CPP 34: Two-dimensional Materials III (joint session HL/CPP)

Time: Wednesday 9:30–13:00 Location: H36

CPP 34.1 Wed 9:30 H36

Defect dominated charge transport and fermi level pinning in TMDC/metal contacts — •Kai Sotthewes, Rik van Bremen, Edwin Dollekamp, Harold Zandvliet, and Pantelis Bampoulis — Physics of Interfaces and Nanomaterials, MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500AE Enschede, The Netherlands

Understanding the electron transport through transition metal dichalcogenides (TMDCs) based semiconductor/metal junctions is vital for the realization of future TMDC based (opto-) electronic devices. Strong Fermi level pinning was observed in TMDC based devices, reducing the tenability of the Schottky barrier height. We use conductive atomic force microscopy to construct nanoscopic metal-TMDC junctions in order to understand the Fermi level pinning mechanism on TMDCs and the influence of defects on the electron transport. The barrier heights of the pristine surface can be explained by metal induced gap states (MIGS), inducing partial Fermi level pinning. The Schottky barrier height further reduces (Fermi level pinning increases) at defects, where the magnitude of the decrease depends on the metal contact. These defects provide low-resistance conduction paths in TMDC-based nanodevices and will play a prominent role as the device junction contact area decreases in size.

CPP 34.2 Wed 9:45 H36

Localized quantum emitters in Van der Waals crystals — •Amlan Mukherjee[1], Nathan Chejanovsky[1,2], Youngwook Kim[2], Durga Dasari[1,2], Jurgen H. Smet[2], and Jörg Wrachtrup[1,2] — [1]3rd Physics Institute and Research Center SCoPE, University of Stuttgart, 70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Point defects in semi-conductors are renowned for single photon emission apart from having important implications on optical and transport properties of their host crystal. Various two dimensional Van der Waals (2D) crystals can provide a plethora of defects [1][2] and have revolutionized scientific research with unique phenomena related to their reduced dimensional. We summarize optical investigations of localized quantum emitters in 2D semi-conductors with sub band-gap excitation energizes, emphasizing those in hexagonal boron nitride that exhibit para-magnetic responses to applied external magnetic fields.

References: [1] Chejanovsky, N. et al. Nano letters 2016, 16, 7037-7045. [2] Chejanovsky, N. et al. Scientific reports 2017, 7, 14758 (1-14).

CPP 34.3 Wed 10:00 H36

High magnetic field measurements of interlayer excitons in van der Waals heterostructures — •Johannes Holler[1], Michael Kempf[1], Jonas Zipfel[1], Mariana Ballottin[2], Anatolie Mitioglu[2], Philipp Nagler[1], Fabian Mooshammer[1], Alexey Chernikov[1], Peter Christianen[2], Christian Schüller[1], and Tobias Korn[3] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Germany — [2]High Field Magnet Laboratory (HFML EMFL), Radboud University Nijmegen, Netherlands — [3]Institut für Physik, Universität Rostock, Germany

In the recent years, research in the field of two-dimensional materials has intensified a lot. Besides graphene, the most prominent representatives for this field are the transition metal dichalchogenides. These materials exhibit interesting physics in the monolayer, such as spin-valley locking, and by combining them to heterostructures new excitonic properties emerge.

Here, we study $MoSe_2$-WSe_2 heterostructures, which create a type-II band alignment. This results in a spatial separation of the electron-hole pairs, leading to the formation of interlayer excitons (IEXs). In low-temperature photoluminescence measurements in magnetic fields up to 30T, we observe a giant valley-selective splitting and a resulting near-unity valley polarization. Furthermore, we probe the valley dynamics of the IEX in dependence of the magnetic field, detecting very long lifetimes in contrast to intralayer excitons. We are able to observe the build-up of the valley polarization after unpolarized excitation, revealing different dynamics and lifetimes for the different valleys.

