O 27: Graphene: Electronic properties, structure and substrate interaction II (joint session O/TT)

Time: Tuesday 10:30–13:15 Location: MA 043

Invited Talk O 27.1 Tue 10:30 MA 043

Inside graphene devices — •Clemens Winkelmann[1], Sayanti Samaddar[1], Alessandro De Cecco[1], Hervé Courtois[1], Indra Yudhistira[2], Shaffique Adam[2], Vladimir Prudkovskiy[1,3], Claire Berger[1,3], and Walt de Heer[3] — [1]Univ. Grenoble Alpes / France — [2]NUS / Singapore — [3]Georgia Inst. of Technol. / USA

The electronic transport properties of devices are governed by microscopic physics which can often only be inferred indirectly from the former. By combining in situ transport and scanning probe experiments in graphene-based devices, we directly test the microscopic pictures used for predicting macroscopic transport properties.

The first part focusses on the charge puddles in diffusive graphene on a disordered dielectric substrate. Because of the linear dispersion relation in monolayer graphene, the puddles are predicted to grow near charge neutrality, a markedly distinct property from conventional two-dimensional electron gases. Using STM/STS on a gated single mesoscopic graphene device, we observe the puddles' growth as the Fermi level approaches the Dirac point. Self-consistent screening theory provides a unified description of both the macroscopic transport properties and the microscopically observed charge disorder.

The second part extends the above technique to a system with very little disorder, namely graphene nanoribbons grown on the sidewalls of steps of a SiC substrate. By performing STM (and the related scanning tunneling potentiometry technique) on such nanoribbons driven out of equilibrium, we gain novel insights into the extraordinary transport properties of graphene nanoribbons.

O 27.2 Tue 11:00 MA 043

Probing bulk and edge transport channels in sidewall graphene nanoribbons by dual-probe spectroscopy — •Johannes Aprojanz[1,2], Stephen Power[3,4], Anti-Pekka Jauho[4], Stephan Roche[3], and Christoph Tegenkamp[1,2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Institut für Physik, Technische Universität Chemnitz, Germany — [3]ICREA - Institucio Catalana de Recerca i Estudis Avancats, Barcelona, Spain — [4]Technical University of Denmark, DTU Nanotech, Center for Nanostructured Graphene (CNG), Lyngby, Denmark

The electronic confinement in graphene nanoribbons (GNR) leads to the formation of subbands as well as topologically protected edge states. GNR epitaxially grown on nanofacets of SiC mesa structures have shown fully spin-polarized ballistic transport signatures for probe spacings larger than 200 nm [1]. By means of a 4-tip STM/SEM contacts with even smaller probe spacings were realized. In this regime sudden jumps to plateaus of multiples of the conductance quantum e^2/h were observed using one blunt tip covering the entire GNR and one sharp tip gradually crossing the ribbon. We attribute these plateaus to edge and bulk transport channels, respectively. Based on tight-binding calculations these findings are explained by transversal electric fields which originate from distinct edge terminations on both sides of the GNR.

[1] Baringhaus et al., Nature **506**, 349 (2014)

O 27.3 Tue 11:15 MA 043

Polycyclic molecules with geometrical frustration via pyrolysis on a metal — •Alexandre Artaud[1], Laurence Magaud[2], Kitti Ratter[3], Bruno Gilles[3], Valérie Guisset[2], Philippe David[2], Jose I. Martinez[4], Jose A. Martin-Gago[4], Claude Chapelier[5], and Johann Coraux[2] — [1]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts Universität zu Kiel, Germany — [2]CNRS, Institut Néel, Grenoble, France — [3]Grenoble INP, SIMAP, Grenoble, France — [4]Materials Science Factory, Instituto de Ciencia de Materiales de Madrid-CSIC, Madrid, Spain — [5]CEA, INAC, PHELIQS, Grenoble, France

The geometry of molecules is a key to several of their properties. In graphene fragments, electron delocalization from one carbon sublattice to the other is frustrated for molecular shapes breaking the balance of sublattices. Optical, electronic, and magnetic properties emerge in this case, but the synthesis of such molecules remains challenging.

Here, a pyrolysis reaction catalysed by the surface of rhenium is investigated using scanning tunneling microscopy and density functional theory. This reaction known to form graphene is found to also yield graphene fragments consisting of well-defined, zigzag-edged polycyclic molecules, some of which have sublattice imbalance. However, they are found in metastable configurations, which is interpreted as a kinetic rather than thermodynamic control of their formation. Hence, metastable molecules are expectedly ubiquitous in graphene growth, and deleterious to achieve perfect graphene. Pyrolysis is conversely a promising route towards molecules with sought-after properties.

