HL 33: Poster II

Topics:
- 2D semiconductors and van der Waals heterostructures
- Focus Session: Graphene quantum dots
- Materials and devices for quantum technology
- Nitrides: Devices
- Nitrides: Preparation and characterization
- Quantum transport and quantum Hall effects
- Semiconductor lasers
- Spin phenomena in semiconductors
- THz and MIR physics in semiconductors
- Transport properties
- Ultra-fast phenomena

Time: Wednesday 17:00–19:00 Location: P1

HL 33.1 Wed 17:00 P1

Pump-probe spectroscopy on a MoSe2 monolayer — •Max Wegerhoff and Stefan Linden — Physikalisches Institut, Universität Bonn, Nussallee 12, 53115 Bonn, Germany

TMDC monolayers are atomically thin semiconductor materials, which, due to their reduced dimensionality and crystal structure, possess unique optical properties. In particular, they host bound electron-hole pairs, so-called excitons, with binding energies of several 100 meVs.

Here, we report on pump-probe spectroscopy on excitons in a MoSe2 monolayer encapsulated in h-BN. We use spectrally broad probe pulses and a spectrometer to measure the transient differential reflectivity spectra. Based on a mode-locked Ti:Sa laser, a temporal resolution of down to 400fs is achieved. A frequency-doubled OPO can be used to generate non-resonant pump pulses in the visible wavelength range. Furthermore, probe pulses with a bandwidth of up to 70nm can be generated via supercontinuum generation in a photonic crystal fiber. The experiments are performed at 4K in a helium-flow cryostat.

Within the first few picosecond after the pump pulse, we observe a blueshift of the exciton resonance. This shift depends on the wavelength of the pump pulses as well as the polarization of the pump- and probe pulses. Further experiments with an electrically gated heterostructure to control the doping of the monolayer are in progress.

HL 33.2 Wed 17:00 P1

A Model Study of the Phonon-Impact on Absorption Spectra of Moiré Exciton-Polaritons — •Kevin Jürgens[1], Daniel Wigger[2], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster, Germany — [2]School of Physics, Trinity College Dublin, Ireland

The interaction of multiple quantum emitters coupled to a resonant optical field can produce interesting collective behavior. Twisted bilayers of transition metal dichalcogenides are a class of materials, where localized quantum emitters, in this case moiré excitons, can occur. According to their strong localization at the minima of the moiré potential, these excitons have a relatively flat band structure. If the heterostructure is placed into an optical cavity, all excitons interact with the same mode of the resonator, leading to the formation of exciton-polaritons which can interact with lattice vibrations.

We model the moiré excitons in the limit of small densities as bosonic particles that couple to a single quantized cavity mode, resulting in lower and uper polariton states. In addition, each exciton is coupled to the same acoustic phonon bath. The interaction with phonons leads to inter- and intraband transitions between the two polariton branches that strongly depend on the curvature of the polariton dispersion.

We calculate absorption spectra and discuss the influence of phonons on the spectral shape and peak positions, and systematically study the influence of the band structures curvature.

HL 33.3 Wed 17:00 P1

Nonlinear optical processes in the layered magnetic semiconductor CrSBr — •Minjiang Dan[1], Paul Herrmann[1], Julian Klein[2], Zdenek Sofer[3], and Giancarlo Soavi[1] — [1]Institute of Solid State Physics, Friedrich Schiller University Jena, Jena, Germany — [2]Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, USA — [3]Department of Inorganic Chemistry, University of Chemistry and Technology Prague, 166 28 Prague 6, Czech Republic

CrSBr has recently emerged as a new member in the family of layered magnetic materials, with the distinct advantages compared to CrI_3 of being stable in air and having a high Néel temperature in the bulk form. Recently polarization-resolved Second Harmonic Generation (SHG) has been employed to reveal the layer-dependent magnetic order and symmetry in multilayer CrSBr [1]. In this work, we use nonlinear optical spectroscopy, i.e. SHG and Third Harmonic Generation (THG) and two photon absorption, to investigate the electronic and excitonic resonances in few-layer and bulk CrSBr as a function of the lattice temperature which, modulates the magnetic properties of the material. Our results show large enhancement (>100) in the SHG and THG for specific wavelengths and range of temperatures, pointing towards the existence of resonances from the magnetic dipole response of the system. This sheds light on the excited state landscape of this new material and offers viable insights towards its application in spintronic, magnonic and opto-electronic devices.

[1] Lee *et al.*, *Nano Letters* **21**, 8, 3511-3517 (2021)

HL 33.4 Wed 17:00 P1

The Impact of Inert Conditions During the Fabrication Process on the Optical Properties of MoS_2 Monolayers — •Alina Schubert[1], Michael Kempf[1], Rico Schwartz[1], Patricia Gant[2], Felix Carrascoso[2], Carmen Munuera[2], Andres Castellanos-Gomez[2], and Tobias Korn[1] — [1]Institut für Physik, Universität Rostock, Rostock, Germany — [2]Instituto de Ciencia de los Materiales de Madrid, Madrid, Spain

Transition-metal dichalcogenides (TMDCs) are layered materials that can be thinned down to monolayers. The optical properties of these flakes depend strongly on the cleanliness of the surfaces. Transferring TMDCs with PDMS is simple to perform and allows the fabrication of large monolayers [1]. The objective of this work was to improve the methodology so that sample quality is enhanced without reducing the yield or increasing the effort required for production. For this purpose, a statistic of 20 monolayers was set up, which were half transferred to a SiO_2 substrate at ambient conditions and half transferred in a glovebox [2]. All samples were characterised by photoluminescence (PL) spectroscopy at room temperature and ∼4 K. By examining the exciton and trion features in the spectra, it could be shown that only the small difference in the transfer process results in changes of the optical properties that can be attributed to a higher sample quality of the samples produced in the glovebox.

[1] Castellanos-Gomez, A. et al. 2D Mater. 1 (2014)
[2] Gant, P. et al. 2D Mater. 7 (2020)

HL 33.5 Wed 17:00 P1

Stokes shift of twisted bilayer WSe2 — •Zihao Liu[1], Yang Pan[1,2], and Dietrich R. T. Zahn[1,2] — [1]Semiconductor Physics, Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [2]Center for Materials, Architectures, and Integration of Nanomembranes (MAIN), Chemnitz University of Technology, Chemnitz, Germany

Transition metal dichalcogenides (TMDCs) with a typical layered structure have exceptional optical properties exhibiting a characteristic absorption and emission at excitonic resonances. The weak van der Waals (vdW) interlayer coupling nature enables the possibility of artificial staking, leading to homo- and hetero-structures formation. It was demonstrated in our previous work that the optical properties can be strongly modified by the twisting angle.

Here, WSe2 monolayers (MLs) were obtained by mechanical exfoliation, which were then transferred onto sapphire substrates by a tear-and-stack method to form twisted homo-bilayers with a precision of 0.08°. We then performed optical transmission and photoluminescence (PL) experiments on monolayers, intrinsic bilayers and twisted bilayers to determine the Stokes shift values on a full period (0°-60°) of twisted bilayer WSe2.

HL 33.6 Wed 17:00 P1

Transport and optical characterization of electrically contacted monolayer TMDCs — •Jan-Niklas Heidkamp, Johannes Krause, Swarup Deb, Rico Schwartz, and Tobias Korn — Institute of Physics, University of Rostock, Rostock, Germany

Since Graphene was introduced in 2004, there has been a great interest in other 2D materials as well. Among the most studied is the group of semiconducting transition metal dichalcogenides (TMDCs). The band structure of these crystals changes from an indirect gap in the bulk to a direct gap in the monolayer limit. Herein, a method for contacting monolayer flakes using photolithography and lift-off processes is showcased. Electrical contacts are pre-defined on SiO_2 substrates and thereafter, TMDC flakes are deposited using a deterministic transfer technique. Flakes of the TMDC WS_2 contacted in this way are characterized via gate-dependent photoluminescence measurements and I-V curves.

HL 33.7 Wed 17:00 P1

Enhancing photoluminescence and Raman signals in TMDC monolayers via plasmonic nanostructures — •Johannes Krause, Annika Bergmann, Jan-Niklas Heidkamp, Rico Schwartz, and Tobias Korn — Institute of physics, university of Rostock, Rostock, Germany

Novel 2D thin film materials garnered a great interest in recent years. The family of Transition metal dichalcogenides (TMDCs) among those materials is especially appealing because of the indirect-direct bandgap transition and the possibility to stack different composites of the TMDCs on top of each other to achieve so called heterostructures. Herein, we present a technique to define nanostructures on a SiO_2 wafer using thermal scanning probe lithography. Further, we deposit individual TMDC monolayer flakes on top of the metallized structures via the deterministic transfer technique. We characterize our flakes utilizing photoluminescence and Raman measurements, reporting major enhancements effects (∼10x) in PL and minor enhancement (∼3x) in Raman signals.

HL 33.8 Wed 17:00 P1

investigation of structural and electronic properties of monolayered MoS2 and graphene compared to the MoS2/graphene heterostructure — •Ateeb Shaban[1], Nebahat Bulut[2], Jakob Kraus[2], Franz Selbmann[1], Jens Kortus[2], and Yvonne Joseph[1] — [1]TU Bergakademie Freiberg, Institute of Electronic and Sensor Materials, Germany — [2]TU Bergakademie Freiberg, Institute of Theoretical Physics, Germany

Graphene and other 2D materials have been shown to have interesting structural and electronic properties. Transition metal dichalcogenides such as molybdenum disulfide (MoS2) and tungsten diselenide (WSe2) have tunable bandgaps that change from indirect to direct when decreasing the number of layers. This property allows for applications such as transistors and sensors. On the other hand, graphene is an ideal channel material. It is used as an electronic sensor in field-effect transistors due to the high sensitivity toward the change in the surrounding environment. These remarkable electronic and structural properties of graphene, being highly susceptible and conductive, have reignited the interest in 2D materials. Subsequently, building variable stacks of 2D van-der-Waals (vdW) structures can open the possibility of designing materials with specific properties across various chemistry's and systems.

