HL 14: Poster: Two-Dimenaional Materials and Topological Insulators

Time: Monday 14:00–18:00 Location: P2-OG3

HL 14.1 Mon 14:00 P2-OG3

Disentangling electronic and phonon contributions to the photoexcited stress in bulk WSe_2 — •Marc Herzog[1], Alexander von Reppert[1], Jan-Etienne Pudell[1], Ehren Mannebach[2], Clara Nyby[3], Friederike Ernst[4,5], Aaron Lindenberg[2,5,6], and Matias Bargheer[1,7] — [1]Dept. of Physics and Astronomy, Univ. of Potsdam — [2]Dept. of Materials Science and Engineering, Stanford Univ. — [3]Dept. of Chemistry, Stanford Univ. — [4]Dept. of Applied Physics, Stanford Univ. — [5]PULSE Institute, SLAC — [6]Stanford Institute for Materials and Energy Sciences, SLAC — [7]Helmholtz Center Berlin for Materials and Energy

Transition metal dichalcogenides (TMDCs) have attracted much technological and scientific interest due to their finite band gaps and the complex interplay of electronic, lattice and spin degrees of freedom. With regard to optoelectronic applications it is important to understand the coupled non-equilibrium dynamics of the different degrees of freedom in TMDCs. We address this issue by investigating the structural response of WSe_2 to ultrashort photoexcitation at different photon energies using time-resolved x-ray diffraction. Two independent stress components are identified: (i) a negative electronic stress through modification of the van der Waals interaction between neighboring layers by photocarriers and (ii) a positive phononic stress. The ultrafast negative stress launches coherent compressive hypersound waves and decays on a timescale of 50 ps revealing the photocarrier lifetime. The relative ratio of negative and positive stress components depends on excitation density and photon energy.

HL 14.2 Mon 14:00 P2-OG3

Polarized hot carrier photoluminescence in graphene — •Thomas Danz, John H. Gaida, Claus Ropers, and Sascha Schäfer — IV. Physical Institute – Solids and Nanostructures, University of Göttingen, Germany

The thermalization of photogenerated hot charge carriers in graphene leads to photoluminescence (PL) at wavelengths far away from that of the exciting pump laser [1,2]. Although a strongly anisotropic carrier distribution is created by linearly polarized optical excitation [3], the polarization properties of the emerging PL have not been reported yet.

In this contribution, we report the anisotropic polarization response of the hot carrier PL in graphene and discuss a possible coherent contribution to the incoherent emission. On the basis of spectral interferometry, we find that any coherent contribution to the emission must be smaller than 4% of the total PL signal. By comparing the experimentally measured degree of polarization to a microscopic model of the carrier dynamics based on Boltzmann rate equations, we are able to determine a time-scale of 12 ± 2 fs for the ultrafast momentum relaxation in graphene [4].

[1] C. H. Lui *et al.*, Phys. Rev. Lett. **105**, 127404 (2010)
[2] W. Liu *et al.*, Phys. Rev. B. **82**, 081408 (2010)
[3] E. Malic *et al.*, Appl. Phys. Lett. **101**, 213110 (2012)
[4] Th. Danz *et al.*, in preparation.

HL 14.3 Mon 14:00 P2-OG3

Modulation of the Optical Gas-Sensing Performance of Single-Layer MoS2 Transistors by Electric Gating — Philip Klement[1], Paula Neuderth[1], Sangam Chatterjee[1], and •Martin Eickhoff[1,2] — [1]Institute of Experimental Physics I, Justus Liebig University Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany — [2]Institute of Solid State Physics, University of Bremen, Otto-Hahn-Allee 1, 28359 Bremen, Germany

Two-dimensional transition metal dichalcogenides such as MoS_2 are promising candidates for gas-sensing applications due to their large surface-to-volume ratio. They offer the possibility of an optical detection of the gas-sensing effect. However, the performance is limited due to a low response, slow recovery and a lack of selectivity [1]. The application of a perpendicular electric field modulates the adsorption of gas molecules and therefore may improve the performance [2]. Here, we detected the adsorption of different gas molecules to MoS_2 optically with a perpendicular electric field. We studied the optical response under different gate voltages and gas concentrations and found a systematic modulation of the optical emission and response.

