2]Masaryk University — [3]ELI Beamlines — [4]Linköpings universitet — [5]Active Fiber Systems — [6]Universität Leipzig — [7]Technische Universität Ilmenau

Structures in the dielectric function (DF), known as critical points (CPs), depend on temperature, strain, composition, and doping. We investigate CPs in the transient DF of Ge, Si, and InP measured with femtosecond pump-probe spectroscopic ellipsometry by calculating the second derivatives of the DF with respect to energy using a linear filter technique, which combines interpolation, noise reduction, scale change, and differentiation. From fitting an n-dimensional CP lineshape to the second derivatives, we find the amplitude, excitonic phase angle, threshold energy, and broadening as functions of delay time. A distinctive change of the CP parameters occurs within the first couple of picoseconds after the pump pulse. In the case of Ge, the CP energies red-shift due to band gap renormalization and an increase in temperature due to laser heating. After about 4 ps, the DF and CP parameters start to recover. Up to about 30 ps, coherent acoustic phonon oscillations are observed in the temporal evolution of the CP parameters. The period of these oscillations is approximately 11 ps, which is in good agreement with theory.

HL 19.23 Thu 13:30 P

X-ray absorption fingerprints in *$LiCoO_2$* and *CoO_2* — •Daniel Duarte Ruiz and Caterina Cocchi — Carl von Ossietzky Universität Oldenburg, Institut für Physik, Oldenburg, Deutschland

$LiCoO_2$ is a popular cathode material for Li-ion batteries, whereby X-ray absorption near-edge structure (XANES) is typically used to characterize electrodes in operando conditions. Identifying the spectral fingerprints of this compound and of its delithiated counterpart is therefore essential to provide references for the interpretation of the experimental spectra. In an *ab initio* work based on all-electron density functional theory and many-body perturbation theory (Bethe-Salpeter equation)[1], the XANES spectra of LiCoO2 and CoO2 are computed and analized for O K-edge as well as for the Co K- and $L_{2,3}$-edges. With the adopted approach, we are able to assess that in all spectra, excitonic effects manifest themselves only via a red-shift on the absorption peaks. Clear signatures distinguishing binary and ternary compounds in the O K-edge and Co $L_{2,3}$-edges spectra can be identified.

[1] C. Vorwerk et al. *Electron. Struc.* 1, 037001 (2019).

HL 19.24 Thu 13:30 P

RF beat note analysis of a semiconductor optical frequency comb — •Duc Nam Nguyen[1], Dominik Auth[1], Quentin Gaimard[2], Abderrahim Ramdane[2], and Stefan Breuer[1,3] — [1]Institute of Applied Physics, TU Darmstadt, Darmstadt, Germany — [2]Centre de Nanosciences et Nanotechnologies, Palaiseau, France — [3]John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, USA

We experimentally study the RF beat note and optical spectra evolution of a frequency-modulated near-infrared semiconductor comb laser. We show and explain a transition towards stable optical frequency comb generation in dependence on the electrical biasing conditions.

HL 19.25 Thu 13:30 P

Contactless Measurement of the Sheet Resistance of two-dimensional Electron Gases — •Timo A. Kurschat, Arne Ludwig, and Andreas D. Wieck — Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum

The aim of this work is to measure the sheet resistance of two-dimensional electron gases in GaAs without the need for built-in contacts. Thus a characterization is possible without destroying the wafer. This method can be used to create spatially resolved maps of whole wafers to evaluate quality and homogeneity prior to further processing.

The sheet resistance is measured by placing two electrodes (round metal plates) close to the sample. These electrodes form capacitances C with the conductive layer. With a high-frequency alternating voltage applied to one electrode, the transmitted power can be measured at the other one. The measured amplitude depends on the sample resistance and the impedance of the capacitances, which are proportional to $1/\omega C$.

The electrodes have a diameter of 3 mm and 6 mm center-to-center distance. The measurement range starts at about 300 $\Omega/\square$ and goes up to 50 k$\Omega/\square$. The sheet resistance is determined by sweeping the frequency between 1 MHz and 400 MHz and then applying a fit.

Besides the measurements of samples with known sheet resistance, maps of complete wafers are shown. The lateral resolution of about 5 mm depends on the size of the electrodes and was estimated by etching a structure on a wafer.

HL 19.26 Thu 13:30 P

Thermal Conductivity Measurements in β-Ga_2O_3 Thin 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. Therefore, it is crucial to investigate the thermal transport in Ga_2O_3 films. Electrical measurements have shown that in very thin films the scattering processes change drastically with decreasing film thickness [3]. In this work, we investigate the thermal conductivity in these thin films, using the 3-ω and 2-ω method.
A variation of the 3-ω method with sub μm heater widths, with heaters thinner than the thickness of the examined films, is used. The heaters are realized by electron beam lithography. We investigate the thermal conductivity in dependence of the temperature and the thickness of the Ga_2O_3 films, with a special interest in changes in the the phonon transport mechanisms in a quasi-ballistic phonon transport regime.

[1] M. Handwerg *et al.*, Semicond. Sci. Technol. **30**, (2015) 024006
[2] M. Handwerg *et al.*, Semicond. Sci. Technol. **31**, (2016) 125006
[3] R. Ahrling *et al.*, Sci. Rep. **9**, 13149 (2019).

