HL 74: Poster IIIA

This poster session includes contributions from the following topic:

- 2D semiconductors and van der Waals heterostructures

Please put up your poster at the beginning of the session and remove the poster immediately after the session. The person peresenting the poster should attend it for at least half of the session duration and indicate the time when to find him/her at the poster.

Time: Thursday 15:00–17:30 Location: P2/2OG

HL 74.1 Thu 15:00 P2/2OG

Radiation-modulation of mono-layer MoSe2 nano emitters by LSPs — •Yuhao Zhang and Stefan Linden — Physikalisches Institut, Universität Bonn

Nano emitters based on transition metal dichalcogenide (TMDC) monolayers is considered as a potential resource for nano-photonic technologies. It is necessary to develop methods to optimize the radiation of this kind of nano emitters. Localized surface plasmons (LSPs) is considered as one of the best choice due to it is a no- propagation method and it is convenient to be controlled. Here, we produced MoSe2 monolayers by mechanical exfoliation, and then the monolayers are transferred to plasmonic nanoantennas by PDMS stamps. In order to change the resonance of LSPs that they produced, the sizes of the nanoantennas are changed from 100 nm to 400 nm. Then the radiation of the nano emitters coupled to different resonance LSPs are measured by a PL microscope. The result shows that the radiation of mono-layer MoSe2 nano emitters is modulated by the resonance of LSPs. When the LSP is resonance with radiation of the nano emitters, the radiation is enhanced 1.5 times compared to the monolayers on the glass substrate. With the resonance of LSPs is off, the radiation of nano emitters descend continuously until they are near-resonance with high-order LSPs. Our results agree well with the FEM simulations. This effect provides an efficient tool to optimize the radiation of TMDC nano emitters.

HL 74.2 Thu 15:00 P2/2OG

Theory of near-field optics in transition metal dichalcogenides — •Robert Salzwedel, Andreas Knorr, and Malte Selig — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

In recent years transition metal dichalcogenides (TMDCs) attracted much attention due to their strong Coulomb and light matter interaction leading to tightly bound excitons with large optical oscillator strength. Due to their finite thickness, those excitons have been shown to be very sensitive to their environment, for instance to a change in their dielectric surrounding [1] or the deposition of a self assembled layer of molecules [2].

Here we present a microscopic theory which is based on a self consistent solution of Maxwell and Bloch equations to study phenomena which are associated with the nearby environment of the TMDC layer, for instance the trapping of excitons by external molecules placed on top of the layer. As an outlook, our approach also allows the description of the launch of in-plane exciton-polaritons and their propagation through the layer.

[1] P. Steinleitner et al., Nano Lett.18, 1402 (2018)
[2] M. Feierabend et al., Nat. Commun. 8, 14776 (2017)

HL 74.3 Thu 15:00 P2/2OG

Direct Measurement of the Radiative Pattern of Exciton Complexes in a Tungsten Diselenide Monolayer — •Lorenz Maximilian Schneider[1], Shanece S. Esdaille[2], Daniel A. Rhodes[2], Katayun Barmak[3], James C. Hone[2], and Arash Rahimi-Iman[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Marburg, 35032, Germany — [2]Department of Mechanical Engineering, Columbia University, New York, NY 10027, USA — [3]Department of Applied Physics and Applied Math, Columbia University, New York, NY 10027, USA

Due to the extraordinary high Coulomb interaction found in monolayers of transition-metal dichalcogenides, not only the binding energies of higher-order excitonic complexes are in the tens of meV's but also their fine structure is considerable, arising from the short- and long-range part of the Coulomb exchange integral. Such strong electronic interaction also leads to the hybridization of dark excitonic states into one dipole-allowed for z-polarization but spin-forbidden exciton branch, referred to as "grey" exciton, and another one that is both spin and dipole forbidden. While there have been some indirect measurement reports revealing the presence of the grey z-polarized exciton mode, no direct measurement of the radiation pattern has been performed. Here, we present an investigation of a high-quality h-BN encapsulated monolayer, where angle resolved spectroscopy has been used to directly reveal and extract the radiation pattern of bright and grey excitons. The in-plane and out-of-plane dipole modes can indeed be directly identified by their emission under low and high emission angles.

