HL 5: Focus Session: Two-dimensional materials I (joined session with TT)

Time: Monday 9:30–12:45 Location: POT 81

Invited Talk HL 5.1 Mon 9:30 POT 81

Van der Waals heterostructures: tunnelling and interaction with light — •Artem Mishchenko — School of Physics and Astronomy, The University of Manchester, Manchester, UK

When graphene or other conducting 2D crystals are separated by an atomically thin insulating 2D crystal (e.g. hexagonal boron nitride), quantum mechanical tunnelling leads to the appreciable interlayer current between the two 2D conductors due to the overlap of their wave functions. These tunnel devices reveal exciting physics and great potential for applications: resonant tunnelling, negative differential conductance, light emission and detection, to name a few. Here, I will update on a current status and perspectives of tunnelling devices and quantum wells based on 2D materials assembled into van der Waals heterostructures. Particularly, I will present the results on tunnelling in mono- and bilayer graphene, tunnelling in 2D crystal-based quantum wells, and tunnelling in superconducting 2D materials. I will overview such effects as momentum and chirality conservation, phonon- and impurity-assisted tunnelling. Furthermore, interaction with light (i.e. photovoltaics, solar cells, light emission, lasing and plasmonics) within these heterostructures will be discussed. Finally, possible practical applications will be outlined.

HL 5.2 Mon 10:00 POT 81

Quantum emission from low dimensional materials — •Nathan Chejanovsky[1,2], Youngwook Kim[2], Andrea Zappe[1], Rainer Stöhr[1], Felipe Favaro de Oliveira[1], Durga Dasari[1,2], Amit Finkler[1], 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

Quantum emitters (QEs) in semi-conductors are at the forefront of optical research. 3D solid state systems [1] and quantum dots [2] are known sources of QEs. Nevertheless, quantum dots have constraints on temperature operation, broad linewidths and emission intermittency rendering these systems problematic. 3D systems suffer from light scattering and are difficult to process into tailored nano-structures.

Low dimensional wide band-gap materials (e.g. Van der Waals crystals) open possibilities for circumventing these obstacles, accessing intra-band gap states using sub-band gap excitation. Fulfilling this criteria, hexagonal boron nitride (h-BN), hosts room temperature QEs. [3] I summarize developments in this field and present results from our recent publication: [3] connecting structural features and QE location, generation of QEs using chemical etching/ion irradiation and analyzing their spectral features and photodynamics.

[1] Jelezko, F. et al. phys. stat. sol. (a) 2006, 203(13), 3207-3225
[2] Lodahl, P. et al. Reviews of Modern Physics 2015, 87 (2), 347-400
[3] Chejanovsky, N. et al. Nano letters 2016, 16, 7037-7045

HL 5.3 Mon 10:15 POT 81

Layered semiconductors coupled to an optical microcavity — •Michael Förg[1], Hisato Yamaguchi[2], David Hunger[3,4], and Alexander Högele[1] — [1]Fakultät für Physik and Center for NanoScience (CeNS), Ludwig-Maximilians-Universität München, Germany — [2]Materials Physics and Applications Division, Los Alamos National Laboratory, USA — [3]Ludwig-Maximilians-Universität München, Schellingstr. 4, München, Germany — [4]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, Garching, Germany

Two-dimensional atomic crystals of transition metal dichalcogenides exhibit remarkable optoelectronic properties in the limit of direct band-gap monolayers [1]. Bilayer heterostructures, on the other hand, feature long-lived indirect excitons potentially viable for studies of condensation phenomena [2]. In the scope of this work we investigate excitons in CVD grown layered semiconductors coupled to an optical microcavity. In our experiments we use a tunable open-access cavity with one curved fiber-based mirror and one planar mirror which supports laterally extended semiconductor flakes. This configuration allows us to combine controlled inter-mirror spacing with lateral scanning capabilities. While the former parameter is used to explore the light-matter coupling as a function of the cavity length, the latter enables two-dimensional cavity imaging of extended monolayer flakes to probe variations in the local crystal quality and the dielectric environment.