HL 19.27 Thu 13:30 P

Contact Preparation and Thermoelectric Properties of Bismuth Nanowires — •Mahni Müller[1], Rüdiger Mitdank[1], Hoda Moosavi[2], Michael Kröner[2], Peter Woias[2], Jeongmin Kim[3], Wooyoung Lee[3], Adnan Hammoud[4], Thomas Lunkenbein[4], and Saskia Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 10099 Berlin, Germany — [2]Laboratory of Design of Microsystems, University of Freiburg, IMTEK, 79110 Freiburg, Germany — [3]Department of Material Science and Engineering, Yonsei University, 03722 Seoul, Repuplic of Korea — [4]Fritz Haber Institute of the Max Planck Society, 14195 Berlin, Germany

Bismuth-based thermoelectric materials have always been promising for improving the thermoelectric figure of merit [1]. Those properties can strongly be modified through nanostructuring and additionally a high surface-to-volume-ratio is obtained with nanowires [2].

However, due to air exposure, a native oxide shell forms around the bismuth core, which leads to non-ohmic contact resistances. To achieve ohmic contacts for low temperature measurements, we present a preparation method with focused-ion-beam-induced deposition (fibid). Measurements of the electrical and thermal conductivity and of the Seebeck coefficient of bismuth nanowires with fibid-contacts between 10 K and 300 K were performed and compared to bulk. We discuss the change in properties and the possible influence of the contacting method.

[1] M. S. Dresselhaus *et al.*, Phys. Solid State **41**, 679-682 (1999).
[2] T. E. Huber *et al.*, Phys. Rev. B **83**, 2354414 (2011).

HL 19.28 Thu 13:30 P

Nonlinear down-conversion in a single 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 study an all optical approach based on nonlinear principles, to tune the emission of the biexciton state in a single quantum dot[1]. After preparation of the biexciton state via phonon-assisted two-photon excitation, we introduce a control-laser which enables a nonlinear down-conversion via a virtual state. Previous theoretical work suggests that the spectral and polarization properties of this stimulated emission can be fully controled by adjusting the respetive properties of the control-laser[2]. In this work we show the first experimental demonstration of this process. The stimulated down-conversion works best if the virtual state is tuned close to the exciton energy and we can achieve a tuning range of about 0.5 meV around the exciton and biexciton emission. We furthermore make use of the spin conservation in the system to demonstrate control of the polarization of the emitted photon.

[1] http://arxiv.org/abs/2105.12393
[2] D. Heinze et al., Nature Communications **6**, 8473 (2015)

HL 19.29 Thu 13:30 P

Spin lasing in bimodal quantum dot micropillar cavities — •Niels Heermeier[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 are highly interesting photonic devices and 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 attractive 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 which is 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.

HL 19.30 Thu 13:30 P

Non-integer high-harmonic generation in a topological insulator — Christoph P. Schmid[1], Leonard Weigl[1], Patrick Grössing[2], Vanessa Junk[2], Cosimo Gorini[2], Stefan Schlauderer[1], Suguru Ito[3], •Manuel Meierhofer[1], Niklas Hofmann[1], Dmytro Afanasiev[1], Jack Crewse[2], Konstantin A. Kokh[4,5], Oleg E. Tereshchenko[5,6], Jens Güdde[3], Ferdinand Evers[2], Jan Wilhelm[2], Klaus Richter[2], Ulrich Höfer[3], and Rupert Huber[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, Germany — [2]Institute of Theoretical Physics, University of Regensburg, Germany — [3]Department of Physics, Philipps-University of Marburg, Germany — [4]V.S. Sobolev Institute of Geology and Mineralogy SB RAS, Novosibirsk, Russia — [5]Novosibirsk State University, Russia — [6]A.V. Rzhanov Institute of Semiconductor Physics SB RAS, Novosibirsk, Russia

We demonstrate multi-THz high-harmonic generation (HHG) in the topological insulator bismuth telluride. The frequency of the driving field discriminates between HHG from the bulk and the topological surface, where long scattering times and the quasi-relativistic dispersion enable unusually efficient HHG. All observed orders, generated in the surface state, can be continuously shifted to arbitrary non-integer multiples of the driving frequency by varying the carrier-envelope phase of the driving field. The anomalous Berry curvature enforces meandering ballistic trajectories of the Dirac fermions, causing a hallmark HH polarization pattern. Our study provides a fascinating new platform to explore topology and relativistic strong-field quantum physics.

HL 19.31 Thu 13:30 P

Exciton-phonon coupling in transition metal dichalcogenides revealed by ultrafast electron diffraction. — •Ahmed Hassanien, Arne Ungeheuer, Mashood Tarek Mir, Lukas Nöding, Arne Senftleben, and Thomas Baumert — Institute of Physics and CINSaT, University of Kassel, Heinrich-Plett-Strasse 40, D-34132 Kassel, Germany

Exciton-phonon coupling (EXPC) is responsible in principle for the temperature-dependence of optoelectronic and transport properties of transition metal dichalcogenides (TMDCs). The signatures of EXPC are usually observed in resonance Raman scattering [1], time-resolved transmission measurements [2], in optical absorption [3] or recently in two-dimensional electronic spectroscopy (2DES) [4]. Using a highly compact femtosecond electron diffractometer developed in our group [5], we were able to probe a polarization-dependent lattice dynamics in mechanically exfoliated few-layers ReS2. These anisotropic structural dynamics followed the photoexcitation by femtosecond laser pulses spectrally in resonance with the lowest excitonic transitions in ReS2 [6].