HL 74.4 Thu 15:00 P2/2OG

Microwave Studies of Graphene/hBN Heterostructures — •Vincent Strenzke[1], Udai Singh[1], Marta Prada[2], Lars Tiemann[1], and Robert Blick[1] — [1]Center for Hybrid Nanostructures, Universität Hamburg, Hamburg, Germany — [2]I. Institute for Theoretical Physics, Universität Hamburg, Hamburg, Germany

Recently, it has been revealed that the band structure of monolayer graphene exhibits a small band gap in the range of tenth of μeV that results from intrinsic spin orbit interaction. Such low energies can be probed in magnetotransport experiments at cryogenic temperatures, by employing a resistively detected microwave resonance method. In this work, graphene was combined with hexagonal boron nitride (hBN), i.e., a two-dimensional material which is a superior substrate for high-quality electronics as compared to silicon substrates. In these graphene/hBN heterostructures, we observed additional features in the microwave resonance spectrum, signalling additional interactions and phenomena. For further fundamental studies on the properties of two-dimensional van der Waals materials, it will be interesting to employ this method on e.g. bilayer graphene or transition metal dichalcogenide heterostructures with a controlled stacking order.

HL 74.5 Thu 15:00 P2/2OG

Magnetic resonance studies of spin defects in a Van der Waals crystal — •Matthias Diez[1], Andreas Gottscholl[1], Christian Kasper[1], Victor Soltamov[1], Andreas Sperlich[1], and Vladimir Dyakonov[1,2] — [1]Experimental Physics VI, Julius Maximilian University of Würzburg, 97074 Würzburg — [2]Bavarian Center for Applied Energy Research (ZAE Bayern), 97074 Würzburg

Spin defects in wide-bandgap semiconductors have shown to be promising systems in terms of realising quantum information processing, quantum sensing and quantum computing. While spin centers in 3D materials especially the NV-center in diamond or silicon vacancy in silicon carbide have been extensively studied, similar defects in 2D materials are yet to be discovered. In this work, we use optically detected magnetic resonance (ODMR) and electron paramagnetic resonance (EPR) to study a recently found spin defect in irradiated hexagonal boron nitride (hBN) in more details [1]. In particular, we identified the defect to be a negatively charged boron vacancy (V_B^-) and determined the parameters of its spin Hamiltonian by analyzing the temperature, illumination and angular dependencies. The defect has a triplet ground state (S=1) with a zero field splitting of $\approx$ 3.5 GHz. These results stimulate the search also for other types of spin defects in 2D materials and heterostructures.

[1] Gottscholl et al., arXiv:1906.03774 (2019)

HL 74.6 Thu 15:00 P2/2OG

Probing spin-valley polarization dynamics in $MoSe_2$/WSe_2 heterostructures — •Michael Kempf[1], Florian Raab[2], Markus Schwemmer[2], Andreas Hanninger[2], Philipp Nagler[2], Christian Schüller[2], and Tobias Korn[1] — [1]Institute of Physics, University of Rostock, Rostock, Germany — [2]Institute of Physics, University of Regensburg, Germany

Transition metal dichalcogenides (TMDC) have revealed many intrigu-

ing properties in recent years. For valleytronics especially, the coupling of spin and valley degree of freedom shows great promise. Combined with valley-selective optical selection rules, a chosen spin polarization can easily be introduced into these systems. Keeping possible future applications in mind, a long spin polarization lifetime is of great importance, yet in pristine monolayer TMDC this is strongly limited due to ultrafast exciton recombination and electron-hole exchange. Through two-color time-resolved Kerr rotation and ellipticity measurements we are able to study the spin-valley dynamics in n-doped $MoSe_2$ and compare it to the undoped case. Here we observe a drastic lifetime increase from the order of pico to nanoseconds, significantly exceeding the lifetimes of excitons and trions. This can be attributed to a transfer of spin polarization to resident carriers [1]. Following a similar reasoning we investigate two-dimensional $MoSe_2/WSe_2$ heterostructures, electrons and holes are spatially separated. This in turn suppresses their radiative recombination as well as exchange interaction thus leading to an increase of spin polarization lifetime.