[1] Ko, K. Y., et al., ACS Nano 10, 9287-9296 (2016). [2] Yue, Q., et al., Nanoscale Res Lett. 8, 425 (2013).

HL 14.4 Mon 14:00 P2-OG3

Charge transport in bottom-up synthesized graphene nanoribbon networks — •Nils Richter[1,2], Zongping Chen[3], Akimitsu Narita[3], Xinliang Feng[4], Mathias Kläui[1,2], and Klaus Müllen[2,3,5] — [1]Institut für Physik, Johannes Gutenberg Universität, Mainz, Germany — [2]Graduate School of Excellence Materials Science in Mainz, Mainz, Germany — [3]Max Planck Institute for Polymer Research, Mainz, Germany — [4]Center for Advancing Electronics Dresden & Department of Chemistry and Food Chemistry, Technische Universität, Dresden, Germany — [5]Institut für Physikalische Chemie, Johannes Gutenberg-Universität, Mainz, Germany

Graphene nanoribbons (GNRs) attract particular attention due to physical phenomena resulting from their geometrical confinement. GNRs with atomically perfect edge structures are synthesized on gold surfaces and transferred to insulating substrates [1, 2]. We determine the conductivity and mobility of chevron edged GNRs with a width of 9 carbon atoms (N=9) using GNR-FET devices. At room temperature the resistivity of such devices lies in the regime of approximately 1 GOhm and the mobility is in the order of 10^{-4} cm^2/Vs. We compare chevron GNRs and armchair GNRs with N=9 to demonstrate the influence of the edge structure. Secondly, armchair GNRs with N=7 and N=9 are studied to test for the influence of the ribbon width. Temperature dependent measurements reveal details of their band gaps [3]. [1] A. Narita et al., Nature Chem. 6, 126 (2014). [2] Z. Chen et al., J. Am. Chem. Soc. in press (2016). [3] N. Richter et al., (manuscript in preparation 2016).

HL 14.5 Mon 14:00 P2-OG3

G-factor determination of excitonic states in monolayer tungsten disulfide (WS_2) — •Jan Kuhnert, Simon Schmitt, Arash Rahimi-Iman, and Wolfram Heimbrodt — Faculty of Physics and Materials Sciences Center, Philipps-Universität Marburg, Renthof 5, D-35032 Marburg, Germany

Layered transition-metal dichalcogenides have attracted great interest in the last few years. Thinned down to monolayers they exhibit outstanding optical properties caused by the direct band gap. Here, we present photoluminescence (PL) measurements of tungsten disulfide monolayers at low temperatures (2 K) in the presence of an external magnetic field in Faraday geometry. In the monolayer limit the inversion symmetry is broken and spin and valley are coupled. The degeneracy between the two equivalent k and k* valleys is broken by applying external magnetic fields. This causes a Zeeman shift of the peak positions of each excitonic species. By fitting the measured PL spectra we determine the g-factors for the free excitonic transitions: exciton and trion; and for three bound exciton states that exhibit slightly different g-factors due to different localization lengths.

HL 14.6 Mon 14:00 P2-OG3

The effects of substrate and chemical treatment on the optical properties of 2D MoS_2 — •Oleg Gridenco, Genrietta Steingelb, Kathrin Sebald, and Jürgen Gutowski — Semiconductor Optics, Institute of Solid State Physics, University of Bremen, Germany

Two-dimensional transition metal dichalcogenide semiconductors are intriguing materials for the realization of quantum light sources due to their opto-electronic properties. We present a systematic study of the optical properties of ultra-thin molybdenum disulfide (MoS_2) layers deposited on different substrates (SiO_2, Si_3N_4, GaN and polymeric dielectric gel-films). It is observed that the optical properties are affected by the interaction with different substrates. These changes can be related to a substrate-induced variation of the doping level, altering the relative intensity of charged and neutral excitons. Along with this, we present the results of a comparative analysis of the influence of different chemical treatments on the optical properties. These results raise the prospect to tune the optical properties of 2D MoS_2 crystal by choosing suitable substrates and chemical treatment.

