TT 53: Graphene

Time: Thursday 15:00–17:45 Location: HSZ 204

TT 53.1 Thu 15:00 HSZ 204

Andreev and normal reflections processes in gated bilayer graphene — •Panch Ram[1], Detlef Beckmann[2], Romain Danneau[2], and Wolfgang Belzig[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Institute for Quantum Materials and Technologies, Karlsruhe Institute of Technology, D-76021 Karlsruhe, Germany

We present our theoretical study of the Andreev and normal reflections processes in a bilayer graphene normal-superconductor junction where gate fields are applied (equal and opposite). Gating can induce a gap in the dispersion of the graphene layer. We employ the Dirac-Bogoliubov-de Gennes equation for the low-energy gated bilayer graphene Hamiltonian and calculate the Andreev and normal reflections probabilities using the scattering theory, and also obtain the differential conductance within the Blonder-Tinkham-Klapwijk formalism [1, 2]. We observe the Andreev retro-reflection (specular-reflection) below (above) the Fermi energy when the bias voltage is within the superconducting gap [3]. Interestingly, both retro-reflection as well as specular reflection are strongly modified in the presence of the gate field. For small gate field, they can be tuned to either specular or retro Andreev reflection by changing the Fermi energy. Moreover, we find double Andreev reflections and double normal reflections (specular and retro) when the gate field becomes comparable to the interlayer coupling strength.

[1] A. F. Andreev, Sov. Phys. JETP 19, 1228 (1964)
[2] G. E. Blonder et al., Phys. Rev. B 25, 4515 (1984)
[3] C. W. J. Beenakker, Phys. Rev. Lett. 97, 067007 (2006)

TT 53.2 Thu 15:15 HSZ 204

Graphene superlattice due to twisted hexagonal boron nitride monolayers — •Ming-Hao Liu — Department of Physics, National Cheng Kung University, Tainan 70101, Taiwan

Stacking of two-dimensional (2D) materials of similar lattice structures on top of each other with a small twist angle leads to the so-called Moiré pattern due to the large-scale lattice inteference. When one of them is a conducting material such as graphene, the Moiré pattern serves as a large-scale periodic potential, turning the host conducting lattice into a superlattice, whose modified electronic properties can be seen in transport experiments and simulations. Graphene placed on a hexagonal boron nitride (hBN) layer is one of the best known graphene superlattices, while twisted bilayer graphene made of two monolayers of graphene is another example under intensive investigations during the past years. Twisted monolayers of hBN also form the Moiré pattern, yet its effect on transport properties of neighboring graphene is less known. Here, we consider graphene put on monolayers of twisted hBN (thBN), and perform quantum transport simulations considering the effect of the charge-polarized superlattice potential [1]. Due to the exceptionally long Moiré wavelength of the twisted hBN, multiple satellite Dirac points emerge in the transmission spectrum within the experimentally accessible range of the carrier density. Possible experiments confirming the model of graphene on thBN as well as further exploring novel transport behaviors due to the thBN will be discussed.

[1] C. R. Woods *et al.*, Nat. Commun. **12**, 347 (2021)

TT 53.3 Thu 15:30 HSZ 204

Transport signatures of Van Hove singularities in mesoscopic twisted bilayer graphene — •Aleksander Sanjuan Ciepielewski[1], Jakub Tworzydło[2], Timo Hyart[1,3], and Alexander Lau[1] — [1]MagTop, IF PAN, Warsaw, Poland — [2]University of Warsaw, Poland — [3]Aalto University, Finland

Magic-angle twisted bilayer graphene (TBG) exhibits quasiflat low-energy bands with Van Hove singularities (VHS) close to the Fermi level. These singularities play an important role in the exotic phenomena observed in this material, such as superconductivity and magnetism, by amplifying electronic correlation effects. In this work [1], we study the correspondence of four-terminal conductance and the Fermi surface topology as a function of the twist angle, pressure, and energy in mesoscopic, ballistic samples of small-angle TBG. We establish a correspondence between features in the wide-junction conductance and the presence of VHS in the density of states. Moreover, we identify additional transport features, such as a large, pressure-tunable minimal conductance, conductance peaks coinciding with nonsingular band crossings, and unusually large conductance oscillations as a function of the system size. Our results suggest that TBG close the magic angle is a unique system featuring simultaneously large conductance due to the quasiflat bands, strong quantum nonlinearity due to the VHS, and high sensitivity to external parameters, which could be utilized in high-frequency device applications and sensitive detectors.

