Symposium Optics and Light-Matter Interaction with Excitons in 2D Materials (SYLM)

jointly organized by
the Semiconductor Physics Division (HL),
the Thin Films Division (DS),
the Surface Science Division (O), and
the Low Temperature Physics Division (TT)

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Atomically thin two-dimensional materials have advanced to the point where they are becoming highly appealing for the study of novel quantum physics and for constructing emergent photonic, electronic and photochemical devices using tailored 2D-heterostructures. The most prominent monolayer 2D material, graphene, has a bandstructure in its pristine form without an electronic bandgap. In contrast, monolayers of transition metal dichalcogenides (TMDCs) tend to be direct gap semiconductors with a bandgap in the visible to near-infrared spectral range. Moreover, the two-dimensional nature of these monolayered semiconductors give rise to very strong excitonic effects, even at ambient conditions and their strong light-matter interactions and spin-valley properties make them highly interesting for e.g. opto-valleytronics and novel coherent light sources. Intriguingly, TMDC crystals can host strongly localized excitons, which result in the possibility to emit quantum light. In this symposium the current status and prospects of the very rapidly evolving field of TMDC research will be summarised including materials properties and synthesis and the exploration of phenomena such as quantum light emission, coherent laser action, spinor excitonics and cavity quantum electrodynamics.

Overview of Invited Talks and Sessions

(Lecture room HSZ 02)

Invited Talks

SYLM 1.1	Thu	15:00–15:30	HSZ 02	**Light matter interaction in TMDs and their heterostructures** — •Ursula Wurstbauer
SYLM 1.2	Thu	15:30–16:00	HSZ 02	**Quantum optics with deterministically positioned quantum emitters in a two-dimensional semiconductor** — •Brian Gerardot
SYLM 1.3	Thu	16:00–16:30	HSZ 02	**Light-matter coupling with atomic monolayers in microcavities** — •Christian Schneider
SYLM 1.4	Thu	17:00–17:30	HSZ 02	**Properties of Synthetic 2D Materials and Heterostructures** — •Joshua Robinson
SYLM 1.5	Thu	17:30–18:00	HSZ 02	**Exciton spectroscopy in transition metal dichalcogenide monolayers and van der Waals heterostructures** — •Bernhard Urbaszek
SYLM 1.6	Thu	18:00–18:30	HSZ 02	**Strain-induced single-photon emitters in layered semiconductors** — •Rudolf Bratschitsch

Sessions

SYLM 1.1–1.6	Thu	15:00–18:30	HSZ 02	**Optics and Light-Matter Interaction with Excitons in 2D Materials (SYLM)**

SYLM 1: Optics and Light-Matter Interaction with Excitons in 2D Materials (SYLM)

Time: Thursday 15:00–18:30 Location: HSZ 02

Invited Talk SYLM 1.1 Thu 15:00 HSZ 02
Light matter interaction in TMDs and their heterostructures — •Ursula Wurstbauer — Walter Schottky Institute and Physics-Department, TU Munich — Nanosystems Initiative Munich (NIM)

Transition metal dichalcogenides (TMDs) such as MoS2 are of current interest for optoelectronic, sensing and energy harvesting applications, but also for studying fundamental aspects of light-matter interaction in strictly two-dimensional semiconductors [1,2]. These materials exhibit a high sun light absorbance of up to 15% in the monolayer limit [3], photocatalytic stability [4] and access to excitonic phenomena in van der Waals heterostructures. We access the complex dielectric function and their fine-structure by spectroscopic imaging ellipsometry [3]. The importance of excitonic effects emerge also in resonant Raman spectroscopy, where unexpected polarization dependence points towards strong exciton-phonon coupling in MoS2. We furthermore achieve strong signatures for interlayer coupling and the formation of presumably long-lived interlayer excitons in such van der Waals heterostructures.

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[1] U. Wurstbauer et al. arXiv:1611.05255 (2016). [2] B. Miller, et al., Appl. Phys. Lett. 106, 122103 (2015). [3] S. Funke et al., J. Phys. Condens. Matter 28, 385301 (2016). [4] E. Parzinger et al. ACS Nano 9(11), 11302 (2015).

Invited Talk SYLM 1.2 Thu 15:30 HSZ 02
Quantum optics with deterministically positioned quantum emitters in a two-dimensional semiconductor — •Brian Gerardot — Institute of Photonics and Quantum Sciences, SUPA, Heriot-Watt University, Edinburgh EH14 4AS, UK

The emergence of single quantum emitters in layered transition metal dichalcogenide semiconductors offers new opportunities to construct a scalable quantum architecture with a coherent light-matter interface. Here I will present results taking steps in this direction. First, using nanoscale strain engineering, we deterministically achieve a two-dimensional lattice of quantum emitters in an atomically thin semiconductor. We create point-like strain perturbations in mono-and bilayer WSe2 which locally modify the band-gap, leading to efficient funnelling of excitons towards isolated strain-tuned quantum emitters that exhibit high-purity single photon emission. Next, we perform resonance fluorescence and high-resolution photoluminescence excitation spectroscopy of these isolated, localized 2D excitons to reveal near ideal single photon fluorescence and uncover dark exciton states ~ 5meV blue-shifted from the bright exciton states. The high-purity single photon emission is stable and bright, yielding detected count rates up to 3 MHz. These results yield a route for intriguing investigations of the spin and valley coherence of localized excitons in 2D-transition metal dichalcogenide semiconductors.