In this theoretical work, we analyze and review the properties of MoS2 and graphene individually and study their cumulative effect on the electronic and structural properties of the MoS2/graphene vdW heterostructure using density functional theory.

HL 33.9 Wed 17:00 P1

Rapid hyperspectral imaging of transition metal dichalcogenides and their heterostructures — •Marc Schütte, David Tebbe, Christoph Stampfer, Bernd Beschoten, and Lutz Waldecker — 2nd Institute of Physics A, RWTH Aachen University, Aachen, Germany

Transition Metal Dichalcogenides are two-dimensional semiconductors with many interesting properties for optical applications, such as direct bandgaps in the visible spectral region or optically addressable inequivalent valleys. It is well known, however, that their optical properties can vary spatially by local changes of dielectric screening, doping or strain. Here, we present a measurement setup capable of performing photoluminescence and reflection contrast measurements of 2D heterostructures approximately twenty times faster compared to scanning a focal spot over the sample. The setup is based on simultaneously taking spectra along a line with an imaging spectrometer (push-broom technique), which enables the measurement of multiple spectra simultaneously. The speed of the technique allows for taking images in multidimensional sweeps of parameters, such as gate voltages or magnetic fields.

In this way, the measurements can be conducted by imaging sample regions up to the full size of the heterostructure for each sweep. This allows to distinguish inhomogeneities and enhances the statistical relevance of the data.

HL 33.10 Wed 17:00 P1

Black phosphorus field-effect transistors and its application — •Zahra Fekri[1], Himani Arora[1], Victoria Constance köst[2], Jens Zscharschuch[1], Krzysztof Nieweglowski[2], Kenji Watanabe[3], Takashi Taniguchi[4], Manfred Helm[1,2], Karlheinz Bock[2], and Artur Erbe[1,2] — [1]Helmholtz Zentrum Dresden Rossendorf, Dresden, Germany — [2]Technische Universität Dresden, Dresden, Germany — [3]Research Center for Functional Materials, National Institute for Materials Science, Tsukuba, Japan — [4]International Center for Materials Nanoarchitectonics, National Institute for Materials Science, Tsukuba, Japan

Black phosphorus (BP) has been known as a more favorable material in many applications compared to other 2D materials due to its exceptional properties. However, its sensitivity to air species has restricted its integration into active devices. In this work, we used a few nm thickness BP for developing field-effect transistors (FETs). Lithography-free via-encapsulation scheme allows us to fabricate fully-encapsulated BP-based field-effect transistors and perform reliable electrical measurements. Based on our results, we find that the electronic properties of the via-encapsulated BP FETs are significantly improved compared to unencapsulated devices. We further demonstrated a gas-sensing performance based on the BP FET. Our Preliminary result shows the promising potential of BP for applications in advanced gas-sensing technology.

HL 33.11 Wed 17:00 P1

Stationary and Time-Resolved Luminescence of Organic-Dye/transition metal dichalcogenide Heterostructures — •Julian Schröer, Tim Völzer, Alina Schubert, Rico Schwartz, Stephan Lochbrunner, and Tobias Korn — University of Rostock, Institute of Physics

Thin layers of organic molecules and layered semiconductors build a new compound material with manifolds of interesting applications. The optoelectronic properties of these heterostructures strongly depend on the chosen compounds. Via stationary and time-resolved photoluminescence experiments, we investigate samples of Perylene-Orange (PO) deposited on top of single-layer tungsten diselenide. This joint material exhibits a type-II band alignment, enabling charge transfer processes between the two material layers. Here, we aim to reveal the temperature dependent dynamics of the charge transfer processes. Our work paves the way for a deeper understanding of organic/inorganic heterointerfaces and the functionalization of organics and TMD's in optoelectronic devices.

HL 33.12 Wed 17:00 P1

Quantum transport in twisted bilayer graphene supermoiré heterostructures — Alexander Rothstein[1], Robin Dolleman[1], Christoph Schattauer[2], •Anthony Achtermann[1], Stefan Trellenkamp[3], Florian Lentz[3], Kenji Watanabe[4], Takashi Taniguchi[5], Dante Kennes[6], Florian Libisch[2], Bernd Beschoten[1], and Christoph Stampfer[1] — [1]2nd Institute of Physics, RWTH Aachen University, Germany — [2]Institute for Theoretical Physics, TU Wien, Austria — [3]Helmholtz Nano Facility, Forschungszentrum Jülich, Germany — [4]Research Center for Functional Materials, National for Material Science, 1-1 Namiki, Japan — [5]International Center for Materials Nanoarchitectonics, National Institute for Materials Science, 1-1 Namiki, Japan — [6]Institute for Theory of Statistical Physics, RWTH Aachen University, and Jara Fundamentals of Future Information Technology, Germany

Twisted bilayer graphene hosts a plethora of correlated quantum phenomena, such as superconductivity, correlated insulators and strange metal phases. The unprecedented in-situ gate-tunability of the system allows the study the underlying physics in detail by means of quantum transport experiments. The microscopic details of the van-der-Waals heterostructure, like the presence of competing moiré lattices, heavily influence the exact characteristics of the device. Here, we investigate different conductance regimes in near-magic angle twisted bilayer graphene devices, focusing on the insulating states. We are able to identify the presence of super-moiré lattices in our devices from magneto-transport experiments and compare our results with theory.

HL 33.13 Wed 17:00 P1

Ultrathin 2D gallium selenide devices for optoelectronics — •Marco N. Dembecki, Simon Bernöcker, Michele Bissolo, Eugenio Zallo, and Jonathan J. Finley — Walter Schottky Institute and TUM School of Natural Sciences, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

The post-transition metal chalcogenides (PTMC, M = [In, Ga], C = [S, Se, Te]) are a group of semiconducting layered materials with a widely tunable band gap and direct-indirect band gap crossover in the few-layer limit. Type II band alignment of PTMC heterostructures makes them good candidates as photoabsorbers [1].

Among PTMCs, GaSe holds promise for optoelectronics, nonlinear optics, and terahertz (THz) generation but its usefulness for devices is inhibited by strong susceptibility to oxidation. Here, we report on the fabrication of dual gated-FET based on fully hBN-encapsulated GaSe multilayers. To preserve the intrinsic properties of the gallium selenide, the encapsulation process was carried out in a controlled nitrogen atmosphere. The gate electrodes are made from few-layer graphene to allow for an optoelectronic investigation. Electrical transport measurements are carried out and a roadmap for future optoelectronic devices will be discussed.

[1] Arora, H., and Erbe, A. Recent progress in contact, mobility, and encapsulation engineering of InSe and GaSe. InfoMat, 3 (6), 662-693, (2021)

HL 33.14 Wed 17:00 P1

Towards thermoelectric transport measurements in dual-gated bilayer graphene — •Moritz Knaak, Martin Statz, and Thomas Weitz — 1st Physical Institute, Faculty of Physics, University of Göttingen, Friedrich-Hund-Platz 1, Göttingen 37077, Germany

The ratio of the thermal voltage to the corresponding temperature difference is defined as the Seebeck coefficient. As a transport coefficient due to its relation to the density of states (DoS) and its underlying link between entropy and charge transport, the Seebeck coefficient can help to better understand materials with interesting DoS and/or phase transitions. One of these materials is trigonally warped bilayer graphene (BLG), in which Lifshitz transitions can be induced by tuning an out-of plane electric field or the charge carrier density. Near these transitions the DoS is high and electron-electron interaction becomes important. To gain further insights into the emerging correlated phases near these Lifshitz transitions [1] and quamtify the changes in the DoS, we measure the thermoelectric voltage and local temperature difference to extract the Seebeck coefficient. For that we combine a hexagonal boron nitride encapsulated, dual-gated BLG device with graphite gates and contacts together with an on-chip heater next to the BLG. The source and drain contacts are simultaneously used as 4-point-probe on-chip resistance thermometers to determine the local temperature differences. The devices are fabricated utilizing the dry transfer method, e-beam lithography, thermal evaporation of contact leads as well as reactive ion etching.

[1] Seiler, A.M. et al. Nature 608, 298-302 (2022)

HL 33.15 Wed 17:00 P1

Niobium-Doping of Atomically Thin Molybdenum Disulfide for Optoelectronic Applications — •Osamah Kharsah, Stephan Sleziona, and Marika Schleberger — Universität Duisburg-Essen, Fakultät für Physik and CENIDE, Germany

Two-dimensional materials are predicted to become a very important disruptive technology, opening the door to a plethora of applications across many fields, especially in the field of optoelectronics. Among these materials, atomically thin molybdenum disulfide (MoS_2) has distinguished itself owing to its electronic properties, good thermal stability, and mechanical durability. However, its intrinsic strong n-type conductivity hinders its implementation. Overcoming this hurdle would allow MoS_2 to be used in structures such as p-n junctions either on its own or in tandem with other 2D materials, with the goal of fabricating the next generation of optoelectronic devices. One approach that could solve this problem is substitutional doping to controllably p-dope MoS_2. We report on the direct growth of niobium-doped monolayer MoS_2, which was characterized by Raman- and photoluminescence spectroscopy. Field-effect transistors, with the as-grown Nb-doped MoS_2, showed n-type transport behavior. After annealing the material in a sulfur atmosphere, this switched to an ambipolar transport behavior, which we attribute to the activation of Nb-doping sites. In addition, the hysteresis of this device exhibited a decrease of 4 orders of magnitude, indicating that the influence of intrinsic defects has been remedied by the annealing process.