[1] A. Sanjuan Ciepielewski, J. Tworzydło, T. Hyart, and A. Lau, Phys. Rev. Research 4, 043145 (2022)

TT 53.4 Thu 15:45 HSZ 204

Coulomb blockade effects in minimally twisted bilayer graphene — •Patrick Wittig[1], Fernando Dominguez[1], Christophe De Beule[2,3], and Patrik Recher[1,4] — [1]Institute for Mathematical Physics, TU Braunschweig, 38106 Braunschweig, Germany — [2]Department of Physics and Materials Science, University of Luxembourg, L-1511 Luxembourg — [3]Department of Physics and Astronomy, University of Pennsylvania, Philadelphia PA19104 — [4]Laboratory of Emerging Nanometrology, 38106 Braunschweig, Germany

In the presence of a finite interlayer electric field, minimally twisted bilayer graphene displays a triangular network of chiral valley Hall states that propagate along the AB/BA interfaces and scatter at the metallic AA regions. Previous studies model the chiral network using a phenomenological scattering matrix approach based entirely on the symmetries of the system [1,3]. So far, the physics of the metallic AA scattering regions has been disregarded, although in the chiral network regime are also flat bands corresponding to a finite density of states in the AA region [2]. Therefore, we include in the phenomenological scattering matrix the AA regions in form of quantum dots: A set of discrete energy levels with Coulomb interaction, which we treat in mean field theory. We study the resulting network through the energy spectrum and magneto-conductance calculations.

[1] D. Efimkin, A. MacDonald, PRB 98, 035404 (2018)
[2] A. Ramires, J. Lado, PRL 121, 146801 (2018)
[3] C. De Beule, F. Dominguez, P. Recher, PRL 125, 096402, (2020)

TT 53.5 Thu 16:00 HSZ 204

Twisted bilayer graphene at charge neutrality: Spontaneous symmetry breaking of SU(4) Dirac electrons — •Nikolaos Parthenios and Laura Classen — Max-Planck Institute for Solid State Research, Stuttgart, Germany

We study possible patterns for spontaneous symmetry breaking in twisted bilayer graphene at charge neutrality. Starting from an effective Dirac Hamiltonian, we show how an SU(4) symmetry emerges that is composed of combined spin, valley and sublattice transformations. We construct the corresponding low-energy model that includes all symmetry-allowed four-fermion interactions and employ a renormalization group treatment to identify the critical points that describe transitions into the different ordered phases. The resulting phase diagram depends on the number of fermion flavours and we argue that for twisted bilayer graphene it is governed by a quantum Hall state or SU(4) manifolds of spin-valley orders with emergent Lorentz symmetry. Due to the large symmetry, small perturbations will determine the final symmetry breaking mechanism.

TT 53.6 Thu 16:15 HSZ 204

Analog gravity in twisted bilayer graphene — •Mireia Tolosa-Simeón[1], Stefan Floerchinger[2], and Michael Scherer[1] — [1]Institut für Theoretische Physik III, Ruhr-Universität Bochum — [2]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena

Condensed-matter systems can sometimes be used to emulate and study phenomena from a completely different field of physics, for example, from elementary particle physics or gravity. Such analog condensed-matter models may provide a novel perspective to approach difficult problems in the original systems, and can potentially be realized experimentally in a well-controlled environment.

In this contribution, we will address the problem of cosmological fermion production in expanding universes using twisted bilayer graphene as an analog model. In particular, we study twisted bilayer graphene's Dirac electrons near charge neutrality, which acquire a mass gap through a symmetry-breaking phase transition. Introducing a time-dependent Fermi velocity, we show the emergence of an

analog of cosmological pair production. Our scenario could be scrutinized experimentally in the future.

15 min. break

TT 53.7 Thu 16:45 HSZ 204

Quantum transport simulation for graphene on transition-metal dichalcogenides — •Wun-Hao Kang and Ming-Hao Liu — Department of Physics, National Cheng Kung University, Tainan, Taiwan

The strength of spin-orbit coupling (SOC) in pristine graphene was found from first-principles calculations to be in the order of μeV [1], which gives nearly no effects in transport experiments. Subsequent studies showed that the SOC can be significantly enhanced to the order of meV by putting graphene on transition-metal dichalcogenides (TMDC) [2]. Very recently, Tiwari P. et al. reported that the enhanced SOC can be experimentally observed in graphene/WSe2 systems [3]. Here we perform quantum transport simulations for graphene on TMDCs based on real-space tight-binding models [4], considering the Fabry-Pérot interferometer by using a gate-induced potential barrier as the cavity.

