HL 2: 2D Materials and Heterostructures: Photonic Aspects

Time: Monday 9:30–13:00 Location: EW 201

HL 2.1 Mon 9:30 EW 201

Measuring the complex valley polarization nonlinear susceptibility in monolayer WSe_2 — •Paul Herrmann, Sebastian Klimmer, Till Weickhardt, and Giancarlo Soavi — Institute of Solid State Physics, Friedrich Schiller University Jena, Jena, Germany

Valleytronics suffers from the lack of an ideal method to probe the valley degree of freedom. Both state of the art methods, namely polarized photoluminescence and Kerr rotation, are insensitive to the complex nature of valley polarization (VP). More generally, one can view measuring VP as probing broken time-reversal (TR) symmetry. As second harmonic generation (SHG) is sensitive to symmetry, it was proposed as a probe of VP. However, said method of probing the rotation in the SHG pattern of elliptically polarized pulses [1] suffers from limited valley adressability and also disregards the complex nature of VP. In this work we overcome both aforementioned problems [2]. We develop and demonstrate a new method that probes the interference between electric-dipole and VP in the SHG signal when we directly excite at ±K resonance with circularly polarized light. We show that such interference can only be explained by taking into consideration the complex nature of VP, in analogy to the magnetic- to electric-dipole interference observed in bulk magnets [3]. Our work provides a new method for detection of VP and we argue that it could be extended to probe broken TR symmetry in other crystal classes.

[1] Herrmann, P. et al.: small 2023 19:2301126
[2] Herrmann, P. et al.: arXiv 2023 2310.16549
[3] Fiebig, M. et al.: PRL 1994 15(73)

HL 2.2 Mon 9:45 EW 201

Theory of in-plane magnetic field dependence of excitonic spectra in atomically thin semiconductors — •Michiel Snoeken, Andreas Knorr, and Henry Mittenzwey — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The linear absorption spectrum of TMDC monolayers under the influence of an in-plane magnetic field is studied by developing a microscopic theory in an excitonic picture. It is shown that in-plane magnetic fields induce coupling between spin-bright and spin-dark exciton transitions, resulting in the brightening of spin-dark excitons in the linear spectrum with increasing in-plane field-strength. Numerical evaluation shows that the energy splitting of these excitonic states increases with field strength and the relative intensities of the A_{1s} and Ad_{1s} converge to saturation after an initial quadratic growth. Some analytical limit cases are discussed.

HL 2.3 Mon 10:00 EW 201

Symmetry and handedness of chiral tellurium under polarized Raman spectroscopy — •Davide Spirito[1], Sergio Marras[2], and Beatriz Martín García[3,4] — [1]IHP-Leibniz-Institut für innovative Mikroelektronik, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]Istituto Italiano di Tecnologia - Materials Characterization Facility, Genova 16163, Italy — [3]CIC nanoGUNE BRTA, 20018 Donostia-San Sebastián, Basque Country, Spain — [4]IKERBASQUE, Basque Foundation for Science, 48009 Bilbao, Spain

Trigonal tellurium is a model low-dimensional material for the study of electrons and phonons in chiral systems. Here we show how the response of tellurium to polarized light depends on the crystal orientation, which has implication for optical properties and electron transport studies. By linearly polarized Raman spectroscopy we identify different crystal faces and the orientation of the trigonal axis, based on typical patterns derived from the analysis of the symmetry of the crystal. Furthermore, by circularly polarized measurements we determine the handedness only for incidence parallel to the trigonal axis, with the observation of different peaks shift for left- and right-handed crystals. We support our findings with X-ray diffraction and chirality-sensitive chemical etching, providing a robust insight for the analysis chiral and low-dimensional materials.

HL 2.4 Mon 10:15 EW 201

Interaction of 2D materials with laser-written waveguide circuits — •Alina Schubert[1], Karo Becker[1], Marco Kirsch[1], Jakob Kuhlke[1], Rico Schwartz[1], Andreas Thies[2], Alexander Szameit[1], Matthias Heinrich[1], and Tobias Korn[1] — [1]Institut für Physik, Universität Rostock, 18059 Rostock, Germany — [2]Ferdinand Braun Institut, Leibnitz Institut für Höchstfrequenztechnik, 12489 Berlin, Germany

The remarkable optical properties of monolayer transition metal dichalcogenides (TMDCs) are determined by strongly bound excitons. Currently, most of the micro-photoluminescence measurements are performed with light polarized in the plane of the TMDC layer. However, so-called dark excitons that emit z-polarized light propagating along the TMDC layer require detection from the side [1, 2].