[1] Xu et al., Nat. Phys. 10, 343 (2014)
[2] Rivera et al., Nat. commun. 6 (2015)

HL 5.4 Mon 10:30 POT 81

Understanding single-photon emission from defects in hexagonal boron nitride — •Sten Haastrup and Kristian S. Thygesen — Center for Atomic-Scale Materials Design, Department of Physics, Technical University of Denmark

Point defects in sheets of hexagonal boron nitride have recently been studied as potential single-photon emitters: Experimental studies have shown that the emission from point defect color centers has extremely narrow bandwidth and mainly takes place in the zero phonon line. From an engineering perspective, a high-quality source of single photons would be extremely useful for many applications including quantum computing and quantum communications. Currently, it is not clear which defect systems in boron nitride have the right properties for use as single-photon emitters; different experimental studies have observed emission at very different energies, indicating that multiple different defect states can produce single photons. This is the starting point for our investigation into which properties of defects are important for single-photon emission, and which properties of boron nitride make it suitable as host. We have used density functional theory to explore the potential energy surfaces of the ground- and lowest excited states around different point defects in hBN. Our calculations shed light on the observed narrow band nature of the emission lines and indicate potential routes for tuning emission energy, line width and lifetime.

HL 5.5 Mon 10:45 POT 81

On the Dynamics of Excitons in Perovskite Nanoplatelets — •Alexander F. Richter[1,2], Verena A. Hintermayr[1,2], Florian Ehrat[1,2], Bernhard Bohn[1,2], Thomas Simon[1,2], Lakshminarayana Polavarapu[1,2], Alexander S. Urban[1,2], and Jochen Feldmann[1,2] — [1]Chair of Photonics and Optoelectronics, Department of Physics and Center for Nanoscience (CeNS), Ludwig-Maximilians-Universität München (LMU), Amalienstraße 54, 80799 Munich, Germany — [2]Nanosystems Initiative Munich (NIM), Schellingstraße 4, 80799 Munich, Germany

Organic-inorganic halide perovskites have received great attention in the past few years due to their remarkably high solar energy conversion efficiency. Their functionality is even more widespread showing vast improvements in light-emitting applications, especially in the form of nanocrystals. We have successfully synthesized two-dimensional perovskite nanoplatelets with a controllable thickness down to a single unit cell. This leads to exciton binding energies in the hundred meV range. Here, we present experimental results on the dynamics of excitons in such nanoplatelets. Time-resolved photoluminescence reveals an increased exciton recombination rate with decreasing crystal thickness. In addition, we derive exciton-phonon scattering rates from a linewidth analysis of linear optical spectra. These results are compared to exciton dephasing rates obtained by transient four-wave-mixing experiments.

Coffee break

Invited Talk HL 5.6 Mon 11:30 POT 81

Excitons in ultra-thin perovskites & van der Waals crystals — •Alexey Chernikov — Department of Physics, University of Regensburg, Germany

Excitons, as first introduced by J. Frenkel in 1931, are fundamental quasiparticles in semiconductors, composed from an excited electron and the remaining hole with an effective positive charge bound together by the Coulomb interaction. The excitons strongly influence the materials‘ response to external fields and perturbations, and are of particular importance for a variety of applications, including solar cells, light emitters, lasers, modulators, and detectors. In addition, they play a major role in more advanced concepts, such as entangled photons from biexciton sources, excitonic qubits, carrier multiplication, and Bose-Einstein condensation.

In this talk, I will focus on the properties of excitonic particles in nanostructured two-dimensional materials: single layers of semicon-

ducting organic-inorganic perovskites and van der Waals crystals as thin as a single unit cell. I will discuss the nature of an unusually strong and unconventional Coulomb interaction shared by these systems and demonstrate how it results in exciton binding energies as large as 0.5 eV with highly efficient light-matter interaction, largely determining the optical response of these ultra-thin layers. Finally, I will outline how the excitons can be externally tuned either by electrical and optical injection of charge carriers or through the dielectric engineering of the environment in heterostructures.