HL 33.16 Wed 17:00 P1

Towards strong coupling of confined excitons to a fiber-based microcavity — •Moritz Scharfstädt, Michael Köhl, and Andrea Bergschneider — Physikalisches Institut, Universität Bonn, Wegelerstraße 8, 53115 Bonn, Germany

Excitons in monolayer transition-metal dichalcogenides (TMD) exhibit large oscillator strengths and hence are well-suited for strong light-matter coupling. While for free excitons strong coupling to photonic cavities has been demonstrated in numerous experiments, nonlinearities in those systems are relatively weak. The recently demonstrated quantum confinement of excitons to length scales of about 20nm is a promising route towards enhancing nonlinearities [1].

We want to realize confined excitons with the prospect of embedding them into a high-finesse microcavity and reach the strong coupling regime. To confine the excitons in transverse direction and tune their energy, we develop a specific electric gate configuration. Our microcavity will be fiber-based and tunable at cryogenic temperatures. With this platform we aim for the realization of a quantum emitter in a cavity by harvesting the enhanced nonlinearity combined with a cavity-enabled photon blockade.

[1] Thureja et al., Nature 606, 298-304 (2022)

HL 33.17 Wed 17:00 P1

Photon assisted tunneling in bilayer graphene double quantum dots — •Tobias Deussen[1], K. Hecker[1,2], L. Banszerus[1,2], A. Schäpers[1], A. Peters[1], S. Möller[1,2], E. Icking[1,2], K. Watanabe[3], T. Taniguchi[4], C. Volk[1,2], and C. Stampfer[1,2] — [1]JARA-FIT & 2nd Institute of Physics, RWTH Aachen — [2]Peter Grünberg Institute, Forschungszentrum Jülich — [3]RCFM, NIMS, Japan — [4]MANA, NIMS, Japan

Spin qubits in semiconductor quantum dots (QDs) are attractive candidates for solid state quantum computation. Singlet-triplet qubits, where the logical qubits are encoded in a two-electron spin system in double quantum dots (DQDs), turned out to be of special interest. In such systems, control over the interdot tunnel coupling and, hence, the exchange interaction is essential. Bilayer graphene (BLG) is an attractive host material for spin qubits due to its small spin-orbit and hyperfine interaction and its gate voltage controllable band gap. Only recently, it has become possible to confine single electrons in BLG QDs and to understand their spin and valley texture. However, microwave manipulation has not been demonstrated, so far. Here, we perform photon-assisted tunneling (PAT) spectroscopy, which relies on resonant microwave excitation of electrons across the interdot transition. We extract a lower bound for charge dephasing, T2*, of about 350 ps. In power-dependent measurements, we explore multi-photon processes. We use PAT as a probe for the interdot tunnel coupling in BLG DQDs and can control and measure the interdot tunnel coupling in a range of several GHz which is suitable for qubit operations.

HL 33.18 Wed 17:00 P1

Coherent coupling dynamics between excitonic complexes in a $MoSe_2$ monolayer — •Daniel Wigger[1], Aleksander Rodek[2], Thilo Hahn[3], James Howarth[4], Takashi Taniguchi[5], Kenji Watanabe[5], Marek Potemski[2,6], Piotr Kossacki[2], and Jacek Kasprzak[2,7] — [1]School of Physics, Trinity College Dublin, Ireland — [2]Faculty of Physics, University of Warsaw, Poland — [3]Institute of Solid State Theory, University of Münster, Germany — [4]National

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In modern heterostructures of layered van der Waals materials that combine graphene, hBN, and TMDCs it is possible to deterministically control the density of free charge carries in a TMDC monolayer. With this approach and the ultrafast nonlinear four-wave mixing (FWM) spectroscopy technique we study the coherent coupling dynamics between neutral and charged excitons in a $MoSe_2$ monolayer. We demonstrate that the so-called Raman coherence between the two exciton species leads to characteristic quantum beats in the FWM signal. By exploiting 2D-FWM spectra, we can conclude that the bias dependent change of dipole strength between the exciton types is not sufficient to explain the experimental findings. Therefore, we conclude that the tuning of the free carrier density directly affects the coherent coupling between neutral and charged excitons.

HL 33.19 Wed 17:00 P1

Resonant Excitation and Resonant Photoluminescence Detection of Silicon Vacancy Centers in 4H Silicon Carbide for Single Photon Emission — •Fedor Hrunski[1], Mike Gerd Georg Köstler[1], Shravan Kumar Parthasarathy[2,1], Maximilian Hollendonner[1], Andre Pointner[1], Christian Gobert[2], Daniel Scheller[1], and Nagy Roland[1] — [1]Chair of Electron Devices (LEB), Friedrich-Alexander-University, Erlangen, Germany — [2]Fraunhofer Institute for Integrated Systems and Device Technology (IISB), Erlangen, Germany

For today, quantum networks deal with the task of entangling several qubits with each other over a larger distance. Therefore, the resonant excitation of the qubits and the resonant detection of emitted photons by them appears to be an essential component of such a network for coherent spin state control. This work hereby deals with the resonant single photon detection of fluorescence, which is emitted by resonantly exited V2 color centers in 4H-SiC. Therefore, a diode laser modulated by an electro-optical modulator performs a pulsed resonant excitation at one of the A_1 or A_2 spin-conservative optical transitions, while the emitted photons are detected by a superconducting single photon detector. However, due to the chromatic equality of the excitation photons and fluorescent photons, they are distinguished by their polarization.

HL 33.20 Wed 17:00 P1

A standalone fiber-bases quantum sensor using ensembles of NV-Centers in diamond — •Benjamin Pohl, Andre Pointner, and Roland Nagy — Chair of Electron Devices, FAU Erlangen-Nuremberg

Though NV-Center magnetometry with diamonds is widely spread in scientific research, it is rarely used in an industrial context. In order to reduce the complexity of the required hardware we fixate the diamond on the tip of a fiber and miniaturize the system so all the required components can be included in a standalone device for magnetic field determination. The measurement is performed with ensembles of NV-Centers used as an optically controlled quantum sensor in a confocal setup. Determination of the magnetic field is achieved through optical detected magnetic resonance (ODMR). In the presence of a local magnetic field, the four orientations of the NV-Centers in the diamond crystal results in up to four different Zeeman splits, which allows the evaluation of the local magnetic field vector. The resulting sensitivity to magnetic fields is strongly dependent on the number of collected signal photons on the detector. Therefore, to increase the sensitivity, the collection efficiency is crucial. Detection of the collected photons is realized by an integrated photodiode and the signal is evaluated by a field programmable gate array (FPGA) which also controls the measurement hardware. Such a standalone device will enable measurements in various environments and provide a system for users without insight to optics or quantum technology, thus greatly extending the possible applications for NV-Centers as quantum sensors.

HL 33.21 Wed 17:00 P1

Realization of remote entanglement using vacancy-centers in 4H-SiC — •Michael Baron[1], Maximilian Hollendonner[1], Fedor Hrunski[1], Daniel Scheller[1], Andre Pointner[1], Shravan Kumar Parthasarathy[2], and Roland Nagy[1] — [1]Chair of Electron Devices FAU — [2]Fraunhofer Institute for Integrated Systems and Device Technology IISB

The overall performance of quantum applications, such as quantum sensors, quantum tokens and optical quantum computers, can be highly improved by realizing a quantum network in which these constituents are connected. The emerging field of quantum technologies based on color centers in silicon carbide (SiC) will play an important part in the realization of such distributed quantum networks. As a physical platform silicon vacancy centers inside 4H SiC offer numerous advantages, such as low electrical field sensitivity making the system robust against stray fields, high photon yield in the Zero-Phonon-Line, good spin-coherence time and an already well-matured industrial fabrication knowledge for SiC. My research is concerned with the technical implementation and realization of a heralded single-photon entanglement protocol using V2 silicon vacancy centers in 4H-SiC. The experiment employs two such vacancies residing in independently operated cryostats separated by 2 meters, which are connected in an interferometer-like setup. This allows the creation of entanglement between both V2 centers and thus the creation of a quantum network based on these color centers.

HL 33.22 Wed 17:00 P1

Towards an integrated nanophotonic and electronic spin platform in 4H-SiC — •Daniel Scheller[1], Daniel Häupl[2], Lin Jin[3], Christian Gobert[4], Jannik Schwarberg[1], Jörg Schulze[1], Nicolas Joly[2], Wolfram Pernice[3], and Roland Nagy[1] — [1]Chari of Electron Devices, Friedrich-Alexander-University Erlangen-Nuremberg, Erlangen, Germany — [2]Max-Planck-Institue for the science of light, Erlangen, Germany — [3]Responsive Nanosystems, University of Münster, Münster, Germany — [4]Fraunhofer IISB, Erlangen, Germany

The solid state spin system of negatively charged silicon vacancies (V_{Si}) V2 in 4H-SiC shows high spectral stability and excellent spin coherence times required for efficient quantum processing. Moreover, silicon carbide provides standardized semiconductor processes enabling the implementation of integrated quantum photonics. However, high-fidelity spin photon coupling and low-loss chip-to-fiber interfaces are necessary to improve experimental rates and, thus, the performance of quantum devices. Recently, high coupling efficiencies of emitted photons from the VSi color center into angle-etched SiC waveguides have been predicted which can be further enhanced by photonic crystal cavities. Further, a low-loss optical interface from on-chip diamond tapered waveguides to tapered optical fibers was shown. Our goal is to combine these properties and implement single VSi color centers into nanophotonic SiC waveguides coupled to tapered fibers for realizing the on-chip entanglement of color centers and two locally separated quantum registers.

