O 109: Focus Session: Proximity Effects in Epitaxial Graphene II

Time: Friday 10:30–13:00 Location: MA 141

Topical Talk O 109.1 Fri 10:30 MA 141

Heavy fermion quantum matter and topological superconductivity in artificial van der Waals heterostructures — •Jose Lado — Department of Applied Physics, Aalto University, Finland

Van der Waals materials provide a versatile platform for realizing a variety of emergent quantum states, including magnetic, correlated, and superconducting states, among others. Here we show that twisted van der Waals heterostructures provide a natural materials platform for realizing heavy fermion quantum materials [1,2] and topological moire superconductors [3,4]. We will discuss how a full heavy-fermion phase diagram can be realized in twisted graphene multilayers [1]. We will further show how heavy-fermion quantum matter can be experimentally realized in a bilayer made of two-dimensional materials [2]. We experimentally demonstrate [3] the emergence of a moire Yu-Shiba-Rusinov electronic structure stemming from the twist between the two van der Waals materials leading to a topological superconducting state. We will furthermore establish [4] a strategy to engineer highly tunable topological superconductivity in twisted graphene bilayers by exploiting a combination of moire patterns and proximity effects to 2D materials. Our results show that moire physics provides a powerful strategy to engineer ultra-clean heavy-fermion materials and artificial topological superconductors using van der Waals materials.

[1] Phys. Rev. Lett. 127, 026401 (2021), [2] Nature 599, 582*586 (2021), [3] Nano Lett. 2022, 22, 1, 328-333 (2022), [4] arXiv:2307.04605 (2023)

O 109.2 Fri 11:00 MA 141

Charge density wave in highly-doped single-layer graphene — Vivien Enenkel[1], Philipp Rosenzweig[2], Hrag Karakachian[2], Fabian Paschke[1], Ulrich Starke[2], and •Mikhail Fonin[1] — [1]Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [2]Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, 70569 Stuttgart, Germany

Recently, an emergence of electron correlation effects, such as superconductivity or charge density waves (CDW), in highly doped graphene monolayer has been predicted [1]. In our work, we perform Yb intercalation underneath zero-layer graphene on SiC to induce heavy electron doping in graphene. As reported previously, under Yd intercalation a van Hove singularity in graphene is pushed to the Fermi level, giving rise to an extended VHS, effectively pinning an almost non-dispersive flat band at E_F [2]. We use low-temperature scanning tunneling microscopy to discriminate between different structures of Yb-intercalated graphene, which correspond to different Yb arrangements at the interface. For three structures, dI/dU measurements show a pronounced gap feature centered at E_F. Together with strong changes of STM contrast upon bias voltage variation, the presence of the gap at E_F points at the formation of a CDW state in the intercalated graphene monolayer. [1] M. L. Kiesel *et al.*, Phys. Rev. B 86, 020507 (2012); [2] P. Rosenzweig *et al.*, Phys. Rev. B 100, 035445 (2019).

O 109.3 Fri 11:15 MA 141

Shaping superconducting proximity effect on graphene with nanometric precision — •Stefano Trivini[1], Eva Cortès-del Rio[6], Tim Kokkeler[9], Jon Ortuzar[1], Vladimir Cherkez[3,4], Jean-Yves Veuillen[3,4], Pierre Mallet[3,4], F. Sebastian Bergeret[8,9], Juan Carlos Cuevas[5,6], Ivan Brihuega[6,5,7], and Nacho Pascual[1,2] — [1]CICnanoGUNE 20018 San Sebastián, Spain — [2]Ikerbasque, 48013 Bilbao, Spain — [3]Institut Néel, F-38400 Grenoble, France. — [4]Universitè Grenoble Alpes, F-38042 Grenoble, France. — [5]IFIMAC, E-28049 Madrid, Spain. — [6]UAM, E-28049 Madrid, Spain. — [7]Instituto Nicolás Cabrera E-28049 Madrid, Spain — [8]DIPC 20018 San Sebastian, Spain — [9]CFM-MPC, E-20018 San Sebastián, Spain