[1] M. Gmitra et al., Phys. Rev. B **80**, 235431 (2009)
[2] M. Gmitra et al., Phys. Rev. B **93**, 155104 (2016)
[3] P. Tiwari et al., npj 2D Mater Appl. **6**, 68 (2022)
[4] M. Zubair et al., Phys. Rev. B **101**, 165436 (2020)

TT 53.8 Thu 17:00 HSZ 204

Theory of broken symmetry quantum Hall states in the $N = 1$ Landau level of Graphene — •Nikolaos Stefanidis[1] and Inti Sodemann[2,1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden 01187, Germany — [2]Institut für Theoretische Physik, Universität Leipzig, D-04103, Leipzig, Germany

We study many-body ground states for the partial integer fillings of the $N = 1$ Landau level in graphene, by constructing a model that accounts for the lattice scale corrections to the Coulomb interactions. Interestingly, in contrast to the $N = 0$ Landau level, this model contains not only pure delta function interactions but also some of its derivatives. Due to this we find several important differences with respect to the $N = 0$ Landau level. For example at quarter filling when only a single component is filled, there is a degeneracy lifting of the quantum hall ferromagnets and ground states with entangled spin and valley degrees of freedom can become favourable. Moreover at half-filling of the $N = 1$ Landau level, we have found a new phase that is absent in the $N = 0$ Landau level, that combines characteristics of the Kekulé state and an antiferromagnet. We also find that according to the parameters extracted in a recent experiment, at half-filling of the $N = 1$ Landau level graphene is expected to be in a delicate competition between an AF and a CDW state, but we also discuss why the models for these recent experiments might be missing some important terms.

TT 53.9 Thu 17:15 HSZ 204

Multi-layered atomic relaxation in van der Waals heterostructures — Dorri Halbertal[1], •Lennart Klebl[2], Valerie Hsieh[1], Jacob Cook[3], Stephen Carr[4], Guang Bian[3], Cory Dean[1], Dante M. Kennes[5,6], and Dmitri N. Basov[1] — [1]Department of Physics, Columbia University, United States — [2]1st Institute of Theoretical Physics, University of Hamburg, Germany — [3]Department of Physics and Astronomy, University of Missouri, United States — [4]Physics Department, Brown University, United States — [5]Institut für Theorie der Statistischen Physik, RWTH Aachen University, Germany — [6]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

When two-dimensional van der Waals materials are stacked to build heterostructures, Moiré patterns emerge from twisted interfaces or from mismatch in lattice constant of individual layers. Relaxation of the atomic positions is a direct, generic consequence of the Moiré pattern, with many implications for the physical properties. Motivated by experimental findings in multi-layered van der Waals heterostructures, we develop a generic continuum approach to model (multi-layered) relaxation processes based on the generalized stacking fault energy functional. The continuum property of the approach enables us to access large scale regimes and achieve agreement with experimental findings. Furthermore, we study the impact of multi-layered relaxation on the local density of states of a twisted graphitic system. We identify measurable implications for the system, experimentally accessible by scanning tunneling microscopy.

TT 53.10 Thu 17:30 HSZ 204

Non-destructive low-temperature contacts to MoS_2 nanoribbon and nanotube quantum dots — •Robin T. K. Schock[1], Jonathan Neuwald[1], Konstantin D. Schneider[1], Matthias Kronseder[1], Luka Pirker[2], Maja Remškar[2], and Andreas K. Hüttel[1] — [1]Institute for Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany — [2]Solid State Physics Department, Institute Jožef Stefan, 1000 Ljubljana, Slovenia

Planar TMDCs are at the center of manifold research efforts due to their intrinsic two dimensional nature. Despite detailed studies of their optical parameters, worldwide efforts to reach single level transport in lithographically designed quantum dots at low temperatures have so far been largely unsuccessful. This is due to the requirement for very small confinement potentials as well as disorder from dangling bonds at the edges of nanoflakes. Both issues can be circumvented by using as-grown MoS_2 nanotubes and nanoribbons. First Coulomb blockade measurements were recently performed on a MoS_2 nanotube[1], so far limited by disorder below the metallic scandium contacts.

Here, we present low temperature measurements on MoS_2 nanotubes and nanoribbons contacted with bismuth[2]. Our data clearly shows the non-destructive and transparent nature of these contacts to our quantum dots and indicates quantum confinement[3].

[1] S. Reinhardt *et al.*, pssRRL **13**, 1900251 (2019)
[2] P. C. Shen *et al.*, Nature **593**, 211 (2021)
[3] R. T. K. Schock *et al.*, arXiv:2209.15515 (2022).