HL 33.23 Wed 17:00 P1

Towards Silicon Vacancy centers based quantum repeaters for a distributed quantum computing network in 4H-SiC — •Maximilian Hollendonner[1], Fedor Hrunski[1], Andre Pointner[1], Shravan Kumar Parthasarathy[2,1], Christian Gobert[2], Daniel Scheller[1], and Roland Nagy[1] — [1]Chair of Electron Devices, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany — [2]Fraunhofer Institute for Integrated Systems and Device Technology IISB, Schottkystraße 10, Erlangen, Germany

For the successful integration of quantum technological systems, like for instance optical quantum computers and quantum sensors [1] into a quantum internet of things it is vital to have quantum repeaters which mediate the exchange of information between various quantum nodes. Due to its excellent optical and spin properties [2], the V_2 silicon vacancy center in 4H-SiC is a promising platform for this task. Within this project we aim at building an interferometer in which after a first 50/50 beam splitter, two single V_2 centers separated by 2 meters are excited by 916nm photons. The single photon emitted by one of the two color centers then enters a second beam splitter, which effectively removes the which-path information and therefore creates a maximally entangled Bell state [3]. Successful demonstration of this entanglement between these two V_2 centers will be a vital step towards realization of a quantum internet of things.

Sources: [1] J. R. Maze *et al.*, *Nature* **455**, 644-647 (2008) [2] R. Nagy *et al.*, *Nat Commun* **10**, 1954 (2019) [3] P. C. Humphreys *et al.*, *Nature* **558**, 268-273 (2018)

HL 33.24 Wed 17:00 P1

On the positioning accuracy of single quantum emitters in photonic nano-structures embedded through in-situ electron beam lithography — •Jan Donges, Johannes Schall, Imad Limame, Ching-Wen Shih, Sven Rodt, and Stephan Reitzenstein — Technische Universitaet Berlin, Hardenbergstr. 36, 10623 Berlin

The precise integration of single quantum emitters at the target position inside of photonic nano-structures is of upmost importance for their optimum performance. Differences between simulated photon extraction efficiencies and experimentally determined values are often at least partially contributed to a spatial misalignment of the emitter. This is a reasonable assumption considering that for instance in the case of Bullseye cavities simulations yield that the efficiency can drop more than 50% just in case of a 50nm misplacement between structure and emitter. The main problem with this approach so far has been that there is no direct way of determining the emitter position inside the structure. Therefore, all statements about the position were based indirectly on results of photoluminescence (PL) experiments. Here, we present a solution for this issue. Through the simultaneous measurement of the structure via cathodoluminescence and electron microscopy we can directly determine the emitter position inside a photonic structure with. Furthermore, this approach enables us to make a clear statement about the positioning accuracy of in-situ electron beam lithography.

HL 33.25 Wed 17:00 P1

Quantum Polyspectra for an uncompromising and universal evaluation of quantum measurements — •Markus Sifft and Daniel Hägele — Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI (AG), Germany

The analysis of a continuous measurement record $z(t)$ poses a fundamental challenge in quantum measurement theory. Different approaches have been used in the past as records can, e.g., exhibit predominantly Gaussian noise, telegraph noise, or clicks at random times. This poster summarizes our latest findings that show that quantum measurements from all cases above can be analyzed in terms of higher-order temporal correlations of the detector output $z(t)$ and be related to the Liouvillian of the measured quantum system. The comparison of temporal correlations via so called quantum polyspectra is based on expressions derived without approximation from the stochastic master equation [1] and automatized without the need for manual post-processing of the detector output. This allows for fitting of system parameters like e.g., tunneling rates in a quantum transport experiment [2]. The very general stochastic master equation approach includes coherent quantum dynamics, environmental damping, and measurement backaction at arbitrary measurement strength. This enables a systematic evaluation of quantum measurements from the realms of conventional spin noise spectroscopy, quantum transport experiments, and, as our newest finding, ultra-weak measurements with stochastically arriving single photons [3]. [1] Hägele et al., PRB 98, 205143 (2018), [2] Sifft et al., PRR 3, 033123 (2021), [3] Sifft et al., arXiv:2109.05862

HL 33.26 Wed 17:00 P1

Detection of half-vortices in confined polariton condensates — •Yannik Brune, Bernd Berger, and Marc Assmann — Department of Physics, TU Dortmund, Germany

A half-vortex describes a rotating quantum fluid carrying a spin dependent topological charge. Theory predicts half-vortices as solutions of the spin dependent GPE. We experimentally demonstrate the existence of half-vortices in an all optical circular confined polariton condensate. Therefore we excite a polariton microcavity across the treshhold using a ringlike excitation profile and observe the polariton emission. Finally, we measure the topological charge of the condensate state, using spin filtered OAM sorting [1], and thereby confirm its half vortex character.

[1]Berger et al., Optics Express 26(24):32248 (2018)

HL 33.27 Wed 17:00 P1

Adaptive Bayesian estimation of an Overhauser field gradient — •Jacob Benestad[1], Jan Krzywda[2], Evert van Nieuwenburg[2,3], Fabrizio Berritta[3], Torbjørn Rasmussen[3], Anasua Chatterjee[3], Ferdinand Kuemmeth[3], and Jeroen Danon[1] — [1]Center for Quantum Spintronics, Norwegian University of Science and Technology, Norway — [2]Leiden Institute of Advanced Computer Science, Leiden University, The Netherlands — [3]Center for Quantum Devices, University of Copenhagen, Denmark

Slow fluctuations of the Overhauser field gradient are an important source for decoherence in singlet-triplet spin qubits hosted in type III-V semiconductors. Single-shot Ramsey experiments are well suited for Bayesian inference of the Overhauser gradient, where smart experiment design and prior knowledge can be leveraged to increase the information gain of a new measurement. This has led to the development of adaptive schemes, where between each measurement one attempts to determine the optimal next experiment in order to gain the most possible information about an Overhauser field gradient before the qubit decoheres. A real-time exact treatment of this problem at each step is difficult to achieve in an experimental setting. However an approximate treatment using only Gaussian distributions has been shown to give an exponential reduction of the distribution variance and would require only tracking two parameters. We propose a modification of this scheme that should make it more robust for gradients distributed around a mean of zero by evaluating the squared values and performing the Bayesian update scheme on the resulting chi-square distribution.

HL 33.28 Wed 17:00 P1

Zero-phonon line and electron-phonon coupling of the NV center in cubic silicon carbide: first-principles calculations — •Timur Biktagirov[1], Hans Jürgen von Bardeleben[2], Jean-Louis Cantin[2], Wolf Gero Schmidt[1], and Uwe Gerstmann[1] — [1]Universität Paderborn, Paderborn, Germany — [2]Sorbonne Université, Paris, France

The nitrogen-vacancy (NV) center in cubic silicon carbide (3C polytype), the analog of the NV center in diamond, has recently emerged as a solid-state qubit with competitive properties and significant technological advantages [1, 2]. Most applications of NV centers are based on optical spectroscopy of the zero-phonon line (ZPL) and the analysis of the spin states. Thus, we use density functional theory (DFT) calculations to provide thorough insight into the ZPL and the related magneto-optical properties of this center. In the case of NV in diamond, the ZPL is known to be in the visible spectral range [3]. In contrast, we identify the ZPL of the NV center in 3C-SiC at 1289 nm (within the telecom O-band), which is more suitable for device applications due to low transmission losses in optical waveguides. An analysis of the measured phonon sideband reveals the Huang-Rhys factor of 2.85 and the Debye-Waller factor of 5.8 %. Along with exceptionally long low-temperature spin-lattice relaxation times [2], these properties make NV in 3C-SiC a strong competitor for qubit applications.

1. S. A. Zargaleh et al., Phys. Rev. B 98, 165203 (2018).
2. H. J. Von Bardeleben et al., Nano Lett. 21, 8119-8125 (2021).
3. M. W. Doherty et al., Phys. Rep. 528, 1-45 (2013).

HL 33.29 Wed 17:00 P1

Design of a microwave resonator for coherent nuclear spin control of ^{13}C and ^{29}Si isotopes near V_2 color centers in 4H-SiC at cryogenic temperatures — •Jan Philipp Ahnfeldt[1], Fedor Hrunski[1], Shravan Kumar Parthasarathy[1,2], Maximilian Hollendonner[1], Daniel Scheller[1], Andre Pointner[1], and Roland Nagy[1] — [1]Chair of Electron Devices, FAU Erlangen-Nürnberg, Erlangen, Germany — [2]Fraunhofer Institute for Integrated Systems and Device Technology (IISB), Erlangen, Germany

One step to meaningful quantum technologies is to scale up the currently developed ones. This can be done by parallelizing several quantum systems through a quantum network. Therefore it is crucial that the network contains quantum memory nodes in which the quantum system used has a long coherence time. This can be ensured by the nuclear spin of the ^{13}C or ^{29}Si isotopes surrounding a silicon vacancy in 4H-SiC. However, due to the low gyromagnetic ratio of a nuclear spin a large magnetic flux is needed for the spin control. Accordingly, a large RF power with a frequency in the upper kHz domain is required. Because the power dissipation causes problems when upscaling these systems, it is important to improve the spin control's efficiency. Hence, a resonator creating a standing magnetic wave polarized perpendicular to the quantization axis of the vacancy seems to be a promising approach. Since it must operate at room and cryogenic temperatures, the resonator must be mechanically stable and needs a wide bandwidth. Therefore, several resonators are investigated which could meet these requirements in a small package of a few cubic centimeters.

HL 33.30 Wed 17:00 P1

Optical Beamsplitter for Orbital Angular Momentum Modes — •Rebecca Aschwanden[1], Bernhard Reineke[2], Lingling Huang[3], Klaus D. Jöns[1], Tim Bartley[1], and Thomas Zentgraf[1] — [1]Department of Physics, Paderborn University, Paderborn, Germany — [2]Institute for Photonic Quantum Systems PhoQS, Paderborn University, Paderborn, Germany — [3]Beijing Institute of Technology, Beijing, China

Metasurfaces consist of periodically arranged antennas of subwavelength dimensions that allow for specifically engineered functionalities and interaction with the incident light beam. They cannot only be used to replace conventional bulk optical elements but also to provide new functionalities. Here, we present the design and fabrication of a dielectric metasurface acting as a beamplitter with multiple output ports for orbital angular momentum (OAM) states. The dielectric metasurface consists of silicon nanofins which are fabricated by electron beam lithography and etching. We show that the metasurface splits the beam containing a superposition of OAM states into four spatially separated output directions.