References:
[1] Yang, Jinho, et al. FlatChem 3 (2017): 64-70. [2] Jeong, Tae Young, et al. Acs Nano 10.5 (2016): 5560-5566. [3] Christiansen, Dominik, et al. Physical review letters 119.18 (2017): 187402. [4] Li, Donghai, et al. Nature communications 12.1 (2021): 1-9. [5] Gerbig, C., et al. New J. Phys. 17.4 (2015):043050. [6] Sim, Sangwan, et al. Nature communications 7 (2016): 13569.

HL 20: Annual General Meeting of the Semiconductor Physics Division

Time: Thursday 18:00–19:00 Location: MVHL

Duration 60 min.

HL 21: Focus Session: Highlights of Materials Science and Applied Physics II (joint session DS/HL)

Jointly organized on the occasion of the 60th anniversary of the *physica status solidi* journals (*pss*, http://www.pss-journals.com), this Focus Session features several invited presentations, talks and posters from key contributors on core condensed matter and applied physics topics. Highlights comprise the latest results on diamond, nitride semiconductors, organic materials, two-dimensional and quantum systems, oxides, magnetic materials, solar cells, thermoelectrics and more.

physica status solidi was launched by Akademie-Verlag Berlin in July 1961 and is published by Wiley-VCH Berlin and Weinheim today, supported by Wiley colleagues in China and the US. While in its first three decades it served as an East-West forum for solid state physics, since 1990 it has evolved into a family of journals with international author- and readership in a globalized scientific world. Its professional editorial services include topical curation, peer review organization, technical editing, special issue and hybrid open access publication.

The Focus session celebrates the numerous close collaborations and the steady support which the journals receive from their Advisory Board members, authors, reviewers and guest editors, including many members of the DPG and the condensed matter physics community in Germany.

(More information on '60 years of *pss*' is available at http://bit.ly/60_years_pss)

Organizers: Stefan Hildebrandt (Editor-in-Chief, pss), Norbert Esser (TU Berlin, ISAS) and Stephan Reitzenstein (TU Berlin)

Time: Friday 10:00–11:00 Location: H1

HL 21.1 Fri 10:00 H1

Additive manufacturing of permanent magnets based on (CoCuFeZr)$_{17}$Sm$_2$ — •Dagmar Goll, Felix Trauter, Philipp Braun, Judith Laukart, Ralf Löffler, Ute Golla-Schindler, and Gerhard Schneider — Aalen University, Materials Research Institute, Beethovenstr. 1, 73430 Aalen, Germany

Lab-scale additive manufacturing of (CoCuFeZr)$_{17}$Sm$_2$-based powder was performed to realize CoSm printed parts with hard magnetic properties. For manufacturing a special inert gas process chamber for laser powder bed fusion was used. A three-step annealing procedure analogous to sintered magnets was applied. This led to a coercivity of 2.77 T, remanence of 0.78 T and maximum energy density of 109.4 kJ/m^3 for the printed parts. Compared to an isotropic sintered magnet of comparable composition and annealing procedure, the coercivity is of the same order. Due to the texture of the printed parts the remanence is 24 % larger.

HL 21.2 Fri 10:15 H1

Structure solution of a large unit cell approximant derived from SrTiO$_3$ on Pt(111) — •Stefan Förster[1], Sebastian Schenk[1], Oliver Krahn[1], Holger L. Meyerheim[2], Marc DeBoissieu[3], and Wolf Widdra[1] — [1]Martin-Luther-Universität Halle-Wittenberg, Halle, Germany — [2]Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany — [3]Universite Grenoble Alps, CNRS, SIMaP, Saint-Martin d'Hères, France

The discovery of two-dimensional oxide quasicrystals (OQC) has caused a great amount of interest in aperiodic structure formation from perovskite materials on metal surfaces [1]. In recent years, a plethora of surface science techniques has been applied to OQCs to get an understanding of this peculiar materials system on the fundamental level [2]. In this contribution, we present low-temperature scanning tunneling microscopy (STM) and surface x-ray diffraction (SXRD) investigation of the largest unit cell approximant known so far in 2D systems. Its unit cell covers an area of approximately 44 Å × 44 Å and has p2gg symmetry. STM measurements show 48 atoms in the unit cell forming the vertices of 48 triangles, 18 squares and 6 rhombuses. The structure has been solved utilizing over 300 independent reflections measured by SXRD with an R-factor better than 0.20. From this analysis a profound understanding of the decoration of all tiles with Sr, Ti, and O ions is derived, which solves the structure of the parent OQC.

[1] S. Förster et. al., Nature 502, 215 (2013).
[2] S. Förster et al., Phys. Status Solidi B 257, 1900624 (2020).

HL 21.3 Fri 10:30 H1

Surface reconstructions: challenges and opportunities for the growth of perovskite oxides — Giada Franceschi, Michael Schmid, Ulrike Diebold, and •Michele Riva — Institute of Applied Physics, TU Wien, Austria

Achieving atomically flat and stoichiometric films of complex multicomponent oxides is crucial for integrating these materials in emerging technologies. While pulsed laser deposition (PLD) can in principle produce these high-quality films, experiments often show rough surfaces and nonstoichiometric compositions.

