HL 47: 2D Materials: Heterostuctures

Time: Thursday 15:00–17:00 Location: EW 201

HL 47.1 Thu 15:00 EW 201

Controlled Encapsulation of Monolayer MoS_2 with Ultrathin Aluminum Oxide for Tunnel Contacts — •Sergej Levashov, Chenjiang Qian, Theresa Grünleitner, Jon J. Finley, Alex Henning, and Ian D. Sharp — Walter Schottky Institut and TUM School of Natural Sciences, Technische Universität München

Two-dimensional (2D) semiconductors have unique optoelectronic properties that provide the opportunity to overcome current scaling and performance limits of semiconductor devices. Harnessing the full potential of 2D materials requires their seamless integration with bulk materials, which is challenging for mono- and few-layer 2D materials since the deposition process may introduce defects, thereby impeding interfacial charge transport. Here, we use low-temperature atomic layer deposition (ALD) to encapsulate monolayer MoS_2 with a van der Waals bonded and ultrathin aluminium oxide (AlO_x) layer. The weakly bonded 18 Å thin AlO_x coating introduces additional charge carriers ($\sim 4\times10^{12}$ cm^{-2}) while it also protects monolayer MoS_2 from defect creation during metallization. Moreover, an AlO_x thickness dependent study revealed an interface-dominated change in excitonic features. Fabricated field-effect transistors (FETs) show an additional charge transfer doping of up to $\sim 8.5\times10^{12} cm^{-2}$ due to trap state relaxation after inert gas annealing and, more importantly, a five-fold reduction in the contact resistance for MoS_2 FETs contacted with an AlO_x interlayer. Overall, this work shows the beneficial effect of the ALD AlO_x adlayer for improving 2D device contacts and provides a scalable route to the damage-free integration of 2D semiconductors.

HL 47.2 Thu 15:15 EW 201

Investigation of electric contacts to 2D semiconductors for optoelectronic and solar energy conversion application — •Ariane Ufer[1], Hendrik Lambers[1], Benjamin Mayer[1], Emeline Nysten[1], Hubert Krenner[1], Rebecca Saive[2], and Ursula Wurstbauer[1] — [1]Institute of Physics, University of Münster, Münster, Germany — [2]MESA+ Institute for Nanotechnology, University of Twente, Enschede, Netherlands

Two-dimensional (2D) semiconducting transition metal dichalcogenides (TMDCs) such as molybdenum disulfide (MoS_2) are of great interest as they exhibit outstanding optoelectronic properties. Due to the highly efficient exciton dominated light-matter interaction, TMDC mono- and multilayers are promising materials for optoelectronic and solar energy conversion applications with the potential to provide lightweight, flexible, versatile, and robust devices. For these applications the contacts between the semiconducting TMDC and the conducting material play a significant role, whereby the major challenge for high power conversion efficiencies (PCE) is the separation and collection of charge carriers. We fabricate semiconductor-metal junctions by transferring MoS_2 mono- and multilayers by dry viscoelastic stamping techniques on top of various nanofabricated metallic contact pads. The samples are characterized via photoluminescence (PL) and Raman spectroscopy. Furthermore, we study the charge transfer across the 2D semiconductor-metal heterojunction using local laser beam induced current measurements.

HL 47.3 Thu 15:30 EW 201

Broadband Dielectric Mirrors and Microcavity Configurations for Multimode Coupling with Excitons in TMDC Heterostructures. — •Chirag Palekar[1], Bárbara Rosa[1], Niels Heermeier[1], Ching-Wen Shih[1], Imad Limame[1], Aris Kaulas-Simos[1], Arash Rahimi-Iman[2], and Stephan Reitzenstein[1] — [1]Institute of Solid State Physics, Technische Universität Berlin, D-10623 Berlin, Germany — [2]I. Physikalisches Institut and Center for Materials Research, Justus-Liebig-Universität Gießen, 35392 Gießen, Germany

