HL 13: 2D Materials III – Interlayer excitons

Time: Monday 16:45–18:30 Location: POT/0081

HL 13.1 Mon 16:45 POT/0081

Robust Interlayer Exciton Interplay in twisted Van der Waals Heterobilayer and Heterotrilayer on a Broadband Bragg Reflector up to Room Temperature — •Bhabani Sankar Sahoo, Shachi Machchhar, Avijit Barua, Martin Podhorsky, Chirag Chandrakant Palekar, and Stephan Reitzenstein — Technische Universität Berlin, Berlin, Germany

The MoSe2/WSe2/WSe2 Heterotrilayer (HTL) shows higher interlayer exciton (IX) emission intensity compared to the MoSe2/WSe2 heterobilayer (HBL) due to the additional WSe2 monolayer in the HTL, which improves interlayer coupling and provides additional radiative pathways. However, its coupling strength and thermal stability with increasing temperature remain unexplored. Here, we fabricate HTL and HBL using H-type stacking with twist angle of 55 and 50 for the MoSe2/WSe2 and WSe2/WSe2 heterostructures (HS) on the chirped distributed Bragg reflectors (cDBRs) centered at 800 nm. Photoluminescence (PL) emission at 4K shows that HTL exhibits more than 10-fold higher intensity compared to HBL. The temperature-dependent valley polarization reveals the interplay of triplet and singlet IX in the PL emission of the HBL and Indicates the influence of band modulation on the PL emission of the HTL. The temperature-dependent lifetime further provides insights into the different decay processes in both the HS, highlights the variations in optical performance between HTL and HBL HS with temperature. Additionally, through the combined effect of controlled stacking angles and the use of cDBR substrate, we successfully achieve room temperature IX across both regions of HS.

HL 13.2 Mon 17:00 POT/0081

Ring-shaped Interlayer Exciton Ensembles in $MoSe_2/WSe_2$ Heterostructures by Laguerre-Gaussian Excitation — •Mirco Troue[1], Johannes Figueiredo[1], Gabriel Mittermair[1], Jonas Kiemle[1], Hendrik Lambers[2], Ana Senkić[2], Ursula Wurstbauer[2], and Alexander Holleitner[1] — [1]Walter Schottky Institute and Physics Department, TU Munich, Am Coulombwall 4a, 85748 Garching, Germany — [2]Institute of Physics, Münster University, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

Transition metal dichalcogenide monolayers exhibit strong light-matter interactions, which promotes them as ideal candidates for novel 2D optoelectronic applications. A vertical stacking into van der Waals heterostacks leads to the formation of long-lived interlayer excitons in adjacent layers. We report on ring-shaped ensembles of interlayer excitons in $MoSe_2/WSe_2$ heterostructures as excited by an optical Laguerre-Gaussian mode. The excitation is achieved with the help of a spatial light modulator. A hyperspectral analysis of the exciton photoluminescence suggests that the excitation scheme generates a non-uniform momentum distribution that favors the accumulation of high-energy excitons in the rings' center. We discuss the mechanisms leading to such a distribution, including exciton-exciton interaction, phase-space filling, and incomplete thermalization.

HL 13.3 Mon 17:15 POT/0081

Exciton-Exciton Interactions in Van der Waals Heterobilayers — •Tommy Schulz[1], Alexander Steinhoff[2], and Frank Jahnke[1] — [1]University of Bremen, Bremen, Germany — [2]Carl von Ossietzky University Oldenburg, Oldenburg, Germany

Optically excited van der Waals heterobilayers hosting long-lived interlayer excitons provide a compelling platform for exploring correlated electronic states. In this work, we compute the exciton energy shift as a function of excitation density and temperature. This shift arises from a subtle interplay of various many-body interaction processes, each of which contributes either a blue- or a redshift, corresponding to repulsive or attractive interactions, respectively. By incorporating the fermionic substructure of excitons as well as dynamical screening effects, we show that the commonly assumed dominant repulsive dipole-dipole interaction is almost perfectly compensated. This finding challenges the simple picture of a purely bosonic exciton gas. Moreover, we identify a crossover from attractive to repulsive behavior at elevated exciton densities. Comparing these results - obtained using first-principle band structures and Coulomb matrix elements - with those from a simpler two-band model highlights the importance of a material-realistic description of the electronic states.

HL 13.4 Mon 17:30 POT/0081

Optical Injection and Detection of Long-Lived Interlayer Excitons in van der Waals Heterostructures — •Anna Seiler, Alperen Tügen, Arthur Christianen, Martin Kroner, and Atac Imamoglu — ETH Zurich, Switzerland

Interlayer excitons, electron-hole pairs spatially separated between two layers of 2D materials, have gained attention for their potential to enable the exploration of bosonic quantum phases. A promising strategy to stabilize these excitons is to use transition metal dichalcogenide (TMD) bilayer structures, where the two TMD layers are separated by a few layers of hexagonal boron nitride (hBN), effectively isolating itinerant electrons and holes. While these systems have primarily been studied through transport measurements, challenges such as difficulties in making ohmic contacts to TMD monolayers and the lack of photoluminescence have limited their broader exploration. Here, we demonstrate optical generation of dipolar interlayer excitons in TMD bilayers separated by up to seven hBN layers. We observe that the 2s excitons in the individual layers remain intact in the presence of opposite charges in both layers, suggesting that the oppositely charged carriers are strongly bound, forming stable interlayer excitons. We measure exciton lifetimes up to ten microseconds, underscoring their potential for studying exotic quantum phases such as Bose-Fermi mixtures and excitonic condensates [1]. These phenomena can be accessed through optical spectroscopy, enabling future exploration.