HL 33.31 Wed 17:00 P1

Integration of free-standing GaAs nanobeam cavities hosting InAs/GaAs QD with LNOI waveguides — •Oscar Camacho Ibarra, Ioannis Caltzidis, Marc Sartison, and Klaus D. Jöns — Paderborn University, Paderborn, Germany

Monolithic integration is the most straightforward approach to incorporate single photon emitters and photonic integrated circuits (PICs). However, this approach limits you to the optical properties of the chosen material platform. Furthermore, the current best emitters on monolithic integration are randomly positioned [1]. Based on this context, hybrid integration, despite also requiring localization, stands out, in this approach different materials are integrated into one PIC, allowing one to exploit the advantages of each different material system (whether they are optical properties of the material or the emitters properties). In our work, we seek to hybridly integrate InAs/GaAs quantum dots embedded in nanobeam cavities with LNOI waveguides. To achieve this, we chose a transfer printing method [2] to place the nanobeam cavities (hosting the emitters) on top of the LNOI waveguides. Therefore, we report on the current progress and challenges for localization and nanofabrication of the free-standing nanobeam cavities.

[1] Marc Sartison et al, Scalable integration of quantum emitters into photonic integrated circuits, Mater. Quantum. Technol. 2 023002, 2022.

[2] Ryota Katsumi et al, Transfer-printed single-photon sources coupled to wire waveguides, Optica Vol. 5, No. 6, 2022.

HL 33.32 Wed 17:00 P1

Observation of quantum Zeno effects for localized spins — •Vitalie Nedelea — Experimentelle Physik 2, Technische Universität Dortmund, 44221 Dortmund, Germany

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

HL 33.33 Wed 17:00 P1

On-demand strain-induced recombination dynamics in semiconductor quantum wells — Daniel Hensel[1], Daniel Schmidt[3], Fariba Hatami[2], and •Peter Gaal[1,3] — [1]Leibniz-Institut für Kristallzüchtung, 12489 Berlin — [2]Humboldt Universität zu Berlin, 12489 Berlin — [3]TXproducts UG, 22547 Hamburg

Todays technology enables the fabrication of semiconductor structures with a high control over the electronic states. New technologies emerged from the manipulation of these states. To gain full control over the quantum state encrypted in a particle one must control both its lifetime and its coherence. Tailored transient strain pulses provide a new tool for the manipulation of nanoscale quantum objects. The strain-induced deformation of the crystal lattice manipulates the electronic bandstructure via deformation potential coupling. A convenient method to administer strain pulses to a sample are so-called surface acoustic waves (SAW). They are generated electronically by interdigitated circuits (IDT). The experimental control is limited by the ability to generate arbitrary lattice deformations on timescales short compared to the quantum decoherence. The photoacoustic method allows controlling the spatial and temporal shape of the optical excitation and thus shapes the strain pulse. In consequence, arbitrary SAWs can be generated on ultrafast timescales. Time-resolved photoluminescence (TRPL) spectroscopy is used to monitor the strain-induced change in electronic bandstructure. The control of the efficiency of radiative transitions of excitons through the applied strain could be the missing step for the realization of a fast on-demand single photon source.

HL 33.34 Wed 17:00 P1

Fiber-based Open Cavity: a tailored solution for Solid-state Quantum Emitters and their characterization. — •Francesco Salusti[1], Lukas Hanschke[1], Eva Schöll[1], Jonathan Noe[2], Manuel Nutz[2], Michael Förg[2], Thomas Hümmer[2], and Klaus D. Jöns[1] — [1]PhoQS, CeOPP, and Department of Physics, Paderborn University, 33098 Paderborn, Germany — [2]Qlibri GmbH, 80337 Munich, Germany and Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 Munich, Germany

For the realization of bright and reliable quantum light emitters, the integration of these emitters into cavity structures represents an elegant solution. However, in many cases, the fabrication of such photonic structure requires remarkable efforts to precisely match the position and the emission wavelength of the emitter with respect to the cavity mode. The required level of control of the materials, size, and positioning makes the realization of a practical cavity resource intensive. Recent works have demonstrated the possibility to take advance of open cavities to easily tailor the cavity around the specifications of individual emitters, such as 2D flakes and quantum dots. In our collaboration between industry and academia, we show that it is possible to take advantage of a fiber-based device to realize a tunable cavity at room and cryogenic temperature. In addition to the advantages of in-situ tuning of an optical resonator to specific emitter resonances, the high finesse of the system enables spatially resolved measurements of the absorption coefficient from oxidized 2D material.

HL 33.35 Wed 17:00 P1

Monolithic, heterogeneous and hybrid Integration of quantum emitters — •Marc Sartison, Oscar Camacho Ibarra, Ioannis Caltzidis, Dirk Reuter, and Klaus D Jöns — Institute for Photonic Quantum Systems, Center for Optoelectronics and Photonics Paderborn, and Department of Physics, Paderborn University, 33098 Paderborn, Germany

Modern integrated quantum photonic devices can be built out of a variety of material platforms like Lithium-Niobate on insulator (LNOI), Silicon-Nitride or Silicon with different kinds of quantum emitters like quantum dots, NV centres or emitters hosted in 2D materials. Exploiting the unique material properties several integration approaches were realized that can coarsely be categorized and belong to one of the following types: Monolithic, heterogeneous, and hybrid integration. In our work we give an overview of the different integration methods and compare them in terms of yield and scalability. We discuss the advantages and disadvantages of monolithic, heterogeneous and hybrid integration methods and provide a perspective on the upcoming challenges to realize scalable systems with high yield.

[M. Sartison et al, Mater. Quantum. Technol. 2 023002 (2022)]

HL 33.36 Wed 17:00 P1

Electrical Stark tuning of multiple waveguides with integrated quantum dots — •Yuhui Yang[1], Shulun Li[1,2], Johannes Schall[1], Chirag Palekar[1], Léo Roche[1], Hanqing Liu[2], Sven Rodt[1], Haiqiao Ni[2], Zhichuan Niu[2], and Stephen Reitzenstein[1] — [1]Institut für Festkörperphysik, TU Berlin, 10623 Germany — [2]Institute of Semiconductors, CAS, 100083, China

Self-assembled quantum dots (QDs) are promising candidates for future photonic quantum technologies owing to their close-to-ideal quantum properties. However, the random spectral and spatial distribution of single QD complicates the controlled integration of single QD into photonic structures using standard nano-processing technologies such as standard electron beam lithography and makes upscaling to complex quantum circuits practically impossible. We overcome these technical issues by combining cryogenic cathodoluminescence (CL) mapping for spectrally selected integration of QDs and the quantum-confined Stark effect for spectral fine-tuning. Two spectrally similar self-assembled QDs in a p-i-n diode membrane are pre-selected and are deterministically integrated into the hybrid structure waveguides using marker-based electron beam lithography. Moreover, the gate voltage-dependent micro photoluminescence spectra reveal the achievement for tuning individual QD in waveguide systems and spectrally overlying them together. Our work demonstrates the high potential of deterministic quantum device processing for the scalable fabrication of complex quantum integrated circuits with multiple single-photon emitters as an attractive platform for future quantum technologies.

HL 33.37 Wed 17:00 P1

Electrical Stark tuning of multiple waveguides with integrated quantum dots — •Yuhui Yang[1], Shulun Li[1,2], Johannes Schall[1], Chirag Palekar[1], Léo Roche[1], Hanqing Liu[2], Sven Rodt[1], Haiqiao Ni[2], Zhichuan Niu[2], and Stephen Reitzenstein[1] — [1]Institut für Festkörperphysik, TU Berlin, 10623 Germany — [2]Institute of Semiconductors, CAS, 100083, China

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HL 33.38 Wed 17:00 P1

Donor Spins in Compressively Strained Silicon — •Basak Cigdem Özcan, David Vogl, and Martin S. Brandt — Walter Schottky Institut and School of Natural Sciences, Technische Universität München, 85748 Garching, Germany

Silicon doped with donors is a promising system for quantum computing applications due to long coherence times, fast spin control and the possibility of scaling as well as integration with conventional microelectronics. In order to achieve long coherence times, coupling to other nuclear spins should be avoided. This is achieved by using isotopically purified Si-28 samples, which is the naturally more abundant isotope without nuclear spin. The conventional architecture to conduct measurements on doped Si-28 involves the placement of control and read-out gate structures on top of the sample. Such additional structures cause strain near the donors, which makes it important to understand the effect of strain on their spin properties. To study this under controlled strain conditions, we utilize a no-contact capacitive read-out scheme, where optical excitation of donor-bound excitons (DBE) followed by an Auger recombination facilitates spin-dependent excitation, spin polarization and spin-state read-out. Combining infrared optical excitation and microwave pulses, we perform electron nuclear double resonance (ENDOR) experiments, with which we achieve coherent control of nuclear spins of the donors. Here, we investigate the strain-dependent shift of DBE resonance frequencies under uniaxial compressive stress. We acknowledge the financial support of MCQST.