Graphene can be turned superconducting by the proximity effect. The role of graphene gate-tunable density of states is crucial for understanding the stabilization of a collective proximitized state. Here, we investigate the proximitized superconductivity in graphene bilayers in contact with Pb islands grown on top. In particular, we compare, using LT-STM, the effect of superconducting Pb on graphene grown on the two faces of a polar SiC(1000) crystal. The effect of surface DOS turns out to be crucial. On the Si-side, we identify a collective superconducting state with a small pseudogap, while in the C-side, superconductivity is strong but local. Furthermore, we developed a method to laterally manipulate the Pb islands on graphene and build controllable Superconductor-Graphene structures.

O 109.4 Fri 11:30 MA 141

Growth optimization and comparison of PASG epitaxial graphene on 4H- and 6H-SiC — •Teresa Tschirner, Yefei Yin, Klaus Pierz, Frank Hohls, and Hans Werner Schumacher — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Fabricating epitaxial graphene by polymer-assisted sublimation growth (PASG) on SiC offers various advantages for application, such as production of large-area ultra-smooth defect- and bilayer-free graphene sheets, as well as reliable reproducibility. With the PASG method, the early formation of a buffer layer stabilizes the SiC surface and prevents step bunching of unfavorably high SiC surface terrace steps. We compare graphene growth on different polytypes of SiC with different parameters (such as miscut, polymer concentration, etc.) and the influence on the electronic properties of graphene. Differences between 4H- and 6H-SiC growth are two and three different terrace types, respectively, having inequivalent surface energies and subsequently different surface decomposition velocities [1]. We observe different step patterns on 6H-SiC of either alternating 0.25 and 0.5 nm high terrace-steps with alternating surface potential or equally distributed 0.75 nm steps. 4H-SiC on the other hand results for optimal growth in equally distributed very low step heights of 0.5 nm and equivalent SiC terraces with equal surface potential. The impact on the electronic transport is investigated by magneto-transport measurements.

[1] D. Momeni et al., Adv. Funct. Mater. 30, 2004695 (2020)

Topical Talk O 109.5 Fri 11:45 MA 141

Superconducting quantum devices in twisted graphene layers — •Klaus Ensslin — Physics Department, ETH Zurich

We realize gate-defined quantum devices on magic-angle twisted bilayer graphene. Different correlated states can be tuned by gate voltages, including superconducting states, band insulators and correlated insulators. This way we have fabricated Josephson junctions [1] as well as a SQUID with tunable symmetry [2]. A novel entirely gate-induced ring geometry [3] was employed to detect the Little-Parks effect [4] where the state of the ring as well as that one of the confining potential inside and outside of the ring became tunable. These experiments pave the way to more complex graphene quantum devices involving superconductivity and possibly Coulomb blockade. These experiments have been done in collaboration with Peter Rickhaus, Fokko de Vries, Elias Portoles, Giulia Zheng, Marta Perego, Alexandra Mestre Tora, Shuichi Iwakiri and Thomas Ihn.

[1] de Vries et al. , Nature Nano 16, 760 (2021) [2] Portolés et al., Nature Nano 17, 1159 (2022) [3] Iwakiri et al., Nano Lett. 22, 6292 (2022) [4] Iwakiri et al., arXiv:2308.07400

O 109.6 Fri 12:15 MA 141

Conductivity of intercalated Pb-monolayer in proximity to graphene — •Markus Gruschwitz, Andreas Cordier, Tim Güldenpfennig, Sergii Sologub, and Christoph Tegenkamp — Institut für Physik, TU Chemnitz, Chemnitz, Germany

Densely-packed monolayer of Pb, intercalated below the buffer layer on 4H-SiC(0001), reveals a long range ordered quasi (10×10) reconstruction, revealing charge neutral graphene and providing further exotic effects, e.g. spin-orbit coupling or a superconducting phase [1]. We investigated this 2D heterostructure in detail by means of in-situ multiprobe-STM as a function of tip geometry, tip spacing and temperature. Thereby, around 3.5 μm wide parallel terraces of intercalated graphene separated by narrow and less conductive barriers are formed, causing a tip-spacing dependent behavior from 1D to 2D and strong lateral anisotropy. We utilize finite element simulations to disentangle the different contributions and finally reveal the conductivity of the 2D heterosystem.

