FRI 11: Quantum 2D-Moiré and Rhombohedral van-der-Waals Systems: Contributed Session to Symposium

Time: Friday 10:45–12:30 Location: ZHG104

FRI 11.1 Fri 10:45 ZHG104

Observation of Floquet states in graphene — •Marco Merboldt[1], Michael Schüler[2], David Schmitt[1], Jan Philipp Bange[1], Wiebke Bennecke[1], Karun Gadge[3], Klaus Pierz[4], Hans Werner Schumacher[4], Davood Momeni[4], Daniel Steil[1], Salvatore R. Manmana[3], Michael Sentef[5], Marcel Reutzel[1], and Stefan Mathias[1] — [1]Georg-August-Universität Göttingen, I. Physikalisches Institut, Germany — [2]Department of Physics, University of Fribourg, Fribourg, Switzerland — [3]Georg-August-Universität Göttingen, Institut für Theoretische Physik, Germany — [4]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [5]Institute for Theoretical Physics, University of Bremen, Bremen, Germany

Floquet engineering – the coherent dressing of matter via time-periodic perturbations – is a mechanism to realize and control emergent phases in materials out of equilibrium. However, the broad applicability of Floquet engineering to quantum materials is in question, especially with respect to (semi-)metals and graphene in particular.

Here, we resolve this long-standing debate by using electronic structure measurements to provide direct spectroscopic evidence of Floquet effects in graphene [1]. We report light-matter-dressed Dirac bands by measuring the contribution of Floquet sidebands, Volkov sidebands, and their quantum path interference to graphene's photoemission spectrum. Fully supported by experiment and theory, we demonstrate that Floquet engineering in graphene is possible.

[1] Merboldt *et al.*, Nature Physics (2025)

FRI 11.2 Fri 11:00 ZHG104

Giant chiral current in gapped graphene at room temperature — •Fanrong Lin[1], Weilong Guo[2], Qingjun Tong[2], and Yanpeng Liu[3] — [1]Georg-August-University of Göttingen, Friedrich-Hund-Platz 1, 37077 Göttingen, Germany — [2]Hunan University — [3]Nanjing university of aeronautics and astronautics

Nonlinear electrical signals serve as a complementary probe for investigating intrinsic quantum geometric properties while also revealing unconventional charge transport phenomena in systems with specific band topologies. A paradigmatic example is the chiral charge transport observed in gapped monolayer graphene, where the chiral Bloch electrons undergo unidirectional skew scattering. However, these nonlinear signals are typically exceedingly weak, necessitating either intrinsic topological band structures or extrinsic circuit enhancements to achieve detectable magnitudes. Here, we introduce a linear projection method that amplifies nonlinear physical, yielding a dramatically enhanced signal even at room temperature. Using this approach, we observe a robust unidirectional skew-scattered current, exhibiting a signal of several microvolt at room temperature. Furthermore, this chiral current exhibits dual tunability via external gate and DC bias voltages, enabling control over both the majority carrier type and the skew conductivity. Finally, we demonstrate nonlocal transport mediated by this tunable chiral current, generating a substantial nonlocal signal in remotely gated Hall bar pairs with a geometric factor of 4. This unconventional charge transport mechanism opens a pathway for long-range control in next-generation electronic devices.

FRI 11.3 Fri 11:15 ZHG104

Thermoelectric Transport Measurements in Dual-Gated Bernal Bilayer Graphene — •Moritz Knaak[1], Martin Statz[1], Kenji Watanabe[2], Takashi Taniguchi[3], and Thomas Weitz[1] — [1]1. Institute of Physics, Faculty of Physics, University of Göttingen, Göttingen, Germany — [2]Research Center for Functional Materials, National Institute for Materials Science, Tsukuba, Japan — [3]International Center for Materials Nanoarchitectonics, National Institute for Materials Science, Tsukuba, Japan

In dual-gated, hexagonal boron-nitride(hBN) encapsulated Bernal bilayer graphene(BLG) devices a cascade of correlated phases have been identified by magnetoconductance measurements. The correlated phases emerge close to Lifshitz-transitions. There, the density of states(DOS) is high and the kinetic energy gets quenched. While conductance measurements alone can be used to study correlated phases, it is difficult to precisely connect the DOS with said phases. The Seebeck coefficient, extracted from thermoelectric transport measurements provides a more direct probe of the DOS. It is defined as the ratio of the thermal voltage to its inducing temperature difference. We demonstrate measurements of the Seebeck coefficient at 4 K up to a calibration factor. For the measurements we employed an on-chip heater next to an hBN-encapsulated BLG device with graphite contacts and dual graphite gates to simultaneously tune the Fermi-level and an out-of-plane electric field. The source-drain contacts were simultaneously used as quasi-4-point-probe on-chip resistance thermometers to determine the local temperature differences between them.

FRI 11.4 Fri 11:30 ZHG104

Two-particle spin and valley blockade in graphene double quantum dots — •Christian Volk[1,2], Samuel Möller[1,2], Luca Banszerus[1,2], Katrin Hecker[1,2], Hubert Dulisch[1,2], Kenji Watanabe[3], Takashi Taniguchi[4], and Christoph Stampfer[1,2] — [1]JARA-FIT and 2nd Institute of Physics, RWTH Aachen University — [2]Peter Grünberg Institute (PGI-9), Forschungszentrum Jülich — [3]Research Center for Functional Materials, NIMS, Tsukuba, Japan — [4]International Center for Materials Nanoarchitectonics, NIMS, Tsukuba, Japan

Double quantum dots (DQDs) are promising building blocks for spin or valley qubits. The weak hyperfine interaction and the weak spin-orbit interaction in bilayer graphene (BLG) promise long spin coherence times. Additionally, the well tunable valley degree of freedom offers the possibility to create valley-based qubits in BLG DQDs. Efficient readout requires a spin- or valley-to-charge conversion, often provided by Pauli blockade. Thus, a comprehensive understanding of the limits and the tunablility of spin and valley blockade in BLG DQDs is necessary for evaluating their potential for hosting qubits.