We introduce chirped distributed Bragg reflectors with a broad stopband (>600 nm), spanning visible to near-infrared wavelengths. Our microcavity configurations employ broadband chirped DBRs which consist SiO2 and Si3N4 layers, demonstrating energetically separated cavity resonances. These modes are utilized to investigate the light-matter interactions with intra- and inter-layer excitons of transition metal dichalcogenide bilayer heterostructures (TMDC HSs). Additionally, our chirped microcavity systems shows cavity-coupled emission of energetically separated intra and interlayer excitons in a WSe2/MoSe2 heterostructure. The microcavity, combined with TMDC HSs, holds promise for studying moiré physics and advancing light-matter interactions in TMDC-based devices. Overall, our approach provides a versatile tool for future studies of spectrally distant and confined excitons in any active medium which paves the way for various applications by enabling precise control and manipulation of excitonic interactions utilizing multimode resonance light-matter interaction.

HL 47.4 Thu 15:45 EW 201

Distance dependence of the energy transfer mechanism in WS_2-graphene heterostructures — •David Tebbe[1], Marc Schütte[1], Kenji Watanabe[2], Takashi Taniguchi[3], Christoph Stampfer[1], Bernd Beschoten[1], and Lutz Waldecker[1] — [1]2nd Institute of Physics A, RWTH Aachen University, Aachen, Germany — [2]Research Center for Functional Materials, National Institute for Materials Science, Japan — [3]International Center for Materials Nanoarchitectonics, Japan

We investigate the mechanism of energy transfer in heterostructures of the two-dimensional semiconductor WS_2 and graphene with variable interlayer distances achieved through spacer layers of hexagonal boron nitride (hBN). Our analysis of the emission and absorption line widths reveals that the energy transfer is dominated by states outside the light cone, indicating a Förster transfer process. The dependence of luminescence intensity on interlayer distances above 1 nm can be quantitatively reproduced using recently calculated values of the Förster transfer rates of thermalized charge carriers and a constant radiative rate. However, at smaller interlayer distances, the experimentally observed transfer rates exceed the predictions and depend on excess energy and excitation density. We conclude that at these distances, the transfer is driven by non-thermalized charge carrier distributions, as the transfer probability of the Förster mechanism depends on the momentum of electron-hole pairs.

HL 47.5 Thu 16:00 EW 201

Evaluation of Disorder in Graphene Layers via Raman Spectroscopy for Enhanced Device Fabrication in Microelectronics — •Farnaz Majnoon[1], Rasuole Lukose[1], Daniele Capista[1], Christian Wenger[1,2], and Mindaugas Lukosius[1] — [1]IHP-Leibniz Institute für innovative Mikroelektronik, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]BTU Cottbus Senftenberg, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany

Graphene, a two-dimensional (2D) material, has emerged as a promising candidate for next-generation microelectronics owing to its exceptional electrical, mechanical, and thermal properties. In this study, we employ Raman spectroscopy as a powerful tool to probe the distinctiveness of graphene. The investigation focuses on elucidating the relationship between Raman spectral features and the quality of graphene layers, offering insights into its suitability for industrial microelectronics applications. Our analysis delves into the vibrational modes exhibited by graphene, exploring the effects of layer thickness, defects, and doping on the Raman spectra. The distinct G, D, and 2D bands provide crucial information regarding the structural integrity and quality of graphene, crucial parameters in evaluating its viability for microelectronic devices. We examine the impact of various contact methods and materials on graphene, aiming to comprehend their role in introducing disorder. Through Raman spectroscopy, this study reveals changes in graphene's properties influenced by these factors. These insights are pivotal in identifying the origins and scale of disorder, essential for refining fabrication processes and to achieve superior performance.

