SYWH 1: Symposium: Physics of van der Waals 2D heterostructures

Van-der-Waals heterostructures based on two-dimensional (2D) layered materials provide a unique platform to engineer and control electronic, magnetic, and optical properties, as also recently recognized by the DFG establishing a new SPP 2244 on *2D-Materialien * die Physik von van der Waals (Hetero-)Strukturen (2DMP)*. Many exciting phenomena have been reported in stacked materials interacting by weak interactions. Most spectacular are strong correlations, magnetism, and superconductivity in twisted bilayer graphene, whose theoretical understanding is currently debated. The aim of this *plenary* symposium is to present an overview of those recent developments by leading experts in this forefront area of condensed matter physics. We plan to structure the symposium to make it appealing to low temperature, semiconductor, as well as magnetism communities, and to provide a communication platform to establish links between the various topics, which is possible by the very nature of van der Waals structures. We also wish to introduce the topic of the aforementioned SPP to a broader DPG audience.

Organizers: Jaroslav Fabian (University of Regensburg), Christoph Stampfer (RWTH Aachen)

Time: Thursday 13:30–16:15 Location: Audimax 2

Invited Talk SYWH 1.1 Thu 13:30 Audimax 2
Spin interactions in van der Waals topological materials and magnets — •Saroj Dash — Chalmers University of Technology, Gothenburg, Sweden

Two-dimensional (2D) quantum materials and their van der Waals heterostructures represent a novel platform to realize different spin-based phenomena. Here, we used large-area CVD graphene as a spin interconnect and demonstrated a spin majority logic gate operation (1). We further engineered 2D material heterostructures by combining the best of different materials in one ultimate unit for the creation of strong proximity induced spin-orbit coupling and magnetism in graphene (2,4,3). Recently, we detected current-induced spin-polarization in topological insulators and Weyl semimetal candidates and their graphene-based heterostructures up to room temperature (4,5). Finally, we demonstrated room temperature spin-valve devices using van der Waals itinerant ferromagnet in heterostructures with graphene (6). These findings open a novel platform for electrical creation and gate-control of spin polarization and provide new opportunities for all-2D heterostructure spintronic devices and integrated circuits.

1. Carbon 161, 892 (2020), Nature Commun. 6, 6766 (2015). 2. Nature Commun. 8, 16093 (2017). 3. 2D Materials 7 (1), 015026 (2019). 4. Nature Commun. 11, 3657 (2020). 5. Advanced Materials, 2000818 (2020). 6. preprint arXiv:2107.00310 (2021).

Invited Talk SYWH 1.2 Thu 14:00 Audimax 2
Exciton optics, dynamics and transport in atomically thin materials — •Ermin Malic[1,2], Samuel Brem[1], Raul Perea-Causin[2], Daniel Erkensten[2], and Roberto Rosati[1] — [1]Philipps-University of Marburg, Germany — [2]Chalmers University of Technology, Sweden

Monolayer transition metal dichalcogenides (TMDs) exhibit a remarkable excitonic landscape including bright and a variety of dark exciton states. Solving 2D material Bloch equations for excitons, phonons and photons, we obtain a microscopic access to the interplay of optics, ultrafast dynamics and diffusion of excitons in TMDs. In joint theory-experiments studies we shed light on the importance of momentum-dark excitons in low-temperature photoluminescence spectra [1], non-equilibrium exciton dynamics visualized in tr-ARPES experiments [2], temperature-resolved exciton-exciton annihilation processes [3], phonon-driven dissociation of excitons [4], and accelerated hot-exciton diffusion [5]. The gained microscopic insights into the spatiotemporal exciton dynamics are crucial for understanding and controlling many-particle phenomena governing exciton optics, dynamics and transport in technologically promising 2D materials.