O 27.4 Tue 11:30 MA 043

Partial dislocations in bilayer graphene — •Reena Gupta[1], Heiko Weber[2], and Sam Shallcross[1] — [1]Theoretische Festkörperphysik, FAU Erlangen-Nürnberg, Staudtstrasse 7/B2, 91058 Erlangen, Germany — [2]Angewandte Physik, FAU Erlangen-Nürnberg, Staudtstrasse 7, 91058 Erlangen, Germany

We study the bernal stacked bilayer in the presence of symmetry lowering networks of partial dislocations. We find that the transport state of the bilayer is essentially determined by the structure of the partial dislocation network, which may result in both a minimal conductivity i.e., the appearance of a pristine bilayer, as well as an insulating phase [1]. We consider both an ideal model of straight partials, which reveals the essential physics, as well as more complex networks of wandering partials. Finally, we examine the topological edge states that exist at the partial dislocation edge, and examine their behaviour in the presence of an applied magnetic field.

[1] S. Shallcross et al., Nature Communications 8, 342 (2017).

O 27.5 Tue 11:45 MA 043

A topological edge state in the graphene twist bilayer — •Maximilian Fleischmann, Reena Gupta, Dominik Weckbecker, and Sam Shallcross — Theoretische Festkörperphysik, FAU Erlangen-Nürnberg, Staudtstrasse 7/B2, 91058 Erlangen, Germany

The edge physics of graphene based systems is well known to be highly sensitive to the atomic structure at the boundary, with localized zero mode edge states found only on zigzag type terminations of the lattice. Here we demonstrate that the graphene twist bilayer supports an additional class of topological edge states, that (i) are found for all edge geometries (and thus are robust against edge roughness), (ii) occur at energies coinciding with twist-induced van Hove singularities in the bulk electronic spectrum and possess an electron density strongly modulated by the moiré lattice. Interestingly, these "moiré edge states" exist only for certain lattice commensurations and thus the edge physics of the twist bilayer is, in dramatic contrast to that of the bulk [1], not uniquely determined by the twist angle.

[1] S. Shallcross et al., Phys. Rev. B **87**, 245403, 2013.

O 27.6 Tue 12:00 MA 043

Structural study of the graphene/n-Ge(110) interface for nanoelectronic applications — •Julia Tesch[1], Fabian Paschke[1], Marko Wietstruk[2], Stefan Böttcher[2], Mikhail Fonin[1], Elena Voloshina[3], and Yuriy Dedkov[3,1] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [2]SPECS Surface Nano Analysis GmbH, 13355 Berlin, Germany — [3]Department of Physics, Shanghai University, 200444 Shanghai, China

While graphene nanoelectronics show great promise to replace silicon-based technology in the future[1], the fabrication of graphene-based electronic units is accompanied by several drawbacks such as organic residue or metal contamination, defects and other transfer related issues. An alternative route to designing nanoscale device components is presented by epitaxial graphene growth directly on semiconducting substrates.

In order to shed light on the interactions at the graphene-semiconductor interface, we present local and macroscopic studies of graphene/Ge(110) regarding both structural and electronic properties investigated by means of low temperature STM/STS[2] as well as ARPES. The arrangement of dopants is discussed with respect to corrugation, Fermi velocity renormalization and doping level of graphene. Due to only a weak interaction between graphene and Ge(110) substrate, the characteristic linear dispersion of graphene is preserved, making it a viable candidate for device applications.

[1] Westervelt, Science 320, 324 (2008). [2] Tesch *et al.*, Carbon 122,

428 (2017).

O 27.7 Tue 12:15 MA 043

Landau-level spectroscopy of twisted epitaxial graphene multilayers on a metal substrate — •Sabina Simon[1], Elena Voloshina[2], Julia Tesch[1], Felix Förschner[1], Vivien Enenkel[1], Charlotte Herbig[3], Timo Knispel[3], Alexander Tries[4], Jörg Kröger[4], Yuriy Dedkov[1,2], and Mikhail Fonin[1] — [1]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [2]Physics Department, Shanghai University, Shanghai 200444, China — [3]Institute of Physics II, University of Köln, 50937 Cologne, Germany — [4]Institut für Physik, Technische Universität Ilmenau, 98693 Ilmenau, Germany

