Symposium Physics of van der Waals 2D heterostructures (SYWH)

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

Jaroslav Fabian
Universität Regensburg
Institut für Theoretische Physik
Universitätsstraße 31
D-93040 Regensburg
jaroslav.fabian@ur.de

Christoph Stampfer
RWTH Aachen
II. Physikalisches Institut
Otto-Blumenthal-Str.
D-52074 Aachen
stampfer@physik.rwth-aachen.de

Van der Waals heterostructures based on 2D layered materials provide an exciting platform to engineer and control electronic, transport, optical and magnetic properties. Novel phenomena, which arise from twisting, straining, gating, or doping of the heterostructures are a subject of intensive investigations in Germany and worldwide. Emergence of strong correlations, stemming from band flattening in twisted bilayer graphene is a spectacular example of how radically the electronic structure can change by misaligning the weakly bonded layers. In addition to twisted graphene bilayers, which exhibit superconductivity at the magic angle, researchers find remarkable effects in twisting transition metal dichalcogenides. Novel topological phases have been observed in engineered 2D nanostructures and van der Waals heterostructures harbor fascinating many-body excitations which give distinct optical responses. Finally, it has been shown that ultrafast laser field application allows for a striking control over the carrier dynamics in the 2D realm, allowing to push the carriers across the valleys in the momentum space. The aim of this symposium is to present an overview of those recent developments by leading experts in this forefront area of condensed matter physics.

Overview of Invited Talks and Sessions

(Lecture hall HSZ 02)

Invited Talks

SYWH 1.1	Wed	15:00–15:30	HSZ 02	**Engineering 2D materials with a twist** — •Cory Dean
SYWH 1.2	Wed	15:30–16:00	HSZ 02	**Flat Bands and Correlated Electronic States in Two Dimensional Atomic Crystals** — •Eva Y. Andrei
SYWH 1.3	Wed	16:00–16:30	HSZ 02	**Lightwave electronics and valleytronics in van der Waals layered materials** — •Rupert Huber
SYWH 1.4	Wed	16:30–17:00	HSZ 02	**Interaction and Topological Effects in Atomically Thin Two-dimensional Materials** — •Steven G. Louie
SYWH 1.5	Wed	17:00–17:30	HSZ 02	**Excitons in 2D Semiconductors and Heterostructures** — •Alexander Högele

Sessions

SYWH 1.1–1.5	Wed	15:00–17:30	HSZ 02	**Physics of van der Waals 2D heterostructures**

SYWH 1: Physics of van der Waals 2D heterostructures

Time: Wednesday 15:00–17:30 Location: HSZ 02

Invited Talk SYWH 1.1 Wed 15:00 HSZ 02
Engineering 2D materials with a twist — •Cory Dean — Columbia University, New York, NY, USA

Abstract: Atomically thin crystals such as graphene, boron nitride and the transition metal dichalcogenides continue to attract enormous interest. Encompassing a wide range of properties, including single-particle, topological and correlated phenomenon, these 2D materials represent a rich class of materials in which to explore both novel physical phenomenon and new technological pursuits. By integrating these materials with one another, an exciting new opportunity has emerged in which entirely new layered heterostuctures can be fabricated with emergent properties beyond those of the constituent materials. In this talk I will discuss some of our recent efforts where, by tuning the geometry of these heterostructures at the nanoscale, we are able to realize yet a new level of control over their electronic properties. In particular I will discuss the significant role played by the rotational alignment between adjacent layers and the approach we are taking towards manipulating this degree of freedom to dynamically tune device properties in ways that are not possible with conventional materials

Invited Talk SYWH 1.2 Wed 15:30 HSZ 02
Flat Bands and Correlated Electronic States in Two Dimensional Atomic Crystals — •Eva Y. Andrei — Department of Physics and Astronomy Rutgers University

Stacking two-dimensional atomic crystals or applying external potentials, can radically change their electronic properties. In particular, it is possible to engineer conditions leading to the creation of flat energy bands, where the quenched kinetic energy provides propitious conditions for the emergence of correlated electronic states. This talk will focus on two such examples: twisted graphene bilayers that develop a flat band at a "magic" twist-angle [1,2], and buckled graphene layers in which a periodically modulated pseudo-magnetic field creates a post-graphene material with flat electronic bands.