To understand the cause, we follow the growth at the atomic scale from its early stages, using STM. We focus on SrTiO$_3$(110) and La$_{0.8}$Sr$_{0.2}$MnO$_3$(110) films. For both, the non-stoichiometries introduced during growth accumulate at the surface. As a result, their surface structure evolves along phase diagrams of surface structure vs. composition [1,2,3]. This can drastically degrade the surface morphology: pits develop on reconstructed areas with different sticking [4]; ill-defined oxide clusters nucleate when the non-stoichiometry introduced is too large to be accommodated in the surface by changing its structure. On the flip side, one can take advantage of the high sensitivity of surface structures to composition deviations to grow films with thickness of several tens of nanometers retaining atomically flat surfaces, and with stoichiometry control better than 0.1% [1].

[1] Phys. Rev. Mater. **3**, 043802 (2019). [2] J. Mater. Chem. A **8**, 22947 (2020). [3] arXiv:2010.05205 (2020). [4] Phys. Rev. Res. **1**, 033059 (2019).

HL 21.4 Fri 10:45 H1

Investigation of Spin Pumping through α-Sn Interlayer — •Leszek Gladczuk[1], Lukasz Gladczuik[2], Piotr Dluzewski[1], Gerrit van der Laan[3], and Thorsten Hesjedal[2] — [1]Institute of Physics, Polish Academy of Science — [2]Department of Physics, Clarendon Laboratory, University of Oxford — [3]Diamond Light Source, Harwell Science and Innovation Campus

Elemental tin in the α-phase is an intriguing member of the family of topological quantum materials. In thin films, with decreasing thickness, α-Sn transforms from a 3D topological Dirac semimetal (TDS) to a 2D topological insulator (TI). Getting access to and making use of its topological surface states is challenging and requires interfacing to a magnetically ordered material. Recently we have successfully performed an epitaxial growth of α-Sn thin films on Co, forming the core of a spin-valve structure, is reported. Time- and element-selective ferromagnetic resonance experiments were conducted to investigate the presence of spin pumping through the spin-valve structure. A rigorous statistical analysis of the experimental data using a model based on the Landau-Lifshitz-Gilbert-Slonczewski equation was applied. A strong exchange coupling contribution was found, however no unambiguous proof for spin pumping. Nevertheless, the incorporation of α-Sn into a spin valve remains a promising approach given its simplicity as an elemental TI and its room-temperature application potential.

HL 22: Focus Session: Emerging Semiconductor Laser Concepts

The fabrication and study of semiconductor lasers lie at the heart of the field of solid-state photonic devices. Current research efforts are driven by the incorporation of emerging emitter materials such as organic dyes, quantum dots or 2D materials on the one side, and by harnessing novel and complex photonic mode engineering concepts like in the case of topological lasers or coupled laser arrays. Combining these two directions opens a rich research direction and paves the way to new fundamental phenomena as well as engineering perspectives for ultra-compact laser devices with additional features and functionalities.

Organizers: Christian Schneider (Universität Oldenburg), Sebastian Klembt (Universität Würzburg)

Time: Friday 10:00–12:45 Location: H4

Invited Talk HL 22.1 Fri 10:00 H4

Two-dimensional gain materials for new nanolaser concepts — •Christopher Gies — Institut für Theoretische Physik, Universität Bremen

The talk will give an overview of the many-facetted physics of nanolasers. A particular focus will be on the gain properties when using TMD (transition metal dichalcogenide) monolayers and heterostuctures inside optical microresonators to design a new class of nanolasers [C. Gies and A. Steinhoff, Laser&Photonics Review 2021, 2000482]. Operating close to the ideal limit, high-β lasers require extra effort in unambiguously identifying laser operation. For this, quantum-optical studies have become the state of the art. Atomically thin TMD semiconductors hold much promise for optoelectronics, but have yet to demonstrate their application potential in new technologies. We will discuss possible gain mechanisms in TMD based nanolasers and identify signatures of lasing operation in these devices. For this, the interplay of excitonic effects caused by strong Coulomb interaction, and plasma effects in the high-excitation-density regime, need to be taken into consideration.

Invited Talk HL 22.2 Fri 10:30 H4

Room-temperature polariton lattices for quantum simulation — •Stephane Kena-Cohen — Polytechnique Montreal, Montreal, Canada

Polaritons are quasiparticles that form in semiconductor microcavities when the light-matter interaction rate is faster than the dissipation rate. At high densities, these quasiparticles can condense into a single macroscopic state that behaves qualitatively like a conventional laser. In addition to possessing intrinsically low lasing thresholds, the strong nonlinearities and tunability of polaritons is currently being exploited to realize efficient nonlinear devices and for quantum information.

In this talk, we will describe 2 platforms that allow for the formation of room-temperature polariton lasers: organic semiconductors and halide perovskites. We will describe the basic physics behind such devices and recent experiments where lattices were used to realize analog quantum simulators (e.g. XY Hamiltonian) under ambient conditions.

Invited Talk HL 22.3 Fri 11:00 H4

Topological nanocavity lasers and topological high-power lasers — •Yasutomo Ota[1,2], Yasuhiko Arakawa[2], and Satoshi Iwamoto[2,3,4] — [1]Keio University — [2]Nanoquine, The University of Tokyo — [3]RCAST, The University of Tokyo — [4]IIS, The University of Tokyo

Topological photonics offers ways to advance optical resonator design. In particular, resonators based on topological edge states emerging at the exteriors of bulk optical structures have been intensively studied because they behave robustly against certain disorders. Combinations of such topological cavities with gain materials also gather enormous interest as a straightforward route to topological lasers. In this contribution, we discuss our recent efforts on topological lasers based on 0D edge states supported in 1D photonic topological structures. We realized single-mode topological nanocavities by interfacing two topologically-distinct photonic crystal nanobeams. Combined with quantum dot gain, we demonstrated the first topological nanocavity laser. Furthermore, we theoretically extended the concept of the 0D topological cavity design to high-power lasers. We considered sizable arrays of coupled resonators that form topological optical bands. In a similar manner to the topological nanocavity, by interfacing two topologically-different cavity arrays, we designed topological interface modes broadly-distributed among the whole systems. Properly supplying gain to the system, we numerically uncovered the possibility of robust single mode lasing from the broad-area mode, paving the way to high-power and high-beam-quality topological lasers.