[1] M. Schwemmer et al. Appl. Phys. Lett. 111, 082404 (2017).

HL 74.7 Thu 15:00 P2/2OG

Diffusion of dark excitons in monolayer WSe_2 at cryogenic temperatures — •Koloman Wagner[1], Jonas Zipfel[1], Jonas D. Ziegler[1], Edith Wietek[1], Barbara Meisinger[1], Takashi Taniguchi[2], Kenji Watanabe[2], and Alexey Chernikov[1] — [1]Department of Physics, University of Regensburg, Regensburg, Germany — [2]National Institute for Materials Science, Tsukuba, Ibaraki, Japan

Exciton propagation is studied in hBN-encapsulated WSe_2 at liquid helium temperature through spatially- and time-resolved photoluminescence microscopy. To monitor diffusion we detect signatures from phonon-assisted recombination of low-energy, inter-valley dark exciton states. At low excitation densities we find efficient diffusion that appears to be intrinsically limited by exciton scattering with linear acoustic phonons in WSe_2. These observations highlight the negligible role of localization through residual disorder and support the assignment of the studied spectral features to originate from free exciton states. At higher densities we detect an effective increase of the diffusion coefficient with distinct signatures of bimolecular recombination, qualitatively similar to the observations at room temperature.

HL 74.8 Thu 15:00 P2/2OG

Time-resolved Faraday Rotation on single-layer MoSe2 — •Simon Raiber[1], Gabriela Hirschinger[1], Matthias Dietl[1], Tobias Korn[2], and Christian Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg — [2]Institut für Physik, Universität Rostock

For an atomically thin layer of MoSe2, a direct band gap emerges at the K points of the hexagonal Brillouin zone. The broken inversion symmetry of the crystal structure gives rise to chiral selection rules, allowing to create a valley polarization. Faraday rotation is sensitive to spin and hence can give direct access to the valley polarization.

We have performed time-resolved Faraday rotation experiments with a femtosecond time resolution on an exfoliated MoSe2 single-layer sample at low temperatures. Measuring the total carrier life time and taking into account direct radiative recombination, dephasing via intervalley exchange interaction and exciton-phonon relaxation processes, we can give a detailed view on the evolution of the valley polarization and determine the corresponding decay times. In the presence of out-of-plane magnetic fields of up to 8 Tesla, it was possible to generate a valley polarization that is independent of the helicity of the incident light. We find that the valley life times exhibit a pronounced magnetic field dependence.

HL 74.9 Thu 15:00 P2/2OG

Photoluminescence monitoring during laser-thinning of transition metal dichalcogenides — •Christian Tessarek, Oleg Gridenco, Kathrin Sebald, Stephan Figge, Jürgen Gutowski, and Martin Eickhoff — Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, D-28359 Bremen, Germany

Laser-thinning is a promising tool for processing of two-dimensional materials such as transition metal dichalcogenides (TMDCs) [1]. By laser exposure it is possible to reduce the number of layers locally from multi- down to a monolayer. For a precise layer-by-layer etching process, thinning and simultaneous monitoring is required which can be performed by Raman or photoluminescence (PL) spectroscopy.

This study focusses on PL monitoring during laser-thinning of different trilayer TMDCs such as MoS_2, WS_2 and ReS_2. It will be shown that MoS_2 and WS_2, which are direct bandgap semiconductors for monolayers, can be thinned down layer-by-layer. The spectral position of the indirect bandgap transition clearly indicates the number of layers, changes abruptly from tri- to bilayer and vanishes for a monolayer. Moreover, a strong increase of the direct bandgap emission indicates thinning from a bi- to a monolayer. Limitations of PL monitoring will also be discussed using the example of ReS_2, which remains an indirect bandgap semiconductor even for a monolayer.