HL 14.7 Mon 14:00 P2-OG3

Excitonic phonon sidebands in monolayer transition metal dichalcogenides — •Dominik Christiansen[1], Malte Selig[1],

Gunnar Berghäuser[2], Robert Schmidt[3], Iris Niehues[3], Robert Schneider[3], Ashish Arora[3], Steffen Michaelis de Vasconcellos[3], Rudolf Bratschitsch[3], Ermin Malic[2], and Andreas Knorr[1] — [1]Nichtlineare Optik und Quantenelektronik, Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Department of Physics, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden — [3]Physikalisches Institut, Westfälische Wilhelms-Universität Münster, Wilhelm-Klemm Str. 10, 48149 Münster, Germany

Monolayer transition metal dichalcogenides (TMDs) are direct band gap semiconductors with an extraordinarily strong Coulomb interaction, leading to the formation of excitonic quasiparticles.

Here, we present a microscopic study of the influence of the exciton-phonon interaction on the absorption line shape of TMDs. A treatment of the exciton-phonon interaction beyond the Markov approximation predicts the appearance of phonon-induced sidebands that are accompanied by a pronounced polaron-red shift. In a joint theory-experiment study, we observe an asymmetry of the absorption line shape due to the interplay of phonon emission/absorption and dark intra- and intervalley excitonic states.

HL 14.8 Mon 14:00 P2-OG3

Optical Absorption and Darkfield Microscopy on Two-Dimensional Semiconductors — •Konstantin Neuhaus[1], Edward Leong[2], Thomas E. Murphy[2,3], Martin Mittendorff[3], and Sangam Chatterjee[4] — [1]Faculty of Physics, Philipps-Universität Marburg, D-35032 Marburg, Germany — [2]Department of Electrical & Computer Engineering, University of Maryland, College Park, MD, 20742, USA — [3]Institute for Research in Electronics & Applied Physics, University of Maryland, College Park, MD, 20742, USA — [4]Institute of Experimental Physics I, Justus-Liebig University Giessen, D-35392 Gießen, Germany

The optical properties of two-dimensional semiconductors offer a great potential in technological applications from FETs, gas sensors and solar cells to new optoelectronic devices. Furthermore, the potential is enhanced by the possibility of assembling heterostructures of different layers, thereby tuning the bandgap and other optoelectronic properties.

Here, we investigate the ability to locate and identify monolayer structures of molybdenum disulfide (MoS2) and black phosphorus by means of optical darkfield microscopy and high spatial resolution absorption measurements at room temperature. Especially MoS2 monolayers are easily identified in darkfield microscopy because of their characteristic triangular shapes.

HL 14.9 Mon 14:00 P2-OG3

Vibrational properties of metal phosphorus trichalcogenides from first principles — •Seyed Arsalan Hashemi Petrudi, Hannu-Pekka Komsa, Arkady Krasheninnikov, and Martti Puska — Finland, Espoo, Otakaari 1, floor 4, room Y427a

Recently, the family of 2D materials was further expanded following the fabrication of single-layer transition metal phosphorus trichalcogenides (TMTCs), with the general formula of MPX3 (where M = V, Mn, Fe, Co, Ni, Zn, Cd, Mg; X = S, Se and Te which are stacked in a X-P-M-P-X fashion). They offer a unique set of material properties that can open up new opportunities in optoelectronic and spintronic applications. Understanding the vibrational properties is critical in the material characterization. However, apart from the calculations on magnetic and electronic properties, a comprehensive ab-initio study of the vibrational properties of these 2D materials is still lacking. To reach this goal, we performed first-principles calculations for the phonon spectra, and Raman and IR intensities of MnPS3, MnPSe3, CdPS3, CdPSe3, ZnPS3 and ZnPSe3. To analyze the vibrational modes, we examine the ionic displacements and the contributions from different elements. Group theory is used to understand the Raman and IR activity of each mode. Finally, we also determined the elastic constants of these materials.