15 min. break.

Invited Talk HL 22.4 Fri 11:45 H4

Topological Insulator Lasers — •Miguel A. Bandres[1], Steffen Wittek[1], Gal Harari[2], Mordechai Segev[2], Demetrios N. Christodoulides[1], and Mercedeh Khajavikhan[3] — [1]CREOL, University of Central Florida — [2]Technion, Haifa, Israel — [3]University of Southern California

Topological insulators are a new phase of matter with insulating bulk but robust edge conductance. These topological edge states are extremely robust, propagate in a unidirectional manner immune to imperfections, defects, or disorder, and as such they are promising unprecedented advantages in technological applications. In recent years, research in topological photonics has flourished with numerous photonic platforms. Until recently research on topological systems in all fields of science was carried out in entirely passive and linear settings. However, the idea of introducing gain and nonlinearity to topological systems has raised many challenges and fundamental questions.

Recently, we demonstrated that topological protection can be combined with gain and loss to give rise to a new kind of laser whose lasing mode is a topologically protected edge mode, a topological insulator laser. The topological insulator laser displays slope efficiency that is considerably higher than in the corresponding trivial realizations even in the presence of defects and disorder, and operates at a single lasing mode even considerably above threshold. These results paved the way towards the new era of active topological photonics, in which topological protection, nonlinearity, and gain, combined in nontrivial ways, to give rise to new active photonic devises.

Invited Talk HL 22.5 Fri 12:15 H4

When polariton condensates have dissipations or have no excitons — •Hui Deng — University of Michigan, Ann Arbor, MI USA

Microcavity exciton-polaritons are formed in a semiconductor with strong exciton-photon coupling and low carrier density. They have been widely studied as a weakly interacting boson gas that can form a Bose-Einstein condensation (BEC) like many-body state in a solid. However, the cavity dissipation and fermionic nature of the electrons can lead to phenomena outside the well established framework for quasi-equilibrium polariton condensation. We discuss two such examples. We first discuss the formation of limit cycles with two coupled condensates, as a result of dissipative coupling and polariton nonlinearity. We then look "inside" the polaritons and reveal an electron-hole-photon condensate that share similar spectral properties as a polariton BEC but with a microscopic origin similar to a BCS-state.

HL 23: Focus Session: Highlights of Materials Science and Applied Physics III (joint session DS/HL)

Time: Friday 11:15–13:00 Location: H1

HL 23.1 Fri 11:15 H1

Free-Standing ZnSe-Based Microdisk Resonators - Influence of Edge Roughness on the Optical Quality and Degradation Reduction with Supported Geometry — •Wilken Seemann[1], Alexander Kothe[1], Christian Tessarek[1], Gesa Schmidt[2], Siqi Qiao[2], Nils von den Driesch[2], Jan Wiersig[3], 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 — [3]Institut für Physik, Universität Magdeburg, Germany

Free-standing microdisks with ZnCdSe quantum wells in ZnMgSe barriers are analyzed using micro-photoluminescence (μPL). Stimulated emission into whispering gallery modes (WGMs) is demonstrated. Deformation functions of the resonators are determined via scanning electron microscopy (SEM). A correlation between edge roughness and optical quality is found. These results are confirmed by calculations based on the boundary element method using the measured deformation functions.

To reduce degradation in the ZnSe structures a fabrication technique new to this material system is introduced. It yields "supported" disks with no underetching which enhances the mechanical stability of the resonator and its thermal contact to the substrate. SEM measurements reveal an excellent structural quality of these resonators. The formation of WGMs in supported ZnSe:Cl resonators is demonstrated in μPL and confirmed by theoretical calculations.

HL 23.2 Fri 11:30 H1

Pyramid formation by etching of InGaN/GaN quantum well structures grown on N-face GaN for nano optical light emitters — •Uwe Rossow, Savutjan Sidikejiang, Samar Hagag, Philipp Henning, Rodrigo de Vasconcellos Lourenco, Heiko Bremers, and Andreas Hangleiter — TU Braunschweig, Inst. f. Angewandte Physik

While growth processes of $In_xGa_{1-x}N$/GaN quantum well structures on the Ga-face of GaN buffer layers are already optimized to obtain high quantum efficiency, the growth on N-face has gained momentum only in the last years. Compared to Ga-face $In_xGa_{1-x}N$ layers are more stable on N-face and the surface can easily be structured by wet chemical etching, which usually leads to the formation of pyramids on the surface. This allows a new way to realize nano optical light emitters which offers the possibility to produce structures with similar emission properties. First we grow $In_xGa_{1-x}N$/GaN (single or multi) quantum well structures on N-face GaN. In a second step pyramids are formed by KOH etching. We demonstrate that pyramids with smooth side facets of the type $(1\bar{1}0\bar{1})$ and sharp tips in the nanometer range can be achieved without any sign of damage. TEM reveals that InGaN quantum dot-like structures are present in the pyramids and in photoluminescence narrow emission lines are observed. The etching process depends on electrolyte composition and temperature, defects at the surface and surface morphology. A better control of this process is required to achieve reproducible nano structures.