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

HL 74.10 Thu 15:00 P2/2OG

Looking for interlayer excitons in hybrid WSe_2/MoS_2 heterostructures — •Rico Schwartz[1], Alina Christine Schubert[1], Antony George[2], Andrey Turchanin[2], and Tobias Korn[1] — [1]Institut für Physik, Universität Rostock, D-18059 Rostock, Germany — [2]Institut für Physikalische Chemie, Friedrich-Schiller-Universität Jena, D-07743 Jena, Germany

Fabrication and optical spectroscopy of transition metal dichalcogenide (TMDC) monolayers and their heterostructures have been intensely studied by a lot of work groups in recent years. One interesting aspect is the excitation of interlayer excitons, that means excitons whose electrons and holes are placed in different monolayers and thus in different materials.

TMDC heterostructures are mostly fabricated by deterministic stacking of exfoliated flakes, which limits their size to a few tens of microns. CVD growth, in contrast, allows large-scale TMDC films which might be interesting for future industrial applications.

We study a hybrid heterostructure consisting of a CVD-grown WSe_2 monolayer on a Si/SiO_2 substrate [1] combined with an exfoliated MoS_2 flake. In photoluminescence studies, we observe a pronounced quenching of intralayer exciton emission in our heterostructure, indicating interlayer charge transfer. Additionally, we find emission from interlayer excitons comparable to those in samples fabricated using only exfoliated layers [2].

[1] A. George et al., J. Phys.: Mater. **2**, 016001 (2019)
[2] J. Kunstmann et al., Nature Physics **14**, 801-805 (2018)

HL 74.11 Thu 15:00 P2/2OG

Control of proximity-induced spin-orbit coupling in graphene/TMDC heterostructures — •Tobias Rockinger, Tobias Völkl, Dieter Weiss, and Jonathan Eroms — Institute of Experimental and Applied Physics, Universität Regensburg, Universitätsstraße 31, 93053 Regensburg

Graphene is known as an ideal candidate for spintronic devices because of its long spin relaxation times. However, for spintronic applications we have to create spin currents as well. Spin currents cannot be created in graphene directly because of graphene's low intrinsic spin-orbit coupling (SOC). Z. Wang et al. [1] showed that one can induce SOC into graphene by proximity-coupling with TMDCs. Because the proximity-induced SOC varies from sample to sample, we strive for a better control over the induced SOC. Theoretical predictions by Y. Li et al. [2] and A. David et al. [3] show that proximity-induced SOC depends on the twist angle between graphene and the TMDC. We therefore fabricated graphene/TMDC heterostructures where the twist angle is controlled during a van der Waals stacking process. To get comparable samples we only use single layer TMDCs on graphene. Four-terminal magnetotransport measurements at low temperatures revealed weak localization and weak anti-localization, showing weak or strong SOC, respectively. The measurements of our first samples agree with theory and show signs of the expected dependence of SOC on the twist angle.

[1] Z. Wang et al., Phys. Rev. X 6, 041020 (2016) [2] Y. Li et al., Phys. Rev. B 99, 075438 (2019) [3] A. David et al., Phys. Rev. B 100, 085412 (2019)

HL 74.12 Thu 15:00 P2/2OG

Dry-transfer process of graphene / hBN heterostructures — •Khairi Fahad Elyas, Asem Ben Kalefa, Lina Bockhorn, Gunnar Schneider, Christopher Belke, and Rolf J. Haug — Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover

Graphene is the first in a large family of two-dimensional (2D) van der Waals (vdW) materials to attract a lot of attention due to its remarkable properties. One of these properties is a zero band gap. The second most popular vdW material after graphene is hexagonal boron nitride (h-BN). The h-BN is a ideal insulator with wide band gap (4.5 eV).