HL 14.10 Mon 14:00 P2-OG3

Transport measurements in high mobility hBN-graphene-WS2 stacks — •Tobias Rockinger[1], Tobias Völkl[1], Martin Drienovsky[1], Kenji Watanabe[2], Takashi Taniguchi[2], Dieter Weiss[1], and Jonathan Eroms[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, D-93053 Regensburg — [2]National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

To induce spin-orbit coupling in graphene, heterostructures of graphene and tungsten disulfide (WS2) are investigated. To achieve high mobilities, we encapsulated graphene between hexagonal boron nitride (hBN) and WS2 via the van der Waals pickup method. Using Cr/Au edge contacts it is possible to achieve reliable, low resistance contacts. In this way we obtained carrier mobilities in graphene between 30.000 cm^2/Vs and 116.000 cm^2/Vs. We observed Shubnikov-de Haas oscillations in graphene sandwiched in between WS2 and hBN. While searching for weak localization and weak antilocalization we get results which are dominated by other effects. It seems that due to the small $(0,8\ \mu m)$ width of the hall bar geometry, propagation of electrons through the structure is mainly influenced by sample edges and ballistic effects. This leads to a peak in the magnetoresistance around 100 mT. With this value we calculated a cyclotron radius of $0,8\ \mu m$ and an effective sample width of $0,4\ \mu m$ which equates 50 percent of the measured width.

HL 14.11 Mon 14:00 P2-OG3

Possible topological insulator / superconductor interfaces for the investigation of Majorana excitations: $(Bi_{1-x}Sb_x)_2Te_3$ and FeSe — •Philipp Küppers[1], Jens Kellner[1], Markus Eschbach[2], Martin Lanius[3], Marcus Liebmann[1], Lukasz Plucinski[2], and Markus Morgenstern[1] — [1]II. Physikalisches Institut B RWTH Aachen University — [2]PGI 6 Forschungszentrum Jülich — [3]PGI 9 Forschungszentrum Jülich

Proximity induced s-type superconductivity (SC) in a topological insulator (TI) can lead to spinless, p-type superconductivity, which is the main ingredient for the creation of Majorana excitations (ME). To prove the existence of such quasi particles within the vortex of a type II SC grown on top of a TI with STS, two requirements have to be fulfilled. The Fermi energy E_F of the system has to be close to the Dirac point energy E_D of the TI and the superconducting gap has to be large in order to differentiate the ME from conventionally excited states within the vortex.

We present a method of tuning E_D with respect to E_F within 10 meV in the ternary TI $(Bi_{1-x}Sb_x)_2Te_3$ by variation of the Sb concentration x [1]. We show first ARPES measurements of the band structure of the SC FeSe grown on $SrTiO_3$. Methods of inducing high temperature SC in FeSe are also presented.

[1] Jens Kellner et al., Appl. Phys. Lett. **107**, 251603 (2015)

HL 14.12 Mon 14:00 P2-OG3

Long Wavelength Rayleigh Waves at the Surface of the Topological Insulator $BiSbTeSe_2$ — •Henning Kuhn, Matteo Montagnese, Jingyi Zhu, Zhiwei Wang, Yoichi Ando, and Paul H.M. van Loosdrecht — II. Physikalisches Institut, Universität zu Köln

Ultrafast transient grating measurements are performed on the topological insulator $BiSbTeSe_2$ in order to generate and investigate the properties of Rayleigh type surface acoustic waves (SAW) in the long wavelength (μm) regime, and their possible interactions with the topological surface states. The SAWs are observed as oscillations in the diffracted signal, with lifetimes exceeding 3 ns. The SAW dispersion and lifetime are measured as a function of temperature (10K to 300K) and for different azimuthal orientations of the SAW wave vector with respect to the crystallographic directions. No conclusive evidence for a coupling to the topological surface state is found.