[1] A. Tüğen, A. M. Seiler, et al., Phys. Rev. Lett. DOI: https://doi.org/10.1103/stgs-2s58

HL 13.5 Mon 17:45 POT/0081

Influence of hBN spacer layers on atomic reconstruction in $MoSe_2/WSe_2$ heterostructures probed by electron microscopy — •Johannes Figueiredo[1,2], Kaiyuan Chen[3], Aubrey Penn[4], Mirco Troue[1,2], Sebastian Loy[1,2], Frances M. Ross[3], Julian Klein[3], and Alexander Holleitner[1,2] — [1]Walter Schottky Institute, TU Munich — [2]MCQST — [3]Massachusetts Institute of Technology — [4]MIT.nano

Atomically thin hexagonal boron nitride (hBN) tunnelling barriers in transition metal dichalcogenide (TMD) heterobilayers have recently facilitated the observation of macroscopic interlayer exciton phases interpreted as possible condensation and superfluid phenomena. However, such hBN spacer layers are also expected to modify moiré-driven atomic reconstruction. Here, we resolve local stacking configurations, lattice relaxation patterns and twist-angle variations across encapsulated $MoSe_2/WSe_2$ heterobilayers using a combination of high-angle annular dark-field scanning transmission electron microscopy (HAADF STEM), convergent-beam electron diffraction and four-dimensional STEM. Our analysis shows that the presence and thickness of the hBN spacer layers alter the balance between elastic relaxation and interlayer registry, producing a reconstruction landscape that differs qualitatively from that of directly contacted $MoSe_2/WSe_2$ bilayers. We also discuss how the resulting changes in structural homogeneity tune the moiré potential experienced by interlayer excitons and outline the implications for realizing spatially uniform macroscopic exciton phases in TMD-based quantum devices.

HL 13.6 Mon 18:00 POT/0081

Spin-bright interlayer exciton and trion ground state in Janus transition metal dichalcogenide bilayers from first-principles — •Franz Fischer[1,2], Carl Emil Mørch Nielsen[1], Marta Prada[1], and Gabriel Bester[1] — [1]University of Hamburg, Institute of Physical Chemistry, 22761 Hamburg, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany

We investigate bilayer Janus transition metal dichalcogenides using ab initio many-body screened configuration interaction calculations [1] and find that MoSSe–WSSe and WSSe–WSSe, with Se–S interfaces, exhibit spin-allowed interlayer exciton and trion ground states [2], in contrast to the spin-forbidden ground states of conventional transition metal dichalcogenides bilayers. This distinctive behavior is driven by the intrinsic structural asymmetry and interface-induced polarization, which significantly modify the electronic band structure. Moreover, we demonstrate that external mechanical strain allows to tune the optical properties of these excitons, enabling precise control over their brightness and potential applications in optoelectronic devices.

[1] Mørch Nielsen, C.E., Fischer, F. & Bester, G. *npj 2D Mater. Appl.* **9**, 11 (2025)
[2] Mørch Nielsen, C.E., Fischer, F., Prada, M. & Bester, G. *2D Mater.* **12** 045015 (2025)

HL 13.7 Mon 18:15 POT/0081

Interplay of excitonic species in vertical and lateral transition metal dichalcogenide heterostructures — •Sai Shradha[1], Md. Tarik Hossain[2], Nicole Engel[1], Luc Oswald[1], Julian Führer[1], Daria Markina[1], Andrey Turchanin[2], and Bernhard Urbaszek[1] — [1]Institute for Condensed Matter Physics, TU Darmstadt, Hochschulstraße 6-8, D-64289 Darmstadt, Germany — [2]Institute of Physical Chemistry, Friedrich Schiller University Jena, Lessingstr. 10, D-07743 Jena, Germany

The properties of transition metal dichalcogenides (TMDs) can be extended beyond those offered by individual monolayers by combining different monolayers to create heterostructures. Vertically stacked heterostructures host quasi-particles such as interlayer and Moiré excitons. In lateral heterostructures (LHs), where monolayers of different materials are covalently bonded in the plane of their atoms, unidirectional exciton transport and the formation of charge-transfer excitons can be realized [1]. Chemical vapour deposition (CVD) has been a key fabrication technique for LHs. This work investigates composite CVD-grown $MoSe_2$-WSe_2 heterostructures consisting of both lateral and vertical interfaces, providing a single platform to study exciton dynamics across different interface types. Optical spectroscopy reveals efficient interlayer coupling in such structures, resulting in a uniquely strong interlayer exciton emission. Several spectroscopy techniques, including magneto-optics, are employed to characterize and shed light on exciton dynamics in such systems.

[1] S. Shradha et. al., arXiv, 2510.21422 (2025)