Here, we demonstrate the dry-release transfer of monolayer and bilayer

graphene of the size up to 20 μm by using poly (propylene) carbonate (PPC) films. We also transfer a few layers h-BN with size up to 45 μm. Due to the strong adhesion between PPC and 2D materials at room temperature, we show that single-layer to low-layer graphene as well as less-layered h-BN can be produced on a spin coated PPC films /SiO_2 / Si substrate by the mechanical peeling method. This method is useful for sample preparations for different applications like TEM measurements. Based on the dry-release transfer samples with high purities are achieved.
We also demonstrate electronic and magnetotransport measurements on graphene/hBN heterostructures.

HL 74.13 Thu 15:00 P2/2OG

Benchmarking calculated excited state properties of 2D materials on substrates and in van de Waals heterostructures against experiments — •Anders Christian Riis-Jensen and Kristian Sommer Thygesen — Technical University of Denmark, Institute of Physics

2D materials and van der Waals heterostructures exhibit extraordinary optical properties because of the reduced screening in two dimensional materials. Due to the possible lattice mismatch and relative twist angle between the layers constituting a van der Waals heterostructure, accurate many-body ab-initio calculations for such many layers heterostructures are not possible.

By combining many-body ab-initio calculations with electrostatic and perturbative models, we calculate quasi-particle band gaps and intra- and interlayer exciton energies in many layers van der Waals heterostructures, and benchmark to what accuracy these properties can be calculated compared to experimental measurements. Furthermore, we show what discrepancy can be expected between ab-initio calculations and experiments for optical properties due to the effect of substrate screening and show how the screening of 2D materials on bulk substrates can be accurately modelled by a generalized analytical 2D hydrogen model. At the end of the talk I will discuss a new screening regime for 2D materials on strongly screening substrates, where the exciton behavior is very different from the well-known picture in 2D materials and van der Waals heterostructures.

HL 74.14 Thu 15:00 P2/2OG

Manipulating transition-metal dichalcogenide monolayers with proximity effects — •Lanqing Zhou[1,2], Sven Borghardt[1,2], Detlev Grützmacher[1,2], and Beata Kardynal[1,2] — [1]PGI-9, Forschungszentrum Jülich, Julich, Germany — [2]Department of Physics, RWTH Aachen University, 52074 Aachen, Germany

Transition-Metal Dichalcogenides (TMDs) monolayers have been shown to exhibit many interesting physical properties related to their crystal structure and strong spin-orbit interactions. In addition,their properties can be manipulated using proximity fields generated when they are placed in contact with functional molecules or films.Here we interface molybdenum diselenide and tungsten diselenide monolayers with thin films of chromium triiodide and chromium trichloride. Both chromium trihalides (CrX3, X =Cl,I) are layered materials which are electronic insulators that are also ferromagnetic at low temperatures. In this contribution, we examine the effects of proximity magnetic field and the band alignment between W(Mo)Se2 and CrX3 on the excitonic states in the heterostructure. The excitonic states are probed via temperature dependent and polarization resolved photoluminescence. We show that both type-I and type-II heterostructures can be fabricated using different combination of monolayers of TDMs and CrX3. We will also show that in the type-II heterostructure the dominant effects originate from the charge transfer between the two component materials. Finally, we explore the use electric field to manipulate the charge separated complexes.

HL 74.15 Thu 15:00 P2/2OG

Computational Design of Quantum Defects in Low-Dimensional Semiconductors — •Fabian Bertoldo and Kristian Thygesen — Technical University of Denmark, Kgs. Lyngby, Denmark

2D materials are known to host intriguing electronic properties and thus offer a fascinating platform for quantum photonics. In particular, 2D materials have been shown to host single-photon emitters (SPE). It is therefore vital to investigate the influence of defects within different host materials which are much easier to create and control in monolayers compared to bulk systems. Based on the computational 2D materials database (C2DB) [1] we first perform a computational screening for intrinsic point defects of stable theoretically predicted and experimentally known low-dimensional semiconductors. We will present a tool within the atomic simulation environment (ASE) [2] to automatically identify intrinsic point defects for given structures and calculate their respective formation energies as well as their charge transition energies.