HL 14.13 Mon 14:00 P2-OG3

Optimization of MBE growth of topological insulator thin films and device fabrication — •Andrea Bliesener, Patrick Janoschka, Fan Yang, Alexey Taskin, and Yoichi Ando — Institute of Physics II, University of Cologne

Topological insulators (TIs) belong to a new class of quantum materials in which a strong spin-orbit coupling leads to a band inversion and, as a consequence, to a gapless metallic state on the surface. The realization of many exciting theoretical predictions about the surface transport properties depends greatly on the sample quality and, first of all, on achieving a negligible bulk conductivity. The MBE growth technique is among the best suited for this challenge. Furthermore to observe the novel quantum phenomena, fabrications of thin-film devices are required which allows for tuning the Fermi level across the Dirac point. Here we show the results of growth of a $Bi_{2-x}Sb_xTe_3$ system, where the optimization of the composition between n-type Bi_2Te_3 and p-type Sb_2Te_3 can give almost perfect compensation. In combination with a greatly reduced bulk-to-surface ratio in the films, this approach allows to obtain TI samples where the surface transport is dominating. We also report a comprehensive method to fabricate a top-gated TI de-

vice consisting of a $Bi_{2-x}Sb_xTe_3$ Hall-bar using photo-lithography and e-beam lithography together with other techniques. With this device we are able to demonstrate the tuning of the chemical potential.

HL 14.14 Mon 14:00 P2-OG3

Puddles in compensated $Bi_{2-x}Sb_xTe_{3-y}Se_y$ — •Alessandro Revelli[1], Nick Borgwardt[1], Jonathan Lux[2], Zhiwei Wang[1], Malte Langenbach[1], Achim Rosch[2], Yoichi Ando[1], Paul van Loosdrecht[1], and Markus Grüninger[1] — [1]II, Physikalisches Institut, Universität zu Köln, Cologne, Germany — [2]Institut für theoretische Physik, Universität zu Köln

The topological insulator $Bi_{2-x}Sb_xTe_{3-y}Se_y$ shows bulk-insulating behaviour due to a low defect density and compensation of acceptors and donors. However, large fluctuations of the Coulomb potential give rise to strong local band bending even in fully compensated samples. This is demonstrated by the formation of electron and hole puddles which some of us have recently detected by infrared absorption measurements on $BiSbTeSe_2$ [1]. Puddles are important for both bulk and surface properties as they may e.g. yield a spatial variation of the surface charge density. According to Monte Carlo simulations [1], the temperature dependence of puddle formation depends on the Coulomb interaction between defects, while their spectral weight additionally depends on the size of the band gap. To test these predictions and to deepen our understanding of puddles, we performed infrared measurements on $Bi_{2-x}Sb_xTe_{3-y}Se_y$ as a function of x and y, varying the level of compensation, the defect density, and the band gap. The experimental results are in excellent agreement with the theoretical predictions for puddles in topological insulators.

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

HL 14.15 Mon 14:00 P2-OG3

Towards one-dimensional topological Josephson junctions on molecular beam grown topological insulator thin films — •Tobias W. Schmitt, Daniel Rosenbach, Peter Schüffelgen, Martin Lanius, Michael Schleenvoigt, Gregor Mussler, Stefan Trellenkamp, Detlev Grützmacher, and Thomas Schäpers — Peter Grünberg Institute 9, Forschungszentrum Jülich & JARA-FIT, 52425 Jülich, Germany

Lateral topological Josephson junctions comprised of two superconducting leads on top of a topological insulator thin film are one way to probe possible Majorana excitations. These exotic quasiparticles are predicted to arise at the interface of a conventional s-wave superconductor to a topological non-trivial surface and possess similar properties as the long sought Majorana fermion. A current across such topological Josephson junctions however does not only contain information about possible Majorana assisted transport but also transport by conventional Andreev bound states.

The contribution of the conventional Andreev bound states to the supercurrent depends on the width of the junction. In a quasi one-dimensional system the width of the junction therefore is adjusted to the Fermi wavelength to allow for only two possible conducting modes, the Majorana bound states. In our recent work we focus on the realization of quasi one-dimensional topological Josephson junctions by selectively depositing topological insulator nanoribbons of reduced width and by increasing the Fermi wavelength by adjusting the Fermi level to the Dirac point of the linear disperse surface states.