HL 47.6 Thu 16:15 EW 201

Effect of Energy Bands Overlap in the Interlayer Energy Transfer Processes in 2D Heterostructures — •Arka Karmakar — University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland

Heterostructures (HSs) made by the monolayers (1Ls) of transition metal dichalcogenides (TMDs) have shown great promises in designing next-generation optoelectronic device applications. Interlayer charge (CT) and energy transfer (ET) processes are the main photocarrier relaxation pathways in the TMD HSs. CT processes mainly occur due to the energy level offset between the materials and can survive only up to a few nm. Whereas, the interlayer ET process mediated by the dipole-dipole coupling between the donor and acceptor materials, can

survive up to several tens of nm. In this talk, I would like to present our recent studies to understand the effect of energy bands overlap in the ET process in TMD HSs. First, we showed that in the type-II HSs formed using the 1Ls of molybdenum diselenide (MoSe2) and rhenium disulfide (ReS2), an ET process dominates over the fast CT process, resulting 360% photoluminescence (PL) enhancement in the HS area. After completely blocking the CT process, this enhancement increased further up to more than 1 order of magnitude higher. Next, we showed that HS formed between the 1Ls of molybdenum disulfide (MoS2) and tungsten disulfide (WSe2), an unusual ET process occur from the lower bandgap WSe2 to higher bandgap MoS2 due to the resonant overlaps between the high-lying excitonic states. These works will help us to realize the complex ET processes in TMD HSs for better development of the TMD-based novel optoelectronic device applications.

HL 47.7 Thu 16:30 EW 201

Fabrication and Characterization of van der Walls Layers with Improved Interfacial Quality — •Laura Nicolette Schusser[1], Nihit Saigal[1], Hossein Ostovar[1], Zdeněk Sofer[2], and Ursula Wurstbauer[1] — [1]University of Münster, Germany — [2]University of Chemistry and Technology Prague,Czech Republic

The rich physical properties of two-dimensional materials, such as transition-metal dichalcogenides (TMDC) and related heterostructures have ushered in a new era of emergent phases and the development of devices [1,2]. Micromechanical exfoliation combined with the deterministic dry transfer of two-dimensional crystals represents a critical advancement in the fabrication of heterostructures through the controlled stacking of two-dimensional materials [2]. However, the presence of interfacial residuals and contaminants adversely affects the quality of heterostructures, consequently impacting the electrical and optical properties of the material. We established a fully automated setup for the dry transfer of two-dimensional materials inside a glovebox in a controlled environment. The quality of bulk crystals plays a crucial role in the fabrication of heterostructures. We utilize photoluminescence (PL) spectroscopy combined with Raman spectroscopy for the characterization of 2D layers exfoliated from differently grown TMDC crystals. [1] N. Saigal et. al., Arxiv Preprint, (2023). [2]Y. Lei et al., ACS Nanoscience Au2.6(2022)

HL 47.8 Thu 16:45 EW 201

Light Sources with Bias Tunable Spectrum based on van der Waals Interface Transistors — •Nicolas Ubrig[1], Hugo Henck[1], Diego Mauro[1], Ignacio Gutiérrez-Lezama[1], Luis Balicas[2], and Alberto Morpurgo[1] — [1]Department of Quantum Matter Physics, University of Geneva — [2]ational High Magnetic Field Laboratory, Tallahassee, FL 32310, USA

Light-emitting electronic devices are ubiquitous in key areas of current technology, such as data communications, solid-state lighting, displays, and optical interconnects. Controlling the spectrum of the emitted light electrically, by simply acting on the device bias conditions, is an important goal with potential technological repercussions. However, identifying a material platform enabling broad electrical tuning of the spectrum of electroluminescent devices is difficult. Here, we propose light-emitting field-effect transistors based on van der Waals interfaces of atomically thin semiconductors as a promising class of devices to achieve this goal. We demonstrate that large spectral changes in room-temperature electroluminescence can be controlled both at the device assembly stage –by suitably selecting the material forming the interfaces– and on-chip, by changing the bias to modify the device operation point. As the physical mechanism responsible for light emission is robust and does not depend on details of the interfaces, these structures are compatible with simple large areas device production methods.