Our intention is to probe TMDCs in this direction by depositing them onto a fused silica glass substrate containing femtosecond laser direct written waveguides [3]. By defining the waveguide near the surface of the glass, interactions of the waveguide's evanescent field and the TMDC are enabled.

Our micro-photoluminescence setup that couples into the waveguides and simultaneously detects light perpendicular to the TMDC layer has the potential to excite and detect the x,y and z polarization of the PL signal, allowing for direct observations of dark excitons.

[1] X.-X. Zhang et al., Phys. Rev. Lett., 115 (2015).
[2] G. Wang et al., Phys. Rev. Lett., 119 (2017).
[3] A. Szameit et al., J. Phys. B.: At. Mol. Opt. Phys., 43 (2010).

HL 2.5 Mon 10:30 EW 201

Simulation of waveguide-coupled graphene-based double-layer straight and ring modulator — •Pawan Kumar Dubey[1], Ashraful Islam Raju[1], Rasuole Lukose[1], Christian Wenger[1,2], and Mindaugas Lukosius[1] — [1]IHP- Leibniz Institut für innovative Mikroelektronik, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany — [2]BTU Cottbus Senftenberg, Platz der Deutschen Einheit 1, 03046 Cottbus, Germany

On-chip integrated, graphene-based optical modulators are state-of-the-art optoelectronics devices with numerous applications in emerging photonics technologies, providing the advantages of high modulation efficiency, high broadband application and low power consumption. Liu et al.2012 experimentally demonstrated a double-layered straight modulator with a modulation depth of just 0.16 dB/μm for the first time. This design had miniscule waveguide light interaction with the graphene layer, resulting in low modulation efficiency. A novel method emerged to elevate this interaction further, where the graphene layer was integrated with silicon nitride-based ring resonators. Taking this approach as a reference, we present an FDTD simulation of double-layer graphene-based ring modulators. We have studied the design parameters of the ring modulator, such as the radius, shape of the resonator, and graphene area, that affect the modulation efficiency. We have optimised the design of the ring resonator working near the critical coupling condition, achieving a modulation depth of 3.5 dB/V, which is 20 times better than our previously simulated double-layer straight modulator design.

HL 2.6 Mon 10:45 EW 201

Second-order temporal coherence of polariton lasers based on an atomically thin crystal in a microcavity — •Hangyong Shan[1], Jens-Christian Drawer[1], Meng Sun[2], Carlos Anton-Solanas[5], Martin Esmann[1], Kentaro Yumigeta[6], Sefaattin Tongay[6], Sven Höfling[4], Ivan Savenko[3], and Christian Schneider[1] — [1]Oldenburg University, Oldenburg, Germany — [2]Beijing University of Technology, Beijing, China — [3]Guangdong Technion Israel Institute of Technology, Shantou, China — [4]Würzburg University, Würzburg, Germany — [5]Universidad Autónoma de Madrid, Madrid, Spain — [6]Arizona State University, Arizona, USA

Bosonic condensation and lasing of exciton-polaritons in microcavities is a fascinating solid-state phenomenon. Here, we study the photon statistics via the second-order temporal coherence of polariton lasing emerging from an optical microcavity integrated with an atomically thin MoSe2 crystal. In our experiments, we observe distinct polariton dispersions and characteristic features of bosonic lasing. With the utility of Hanbury Brown and Twiss (HBT) setup, we investigate macroscopic polariton phase transition for varying excitation powers and temperatures. The lower-polariton exhibits photon bunching below the threshold, implying a dominant thermal distribution of the emission, while above the threshold, the second-order correlation transits towards unity, which evidences the formation of a coherent state. Our

findings are in agreement with a microscopic numerical model based on the Lindblad master equation, which explicitly includes scattering with phonons on the quantum level.

15 min. break

HL 2.7 Mon 11:15 EW 201

Magnification of Plasmon Resonances in Monolayer MoS2 via Conjugated Molecular Adsorbates — Juan Pablo Guerrero-Felipe[1], •Ana M. Valencia[2,3], and Caterina Cocchi[2,3] — [1]Department of Physics, Freie Universität Berlin — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg — [3]Physics Department and IRIS Adlershof, Humboldt-Universität zu Berlin

The adsorption of carbon-conjugated molecules represents an established route to tune the electronic and optical properties of transition metal dichalcogenide (TMDC) monolayers. Here, we demonstrate from the first principles such a functionalization with prototypical compounds pyrene and tetracene enhance the magnitude of selected plasmon resonances in the MoS2 layer, without significantly altering their energy and dispersion. Our results indicate that such a magnification can be achieved by proper alignment of the molecules concerning the direction of the transferred momentum. The distinct signatures in the loss function of the interface compared to those of its constituents suggest not only the presence of non-negligible interactions between them but also the possibility of using electron energy loss spectroscopy to detect the presence and the orientation of molecular adsorbates on TMDCs. J.P. Guerrero-Felipe, et al., arXiv:2311.17613 [cond-mat.mtrl-sci]