CPP 34.4 Wed 10:15 H36

Tunable 2D superlattices in graphene — •Robin Huber[1], Martin Drienovsky[1], Andreas Sandner[1], Kenji Watanabe[2], Takashi Taniguchi[2], Dieter Weiss[1], and Jonathan Eroms[1] — [1]Institue of Experimental and Applied Physics, University of Regensburg, Germany — [2]National Institute for Materials Science, Tsukuba, Japan

One fascinating way to study the effect of superlattices on graphene are graphene/hBN heterostructures in which moiré superlattices with lattice periods of about 10 nm can be created. These systems made it possible to observe e.g. the famous Hofstadter butterfly in all its beauty. Here we present an alternative method to induce tunable superlattice effects in graphene by the combined action of a global silicon backgate and a patterned bottom gate made from few layer graphene using standard e-beam lithography techniques. We show low temperature transport measurements on an artificially fabricated and gate tunable 2D superlattice in graphene with a lattice period of 40 nm. By switching on a 2D periodic charge carrier density modulation additional Dirac peaks can be observed which are the source of additional Landau fans in magnetotransport. Due to the interplay between the lateral 2D superlattice and a magnetic field, features of the Hofstadter butterfly energy spectrum can be resolved. In addition we show magnetotransport data at an elevated temperature of 120 K where Landau quantization vanishes but Brown-Zak oscillations, which are caused by the 2D periodic potential, are still visible.

CPP 34.5 Wed 10:30 H36

Charge carrier localization in molybdenum disulfide nanobubbles due to the interplay of surface wrinkling, strain, and dielectric confinement — •Christian Carmesin, Michael Lorke, Matthias Florian, Daniel Erben, Tim O. Wehling, and Frank Jahnke — Institut für Theoretische Physik, Universität Bremen

The observation of quantum light emission from atomically thin transition metal dichalcogenides has opened a new field of applications for these material systems. The corresponding charge carrier localization has been linked to defects and strain, however open questions remain about the microscopic origin. We demonstrate that bending of two-dimensional layers leads to surface wrinkling due to bond deformation within the atomically thin sheet. The resulting strain-field facilitates strong charge carrier localization due to its pronounced influence on the band gap. Additionally, we consider confinement as a result of local changes of the dielectric environment and show that both effects contribute to modified electronic states and optical properties. The interplay of surface wrinkling, strain-induced confinement and local changes of the dielectric environment is demonstrated for the example of nanobubbles that form when monolayers are deposited either on substrates or other two-dimensional materials.

CPP 34.6 Wed 10:45 H36

Electric field control of interlayer excitons in MoS2/WS2 heterobilayers — •Fabian Kronowetter[1], Jonas Kiemle[1], Florian Sigger[1,2], Alexander Holleitner[1,2], and Ursula Wurstbauer[1,2,3] — [1]Walter Schottky Institut and Physics-Department, Technical University of Munich, Germany — [2]Nanosystems Initiative Munich (NIM), Germany — [3]Institute of Physics, WWU Münster, Germany

Ensembles of interlayer excitons (IXs) are intriguing systems to explore classical and quantum phases of interacting bosonic ensembles with enlarged lifetimes due to reduced overlap of the electron-hole wave functions. We demonstrate electric field control of the IX in MoS2/WS2 heterobilayer embedded in a field effect structure with few layer hexagonal boron nitrite (hBN) as insulator and few-layer graphene as gate-electrodes. We observe a multiplet structure in the IX emission band even at room temperature. Stark shift measurements reveal the presence of a finite out-of plane dipole of the IX. The different strength of the dipole and a distinct temperature dependence identify the IXs to stem from optical interband transitions with electrons and holes located in different valleys of the heterostructures. For the lowest emission line, we observe field dependent level anti-crossing at low temperatures. We discuss this behavior in terms of coupling of electronic states from the two TMDC monolayers. Our results demonstrate the design of novel nano-quantum materials prepared from artificial van der Waals solids with the possibility to in-situ control their physical properties via external stimuli such as electric fields.

15 min. break

CPP 34.7 Wed 11:15 H36

excitons localized by physisorbed gas molecules in MoSe2 monolayer — •Tommaso Venanzi[1,2], Stephan Winnerl[1], Alexej Pashkin[1], Manfred Helm[1,2], and Harald Schneider[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany

In the study of 2D materials an extremely relevant topic is the presence of defects. We have studied excitons localized by physisorbed gas molecules in MoSe2 monolayer by means of low-temperature photoluminescence. We have investigated how the localized exciton depends on temperature taking care of the effects of laser irradiation. We observe a red-shift of the photoluminescence peak with temperature that is not only addressable to renormalization of the bandgap or thermal instability of the localization. On the other hand we observe a blue-shift of the peak when increasing the laser irradiation dose. Finally we propose a physical mechanism that can explain our experimental observations.