HL 23.3 Fri 11:45 H1

Bulk and interfacial effects in the Co/Ni_xMn_{100-x} exchange-bias system due to creation of defects by Ar^+ sputtering — •Tauqir Shinwari[1], Ismet Gelen[1], Yasser A. Shokr[1,2], Ivar Kumberg[1], Ikram Ullah[3], Muhammad Sajjad[3], M. Yaqoob Khan[3], and Wolfgang Kuch[1] — [1]Freie Universität Berlin, Arnimallee 14, Berlin 14195, Germany — [2]Faculty of Science, Department of Physics, Helwan University, 17119 Cairo, Egypt — [3]Department of Physics, Kohat University of Science and Technology, Kohat, Khyber Pakhtunkhwa 26000, Pakistan

A series of experiments is carried out to identify the contribution of interface and bulk antiferromagnetic (AFM) spins to exchange bias (EB) in ultrathin epitaxial ferromagnetic (FM)/AFM bilayer samples. These are single-crystalline AFM Ni_xMn_{100-x} and FM Co layers on $Cu_3Au(001)$, in which structural or chemical defects are introduced by controlled Ar^+ sputtering at the surface of the AFM layer or at a certain depth inside the AFM layer. Comparison of the magnetic properties measured by magneto-optical Kerr effect for sputtered and non-sputtered parts of the same sample then allows a precise determination of the influence of sputtering on the AFM layer during the sample preparation. The results show that the creation of defects in the bulk of the AFM layer enhances the magnitude of EB and its blocking temperature, but not the ones at the interface. We also observed that the deeper the insertion of defects in the AFM layer, the higher the EB field and the larger the coercivity. These findings are discussed as the effect of additional pinning centers in the bulk of the AFM layer.

HL 23.4 Fri 12:00 H1

Study of annealing effect on RF-sputtered Bi2Te3 thin films with full figure of merit characterization. — •Gyuhyeon Park, Maksim Naumochkin, Kornelius Nielsch, and Heiko Reith — Leibniz Institute for Solid State and Materials Research Dresden (IFW Dresden), Institute for Metallic Materials, Helmholtzstrasse 20, 01069 Dresden, Germany

Thermoelectric (TE) devices enable the direct conversion of heat into electricity and vice versa. The demand of micro TE harvesting or Peltier cooling devices for application in autonomous sensor systems required for the internet of things (IoT) will prospectively drastically increase in the coming years. Such microdevices are typically fabricated using electrodeposition or physical vapor deposition, where the successful optimization of the thermoelectric figure of merit, zT, which is the key enabler for the introduction of these devices to application. Accordingly, thin film fabrication methods and material investigation are of high interest. In this study, we report on the thermoelectric characterization of RF sputtered n-Bi2Te3 thin films with various thicknesses. For the in-plane Seebeck coefficient, Hall coefficient, electrical, and thermal conductivity measurement a thin film analyzer (TFA) has been used. We will discuss the influence of temperature effects on the transport properties, including in-situ annealing experiments and the relation to the structure, grain size, and chemical composition which was analyzed with XRD, SEM and EDX.

HL 23.5 Fri 12:15 H1

Passivating polysilicon recombination junctions for crystalline silicon solar cells — •Franz-Josef Haug[1], Audrey Morisset[1], Philippe Wyss[1], Mario Lehmann[1], Aicha Hessler-Wyser[1], Andrea Ingenito[1], Quentin Jeangros[1], Christophe Ballif[1], Shyam Kumar[2], Santhana Eswara[2], and Nathalie Valle[2] — [1]Ecole Poiytechnique Fédérale de Lausanne (EPFL), School of Engineering, PV-Lab, Switzerland — [2]Luxembourg Institute of Science and Technology (LIST), Materials Research and Technology Department, Luxembourg

We investigate polysilicon recombination junctions, whose n-type bottom layer also acts as passivating contact to the silicon surface. They are a key element in tandem devices with a silicon bottom cell, and they could be used to simplify the processing sequence of single-junction cells with interdigitated back contacts. Processing requires high temperatures to crystallize the layers, however, this step can also deteriorate the tunnelling junction by diffusion of dopants. We analyse depth profiles of the doping concentrations in the layers and diffusion across the interface between them by secondary ion mass spectrometry (SIMS) in dynamic mode. We show that undesired diffusion is suppressed by modifying the interface with C, O, or a combination of these. Moreover, we demonstrate that this modification does not interfere with the diffusion of H which is an essential element to passivate defects at the wafer surface. Thus, we find implied open-circuit voltages up to 740 mV for contact resistivities less than 40 mΩcm2, and we demonstrate tandem cells with efficiency above 20%.

