# HL 25: 2D semiconductors and van der Waals heterostructures II (joint session HL/DS)

Time: Friday 13:30–14:45 Location: H4

HL 25.1 Fri 13:30 H4

**Femtosecond contact-free nanoscopy of ultrafast interlayer transport in 2D heterostructures** — •Felix Schiegl[1], Markus Plankl[1], Paulo Eduardo Faria Junior[1], Fabian Mooshammer[1], Tom Siday[1], Martin Zizlsperger[1], Fabian Sandner[1], Simon Maier[1], Markus Andreas Huber[1], Martin Gmitra[1,4], Jaroslav Fabian[1], Jessica Louise Boland[1,2], Tyler Liam Cocker[1,3], and Rupert Huber[1] — [1]Department of Physics and Regensburg Center for Ultrafast Nanoscopy (RUN), University of Regensburg, Regensburg, Germany — [2]Photon Science Institute, Department of Electrical and Electronic Engineering, University of Manchester, Manchester, UK — [3]Department of Physics and Astronomy, Michigan State University, East Lansing, MI, USA — [4]Institute of Physics, Pavol Jozef Šafárik University in Košice, Košice, Slovakia

Tunneling is one of the most direct results of quantum mechanics, and a hallmark of interlayer exciton formation in semiconducting van der Waals heterostructures. Here, we introduce a new contact-free terahertz nanoscopy technique to trace ultrafast charge dynamics in both conducting and non-conducting materials. We demonstrate $< 50\,\mathrm{nm}$ spatial and subcycle temporal resolution and probe the interlayer tunneling across an atomically sharp $WSe_2/WS_2$ interface. Pronounced variations of the formation and annihilation of excitons emerge as a direct result of nanoscale strain and changes in atomic registry. Our results show the potential of this technique for revealing how ultrafast tunneling shapes the functionalities of a broad range of condensed matter systems.

HL 25.2 Fri 13:45 H4

**Moiré phonons in twisted $MoSe_2$-$WSe_2$ heterobilayers and their correlation with interlayer excitons** — •Philipp Parzefall[1], Johannes Holler[1], Marten Scheuck[1], Andreas Beer[1], Kai-Qiang Lin[1], Bo Peng[2], Bartomeu Monserrat[2,3], Philipp Nagler[1], Michael Kempf[4], Tobias Korn[4], and Christian Schüller[1] — [1]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Deutschland — [2]Theory of Condensed Matter Group, Cavendish Laboratory, University of Cambridge, UK — [3]Department of Materials Science and Metallurgy, University of Cambridge, UK — [4]Institut für Physik, Universität Rostock, Deutschland

We report about the investigation of twisted $MoSe_2$-$WSe_2$ heterobilayers by means of low-frequency Raman spectroscopy (LFRS) and low-temperature micro photoluminescence ($\mu$PL). We identify moiré phonons of both constituting materials in heterobilayers, which enables us to determine the relative twist angles of the heterobilayers on a local scale with high precision. Atomically reconstructed regions, which are identified by the observation of an interlayer shear mode in LFRS experiments, exhibit in $\mu$PL a strong, momentum-allowed interlayer-exciton signal.

HL 25.3 Fri 14:00 H4

**Transport Properties of Bulk Black Phosphorus Below and Above the Quantum Limit** — •Davide Pizzirani[1], Jasper Linnartz[1], Claudius Müller[1], Brian Kiraly[2], Alexander Khajetoorians[2], and Steffen Wiedmann[1] — [1]High Field Magnet Laboratory (HFML-EMFL), Radboud University, Nijmegen, Netherlands — [2]Institute for Molecules and Materials, Radboud University, Nijmegen, the Netherlands

Black phosphorus (bPh) has emerged as a promising and novel platform for nano-electronic applications due to its in-plane anisotropy and direct band gap that depends on the sample thickness. We present low-temperature magneto-transport experiments on bulk bPh up to 30 T with thicknesses ranging from 40 to 100 $\mu$m. A negative magnetoresistance (MR) that turns into a positive linear one is found by increasing the magnetic field. This MR remains quasi-isotropic upon changing the tilt angle from out-of-plane to in-plane with respect to the applied magnetic field. Using samples with different carrier concentrations, we are able to determine the transport properties below and above the quantum limit, and in the regime of variable range hopping.

HL 25.4 Fri 14:15 H4

**Excitation-induced optical nonlinearities and charge carrier localization in atomically thin TMD semiconductors** — •Daniel Erben, Alexander Steinhoff, Michael Lorke, Christian Carmesin, Matthias Florian, and Frank Jahnke — Institute for Theoretical Physics, University of Bremen

To interpret the nonlinear optical properties of atomically thin transition metal dichalcogenides (TMD), the density of photoexcited carriers is of central importance. However, in experiments the excited carrier density is practically not accessible. For above band-gap optical pumping of TMD monolayers, we utilize the semiconductor Bloch equations to determine the excitation density as function of the optical pump fluence. Our theory includes Pauli-blocking, band-gap renormalization, dephasing and screening of the Coulomb interaction due to excited carriers. The excitation density strongly depends on the wavelength of the exciting laser pulse. For pumping at the band gap, Pauli blocking of available phase space and renormalizations of the single particle energies are the dominant sources of a nonlinear density dependence, even at small pump fluence. In another study, we investigate the charge-carrier confinement in TMD nanobubbles. These are formed during stacking processes and exhibit quantum light emission upon optical excitation. We demonstrate that the emission originates from strong carrier localization, caused by the interplay of surface wrinkling, strain-induced confinement, and local changes of the dielectric environment. These effects combine to a specific localization signature that is found in recent spatially resolved photoluminescence experiments.

HL 25.5 Fri 14:30 H4

**Spatio-temporal dynamics of phonon sidebands in 2D materials** — •Roberto Rosati[1], Koloman Wagner[2], Samuel Brem[1], Raül Perea-Causín[3], Jonas D. Ziegler[2], Jonas Zipfel[2], Takashi Taniguchi[4], Kenji Watanabe[4], Alexey Chernikov[2,5], and Ermin Malic[1,3] — [1]Philipps University of Marburg — [2]University of Regensburg — [3]Chalmers University of Technology — [4]National Institute for Materials Science — [5]Dresden University of Technology

The semiconducting monolayers of transition metal dichalcogenides (TMDs) display a complex manifold of bright and dark exciton states, the latter giving rise to sharp phonon sidebands (PSB) in low-temperature photoluminescence. In this joint theory-experiment study we theoretically predict and experimentally demonstrate time-resolved low-temperature PSB, thus gaining direct access to the evolution of dark excitons in time, energy and space [1,2]. In an excellent theory-experiment agreement we reveal a spectral red-shift of phonon sidebands on a time scale of tens of picoseconds due to phonon-driven thermalization of initially-formed hot momentum-dark excitons [1]. After confined optical excitation, such hot-exciton distribution gives rise to a transient exciton diffusion one order of magnitude faster than the conventional diffusion observed at later times [2]. The obtained insights are applicable to other 2D materials with multiple exciton valleys.

[1] Rosati, R. et al. ACS Photonics 7, 2756 (2020).
[2] Rosati, R. et al. arXiv:2105.10232 (2021).