[1] S. Brem et al., Nano Lett. 20, 2849 (2020)
[2] R. Wallauer et al., Nano Lett. 21, 5867 (2021)
[3] D. Erkensten et al., arXiv 2106.05035 (2021)
[4] R. Perea-Causin et al., Nanoscale 13, 1884 (2021)
[5] R. Rosati et al., arXiv 2105.10232 (2021)

Invited Talk SYWH 1.3 Thu 14:30 Audimax 2
Correlated Electrons in van der Waals Superlattices: Control and Understanding — •Tim Wehling — University of Bremen, 28359 Bremen, Germany

The interplay of electronic correlations, lattice degrees of freedom and topology holds the promise for the realization of exotic states of quantum matter. Here, we discuss routes to understand and control this interplay in van der Waals superlattice systems. The nature of superconducting order presents a recurring overarching open question in this context. We will first address doping fingerprints of superconductivity arising from spin and lattice fluctuations in moiré superlattice systems [1]. We will show how doping-dependent measurements of the superconducting transition temperature provide direct access to probing the superconducting pairing mechanism in twisted van der Waals materials. We will then analyze possibilities of Coulomb and superlattice engineering in these systems. We will discuss confinement and deconfinement [2] pathways to create correlated Dirac fermions in stacks of transition metal dichalcogenides and identify knobs to control topology, electron correlations and emergent order in these systems.

[1] N. Witt, J. M. Pizarro, T. Nomoto, R. Arita, T. O. Wehling, arXiv:2108.01121 (2021).
[2] J. M. Pizarro, S. Adler, K. Zantout, T. Mertz, P. Barone, R. Valentí, G. Sangiovanni, T. O. Wehling, npj Quantum Materials 5, 79 (2020).

15 min. break.

Invited Talk SYWH 1.4 Thu 15:15 Audimax 2
Exciton manipulation and transport in 2D semiconductor heterostructures — •Andras Kis — École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

New opportunities are enabled by the band structure of transition metal dichalcogenides (TMDCs) in which we could harness the valley degree of freedom for valleytronics and next-generation photonics. Long-lived interlayer excitons in van der Waals heterostructures based on TMDCs have recently emerged as a promising platform for this, allowing control over exciton diffusion length, energy and polarization. I will show here how by using MoS2/WSe2 van der Waals heterostructures, we can realize excitonic transistors with switching action, confinement and control over diffusion length at room temperature in a reconfigurable potential landscape. On the other hand, the weak interlayer interaction and small lattice mismatch in MoSe2/WSe2 heterostructures results in brightening of forbidden optical transitions, allowing us to resolve two separate interlayer transitions with opposite helicities and meV-scale linewidths.Our more advanced excitonic devices now also offer the way to manipulate the motion of valley (spin) polarized excitons.

Invited Talk SYWH 1.5 Thu 15:45 Audimax 2
Chern Insulators, van Hove singularities and Topological Flat-bands in Magic-angle Twisted Bilayer Graphene* — •Eva Andrei, Shuang Wu, and Zhenyuan Zhang — Dept. of Physics, Rutgers University, Piscatay NJ 08904, USA

Magic-angle twisted bilayer graphene exhibits intriguing quantum phase transitions triggered by enhanced electron-electron interactions when its flat-bands are partially filled. These phases and their experimental manifestations provide clues to the underlying non-trivial band topology. In particular, transport measurements revealed a succession of doping-induced phase transitions at integer moiré fillings. We have shown that these transitions are accompanied by van Hove singularities (VHS) which facilitate the emergence of correlation-induced gaps and topologically non-trivial sub-bands. In the presence of a magnetic field, well quantized Hall plateaus at filling of 1, 2, 3 carriers per moiré-cell reveal the sub-band topology and signal the emergence of Chern insulators. Surprisingly, for magnetic fields exceeding 5T we observe a VHS at a filling of 3.5, suggesting the emergence of a fractional Chern insulator.

Shuang Wu, Zhenyuan Zhang, K. Watanabe, T. Taniguchi, Eva Y. Andrei, Nature Materials, 20 (2021) p488