HL 14.16 Mon 14:00 P2-OG3

Growth and transport measurements of gapless HgCdTe. — •Raimund Schlereth, Christoph Brüne, Hartmut Buhmann, and Laurens Molenkamp — Universität Würzburg, EP3

Three dimensional gapless semiconductors show promising new transport phenomena, due to their linear dispersion in all three momentum directions.

In this work we focus on HgTe/CdTe based compounds which crystalize in a zinc blende structure. Tensile strained HgTe is a three dimensional topological insulator [1] with an inverted band structure where the Γ8-bands lie above the Γ6-band. To get a linear dispersion, the band gap of the HgTe needs to be closed. Hg and Cd substitute each other in alloys of HgCdTe nearly randomly, making any Hg/Cd ratio possible. Therefore we can adjust the band structure in such a way, that the Γ8-band touches the Γ6-band, creating a linear dispersion. This linear dispersion however is not protected by symmetry or topology, but is achieved by fine-tuning of a system parameter (Hg/Cd ratio) [2]. We present magnetic field and gate voltage dependent transport data of HgCdTe with varying Hg concentration around the transitional point from the Cd rich to the Hg rich band structure.

HL 14.17 Mon 14:00 P2-OG3

Magnetotransport measurements on $Bi_4Br_xI_{4-x}$ bulk single crystals — •Marco Busch[1], Olivio Chiatti[1], Anna Isaeva[2], and Saskia F. Fischer[1] — [1]Novel Materials Group, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Group Inorganic Chemistry II, Technische Universität Dresden, 01069 Dresden, Germany

Recent progress in the field of topological states of matter has largely been initiated by the discovery of bismuth chalcogenide bulk topological insulators, followed by closely related ternary compounds. Recently, Bi_4I_4 was found as a quasi-one-dimensional topological insulator with highly anisotropic surface-state Dirac fermions which suggests the possibility of combining topological order with other types of ordering characteristic to one-dimensional systems. Here, we present the results of our study on the mixed bismuth monohalides $Bi_4Br_xI_{4-x}$ with $x = 1, 2, 3, 4$, which were prepared by the reactions of bismuth metal with bismuth trihalides taken in stoichiometric amounts. The crystal composition was verified by electron-dispersive X-ray spectroscopy and the crystal structure was tested by X-ray diffraction. We investigated the magnetotransport properties of $Bi_4Br_xI_{4-x}$ bulk single crystals down to a temperature of $T = 0.3$ K for magnetic fields up to $B = 10$ T as previously for Bi_2Se_3 [2].

[1] G. Autès *et al.*, Nature Mater. **15**, 154 (2016)
[2] O. Chiatti *et al.*, Sci. Rep. **6**, 27483 (2016)

HL 14.18 Mon 14:00 P2-OG3

Influence of magnetic doping on the behavior of Bi_2Se_3 — •Jakub Sebesta, Pavel Balaz, and Karel Carva — Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 3 121 16 Praha 2, Czech Republic

Magnetic doping of topological insulators represents a way which enables us to control transport properties related to the presence of the conducting surface states in these materials. The conducting states are topologically protected while the time symmetry exists there. We can remove it by including a magnetic field that originates for instance from magnetically ordered impurities. In our work we focus on studying physical properties of topological insulators containing magnetic impurities or structural defects by using the ab-initio computations and the simulations of the magnetization dynamic. The basis of our research consists in computing of electronic structures by ab-initio TB-LMTO + CPA calculations, where we are interested in the influence of a doping or defects on the position of the Fermi level or on magnitudes of exchange interactions. In this contribution we show our results achieved in Bi_2Se_3 which contains Mn impurities or others structural defects. The obtained results are used to simulate a magnetic behavior of magnetic dopants in non-zero temperatures by the Monte-Carlo or spin dynamic simulations to obtain the ordering temperature etc. Also, we compare obtained results with an experiment.