HL 2.8 Mon 11:30 EW 201

Coupling of excitons in few-layer WS2 films with a hybrid plasmon polariton at room temperature — •Yuhao Zhang[1], Hans-Joachim Schill[1,2], Stephan Irsen[2], and Stefan Linden[1] — [1]Physikalisches Institut, Rheinische Friedrich-Wilhelms-Universität Bonn, 53115 Bonn, Germany — [2]Electron Microscopy and Analytics, Center of Advanced European Studies and Research (caesar), 53175 Bonn, Germany

Composite structures formed by the combination of plasmonics nanostructures that tightly confine light and TMDC thin film with a strong exciton resonance offer unique capabilities to investigate and engineer light-matter interactions in solid-state systems. So far, most research has focused on the strong coupling between plasmonic structures and TMDC monolayers. The strong coupling between few-layer TMDC with extended plasmonic nanostructures is still a largely unexploited territory.

In this work, we report on the room-temperature interaction of few layer WS2 thin films (monolayer to qudrilayer) with a tapered nanograting structure milled into a monocrystalline silver flake. The bare nanograting structure features hybrid plasmon polaritons (HPP) with three polariton branches. When a WS2 monolayer is deposited on the nanogroove array with an optimized design, the reflection spectra show an avoided crossing of the exciton mode and the lower plasmon polariton branch with a Rabi splitting of 68 meV indicating strong exciton-plasmon polariton coupling. The Rabi splitting increases to more than 100 meV in the case of the quadrilayer.

HL 2.9 Mon 11:45 EW 201

Spectrally and topologically tunable polaritons based on two-dimensional crystals in a photonic lattice — Lukas Lackner[1], Christoph Bennenhei[1], Oleg Egorov[2], Anthony Enzerhof[1], Victor Mitryakhin[1], Falk Eilenberger[2], Sefaattin Tongay[3], •Martin Esmann[1], and Christian Schneider[1] — [1]Carl von Ossietzky University, Oldenburg, Germany — [2]Friedrich Schiller University, Jena, Germany — [3]Arizona State University, Tempe, Arizona, USA

Engineering hybrid light-matter states in tailored photonic lattices is a key asset for the emulation of topological Hamiltonians interlinking fundamental aspects of photonics, information processing and solid state physics. Room temperature-stable excitons in atomically thin crystals are an ideal active medium for this purpose, since they couple strongly to light and bear the potential to harness giant non-linearities. Here, we study spectrally tunable exciton-polaritons of a WS2 monolayer in a high quality open cavity at room temperature [1]. We imprint a photonic lattice into the cavity, which emulates the canonical Su-Schrieffer-Heeger (SSH) Hamiltonian [2] and generate a topological mode at a domain boundary between two lattices characterized by different topological invariants. Our optical experiments reveal a spectral tunability of the topologically protected mode over a range as large as 80 meV. Utilizing the unique tilt-tunability of our implementation, we transform the SSH-lattice into a Stark-ladder and fundamentally change its topological class.

[1] L. Lackner et al., Nat Commun 12, 4933 (2021)
[2] W. P. Su et al. PRL 42, 1698 (1979)

HL 2.10 Mon 12:00 EW 201

2D Semiconductor-Plasmonic Hybrids: Strong Coupling, Exciton Localization, and Single Photon Emission — •Lara Greten, Robert Salzwedel, Malte Selig, and Andreas Knorr — Nichtlineare Optik und Quantenelektronik, Institut für Theoretische Physik, Technische Universität Berlin, Germany

Monolayers of transition metal dichalcogenides (TMDCs) display strong light-matter interaction dominated by tightly bound excitons. In contrast, metal nanostructures support localized plasmons, allowing for nanoscale electric field control. This talk is focused on a microscopic description of the interplay between excitons and plasmons, combining Maxwell's and excitonic Bloch equations [1,2,3]. The theory is applied to three situations: (a) exciton localization within plasmon-induced near-field potentials [2], (b) exciton-plasmon strong coupling in 2D lattices with a spectral splitting of 100 meV [3], and (c) Purcell-enhanced single-photon generation [4].