Here, we show spin and valley blockade in two-electron BLG DQDs. Magnetotransport measurements reveal a rich level spectrum and we observe a magnetic field tunable spin and valley blockade, which is limited by the orbital splitting, the strength of the electron-electron interaction and the difference in the valley g-factors between the symmetric and antisymmetric two-particle orbital states. Our findings are supported by transport simulations following a rate equation approach.

FRI 11.5 Fri 11:45 ZHG104

Electronic Transport in Twisted Bilayer Graphene: Towards Quantum Moiré-tronics — •Thomas Stegmann — Instituto de Ciencias Físicas, Universidad Nacional Autónoma de México

We investigate electronic transport in twisted bilayer graphene (TBLG) at small - though not magic - twist angles. In the first part of the talk, we propose a device in which the direction of the current flow can be steered by the twist between the layers. The observed current steering angle exceeds significantly the twist angle itself and arises over a broad range of experimentally accessible parameters. This behavior is attributed to the trigonal warping of the energy bands beyond the van Hove singularity, induced by the moiré pattern. Since the shape of these bands depends on the valley degree of freedom, the resulting current is partially valley-polarized, highlighting potential applications in valleytronics [1]. In the second part, we report anomalous edge states in TBLG at a twist angle of 1.696°. These edge states support electronic transport with conductance values near the conductance quantum and give rise to a nonlocal resistance. Notably, this nonlocal effect is not due to chiral edge transport, but due to the fact that these states are localized only at certain edges of the system, depending on how the nanoribbon has been cut from the bulk [2]. Finally, we discuss briefly how the electronic transport in graphene can be guided along atomically thin current paths through the engineering of Kekulé distortions, offering yet another route toward nanoscale current steering [3].

[1] J. Phys: Mater. 5:024003 (2022)
[2] Phys. Rev. B 110:205432 (2024)
[3] Nano Letters 24:2322 (2024)

FRI 11.6 Fri 12:00 ZHG104

Persistent Haldane Phase in Carbon Tetris Chains — •Anas Abdelwahab[1], Christoph Karrasch[2], and Roman Rausch[2] — [1]Leibniz Univesität Hannover, Institut für Theoretische Physik, Hannover — [2]Technische Universität Braunschweig

We introduce the concept of "tetris chains", which are linear arrays of 4-site molecules that differ by their intermolecular hopping geometry. We investigate the fermionic symmetry-protected topological Haldane phase in these systems using Hubbard-type models. The topological phase diagrams can be understood via different competing limits and mechanisms: strong-coupling $U \gg t$, weak-coupling $U \ll t$, and the weak intermolecular hopping limit $t' \ll t$. Our particular focus is on two tetris chains that are of experimental relevance. First, we show that a "Y-chain" of coarse-grained nanographene molecules (triangulenes) is robustly in the Haldane phase in the whole $t' - U$ plane due to the cooperative nature of the three limits. Secondly, we study a near-homogeneous "Y′-chain" that is closely related to the electronic model for poly(p-phenylene vinylene). In the latter case, the above mechanisms compete, but the Haldane phase manifests robustly and is stable when long-ranged Pariser-Parr-Popple interactions are added. The site-edged Hubbard ladder can also be viewed as a tetris chain, which gives a very general perspective on the emergence of its fermionic Haldane phase. Our numerical results are obtained using the density-matrix-renormalization group as well as the variational uniform matrix-product state (VUMPS) algorithms.

FRI 11.7 Fri 12:15 ZHG104

A Wannier approach to electronic structure in twisted van der Waals bilayers — •Ruven Hübner[1], Matthias Florian[2], and Alexander Steinhoff[1] — [1]Institute for Physics, Faculty V, Carl von Ossietzky University Oldenburg, 26129 Oldenburg, Germany — [2]University of Michigan, Dept. of Electrical Engineering and Computer Science, Ann Arbor, MI, USA

Moiré structures in two-dimensional van der Waals materials offer an interesting platform to explore the interplay of quantum phenomena across vastly different length scales—from the atomic scale, on the order of Ångström, to the supercell scale, reaching up to $\sim 40\,\mathrm{nm}$. While DFT calculations have made remarkable progress in handling large systems, they do not readily reveal the dominant mechanisms that govern the electronic structure. In fact, it seems natural to retain much of the electronic structure of the individual monolayers and treat the interlayer interaction as a relatively small perturbation. This view can be well motivated by the model of Koshino, who introduced a tight-binding framework for moiré bilayers where a simple basis transformation reveals dominant interlayer couplings in reciprocal space, enabling a significant reduction in basis states [1]. We take this approach one step further by incorporating the Wannier projection method, based on multiple DFT calculations of untwisted bilayers with different stacking configurations. Besides providing a computationally efficient model, our framework enables analytical insight into moiré band splitting within the original Brillouin zones of the monolayers. [1] Mikito Koshino 2015 New J. Phys. **17** 015014