[1] The Computational 2D Materials Database: High-throughput modeling and discovery of atomically thin crystals, S. Haastrup et al. 2D Materials 5, 042002 (2018)

[2] The atomic simulation environment - a Python library for working with atoms, A. Larsen et al. Journal of Physics: Condensed Matter, 29(27): 273002, 2017

HL 74.16 Thu 15:00 P2/2OG

Manufacturing and magnetotransport properties of weakly coupled double trilayer graphene — •Xiao Xiao, Sung Ju Hong, Christopher Belke, and Rolf Haug — Festkörperphysik-Institut, Hannover, Germany

We have investigated magnetotransport of double trilayer graphene (DTLG). The DTLG was fabricated by stacking two trilayer graphene (TLG) flakes with polypropylene carbonate in a dry transfer method. Analysing the edges of the two flakes in the optical microscope, we identified a large twist angle around 24°. This is consistent with the electrical measurement which show the superposition of two independent magnetotransport properties. As in twisted bilayer graphene, the large twist angle seems to result in a weak coupling between the two layers. In the observed Landau fan diagram, one of the DTLG turns out to be ABA-stacked TLG. Furthermore, we found an additional high carrier density which comes from the other TLG.

HL 74.17 Thu 15:00 P2/2OG

STM-induced excitonic luminescence of a 2D semiconductor — Delphine Pommier[1], •Rémi Bretel[1], Luis Parra López[2], Florentin Fabre[2], Andrew Mayne[1], Elizabeth Boer-Duchemin[1], Gérald Dujardin[1], Guillaume Schull[2], Stéphane Berciaud[2], and Eric Le Moal[1] — [1]Institut des Sciences Moléculaires d'Orsay, CNRS, Université Paris Sud, Université Paris-Saclay, F-91405 Orsay, France — [2]Institut de Physique et Chimie des Matériaux de Strasbourg, Université de Strasbourg, CNRS, IPCMS, UMR 7504, F-67000 Strasbourg, France

Transition metal dichalcogenides (TMDs) are 2D layered materials that have gained a lot of interest as their unique and tunable excitonic properties are very promising for new compact optoelectronic devices. To fully understand processes involving excitons requires studies at the nanometer scale. Scanning tunneling microscopy (STM) may be used to carry out such studies, as a local electrical source for the excitation of excitons in TMDs. In this work, we report the STM-induced light emission (STM-LE) of the semiconducting, direct bandgap monolayer (1ML) molybdenum diselenide (MoSe2) at room temperature in air. The emitted light is collected in transmission through an oil-immersion objective. STM-LE is compared with laser-induced photoluminescence. The emission is identified as the radiative decay of bright A exciton and the excitation mechanism here is found to be a resonant energy transfer, which contrasts with previous results from other electroluminescence studies on TMDs [1].

[1] Pommier et al, Physical Review Letters 123.2 (2019): 027402.

HL 74.18 Thu 15:00 P2/2OG

Phase transition measurements of atomically thin 1T-TaS2 probed with ultrafast electron diffraction — •Mashood Tariq Mir, Arne Ungeheuer, Ahmed Hassanien, Arne Senftleben, and Thomas Baumert — Institute of Physics and CINSaT, University of Kassel, Heinrich-Plett-Strasse 40, D-34132 Kassel, Germany

The layered transition metal dichalcogenides (TMDs) host a rich collection of physical properties which may open many different applications with atomically thin films such as sensors, electronic switching or energy storage. Among those materials, 1T-TaS2 exhibits a complex phase diagram depending on temperature encompassing charge density waves (CDW) with diverse commensurabilities. We aim to use femtosecond laser pulses to induce rapid structural changes and probe the following with ultrafast electron diffraction (UED). In this work, free-standing single-crystalline sample were prepared down to a few nanometer thicknesses to allow electron diffraction in transmission mode. The samples were mechanically exfoliated from different adhesive surfaces. The preparation method was optimized using atomic force microscopy and optical microscopy to isolate atomically thin flakes.