HL 33.39 Wed 17:00 P1

Application of low-cost visible light LEDs in avalanche mode as sensitive photoreceivers in a plastic optical fiber data transmission system — •Heinz-Christoph Neitzert — Dept. of Industrial Engineering (DIIN) Salerno University Fisciano, Italy

Commercial low-cost light emitting diodes have been tested as photoreceivers without and with applied reverse bias voltage. In particular the possibility to operate the devices in the breakdown regime as sensitive avalanche photodiodes has been succesfully tested. High photogain amplification at relatively low breakdown voltage values has been observed. Based on this possibility to operate the LEDs efficiently not only as emitters but also as photoreceivers, a simple half-duplex bidirectional optical transmission scheme, which is based on the plastic-optical-fiber (POF) as transmission medium and green LEDs as receiving/emitting elements has been developed. The choice of the green wavelength range gives the possibility to operate the system at the minimum absorption of the plastic optical fiber

HL 33.40 Wed 17:00 P1

High Resolution Spectroscopy for (Al,In)GaN Laser Diodes — •Dominic J. Kunzmann, Raphael Kohlstedt, and Ulrich T. Schwarz — TU Chemnitz, 09126 Chemnitz, Germany

We investigate laser diodes based on the (Al,In)GaN material system with the help of high-resolution spectroscopy. Therefore, we use two setups, one with a grating spectrometer and a Fabry-Pérot-Interferometer. The grating spectrometer is used to measure the longitudinal mode spectra above and below the threshold current. Below the threshold we perform Hakki-Paoli gain spectroscopy to obtain the internal losses of laser diodes which is getting even more challenging, when the diodes get better and the losses smaller. Above the threshold wavelength shifts with current and temperature can be observed and with these shifts the thermal resistance is available. Additionally for broad ridge high power laser diodes the interplay of different longitudinal mode combs is investigated with the high-resolution spectrometer. The Fabry-Pérot-Interferometer enables us to go to even higher resolutions and to verify single mode behavior of laser sources and to observe much smaller wavelength shifts.

HL 33.41 Wed 17:00 P1

Indium incorporation in thin c-plane GaInN/GaN quantum wells grown via plasma-assisted molecular beam epitaxy — •Farouk Aljasem, Heiko Bremers, Uwe Rossow, and Andreas Hangleiter — Institut für Angewandte Physik & Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Germany

This work aims to investigate the physical mechanisms of the incorporation of indium atoms in GaInN QW structures with an emphasis on interface properties by growing thin GaInN multiple quantum wells. A comparison of the obtained results using MBE with the results from the previous work using MOVPE offers more information about indium incorporation mechanisms. As well known, the flux of the activated nitrogen in the plasma-assisted molecular beam epitaxy (PAMBE) is independent of the growth temperature. This feature enables the growth of GaInN MQWs at low temperatures and in different growth regimes compared to MOVPE. Fivefold thin GaInN/GaN MQWs are grown via PAMBE in the c-direction using MOVPE-grown GaN templates on sapphire as substrates. The GaInN/GaN MQW samples were grown at different growth temperatures with various III/V ratios and QW thicknesses. MQW thickness ranged between less than half a c-lattice constant and 2 nm with no significant relaxation. To provide a precise understanding of the physical processes during the growth process of GaInN monolayers, the samples were characterized using HR-XRD, AFM, HR-TEM and CW-PL.

HL 33.42 Wed 17:00 P1

Temperature dependent Raman spectroscopy on GaN:Si — •Christina Harms, Jona Grümbel, Martin Feneberg, and Rüdiger Goldhahn — Institut für Physik, Otto-von-Guericke-Universität Magdeburg, Germany

GaN structures are of high interest for optical and electronic applications in current research projects. We investigate the Raman excitations of hexagonal bulk GaN:Si under temperature variation from 80 K up to 300 K. Seven samples with carrier concentrations ranging between 10^{12} - 10^{19} cm^{-3} were measured using laser excitation of 532 nm. It is shown, that within room temperature measurements both coupled phonon-plasmon-modes ($LPP_{\pm}$) are visible and follow the prediction of polaritonic excitations. Under variation of temperature the LPP_{+} mode shows a weak frequency shift with elevated temperature or remains unaffected for low carrier concentrations. Surprisingly, the LPP_{-} mode shifts towards lower frequencies with increasing temperatures for all samples, which contradicts previous assumptions. A qualitative description of the results and possible interpretations will be presented. Additionally, we also investigated the temperature dependent FWHM of the $LPP_{\pm}$ mode and the E_2 phonon mode. Here, both behaviours match the theoretical and experimental previous research.

HL 33.43 Wed 17:00 P1

Indium incorporation during GaInN quantum well growth: role of underlayer surface morphology — •Rodrigo de Vasconcellos Lourenço[1,2], Uwe Rossow[1], Philipp Horenburg[1], Heiko Bremers[1,2], and Andreas Hangleiter[1,2] — [1]Institute of Applied Physics, Technische Universität Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Germany

The control of Indium incorporation is a key factor for the optoelectronic devices in the visible and near UV spectral region. The luminescence efficiency of such devices has been improved by the so-called underlayer, i.e the layer grown just before the active region. We investigate the surface morphology as function of the underlayer (UL) composed of GaN or InAlN. For GaN UL, we find extended, very smooth terraces separated by macrosteps in a range of growth temperature from 770 to 950 °C. Additionally, morphologies associated to the Ehrlich-Schwöbel barrier are not observed. On the other hand, for InAlN UL lattice matched to GaN, evidence for nuclei forming at step edges is observed, which may be due to lower surface mobility of Al compared to Ga or In. In the next step, we want to understand how the underlayer morphology affects the Indium incorporation of GaInN quantum wells.

HL 33.44 Wed 17:00 P1

The impact of laser lift-off on the optical properties of InGaN/GaN LEDs — •Stefan Wolter, Steffen Bornemann, Hendrik Spende, and Andreas Waag — Institut für Halbleitertechnik, Technische Universität Braunschweig, 38106 Braunschweig

InGaN/GaN LEDs are typically grown on sapphire, but sapphire is a disadvantageous material when it comes to electrical or thermal conductivity. This limits the performance, when the LED structure is processed into a device. For this reason, it is useful to transfer the LED structure to another carrier after growth, which can be achieved by laser lift-off (LLO). In this process, a pulsed laser beam is focused on the sapphire/GaN interface, leading to absorption of the laser photons in the GaN layer and subsequent decomposition of GaN near the interface resulting in detachment of the GaN film from sapphire. The usage of ultra short laser pulses can reduce the required laser fluence compared to nanosecond pulses, but has the disadvantage of penetrating deep into the LED structure and possibly even reaching the active region. This leads to a change in the characteristic properties of the LED, which is investigated in this study. For this purpose, in-house grown blue InGaN/GaN LEDs are investigated before and after LLO, which was conducted with sub-bandgap (520 nm) and above-bandgap (347 nm) laser light at a pulse width of 0.4 ps. Temperature-dependent photoluminescence experiments in the temperature range of 6 K to 295 K indicate that the maximum internal quantum efficiency decreases by at least 10 % after LLO. Furthermore, LLO can have an impact on the localization strength of the carriers inside the active region.

HL 33.45 Wed 17:00 P1

haracterization of a semiconductor microstructure analogous to a Venturi pump — •Severin Krüger, Fabian Liedtke, Peter Zajac, Andreas Wieck, Arne Ludwig, and Ulrich Kunze — Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum, Germany

Micro-structuring a high-mobility two-dimensional electron gas allows investigation of the ballistic transport regime for electrons. The electrons in the examined channel structures show edge effects like a minimal resistance at finite currents [1]. Furthermore, the electrons show hydrodynamical behavior and can create a rectifing voltage at the narrow channel, similar to the Venturi-effect [2]. Here, first results of measurements regarding the Venturi analogon with different channel sizes, gate voltages and source-drain currents are presented.

[1] Gurzhi, R.N.: "Minimum of Resistance in Impurity-free conductors" *Soviet Phys. JETP 17*, 521-522 (1963).
[2] Szelong, M.: "Ballistische und hdydrodynamische Vollwellengleichrichtung in nanoskaligen elektronischen GaAs/AlGaAs-Kreuzstrukturen" Disseration, Ruhr-Universität Bochum (2017).

HL 33.46 Wed 17:00 P1

Novel approach to real-space renormalization group analysis of the quantum Hall effect — •Nathan Shaw and Rudolf A. Römer — Department of Physics, University of Warwick, Coventry, CV4 7AL, UK

Consensus on the value of the critical exponent ν of the plateau-to-plateau transitions in the quantum Hall effect has not yet been achieved. Recent work has highlighted a discrepancy between field theory based predictions and numerical high-precision estimates. A necessarily approximate real-space renormalization group (RG) approach to the Chalker-Coddington model has previously been shown to suggest a critical exponent of $\nu \approx 2.3$. However, most recent numerical estimations suggest that $\nu = 2.58(3)$. In this study, we experiment with varying the analytical form of the scattering matrix elements with the goal of increasing the numerical stability of the fixed point distribution constructed by the RG flow. Using this improved distribution, we recalculate the critical exponent with higher accuracy.

HL 33.47 Wed 17:00 P1

Epitaxial growth of high-density short wavelength InGaAs QDs for low-threshold VCSELs — •Sarthak Tripathi, Kartik Gaur, Ching-Wen Shih, Imad Limame, Sven Rodt, and Stephan Reitzenstein — Inst. for Solid State Phys., Technical Univ. of Berlin, Germany

Self-assembled growth of InGaAs quantum dots by MOCVD is used to form the active region of low-threshold vertical-cavity surface-emitting lasers (VCSELs). In our work, we optimize the QD gain medium for room-temperature lasing at 935-955 nm which is attractive for gas sensing applications. Multiple layers of high-density InGaAs quantum dots are stacked in order to maximize the modal gain. The density of dislocations and point defects in QD heterostructures is strongly reduced by annealing which enables a significant reduction of the spacer thickness (thinner active region) between stacked QD layers without forfeiting their crystalline quality. Surface characterization is performed using atomic force microscopy AFM to determine the QD density. Moreover, during growth optimization photoluminescence studies are conducted to evaluate the optical properties of single and stacked layers of QD emitting in the target wavelength range. In future, the resulting QDs will be integrated in an active region embedded VCSELs with monolithically integrated high contrast grating (MHCG) hybrid structure.