HL 23.6 Fri 12:30 H1

Homoepitaxial diamond lateral growth: a new methodology for the next generation of power devices — •Fernando Lloret[1], Daniel Araujo[2], David Eon[3], and Etienne Bustarret[3] — [1]Department of Applied Physics, University of Cádiz, 11510, Puerto Real (Cádiz) Spain — [2]Department of Material Science, University of Cádiz, 11510, Puerto Real (Cádiz) Spain — [3]Univ. Grenoble-Alpes, CNRS, Institut Néel, 38000 Grenoble, France

Diamond is expected to be the base material for future power electronic devices. However, the technological steps and the particularities inherent to the material remain impassable issues for its industrial implementation. Shortcomings such as the high density of substrate defects and small substrate sizes (less than 1 cm2), the large number of required non-fully-controlled technology steps (etch and deposition or growth) or electrical problems related to the classical geometries (high electric fields, leakages*) can be overcome by using lateral growth. The progress of this promising diamond deposition methodology, capable of drastically reducing defects density, promoting selective doping and providing a wealth of alternative geometries for the device, is here reviewed.

HL 23.7 Fri 12:45 H1

Impact of electrical current on single GaAs nanowire structure — •Ullrich Pietsch[1], Danial Bahrami[1], Ali AlHassan[1], Arman Davtyan[1], Taseer Anjum[1], Ren Zhe[2], Rainer Timm[2], Lutz Geelhaar[3], Jesus Herranz[3], and Dmiri Novikov[4] — [1]University of Siegen, Siegen, Germany — [2]University of Lund, Lund , Sweden — [3]Paul Drude Institute, Berlin, Germany — [4]DESY, Hamburg, Germany

The impact of electrical current on the structure of single free-standing Be-doped GaAs nanowires grown on a Si 111 substrate has been investigated by X-ray nano-diffraction before and after the application of an electrical current. The conductivity measurements of same nanowires in their as-grown geometry have been realized via W-probes installed inside a dual beam focused ion beam/scanning electron microscopy chamber. Comparing reciprocal space maps of the 111 Bragg reflection before and after the conductivity measurement, we find a deformation of the hexagonal nanowire cross-section, tilting and bending with respect to the substrate normal. For electrical current densities above 347 A/mm^2, the diffraction pattern was completely distorted. Confirmed by SEM the reconstructed cross-section of the illuminated nanowire shows elongation of two pairs of opposing side facets accompanied by shrinkage of the third pair of facets. To explain our findings, we suggest material melting due to Joule heating during voltage/current application accompanied by anisotropic deformations induced by the W-probe.

HL 24: Quo Vadis Quantum Technologies? About Promises, Prospects, and Challenges

In 2016 the quantum satellite 'Micius' started its successful mission in space, and about a year ago, Google announced the achievement of reaching a quantum advantage with a quantum computer based on superconducting qubits. Both stories impressively illustrate the transition from basic research in quantum physics to applications of quantum technologies. In this light we will have a panel discussion on "Quo Vadis Quantum Technologies? About Promises, Prospects, and Challenges"

Time: Friday 13:30–15:00 Location: Audimax 2

Discussion HL 24.1 Fri 13:30 Audimax 2

Panel Discussion on Quantum Technologies — •Tobias Heindel[1] and Doris Reiter[2] — [1]Technische Universität Berlin — [2]Universität Münster

The panel discussion brings together experts and young scientists of different communities to jointly discuss viewpoints on the second quantum revolution and quantum technologies. We will exchange our ideas and perspectives of the different fields and how they might develop. Beyond identifying urgent scientific questions, we also aim to discuss the potential impact on industry, politics, and society in general, and to which extend we believe that these promises are realistic. The discussions will be moderated by the spokespersons of AGyouLeaP, Doris Reiter and Tobias Heindel. We invite in particular students and young researchers to join in and learn what to expect when they enter the field.

We are excited to welcome to the discussion panel: Jens Eisert (Freie Universität Berlin), Brian Geradot (Heriot-Watt University), Tracy Northup (Universität Innsbruck), Simone Portalupi (Universität Stuttgart), Rupert Ursin (TBC, IQOQI Wien), Jian-Wei Pan (TBC, University of Science and Technology of China, Hefei)

HL 25: 2D semiconductors and van der Waals heterostructures II (joint session HL/DS)

Time: Friday 13:30–14:45 Location: H4

HL 25.1 Fri 13:30 H4

Femtosecond contact-free nanoscopy of ultrafast interlayer transport in 2D heterostructures — •Felix Schiegl[1], Markus Plankl[1], Paulo Eduardo Faria Junior[1], Fabian Mooshammer[1], Tom Siday[1], Martin Zizlsperger[1], Fabian Sandner[1], Simon Maier[1], Markus Andreas Huber[1], Martin Gmitra[1,4], Jaroslav Fabian[1], Jessica Louise Boland[1,2], Tyler Liam Cocker[1,3], and Rupert Huber[1] — [1]Department of Physics and Regensburg Center for Ultrafast Nanoscopy (RUN), University of Regensburg, Regensburg, Germany — [2]Photon Science Institute, Department of Electrical and Electronic Engineering, University of Manchester, Manchester, UK — [3]Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA — [4]Institute of Physics, Pavol Jozef Šafárik University in Košice, Košice, Slovakia

Tunneling is one of the most direct results of quantum mechanics, and a hallmark of interlayer exciton formation in semiconducting van der Waals heterostructures. Here, we introduce a new contact-free terahertz nanoscopy technique to trace ultrafast charge dynamics in both conducting and non-conducting materials. We demonstrate $< 50\,\mathrm{nm}$ spatial and subcycle temporal resolution and probe the interlayer tunneling across an atomically sharp WSe_2/WS_2 interface. Pronounced variations of the formation and annihilation of excitons emerge as a direct result of nanoscale strain and changes in atomic registry. Our results show the potential of this technique for revealing how ultrafast tunneling shapes the functionalities of a broad range of condensed matter systems.