CPP 34.8 Wed 11:30 H36

Silicene passivation by few-layer graphene — •Jakob Genser[1], Viktoria Ritter[1], Daniele Nazzari[1], Ole Bethge[2], Emmerich Bertagnolli[1], and Alois Lugstein[1] — [1]Institute of Solid State Electronics, Technische Universität Wien, Gußhausstraße 25-25a, 1040 Vienna, Austria — [2]Infineon Technologies Austria AG, Siemensstraße 2, 9500 Villach, Austria

Silicene is of foremost interest for the development of next generation, high performance devices, due to its ultra-high carrier mobility combined with a tuneable bandgap and good integrateability into the current silicon based semiconductor industry. However, the synthesis of silicene remains challenging and thus far is only achieved under UHV conditions, whereas exposure to air leads to an immediate degradation. Therefore, the stabilization of silicene at ambient conditions is essential for its characterization, future processing and device integration. Here, we demonstrate the first in-situ encapsulation of 4x4 silicene grown on Ag(111) by exfoliated few-layer graphene (FLG) flakes. This encapsulation method allowed subsequent highly detailed Raman analysis that so far has only been possible by means of in-situ Raman measurements. The acquired data proved that FLG capping serves as an effective passivation layer, preventing degradation of silicene for up to several days. Additional polarization-dependent measurements showed that the symmetry properties of silicene remain unaltered by the capping process. Furthermore, the experiments demonstrated the compatibility between graphene and silicene, representing a step forward towards the possible integration of silicene into 2D heterostructures.

CPP 34.9 Wed 11:45 H36

Internal structure and ultrafast dynamics of interlayer excitons in van der Waals heterostructures — •Philipp Merkl[1], Philipp Steinleitner[1], Fabian Mooshammer[1], Kai-Qiang Lin[1], Philipp Nagler[1], Johannes Holler[1], Christian Schüller[1], John M. Lupton[1], Tobias Korn[1], Simon Ovesen[2], Samuel Brem[2], Ermin Malic[2] und Rupert Huber[1] — [1]Department of Physics, University of Regensburg, D-93040 Regensburg, Germany — [2]Department of Physics, Chalmers University of Technology, SE-41258 Göteborg, Sweden

In heterostructures of transition metal dichalcogenides, electrons and holes residing in adjacent monolayers can bind into spatially indirect excitons. Even though these interlayer bound pairs have attracted tremendous interest owing to their strong promise for novel optoelectronics and valleytronics, their binding energies have not been directly measured. Here we introduce a direct ultrafast access to Coulomb correlations acting between monolayers. For the prototypical case of WSe2/WS2 hetero-bilayers, phase-locked mid-infrared pulses allow us to measure the binding energy of interlayer excitons of 118 meV by revealing a novel 1s-2p resonance, well explained by a fully quantum mechanical model. Furthermore, we trace how an exciton gas photogenerated in the WSe2 layer directly transforms into interlayer excitons, without a strong intermediate phase of unbound electron-hole pairs. Depending on the stacking angle, intra- and interlayer species coexist on picosecond scales and relax into quantum confined states in moiré-induced nanodots.

CPP 34.10 Wed 12:00 H36

Plasmonic Coupling and Engineering of Single Photon Emitters in WSe2 Monolayers — •Oliver Iff[1], Nils Lundt[1], Simon Betzold[1], Łukasz Dusanowski[1], Magdalena Moczała-Dusanowska[1], Laxmi Narayan Tripathi[1], Young Jin Lee[2], Soon-Hong Kwon[2], Sven Hoefling[1,3], and Christian Schneider[1] — [1]Technische Physik, Universität Würzburg, Wuerzburg, Germany — [2]Department of Physics, Chung-Ang University, Seoul, South Korea — [3]SUPA, School of Physics and Astronomy, University of St Andrews, St Andrews, UK

Single photon sources are an important building block in quantum technologies. The rediscovery of transition metal dichalcogenides this century revealed the availability of quantum emitters in monolayers of WSe2 or MoSe2. Here, we investigate the resonant coupling of such emitters to metallic nanostructures of different shapes and sizes. Auto correlation measurements prove their single photon emission as well as lifetime measurements unveil a reduction in their decay times, confirming the coupling between the metal surface and the quantum emitters. Furthermore, by utilizing an array of gold nanopillars as well as strain-engineering and -tuning of monolayers, site-controlled positioning of localized emitters is possible and represents an important step towards their reproducible manipulation. These findings demonstrate the potential of transition metal dichalcogenide based, strain engineered devices for quantum electrodynamic systems.