HL 33.48 Wed 17:00 P1

Simulation and fabrication of a WS_2-nanobeam cavity with a $MoSe_2$ monolayer as active material — •Aris Koulas-Simos[1], Bárbara Rosa[1], Chirag Palekar[1], Léo Roche[1], Yang Yuhui[1], Felix Binkowski[2], Sven Burger[2,3], Battulga Munkhbat[4], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Zuse Institute Berlin (ZIB), 14195 Berlin, Germany — [3]JCMwave GmbH, D-14050 Berlin, Germany — [4]Department of Electrical and Photonics Engineering, Technical University of Denmark, 2800 Kongens Lyngby, Denmark

Transition metal dichalcogenides (TMDCs) exhibit extraordinary optical, electrical, and mechanical properties that can be easily tailored for novel integrated photonic applications. Different TMDCs can be combined to form novel nanostructures with highly interesting complex dynamics. Here, we report on the simulation and fabrication of a WS_2-nanobeam cavity with a $MoSe_2$ monolayer (ML) as active material. Utilizing a FEM eigenfrequency solver, cavity simulations are performed on a 3D stripe of WS_2 with a finite periodic air hole arrangement. The calculated eigenmodes exhibit high Q-factors and tight mode confinement with mode volumes near the fundamental diffraction limit after parameter optimization. The final parameter set is employed in the fabrication process of WS_2-nanobeam cavities with a $MoSe_2$ ML embedded in them. This work paves further the way toward the realization of novel nanolaser devices consisting purely of TMDC materials.

HL 33.49 Wed 17:00 P1

Design and optimization of Monolithic High Contrast Grating for tuneable quantum dot VCSEL arrays — •Floriana Laudani[1], Mikołaj Janczak[2], Bartosz Kamiński[3], Niels Heermeier[1], Anna Musiał[3], Grzegorz Sek[3], Tomasz Czyszanowski[2], Sven Rodt[1], and Stephan Reitzenstein[1] — [1]Institute of Solid State Physics, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institute of Physics, Lodz University of Technology, 90-924 Łódź, Poland — [3]Department of Experimental Physics, Wroclaw University of Science and Technology, 50-370 Wrocław, Poland

Water vapor measurements are essential for industrial applications to ensure a qualitative processing and control chain and require gas sensors with short response times in a broad wavelength range. In contrast to standard vertical-cavity surface-emitting lasers (VCSELs), devices with monolithically integrated high contrast gratings (MHCGs) can provide a high flexibility with respect to the emission wavelength. We compare reflectivity measurements and theoretical results on GaAs-based MHCGs for a target wavelength around 940 nm. A numerical model based on Plane-Wave Admittance Method solving set of Maxwell equations was used to search for optimal geometric parameters for effective device optimization, allowing a controlled parameter tuning throughout the fabrication process based on high-resolution electron-beam lithography. Since MHCGs can be custom designed before fabrication, they offer great potential for realizing on-chip tuneable VCSEL arrays, e.g. in a variety of short-range communication systems.

HL 33.50 Wed 17:00 P1

In-plane coupling between a WGM micropillar laser and a ridge waveguide — •Léo Roche[1], Imad Limame[1], Ching-Wen Shih[1], Aris Koulas-Simos[1], Yuhui Yang[1], Sven Burger[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik (TUB), Berlin, Germany — [2]JCMwave GmbH, Berlin, Germany

Integrated quantum photonic circuits (IQPCs) are very promising candidates for scalable and flexible on-chip quantum computation and quantum communication hardware. One critical requirement for their realization is the scalable integration of on-demand indistinguishable single-photon emitters. This is potentially possible through the resonant excitation of an integrated QD in a waveguide by means of an on-chip integrated coherent light microlaser. Towards this goal, we investigate the coupling and lasing properties of coherent light laterally emitted from a whispering gallery mode (WGM) type micropillar laser evanescently coupled to a single mode ridge waveguide. Using finite element method (FEM) simulations, we predict the pillar dimensions allowing for lasing modes in the typical emission wavelength of InGaAs QD (930nm) and investigate the coupling efficiency and the Q-factor of the pillar-waveguide system for different angular mode number, pillar-waveguide air gap distances and interface types (point-like or pulley coupling). The III-V semiconductor type nanostructures composed of a GaAs cavity with InGaAs QDs and distributed Bragg reflectors are processed using high-resolution electron beam lithography. Simulation predictions and micro-photoluminescence spectroscopy performed on the nanoprocessed devices are compared and discussed.

HL 33.51 Wed 17:00 P1

Relativistic calculation of hyperfine splittings of hydrogen-like atoms with finite-size nuclei — •Katharina Lorena Franzke, Wolf Gero Schmidt, and Uwe Gerstmann — Paderborn University, Warburger Str. 100, 33098 Paderborn

The hyperfine splittings of spin qubits play an important role in quantum information and spintronics application. They allow for readout of the spin qubits, while simultaneously being the dominant mechanism for the detrimental spin decoherence. Their exact knowledge is thus of prior relevance. In this work we show that the formula of Blügel et al. [1] also holds in the full relativistic regime even if finite-size structure of the nuclei are taken into account. For this purpose, different models for the nuclear charge and spin distributions are compared analytically. The calculated hyperfine splittings of H-like alkali atoms up to ^{133}Cs show a good agreement for all nuclei models. For the real one-electron systems ^{1}H, ^{2}H, ^{3}H, ^{3}He^{+} they are also in very good agreement with available experimental data. Deviations of DFT-predicted hyperfine splittings from experiment are thus actually due to the use of the frozen-core approximation and limitations of the exchange-correlation (XC) functional.

[1] S. Blügel et al., *Hyperfine fields of 3d and 4d impurities in nickel.* Physical Review B **35**, 3271 (1987).

HL 33.52 Wed 17:00 P1

Calculation of zero-field splitting in high-spin defects in semiconductors — •Timur Biktagirov, Wolf Gero Schmidt, and Uwe Gerstmann — Universität Paderborn, Paderborn, Germany

High-spin defects in semiconductors represent an attractive class of potential solid-state qubits [1]. One of their key spectroscopic fingerprints is the splitting of their spin sublevels in the absence of external magnetic fields. Here we discuss recent progress and open challenges in the theoretical prediction of this zero-field splitting [2, 3].

1. J. R. Weber et al., PNAS 107, 8513-8518 (2010).
2. T. B. Biktagirov and U. Gerstmann, Phys. Rev. Research 2, 023071 (2020).
3. T. B. Biktagirov et al., Phys. Rev. Research 2, 022024 (2020).

HL 33.53 Wed 17:00 P1

Electro-optic response function of thin Quartz for sampling of high-field THz pulses — •Maximilian Frenzel, Michael S. Spencer, and Sebastian F. Maehrlein — Fritz Haber Institute of the Max Planck Society, Faradayweg 4-6, 14195 Berlin, Germany

As high-field THz sources are currently getting more broadly employed, it becomes increasingly important to characterize intense single-cycle THz fields (>1 MV/cm) in amplitude and phase without saturation or nonlinearities in the electro-optic detection. After previous attempts of spectrally neutral attenuation, z-cut α-Quartz has been recently found as a suitable electro-optic sampling (EOS) crystal. Nevertheless, its accurate response function, which allows the THz electric field to be exactly determined from the measured EOS signal, is still missing. Here, we employ intense THz fields (0.5 - 4 THz) generated via optical rectification in $LiNbO_3$ to measure EOS in Quartz of various thicknesses between 30 and 150 μm. We find that both EOS peak amplitude and signal shape are significantly thickness-dependent. By modeling the Quartz EOS detector response function, we find good agreement between parameter free theory and experiment, thus explaining the measured thickness dependence. Our work will therefore allow accurate measurement of intense THz electric fields wherever conventional EOS materials are facing saturation effects.

HL 33.54 Wed 17:00 P1

Fourier Transform Infrared Spectroscopy of Quantum Dot and Bragg Mirror Layers in Semiconductor Heterostructures — •Nikolaj Lehl, Andreas Wieck, Nathan Jukam, and Amar Alok — Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Deutschland

A purposefully designed distributed Bragg reflector (DBR) in a semiconductor heterostructure improves this device's photon yield gathered from its quantum dot (QD) layer. In this master thesis the transmission spectra of such semiconductor heterostructure samples are taken using Fourier-transform infrared spectroscopy (FTIR). The molecular beam epitaxy (MBE) grown gallium arsenide (GaAs) based samples include indium arsenide (InAs) QDs, and DBRs made of sequences of GaAs layers and aluminium arsenide (AlAs) layers. The DBR stopband measurements are taken in the near-infrared (NIR) and mid-infrared (MIR) region, in vacuum, under room temperature. Furthermore, it is planned to investigate the QD intersubband transitions implied in the far-infrared (FIR) transmission spectra as a function of applied voltage at liquid nitrogen and liquid helium temperatures. All acquired spectra are compared to the devices' simulated spectra, in order to make a conclusion on the initially expected growth rates and the growth rates resulting from the measurements.

HL 33.55 Wed 17:00 P1

MIR Time-Domain Ellipsometry via 2D Electrooptic Sampling — •Leona Nest, Michael Scott Spencer, Martin Wolf, and Sebastian Maehrlein — Fritz Haber Institute of the Max Planck Society, Department of Physical Chemistry, Faradayweg 4-6, 14195 Berlin, Germany

Terahertz time-domain spectroscopy (THz-TDS) has been established as a powerful tool in fundamental material science as it allows to measure conductivities, dielectric functions, and related phase transitions in e.g. semiconductors, topological insulators, and high-temperature super-conductors. Moreover, THz-TDS is well suited to investigate ultrafast, and thus non-equilibrium, quasi-particle dynamics in such solid- state systems. The time-resolved detection of the electric field provides direct access to complex-valued static and transient material properties. Here, we extend this technique to additionally measure the temporal evolution of the field's polarization for direct determination of complex tensorial material responses. Operating our time-domain ellipsometer in the mid-Infrared (MIR, 15-40 THz) enables anisotropic transmittivity or reflectivity studies in a spectral region where fundamental resonances such as phonons can be found. As a benchmark system, we extract the complex-valued dielectric tensor components of y-cut α-quartz in the vicinity of its anisotropic 21 THz and 24 THz phonon resonances. Good agreement with free-electron-laser-based studies shows that we developed a versatile table-top time-domain ellipsometer that will be used to also measure non-equilibrium tensorial properties in the near future.