Due to its potential in the development of new generation technologies, graphene remains the focus of many theoretical and experimental studies, principally when considering high-quality, large-scale epitaxial growth. In this work we investigate multilayered graphene systems epitaxially grown on Ir(111). Large patches of graphene twisted layers of high quality are fabricated upon atomic carbon intercalation underneath a continuous graphene sheet. By means of scanning tunneling spectroscopy in magnetic filed we study the evolution of the Landau-level spectra reflecting the variation of local electronic properties of the top graphene layer. We show that bilayers with large twist angles as well as twisted trilayers exhibit the electronic properties characteristic for a pristine graphene monolayer, pointing towards an effective decoupling of the top layer from the metal substrate. Complementary, we investigate changes in electronic properties of twisted graphene induced by subsequent alkali metal intercalation.

O 27.8 Tue 12:30 MA 043

Strong spin-orbit interaction in graphene/WSe_2 probed at local scale — •Mikhail Fonin[1], Felix Förschner[1], Fabian Paschke[1], Lena Stoppel[1], Julia Tesch[1], Yuriy Dedkov[2,1], and Andor Kormányos[1] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [2]Department of Physics, Shanghai University, 200444 Shanghai, China

Deposition on transition metal dechalcogenide substrates allow to considerably modify the strength of spin-orbit interaction (SOI) in graphene, as shown in recent magnetotransport experiments [1,2]. Here we investigate structure and electronic properties of graphene on tungsten diselenide (WSe_2) by means of scanning tunneling microscopy and spectroscopy. In external magnetic field local spectroscopic measurements reveal pronounced Landau level sequences on graphene/WSe_2. Detailed analysis of the obtained tunneling spectra shows that each Landau level is split into subpeaks, where the splitting strength grows with increasing magnetic fields. We attribute the splittings to the manifestation of substrate induced SOI in graphene. A comparison of the experimental splitting strengths with the those yielded by a spin-dependent low-energy effective Hamiltonian allows the determination of the SOI coupling constants for the Rashba term and the so-called spin-valley coupling term. Furthermore, we map the real space fluctuations of the SOI coupling strength which correlate with the variations of local electronic potential.

[1] Z. Wang *et al.*, Nature Comm. **6**, 8339 (2015). [2] Z. Wang *et al.* Phys. Rev. X **6**, 041020 (2016).

O 27.9 Tue 12:45 MA 043

Origin of the band gap in Bi-intercalated graphene on Ir(111) — •Maxim Krivenkov[1,2], Dmitry Marchenko[1], Evangelos Golias[1], Jaime Sánchez-Barriga[1], Oliver Rader[1], and Andrei Varykhalov[1] — [1]Helmholtz-Zentrum Berlin für Materialien und Energie, Albert-Einstein-Str. 15, D-12489 Berlin, Germany — [2]Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany

We report a study of the structural and electronic properties of epitaxial graphene on Ir(111) intercalated with Bi. A novel structural phase of intercalated Bi was observed which is remarkably different from the phase reported earlier by Warmuth et al. [1]. This novel phase is more dense and, as seen by angle resolved photoemission spectroscopy, provides a quasifreestanding graphene with a very small band gap (∼180 meV) and nearly ideal band structure without band replicas and electronic hybridization with the substrate. Furthermore, we demonstrate the possibility of fine tuning (±30 meV) of the band gap width in the Dirac cone by varying concentration of Bi.

To determine a possible origin of the observed band gap in Dirac point, we analyze the effect of structural corrugation on graphene band structure as well as interference effects in photoemission from graphene. The band gap was concluded to be of trivial nature and is ascribed to the breaking of sublattice symmetry of graphene.

[1] Warmuth et al. in Phys. Rev. B 93, 165437 (2016)

O 27.10 Tue 13:00 MA 043

Extremely flat band in bilayer graphene on silicon carbide — •Dmitry Marchenko[1], Daniil Evtushinsky[1], Vagelis Golias[1], Andrei Varykhalov[1], Thomas Seyller[2], and Oliver Rader[1] — [1]Helmholtz-Zentrum Berlin fur Materialien und Energie GmbH — [2]Technische Universitat Chemnitz

In the present work we discover by angle-resolved photoemission an extremely flat band forming a strong 2D-extended van Hove singularity near the K point in bilayer graphene on SiC. We present a novel model for flat band formation in bilayer graphene and other bipartite lattices. Our finding implies that we can expect strong propensity towards a superconducting transition with high critical temperature.