CPP 34.11 Wed 12:15 H36

Understanding the formation of interlayer excitons in the case of MoS_2 on GaSe. — •Christian Wagner[1,2], Mahfujur Rahaman[2], Dietrich R.T. Zahn[2], and Sibylle Gemming[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute of Physics, Technische Universität Chemnitz, Chemnitz, Germany

The fabrication of hybrid van-der-Waals heterostructures of two-dimensional nano materials is an emerging field of study: The (weak) electronic interaction between two layers is often reasonably described by a perturbation of the physical effects of the isolated layers, such as electrostatic doping and screening of intralayer excitons. However, it turns out that this picture of the weak interaction is not exhaustive in terms of optical properties: the formation of bound excitons from electrons of one layer and the holes from another layer yields the formation of interlayer excitons. These states are measured experimentally by photoluminescence and photocurrents, e.g. in the case of MoS_2 on GaSe due to type-II band alignment.

This contribution elucidates the conditions for the formation of interlayer excitons from a first-principles point of view. For this, first-principles studies of a minimal test system are conducted. One perspective is then to predict these states as a function of the heterostack in order to specifically taylor efficient solar cells.

CPP 34.12 Wed 12:30 H36

Transfer of electrodeposited MoS_2 to silicon substrate for electronic devices — •Talha Nisar, Torsten Balster, and Veit Wagner — Jacobs University Bremen gGmbH, Campus Ring 1, 28759, Bremen, Germany

Molybdenum disulfide is a promising candidate for future electronics due to its 2 dimensional nature. It can be deposited by various methods such as mechanical exfoliation and chemical vapor deposition (CVD). In our approach we use electrodeposition as an alternative large area deposition method to CVD. For this purpose a MoS_4 ion precursor is used in the anodic regime. The electrodeposited layer consists of MoS_3 as confirmed by Raman and XPS measurements. Such layers are converted to MoS_2 by post annealing at temperature above 450°C. Raman analysis shows that the crystallinity of such film improves with higher post annealing temperatures. In addition, UV-Vis and AFM measurements confirm MoS_2 formation in flakes with smooth surface. We demonstrated that these layers can successfully be mechanically transferred to a SiO_2/Si.

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Optical properties of Monolayer MoS_2 exposed to helium ions — Julian Klein[1,2], •Sergio Rey Puentes[1], Michael Lorke[3], Matthias Florian[3], Florian Sigger[1,2], John Cerne[4], Jakob Wierzbowski[1,2], Kai Müller[1,2], Lukas Sigl[1,2], Takashi Taniguchi[5], Kenji Watanabe[5], Michael Kaniber[1,2], Ursula Wurstbauer[1,2], Michael Knap[6], Richard Schmidt[6], Jonathan Finley[1,2], and Alexander Holleitner[1,2] — [1]Walter Schottky Institut and Physik Department, Technische Universität München, Garching, Germany — [2]Nanosystems Initiative Munich (NIM), Munich, Germany — [3]Institut für Theoretische Physik, Universität Bremen, Bremen, Germany — [4]Department of Physics, University at Buffalo, The State University of New York, Buffalo, USA — [5]National Institute for Materials Science, Tsukuba, Japan — [6]Department of Physics and Institute for Advanced Study, Technical University of Munich, Garching, Germany

We present a spectroscopic study on mono- and few-layers of 2H stacked MoS_2 and WSe_2 exposed with helium ions. Distinct changes of the first-order Raman bands, additional defect luminescence and strong modification of the intrinsic valley spin relaxation properties are observed. The exposed locations were investigated by Raman spectroscopy, low-temperature confocal micro-photoluminescence (μ-PL) and atomic force microscopy (AFM). Our results demonstrate the potential of helium ion microscopy applied to 2D layered materials for modifying intrinsic optical properties and fundamental understanding of disorder.