[1] Y. Jiang, J. Mao, X. Lai, K. Watanabe, T. Taniguchi, K. Haule, E. Y. Andrei, Charge order and broken rotational symmetry in magic-angle twisted bilayer graphene. Nature **573**, 91 (2019)
[2] G. Li, A. Luican, J.M. B. Lopes dos Santos, A. H. Castro Neto, A. Reina, J. Kong and E.Y. Andrei, Observation of Van Hove singularities in twisted graphene layers, Nature Physics **6**, 109 (2010)

Invited Talk SYWH 1.3 Wed 16:00 HSZ 02
Lightwave electronics and valleytronics in van der Waals layered materials — •Rupert Huber — Department of Physics, University of Regensburg, Germany

Using the carrier wave of intense light pulses as a transient bias field to accelerate electrons in van der Waals layered materials, we explore a fascinating world of coherent quantum dynamics, on time scales shorter than a single cycle of light. This includes Bloch oscillations, quasiparticle collisions, and high-harmonic generation. In topologically non-trivial solids, electrons can be accelerated like relativistic bullets over large distances without scattering, which moves minimally dissipative devices at optical clock rates into reach. While lightwave electronics has mainly concentrated on the control of the translational motion of electrons, internal quantum attributes of spin and valley pseudospin have not been switchable on the same scale. In monolayers of transitions metal dichalcogenides, the carrier field of mid-infrared light can move photogenerated electron-hole pairs from the K to the K' valley and thus switch the valley pseudospin in less than 5 fs. Lightwave electronics and valleytronics, thus, opens fundamentally new pathways for ultimately fast quantum control – especially on the new platform of custom-cut stacks of layered heterostructures. In combination with scanning tunneling microscopy, this concept even allows for atomic scale videography on subcycle time scales.

Invited Talk SYWH 1.4 Wed 16:30 HSZ 02
Interaction and Topological Effects in Atomically Thin Two-dimensional Materials — •Steven G. Louie — Physics Department, University of California at Berkeley, and Lawrence Berkeley National Lab, Berkeley, CA 94720 U.S.A.

Symmetry, interaction, and topological effects dominate many quantum properties of reduced-dimensional systems, leading often to manifestation of novel phenomena not seen in bulk materials. In this talk, I present some fascinating discoveries in recent theoretical studies of atomically thin one-dimensional (1D) and two-dimensional (2D) materials, including strongly bound excitons (electron-hole pairs) with novel energy level structures and optical selection rules, tunable magnetism and plasmonic properties, new topological phases, correlated multi-particle excitations, etc. – adding to the promise of these 1D and 2D materials for exploration of new science and valuable applications.

This work is supported by the U.S. Department of Energy, National Science Foundation, and Office of Naval Research.

Invited Talk SYWH 1.5 Wed 17:00 HSZ 02
Excitons in 2D Semiconductors and Heterostructures — •Alexander Högele — Fakultät für Physik, Munich Quantum Center, and Center for NanoScience (CeNS), Ludwig-Maximilians-Universität München, München, Germany

Van der Waals crystals of transition metal dichalcogenide (TMD) semiconductors have evolved as an increasingly significant material platform for condensed matter research. They can be routinely exfoliated down to the monolayer limit or assembled into rationally designed vertical heterostructures. Both semiconductor systems host strongly bound excitons that dominate the optical properties via valley-contrasting dipolar transitions. Using optical spectroscopy at cryogenic temperatures and in the presence of external magnetic fields, we study the characteristic signatures of spin-valley polarized excitons in TMD monolayers and heterostructures, and discuss their role for the elementary optical responses in absorption and emission.