HL 33.56 Wed 17:00 P1

Comprehensive model for the thermoelectric properties of two-dimensional carbon nanotube networks — •Aditya Dash, Dorothea Scheunemann, and Martijn Kemerink — Institute for Molecular Systems Engineering and Advanced Materials, Heidelberg University, Im Neuenheimer Feld 225, 69120 Heidelberg, Germany.

Networks of semiconducting single-walled carbon nanotubes (SWCNTs) are interesting thermoelectric materials due to the interplay between CNT and network properties. Here we present a unified model to explain the charge and energy transport in SWCNT networks. We used the steady-state master equation for the random resistor network containing both the intra- and inter-tube resistances, as defined through their 1D density of states that is modulated by static Gaussian disorder. The tube resistance dependence on the carrier density and disorder is described through the Landauer formalism. Electrical and thermoelectric properties of the network were obtained by solving

Kirchhoffs laws through a modified nodal analysis, where we used the Boltzmann transport formalism to obtain the conductivity, Seebeck coefficient, and electronic contribution to the thermal conductivity. The model provides a consistent description of previously published experimental data for temperature and carrier density-dependent conductivities and Seebeck coefficients, with energetic disorder being the main factor explaining observed mobility upswing with carrier concentration. For lower disorder, the Lorentz factor obtained from simulation is in accordance with the Wiedemann-Franz law. Suppressed disorder and lattice thermal conductivity can be a key to higher zT.

HL 33.57 Wed 17:00 P1

Electric field assisted transport in photodiodes studied by EBIC and STEM — •Lennart Nolte[1], Christoph Flathmann[1], Tobias Meyer[2], and Michael Seibt[1] — [1]IV. Physical Institute, University of Goettingen, Göttingen, Germany — [2]Institute for Materials Physics, University of Goettingen, Göttingen, Germany

P-i-n diodes consist of an intrinsic layer sandwiched between an n- and p-doped layer. Due to lack of carriers in the intrinsic layer, it shows a high Ohmic resistance and realizes more extended depletion zones compared to a typical p-n junction. This makes p-i-n-diodes particularly interesting for high frequency and high voltage electronic applications in addition to photo detection. In this study, we perform electron beam induced current (EBIC) investigations in cross-section geometry combined with scanning transmission electron microscopy (STEM) in order to study electric field assisted diffusion of excess carriers on a nanometer scale under well-defined experimental conditions. Special focus will be on carrier recombination at surfaces produced by focused ion beam (FIB) preparation.

HL 33.58 Wed 17:00 P1

Investigating the influence of stoichiometry-fluctuations on the electronic properties of ultra-scaled HBTs — •Daniel Dick[1,3], Jörg Schuster[1,2,3], Florian Fuchs[2,3], and Sibylle Gemming[3,4] — [1]Center for Microtechnologies, Chemnitz University of Technology, Chemnitz, Germany — [2]Fraunhofer Insitute for Electronic Nano Systems (ENAS), Chemnitz, Germany — [3]Center for Materials, Architectures and Integration of Nanomembranes (MAIN), Chemnitz University of Technology, Chemnitz, Germany — [4]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany

Silicon-germanium (SiGe) heterojunction bipolar transistors (HBTs) have found widespread use in high-frequency applications. Scaling of the HBT base layer thickness to 5 nm and below makes an atomistic treatment indispensable as fluctuations of dopant concentrations play a bigger role.

We investigate the effect of scaling on properties such as band gap and carrier effective mass and obtain effective material parameters for use in simulations at a larger scale. The use of semi-empirical methods such as extended Hückel theory enables us to simulate a large number of permutations of the atomic structure and study statistical variation of its properties while first-principles methods such as density functional theory allow us to verify the results. Finaly, using the non-equilibrium Green's function method we investigate the effect of alloy and phonon scattering on transport through such a layer.

HL 33.59 Wed 17:00 P1

Investigation of Transport Phenomena Through Functionalized Single Molecules Using Liquid Mechanically Controllable Break Junctions — •Harpreet Sondhi — FWIO-T, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany

The creation of molecular components for use as electronic devices has made enormous progress. In order to advance the field further toward realistic electronic concepts, methods for the controlled modification of the conducting properties of the molecules contacted by metallic electrodes need to be further developed. Here a comprehensive study of charge transport in a class of molecules that allows modifications by introducing metal center/side chain groups into organic structures is presented. Single molecules are electrically contacted and characterized in order to understand the role of the metal center/side chain groups in the conductance mechanism through the molecular junctions. It is shown that the presence of single metal ions/side chain groups modifies the energy levels and the coupling of the molecules to the electrical contacts, and that these modifications lead to systematic variations in the statistical behavior of transport properties of the molecular junctions.

HL 33.60 Wed 17:00 P1

Time-gated coherent two-dimensional spectroscopy on the nanoscale — •Luisa Brenneis, Julian Lüttig, Matthias Hensen, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

The observation of the temporal dynamics of excitons, i.e., electron-hole pairs, is essential for the understanding of fundamental phenomena in nature, e.g., photosynthesis [1]. The method of optical two-dimensional (2D) spectroscopy has proven to be particularly suitable for this purpose. For example, electronic couplings and energy transport phenomena can be directly revealed as cross peaks in a 2D spectrum, i.e., a correlation spectrum of excitation and probe frequency as a function of time. To additionally decipher the spatial dynamics of a system in a nanostructured environment beyond the optical diffraction limit, we have combined 2D spectroscopy with photoemission electron microscopy to realize coherent “2D nanoscopy” [2,3]. Here, using coupled molecular dimers in numerical simulations, we investigate the potential of 2D nanoscopy. In particular, we show how the exciton and biexciton dynamics can be disentangled by resolving the kinetic energy spectrum of photoemitted electrons and by realizing a time gate using an additional ionization pulse.

[1] T. Brixner et al., Nature **434**, 625-628 (2005).
[2] M. Aeschlimann et al., Science **333**, 1724 (2011).
[3] S. Pres et al., Nat. Phys. (2022) (accepted).

HL 33.61 Wed 17:00 P1

Negative thermal expansion in HgTe/CdTe heterostructures on ultrafast timescales — •Marc Herzog[1], Matthias Rössle[2], Jan-Etienne Pudell[3], Maximilian Mattern[1], Lukas Lunczer[4], Claus Schumacher[1], Hartmut Buhmann[1], Laurenz Molenkamp[1], and Matias Bargheer[2,3] — [1]Institut für Physik und Astronomie, Universität Potsdam, Germany — [2]Helmholtz-Zentrum Berlin, Germany — [3]European XFEL, Germany — [4]Physikalisches Institut EP3, Universität Würzburg, Germany

Materials that would exhibit an ultrafast negative thermal expansion (NTE) are desirable to generate ultrashort and high-amplitude acoustic waves as unconventional stimulus e.g. in the context of nonlinear acoustics or magnetoelastic effects. Both semimetallic HgTe and semiconducting CdTe exhibit pronounced NTE behaviour in thermal equilibrium below their Debye temperatures $\Theta_D \approx 150\,K$ owing to a negative Grüneisen parameter and correspondingly negative stress by transverse acoustic (TA) phonons.

Using ultrafast x-ray diffraction we investigate the coherent (sound) and incoherent (heat) lattice response in HgTe thin films on a CdTe substrate to ultrashort laser pulse excitation. While above Θ_D both materials exclusively expand upon excitation, below Θ_D a pronounced NTE is observed. However, the time scale for this NTE to develop is a few 100 ps suggesting a slow excitation of the TA modes. At few-ps time scales, however, a strong expansion of HgTe prevails at all measured excitation densities indicating a fast and dominant positive stress due to non-TA phonon modes and/or hot carriers.

HL 33.62 Wed 17:00 P1

h-BN as a protective encapsulation layer for monolayer graphene — •V. Calvi[1], M. Barnes[1], M. Buscema[1], D. Wehenkel[1], I.M.N. Groot[2], and R. van Rijn[1] — [1]Applied Nanolayers B.V., Feldmannweg 17, 2628 CD Delft, The Netherlands — [2]Leiden Institute of Chemistry, Leiden University, P.O. Box 9502, 2300 RA Leiden, The Netherlands

Graphene surface contamination by polymer residues used in the graphene processing is a key problem for certain device applications. PMMA is used for graphene transfer from a growth substrate to a target substrate. Transfer process leaves polymer residues on the graphene monolayer which causes p-doping. Technique used for the removal of polymer residue is annealing in different gas or vacuum atmospheres. Annealing in oxygen rich environment effectively removes polymer residue, but at the same time also causes damage to the graphene monolayer.

We have investigated stacking a monolayer of h-BN on top of a monolayer of graphene prior to transfer of the graphene. In this way the polymer necessary for the transfer only has direct contact with the surface of the h-BN and graphene would be protected in this way. We compared the damage and cleanliness to both bare graphene and stacked h-BN/graphene by Raman spectroscopy and AFM. We tested different annealing temperatures between 100°C and 500°C and found that the graphene is indeed protected from damage from the annealing process by covering it with a layer of h-BN. At the same time, we were able to show that polymer residue is effectively removed at the higher annealing temperatures.