[1] L. Greten, R. Salzwedel et al., physica status solidi (a) 2300102 (2023)
[2] R. Salzwedel, L. Greten et al., arXiv:2305.11099 (2023)
[3] L. Greten, R. Salzwedel et al., arXiv:2309.09673 (2023)
[4] M. von Helversen, L. Greten et al., 2D Mater. 10 045034 (2023)

HL 2.11 Mon 12:15 EW 201

Light-matter interaction of TMDCs in an open cavity — •Shiyu Huang[1], Edith Wietek[2], Johannes Düreth[1], Simon Betzold[1], Monika Emmerling[1], Takashi Taniguchi[3], Kenji Watanabe[3], Sven Höfling[1], Alexey Chernikov[2], and Sebastian Klembt[1] — [1]Julius-Maximilians-Universität Würzburg, Physikalisches Institut and Würzburg-Dresden Cluster of Excellence ct.qmat, Lehrstuhl für Technische Physik, Am Hubland, 97074 Würzburg, Deutschland — [2]Institute of Applied Physics and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universität Dresden, 01062 Dresden, Germany — [3]Research Center for Materials Nanoarchitectonics, National Institute for Materials Science, 1-1 Namiki, Tsukuba 305-0044, Japan

Excitons in monolayer transition metal dichalcogenides (TMDCs) and their heterostructures can strongly couple to electromagnetic fields, and monolayer WS_2 is a fascinating medium for studying hybrid light-matter states at room temperature. We report the monolayer WS_2 encapsulated in hBN employed in an open cavity, where two distributed Bragg reflectors were utilized to strongly confine the photonic field. When reducing the cavity length and thus the number of cavity modes, we reach the strong coupling regime of light-matter interaction at room temperature. Structured cavity mirrors are employed to study polariton physics and has potential to investigate exciton-polariton interactions. Furthermore, the open cavity approach paves the way to integration of WS_2/WSe_2 heterostructure with Moiré supperlattices in high-Q microcavities, which is promising to study exciton topology.

HL 2.12 Mon 12:30 EW 201

Tunable All-Graphene Metasurfaces Based on Bound States in the Continuum — •Michael Hirler, Thomas Weber, Jonas Biechteler, and Andreas Tittl — Chair in Hybrid Nanosystems, Ludwig-Maximilians-University Munich, Germany

We present an all-graphene optical metasurface based on Bound States in the Continuum (BICs). While graphene excels with tunable, long-lived plasmons with outstanding near-field confinement in the mid-infrared, the physics of BICs allows for the generation of spectrally narrow resonances with precise control over the radiative loss channel. This can be achieved by means of patterning monolayer graphene at subwavelength dimensions in various asymmetric structures. Furthermore, the incorporation of a bottom gate separated by an insulating layer allows for electric gating and, thus, the post-fabrication tuning of the plasmonic response. In particular, leveraging the tunability via asymmetric gating opens a new gateway for dynamic control of light-matter-interaction. On the basis of numerical simulations, we discuss the potential and limits of these metasurfaces, while progresses and challenges in realizing a first prototype via electron beam lithography are also outlined. Our metasurface constitutes a promising platform for compact, affordable point-of-care applications such as optical biosensors.

HL 2.13 Mon 12:45 EW 201

Strained Monolayer MoTe2 as a Photon Absorber in the Telecom Range — •Muhammad Sufyan Ramzan[1] and Caterina Cocchi[1,2] — [1]Institut für Physik, Carl von Ossietzky Universität, 26129 Oldenburg, Germany. — [2]Center for Nanoscale Dynamics (CeNaD), Carl von Ossietzky Universität, 26129 Oldenburg, Germany.

For the technological application of two-dimensional (2D) materials, it is of paramount importance to understand the interplay between their electronic and structural characteristics. Using density-functional theory, we study the impact of uniaxial strain on the electronic and optical properties of monolayer $MoTe_2$[1]. Straining up to ±10% along the armchair and zigzag direction of 2D sheet, we examine how the fundamental gap, the dispersion of the bands, the frontier states, and the charge distribution are affected. Under tensile strain, the system remains a semiconductor but a direct-to-indirect band gap transition occurs above 7%. Compressive strain, instead, is highly direction-selective. When it is applied along the armchair edge, the material remains a semiconductor, while along the zigzag direction a semiconductor-to-metal transition happens above |8|%. The characteristics of the fundamental gap and wave function distribution are also largely dependent on the strain direction, as demonstrated by a thorough analysis of the band structure and of the charge density. Additional calculations based on many-body perturbation theory confirm the ability of strained $MoTe_2$ to absorb radiation in the telecom range, thus suggesting the application of this material as a photon absorber upon suitable strain modulation. [1]10.3390/nano13202740