Invited Talk SYLM 1.3 Thu 16:00 HSZ 02
Light-matter coupling with atomic monolayers in microcavities — •Christian Schneider — Technische Physik, University of Wuerzburg, Germany

Transition metal dichalcogenides represent a novel emerging class of materials which seems almost ideal to study light-matter coupling in solid state. In this talk, I address the case of a single atomic monolayer embedded in dielectric and metal-based photonic structures. I will discuss the formation of exciton-polaritons from cryogenic temperatures up to ambient conditions in compact and flexible Tamm-structures. I will also discuss peculiarities which arrise from the moderate quality factors in these structures, yielding significantly different anticrossings in luminescence and reflection. Finally, a focus is set on the interplay of excitons and trions, both in the weak and strong coupling limit.

Coffee Break

Invited Talk SYLM 1.4 Thu 17:00 HSZ 02
Properties of Synthetic 2D Materials and Heterostructures — •Joshua Robinson — Pennsylvania State University, University Park, PA, USA

The last decade has seen nearly exponential growth in the science and technology of two-dimensional materials. Beyond graphene, there is a huge variety of layered materials that range in properties from insulating to superconducting. Furthermore, heterogeneous stacking of 2D materials also allows for additional dimensionality for band structure engineering. In this talk, I will discuss recent breakthroughs in two-dimensional atomic layer synthesis and properties, including novel 2D heterostructures and novel 2D nitrides. Our recent works include development of an understanding of substrate impact on 2D layer growth and how we can tune the substrate to acheive near-single crystal 2D materials over large areas. I will also dsicuss doping of 2D materials with magentic elements, selective area synthesis of 2D materials, and the first demonstration of 2D gallium nitride (2D-GaN). Our work and the work of our collaborators has lead to a better understanding of how substrate not only impacts 2D crystal quality, but also doping efficiency in 2D materials, and stabalization of nitrides at their quantum limit.

Invited Talk SYLM 1.5 Thu 17:30 HSZ 02
Exciton spectroscopy in transition metal dichalcogenide monolayers and van der Waals heterostructures — •Bernhard Urbaszek — CNRS - Toulouse University, France

Excitons in transition metal dichalcogenide monolayers (MLs) provide exciting opportunities for applications and new frontiers in physics: (i) with binding energies of several hundred meV, excitons dominate optical properties even at room temperature, (ii) strong exciton oscillator strength leads to absorption of up to 20 % per ML, and (iii) the interband selection rules are valley selective. In combination with strong spin-orbit splittings this allows studying spin-valley physics. Although ML samples on Si/SiO2 substrates are widely studied in the literature, conclusive measurements on the excited exciton states and fine structure (2s/2p) are still missing. In hBN / ML WSe2 / hBN samples we measure for the linewidth of the neutral and charged exciton emission values down to 1.6 meV at T=4K, close to the homogenous limit. This allows us to perform 1 and 2-photon spectroscopy which reveal details previously masked by inhomogeneous broadening. Also, we demonstrate control of the exciton valley coherence in ML WSe2 on SiO2 by tuning the applied magnetic field B perpendicular to the ML plane. Linearly polarized laser excitation prepares a coherent superposition of valley states and the induced valley Zeeman splitting between K+ and K- results in a change of the oscillation frequency of the superposition of valley states. This corresponds to a rotation of the exciton valley pseudo-spin by angles as large as 30 degrees for fields up to B=9T.

Invited Talk SYLM 1.6 Thu 18:00 HSZ 02
Strain-induced single-photon emitters in layered semiconductors — •Rudolf Bratschitsch — Westfälische Wilhelms-Universität Münster, Münster, Deutschland

Single-photon sources are important building blocks for quantum information technology. Emitters based on solid-state systems provide a viable route for their integration in photonic devices. Recently, we have found single-photon emitters in the atomically thin semiconductor WSe2 [1]. We show that the quantum light sources are strain-induced and demonstrate deterministic positioning of the emitters on the nanoscale [2]. Finally, we present single-photon emission from the layered semiconductor GaSe and provide evidence that the incorporated non-classical light sources are also strain-induced [3].

[1] P. Tonndorf et al., Optica 2, 347 (2015)
[2] J. Kern et al., Advanced Materials 28, 7101 (2016)
[3] P. Tonndorf et al., 2D Materials (2016)