At room temperature the conductivity amounts to 600 kS/m. As the temperature is lowered, the conductivity decreases below 100 K similar to previous results [2]. Assuming combined transport channels in the metallic Pb layer and graphene, the increase in resistance is not in

agreement with former T-dependent resistance measurements of monolayer graphene. We rather assume a small gap in the range of 2.5 meV in graphene, e.g. induced by spin-orbit coupling into graphene.

[1] Adv. Mater. Interfaces 10, 2300471 (2023); [2] Materials 14, 7706 (2021)

O 109.7 Fri 12:30 MA 141

Magnetotransport of Bi(110) islands on epitaxial graphene — •Julian Koch[1], Sergii Sologub[1,2], Chitran Ghosal[1], and Christoph Tegenkamp[1] — [1]Institut für Physik, TU Chemnitz, Reichenhainerstr. 70, 09126 Chemnitz — [2]Institute of Physics, NAS of Ukraine, Nauki avenue 46, 03028 Kyiv

Magnetotransport measurements using a 4 T magnet were performed on Bi islands on monolayer graphene/SiC with average thickness up to 3.6 bilayers (BL). They are supported by structural investigations using SPA-LEED and STM, which reveal that Bi predominately grows as needle-like islands with a (110) termination (see also [1]).

The carrier concentration determined from the SdH oscillations remains at 1×10^{13} cm^{-1} independent of the Bi coverage. In contrast, photoemission spectroscopy shows a strong doping of the graphene by Bi [2], indicating that the carrier concentration is highly anisotropic. This is confirmed by a positive, temperature independent contribution to the magnetoresistivity, which indicates that the Bi covered regions are electrically dead zones causing the electrons to scatter at the boundaries. This reduces the mobility from around 2250 cm^2/(Vs) for MLG to 1920 cm^2/(Vs) at 2.4 BL Bi, a decrease of approximately 14%. The weak localization of the clean surface is gradually reduced with increasing Bi coverage. This is caused solely by a decrease of the coherence length of the scattered electrons. The scattering lenghts associated with inter- and intravalley scattering remain unchanged.

[1] Koch et al. *J. Phys.: Condens. Matter* **36**, 065701 (2024)
[2] Gierz et al. *Nano Lett.* **8**, 12, 4603 (2008)

O 109.8 Fri 12:45 MA 141

long-term stable epitaxial graphene-based quantum Hall resistance standard for operating under relaxed conditions — •Yefei Yin[1,2], Mattias Kruskopf[1], Pierre Gournay[3], Benjamin Rolland[3], Martin Götz[1], Eckart Pesel[1], Davood Momeni[1], Frank Hohls[1], Klaus Pierz[1], Hansjörg Scherer[1], Rolf J. Haug[2], and Hans W. Schumacher[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, 30167, Hannover, Germany — [3]Bureau International des Poids et Mesures (BIPM), Pavillion de Breteuil, 92312 Sevres, France

The epitaxial graphene-based quantum Hall resistance standard (QHRS) has excellent potential for resistance metrology due to its large Landau level gap and strong Fermi level pinning. However, since as-grown epitaxial graphene has an electron density of 10^{13} cm^{-2}, permanent control of the carrier density and maintenance of the Hall resistance quantization are essential for practical graphene-based QHRS. This desirable goal is now achievable through the molecular doping by spin-coating F4-TCNQ dopant stacks on the graphene surface [1]. Our graphene-based QHRS show a Hall resistance quantization with an accuracy of $(2 \pm 2) \times 10^{-9}$ (k=2) under relaxed conditions of B = 4.5 T, I = 232.5 μA, and T= 4.2 K simultaneously. The accurate quantization has not shown any signs of degradation over two years, so far. Furthermore, the graphene-based QHRS has maintained quantization accuracy despite shipping between PTB and BIPM.[1] Y. Yin, et al., Adv. Physics Res. 1, 2200015 (2022)