HL 5.7 Mon 12:00 POT 81

Carrier dynamics in MoS2 — •Michael Lorke, A. Steinhoff, M. Florian, C. Gies, M. Roesner, T. Wehling, and F. Jahnke — Institute for Theoretical Physics, University of Bremen, Germany

In the context of the current interest in transition-metal dichalcogenides, we study the optical generation and relaxation of excited carriers and their influence on optical properties. In these two-dimensional atomically thin semiconductors, the Coulomb interaction is known to be much stronger than in quantum wells of conventional semiconductors like GaAs, as witnessed by the up to 50 times larger exciton binding energy. The question arises, whether this translates into equivalently faster carrier-carrier Coulomb scattering of excited carriers. We answer this question by combining ab-initio band-structures and single-particle wave functions with kinetic equations for the Coulomb-induced carrier scattering in the full Brillouin zone, We find an ultrafast redistrubution of carriers into different valleys of the band structure on a 100fs timescale. The other main source of carrier relaxation is the interaction of the excited carriers with phonons. To analyze carrier-phonon scattering and dephasing, we solve kinetic equations, based on ab-initio carrier-phonon interaction matrix elements, both for carriers and phonons, including heating effects due to the excitation of non-equilibrium phonons. We find that within 100fs the electrons have relaxed into the valleys of the bandstructure, demostrating fast carrier dynamics, which is accompanied by the generation of non-equilibrium phonons. This process is followed by carrier cooling on a timescale of about 1ps, which is consistent with recent experimental findings.

HL 5.8 Mon 12:15 POT 81

Optical Properties of WSe_2 monolayers on metal films — •Laxmi Narayan Tripathi, Oliver Iff, Simon Betzold, Sven Hoefling, and Christian Schneider — Technische Physik and Wilhelm-Conrad-Roentgen Research Center for Complex Material Systems, Universitaet Wuerzburg, Wuerzburg, Am Hubland, D-97074 Germany

Single photon generation is essential for quantum communications. For efficient quantum communication devices, a core requirement are single photon sources which are stable, bright, and which can be replicated. Recently, quantum light emission from inorganic two dimensional layers of transition metal dichalcogenides (TMDC), such as WSe_2, has been demonstrated.

In this contribution, we present our spectroscopy results from a metal-TMDC hybrid device. We performed low temperature (5K) photoluminescence measurement on a WSe_2 monolayer transferred mechanically on metal surface and obtained stable and sharp emission features as compared to bare TMDC monolayer on dielectric substrate. The nanoscale metal surface sample were prepared in the group of Prof Dai-Sik Kim, Seoul National University, South Korea. We envisage that the results will find application in quantum photonics.

HL 5.9 Mon 12:30 POT 81

Tamm-Plasmon Exciton-Polaritons with a WS2 monolayers at room temperature — •Sebastian Stoll[1], Nils Lundt[1], Christian Schneider[1], and Sven Höfling[1,2] — [1]Technische Physik and Wilhlem-Conrad-Röntgen Research Center for Complex Material Systems, Universität Würzburg, D-97074 Würzburg, Am Hubland, Germany — [2]SUPA, School of Physics and Astronomy, University of St. Andrews KY 16 9SS, UK

We demonstrate the formation of room temperature Tamm-plasmon Exciton-polaritons with a WS2 monolayer. Due to their high oscillator strength and stable excitonic complexes at 300 K, transition metal dichalcogenide monolayers have awaken strong interest in the field of light-matter interaction at high temperatures. Recently, WS2 was brought into the strong coupling regime by embedding it into both an open-cavity [1] and a Fabry-Perot-cavity consisting of two silver mirrors [2]. In this experiment, the use of a Tamm structure provides us with a narrower cavity linewidth and thus with a higher cavity Q-factor. The exciton-polariton dispersion was measured by momentum-resolved PL spectroscopy. The acquired dispersion shows the expected avoided crossing behaviour of the two polariton branches and yields a Rabi splitting of around 27 meV. References: [1] L.C. Flatten et al., Scientific Reports 6, 33134 (2016) [2] S. Wang et al., Nano Letters 16, 7 (2016)