In addition, we present an initial UED study of CDW phases of 1T-TaS2. Upon lattice heating, the material undergoes several phase transitions. We are focusing on the reversible phase transition from the nearly commensurate to incommensurate phase in which the commensurate phase disappears, while the incommensurate phase emerges without causing irreversible damage to the underlying crystal.

HL 74.19 Thu 15:00 P2/2OG

Effect of ion irradiation on electrical and optical properties of molybdenum disulfide — •Zahra Fekri[1], Phanish Chava[2], Tommaso Venanzi[3], Gregor Hlawacek[4], Antony George[5], Andrey Turchanin[6], and Artur Erbe[7] — [1]HZDR — [2]HZDR — [3]HZDR — [4]HZDR — [5]University Jena — [6]University Jena — [7]HZDR

Since silicon transistors are reaching their physical limit to shrink, there is a need for the discovery of new materials to keep on with Moore's law. Two-dimensional (2D) materials, which have gained enormous attention since the discovery of graphene, could enable transistors to keep scaling. MoS2 is among the most well-known 2D materials due to its unique properties. Tunable bandgap, high mobility, and flexibility make MoS2 a promising material in future electronics, sensing and photo-detection applications. The ability to modify materials at the atomic scale is crucial for the fabrication of novel nanodevices. The electrical and optical properties of MoS2 strongly depend on defects. Deficiencies in the structure can be detected by spectroscopic techniques which provide the understanding of new functionalities of MoS2 based devices. Helium ion microscope promises to be a suitable tool to create controllable defects on 2D materials. A nice aspect of this method is that the electrical measurement can occur in situ in the microscope so that the effect of irradiation can be assessed immediately. This research focuses on modifying the electrical and optical properties of MoS2 based field effect transistor using helium ion microscope.

HL 74.20 Thu 15:00 P2/2OG

Optical characterization of ion implanted monolayer molybdenum dichalcogenides — •Minh Bui[1], Stefan Rost[2], Manuel Auge[3], Jhih-Sian Tu[1], Sven Borghardt[1], Hans Hofsäss[3], and Beata Kardynał[1] — [1]Peter Grünberg Institut (PGI-9), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]Peter Grünberg Institut (PGI-1 / IAS-1), Forschungszentrum Jülich, 52425 Jülich, Germany — [3]II. Physikalisches Institut, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany

Monolayers (MLs) of semiconducting transition metal dichalcogenides (TMDCs) possess unique band structure leading to exotic optical properties, suitable for valley- and exciton-based optoelectronic applications. Tuning those properties is desirable to further exploit their potentials, for which deterministic doping is a viable technique that has proven suitable for bulk semiconductors. Here, implantation with low energy ions is explored as a method to introduce dopant atoms into TMDC MLs, with the prototypical system of Se-implanted MoS_2. Isoelectronic substitution of Se for S in MoS_2 converts the material into $MoSe_{2x}S_{2(1-x)}$ without creating free carriers. For the optimal compromise between Se incorporation and defect formation, different implantation conditions were investigated, including treatment for healing defects. Structural and electronic effects of implantation on MLs were studied using Raman, reflectance and photoluminescence spectroscopies. Implantation levels much higher than required for doping, up to 20%, were achieved. Results of $MoSe_2$ implanted with P for p-type dopants, and Cr for substitution in Mo sites are also discussed.

HL 74.21 Thu 15:00 P2/2OG

2D van der Waals heterostructures for electronic devices — •Phanish Chava[1], Vivek Koladi[1], Himani Arora[1], Kenji Wanatnabe[2], Takashi Taniguchi[2], Manfred Helm[1], and Artur Erbe[1] — [1]Helmholtz Zentrum Dresden Rossendorf, Bautzner Landstrasse 400, 01328 — [2]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

The interlayer van der Waals(vdWs) interaction allows 2D materials to be easily stacked to form various heterostructures with unique and novel features. Layer dependent electronic band structure and the absence of surface dangling bonds make them promising candidates for electronic devices. In this study, we focus particularly on devices that enable lower operating voltages thereby forming a basis for energy efficient circuits. This is done by investigating the idea of a Tunnel Field Effect Transistor (TFET) based on vdWs hetrostructures.