HL 25.2 Fri 13:45 H4

Moiré phonons in twisted $MoSe_2$-WSe_2 heterobilayers and their correlation with interlayer excitons — •Philipp Parzefall[1], Johannes Holler[1], Marten Scheuck[1], Andreas Beer[1], Kai-Qiang Lin[1], Bo Peng[2], Bartomeu Monserrat[2,3], Philipp Nagler[1], Michael Kempf[4], Tobias Korn[4], and Christian Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Deutschland — [2]Theory of Condensed Matter Group, Cavendish Laboratory, University of Cambridge, UK — [3]Department of Materials Science and Metallurgy, University of Cambridge, UK — [4]Institut für Physik, Universität Rostock, Deutschland

We report about the investigation of twisted $MoSe_2$-WSe_2 heterobilayers by means of low-frequency Raman spectroscopy (LFRS) and low-temperature micro photoluminescence (μPL). We identify moiré phonons of both constituting materials in heterobilayers, which enables us to determine the relative twist angles of the heterobilayers on a local scale with high precision. Atomically reconstructed regions, which are identified by the observation of an interlayer shear mode in LFRS experiments, exhibit in μPL a strong, momentum-allowed interlayer-exciton signal.

HL 25.3 Fri 14:00 H4

Transport Properties of Bulk Black Phosphorus Below and Above the Quantum Limit — •Davide Pizzirani[1], Jasper Linnartz[1], Claudius Müller[1], Brian Kiraly[2], Alexander Khajetoorians[2], and Steffen Wiedmann[1] — [1]High Field Magnet Laboratory (HFML-EMFL), Radboud University, Nijmegen, Netherlands — [2]Institute for Molecules and Materials, Radboud University, Nijmegen, the Netherlands

Black phosphorus (bPh) has emerged as a promising and novel platform for nano-electronic applications due to its in-plane anisotropy and direct band gap that depends on the sample thickness. We present low-temperature magneto-transport experiments on bulk bPh up to 30 T with thicknesses ranging from 40 to 100 μm. A negative magneto-resistance (MR) that turns into a positive linear one is found by increasing the magnetic field. This MR remains quasi-isotropic upon changing the tilt angle from out-of-plane to in-plane with respect to the applied magnetic field. Using samples with different carrier concentrations, we are able to determine the transport properties below and above the quantum limit, and in the regime of variable range hopping.

HL 25.4 Fri 14:15 H4

Excitation-induced optical nonlinearities and charge carrier localization in atomically thin TMD semiconductors — •Daniel Erben, Alexander Steinhoff, Michael Lorke, Christian Carmesin, Matthias Florian, and Frank Jahnke — Institute for Theoretical Physics, University of Bremen

To interpret the nonlinear optical properties of atomically thin transition metal dichalcogenides (TMD), the density of photoexcited carriers is of central importance. However, in experiments the excited carrier density is practically not accessible. For above band-gap optical pumping of TMD monolayers, we utilize the semiconductor Bloch equations to determine the excitation density as function of the optical pump fluence. Our theory includes Pauli-blocking, band-gap renormalization, dephasing and screening of the Coulomb interaction due to excited carriers. The excitation density strongly depends on the wavelength of the exciting laser pulse. For pumping at the band gap, Pauli blocking of available phase space and renormalizations of the single particle energies are the dominant sources of a nonlinear density dependence, even at small pump fluence. In another study, we investigate the charge-carrier confinement in TMD nanobubbles. These are formed during stacking processes and exhibit quantum light emission upon optical excitation. We demonstrate that the emission originates from strong carrier localization, caused by the interplay of surface wrinkling, strain-induced confinement, and local changes of the dielectric environment. These effects combine to a specific localization signature that is found in recent spatially resolved photoluminescence experiments.

HL 25.5 Fri 14:30 H4

Spatio-temporal dynamics of phonon sidebands in 2D materials — •Roberto Rosati[1], Koloman Wagner[2], Samuel Brem[1], Raül Perea-Causín[3], Jonas D. Ziegler[2], Jonas Zipfel[2], Takashi Taniguchi[4], Kenji Watanabe[4], Alexey Chernikov[2,5], and Ermin Malic[1,3] — [1]Philipps University of Marburg — [2]University of Regensburg — [3]Chalmers University of Technology — [4]National Institute for Materials Science — [5]Dresden University of Technology

The semiconducting monolayers of transition metal dichalcogenides (TMDs) display a complex manifold of bright and dark exciton states, the latter giving rise to sharp phonon sidebands (PSB) in low-temperature photoluminescence. In this joint theory-experiment study we theoretically predict and experimentally demonstrate time-resolved low-temperature PSB, thus gaining direct access to the evolution of dark excitons in time, energy and space [1,2]. In an excellent theory-experiment agreement we reveal a spectral red-shift of phonon sidebands on a time scale of tens of picoseconds due to phonon-driven thermalization of initially-formed hot momentum-dark excitons [1]. After confined optical excitation, such hot-exciton distribution gives rise to a transient exciton diffusion one order of magnitude faster than the conventional diffusion observed at later times [2]. The obtained insights are applicable to other 2D materials with multiple exciton valleys.

[1] Rosati, R. et al. ACS Photonics 7, 2756 (2020).
[2] Rosati, R. et al. arXiv:2105.10232 (2021).