HL 74.22 Thu 15:00 P2/2OG

Optical phonon mediated valley depolarization in monolayer WSe2 — •Robin Bernhardt, Julian Wagner, Jingyi Zhu, and Paul van Loosdrecht — Universität zu Köln, II. Physikalisches Institut, D-50937 Köln, Germany

The valley degree of freedom in semiconducting transition metal dichalcogenide monolayers is considered as a potential basis for novel information technology. Key to this is the degree and lifetime of an induced valley polarization. We investigated the temperature dependent transient valley polarization using circularly polarized and femtosecond time-resolved photoluminescence spectroscopy on exfoliated WSe2. Using these data, the intervalley scattering rate is evaluated over a broad temperature range, showing that optical-phonon assisted scattering is the dominant intervalley scattering mechanism.

HL 74.23 Thu 15:00 P2/2OG

Optical characterization of $MoTe_2$-based monolayer-monolayer heterostructures — •Mohammed Adel Aly[1], Shachi Machchhar[1], Manan Shah[1], Lorenz Maximilian Schneider[1], Saeideh Edalati Boostan[2], Claudia Draxl[2], Wolfram Heimbrodt[1], and Arash Rahimi-Iman[1] — [1]Faculty of Physics and Materials Sciences Center, Philipps-Universität, Marburg, 35032 Germany — [2]Theoretical solid state physics, Institute for Physics, Humboldt-Universität Berlin, 12489 Berlin, Germany

Van-der-Waals heterostructures (vdW-HSs) based on 2D layered materials have received huge attention due to their strong light matter interaction and the promise of bandgap engineering capabilities. Owing to the strong out-of-plane quantum confinement and electronic interaction between the layers, the HSs can exhibit exotic properties. Moreover, the strain effect is recognized as an effective parameter in the modulation of electronic properties. Although in recent years a few reports on $MoTe_2/WSe_2$ HS have emerged, a comprehensive study exploring their properties is still lacking. Here, we present our cooperative theoretical/experimental work on $MoTe_2/WSe_2$ type-I and $MoTe_2/MoSe_2$ type-II vdW-HSs. We have investigated our specimen using μ–PL and reflection contrast, shedding light on exciton physics in such structures, band alignment and possible charge transfer between type-II layers. We performed μ–Raman spectroscopy to determine the characteristic phonon modes and their separation to extract possible strain values. Our overall strain estimation is derived from the variation in the excitonic peaks and Raman modes' positions.

HL 74.24 Thu 15:00 P2/2OG

Small angle twisted bilayer graphene — Simon Wagner[1], Tobias Rockinger[1], Kenji Watanabe[2], Takashi Taniguchi[2], Dieter Weiss[1], and •Jonathan Eroms[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

One recent observation in graphene is the appearance of interaction effects in twisted bilayer graphene (TBG) with a twist angle of about 1.1°, which is called magic angle. Depending on the angle between the two layers the band structure changes and can show flat bands. At the magic angle, the band width is minimal. This leads to enhanced carrier-carrier interaction resulting in both Mott-like insulating behavior and superconductivity. Both effects were recently discovered by Cao *et al.* in magic angle bilayer graphene. We fabricated TBG by van der Waals stacking of two parts of a single graphene monolayer (the tear and stack-technique), which we encapsulate in hexagonal boron nitride. During fabrication the twist angle is controlled in a dedicated setup and can be verified afterwards by the position of secondary Dirac peaks and flux-dependent features in a Landau fan diagram. In a sample with a twist angle of about 0.9°, we observe those signatures of a superlattice potential, and also detect additional insulating states at gate voltages corresponding to filling 1, 2 or 3 electrons per moire unit cell.

Y. Cao, *et al.*, Nature **556**, 80 (2018), *ibid.* 43