O 30: Poster: Proximity Effects in Epitaxial Graphene

Time: Tuesday 12:30–14:30 Location: Poster A

O 30.1 Tue 12:30 Poster A

Quasi-freestanding graphene on SiC(0001) by intercalation of silicon — •Niclas Tilgner and Thomas Seyller — TU Chemnitz Institut für Physik

To observe the extraordinary properties of freestanding graphene, the atmospheric pressure growth of epitaxial graphene has proven itself in recent years. Thereby the annealing of SiC samples in [0001] direction gives rise to a graphitisation of the surface and a carbonrich $(6\sqrt{3}\times6\sqrt{3})R30^\circ$ reconstruction is formed. This so-called buffer layer is topological equivalent to graphene, but the π-bands are strongly deformed due to remaining bonds to the substrate. One way of decoupling is the intercalation of foreign atoms, which gives rise to a quasi-freestanding graphene layer. In the presented work the decoupling could be achieved by intercalation of silicon. The poster focuses on the discussion of three different preparation techniques in terms of their influence on the sample quality. The investigated methods are the silicon deposition at elevated temperatures, the sequential deposition/annealing and an exchange intercalation. For the latter one, the buffer layer was first decoupled with hydrogen before the process with silicon. Experiments using the diffraction of low energy electrons (LEED) reveal that only with one technique a sufficiently ordering of the silicon could be achieved. Further investigations with photoemission (ARPES, XPS) show the appearance of several surface states on the ordered samples, which are partly attributed to one of the Hubbard bands of the silicon dangling bonds.

O 30.2 Tue 12:30 Poster A

Nanoscopic transport measurements on intercalated epitaxial graphene — •Andreas Cordier, Markus Gruschwitz, Tim Güldenpfennig, and Christoph Tegenkamp — Institut für Physik, TU Chemnitz, Chemnitz, Germany

To further enhance the electronic properties of graphene, intercalation experiments are currently performed in mayn groups. Electronic transport experiments are a direct way to probe the electronic properties. However, the intercalation is often kinetically limited, thus the intercalated areas are inhomogeneous on a nm-scale. Moreover, the buffer layer/SiC(0001) surfaces also exhibit steps on a μm-scale, which further introduces anisotropy to the system. In order to account for these imperfections, we performed nanoscopic 4ppSTM transport measurements, varying the tip distances and geometry.

We realized tip configurations on single terraces as well as across many terraces, thus revealing 2D/1D/2D transport signatures, while increasing the tip distances. Moreover, using square tip configurations, the rotation of this configuration with respect to the step direction, allowed us to determine the anisotropy, which is as high as 2500. The analysis of these results allowed us to deduce the conductivity of the terraces from the conductance which amounts to $\sigma = 600$ kS/m. These experiments experimental taken at room temperature are supported by finite element simulations. Furthermore a metal-insulator transition has been found at 100K that we ascribe to the formation of a band gap in graphene, e.g. due to the induction of spin-orbit coupling in graphene by the intercalated Pb.

O 30.3 Tue 12:30 Poster A

Growth and structure of two-dimensional Pb-Layers below Epitaxial Graphene on SiC(0001) — •Peter Richter[1,2], Franziska Schölzel[1,2], Philip Schädlich[1,2], and Thomas Seyller[1,2] — [1]Technische Universität Chemnitz, Institut für Physik, Chemnitz, 09126 Chemnitz — [2]Center for Materials, Architectures, and Integration of Nanomembranes (MAIN), 09126 Chemnitz

The intercalation of epitaxial graphene (EG) on SiC with various elements has widely been utilized to tailor the electronic properties of the graphene sheet. The ability of elements with strong spin-orbit coupling or even superconducting phases to induce this behavior into the graphene, moves heavy atoms such as Pb into the spotlight [1]. Beyond that, intercalation enables the manufacturing of otherwise unstable 2D-materials and protect it against oxidation.

We investigated the intercalation of EG with Pb in real time by means of Low Energy Electron Microscopy (LEEM), unraveling a strong temperature dependence. Interestingly, intercalation at lower temperatures results in a new phase of the intercalated Pb-layer contrasting the already reported striped- and bubble-phase [2]. Angle-resolved photoemission spectroscopy (ARPES) and low energy electron diffraction (LEED) investigations suggest a strict (1×1) periodicity. Moreover, we studied the phase transition from (1×1) Pb-phase to 'bubble'-phase occurring at 600 °C by X-Ray photoelectron spectroscopy (XPS), thus connecting our intercalation recipe to earlier reports. [1] N.B. Kopnin et al., Phys. Rev. B, 064524, 84 (2011) [2] M.Gruschwitz et al., Materials, 7706, 14 (2021)

O 30.4 Tue 12:30 Poster A

Intercalation of Pb using buffer layer on 4H/SiC(0001) — •Sergii Sologub[1,2], Markus Gruschwitz[2], and Christoph Tegenkamp[2] — [1]Institute of Physics, NAS of Ukraine, Nauki avenue 46, 03028 Kyiv — [2]Institut für Physik, TU Chemnitz, Reichenhainer Str. 70, 09126 Chemnitz

Charge neutrality [1] as well as potential superconductivity [2] and induced SOC of epigraphene by Pb intercalation recently sprouted great interest. We investigated the peculiarities of the intercalation of Pb using buffer layer on 4H/SiC(0001) by SPA-LEED, SEM and STM techniques. Although proposed as an energetically unfavorable process [3], we optimize the intercalation by varying the coverage of deposited Pb, annealing temperature and duration, as well as numbers of deposition-annealing cycles. In particular, repeated cycles of 10 ML Pb-deposition at RT followed by annealing to 500°C for 5 min were effective for the formation of the stripe intercalation phase, especially with additional annealing to 700°C in every two cycles. On the other hand, the long-term annealing (about 15 hours at 350°C) of the 20 ML Pb coverage deposited on the stripe-phase substrate resulted in transformation of the stripe phase into the bubble one which was accompanied by corresponding changes in STM images and LEED patterns. Also of importance is that residual Pb clusters remaining on the surface after the intercalation processes can be mainly removed by annealing to 400°C.

[1] Adv. Mater. Interfaces 10, 2300471 (2023); [2] Nat. Phys. 6, 104 (2010); [3] Carbon 205, 336 (2023)

O 30.5 Tue 12:30 Poster A

Simulations of electronic transport in inhomogeneous intercalated graphene systems — •Tim Güldenpfennig, Markus Gruschwitz, and Christoph Tegenkamp — Institut für Physik, Technische Universität Chemnitz

Pb intercalated buffer layer on 4H-SiC(0001) creates charge neutral quasi-freestanding graphene [1]. The presence of a densely packed Pb monolayer at the interface triggers interest in transport experiments hunting for a superconductivity or proximity-induced SOC in graphene. However, nanoscale measurements sensitively depend on the local distribution of conductive phases. Multiprobe-STM reveal an 1D to 2D transition with increasing tip spacing s on a single terrace. Angle dependent measurements show a discrete anisotropy behavior. We approach the separation of contributing conductive phases by finite element simulations using COMSOL multiphysics. Our model - based on dimensions measured by SEM and XSW - consists of a series of 3.5 μm wide terraces separated by 100 nm wide barriers of alternating conductivities, respectively. Starting with the measured terrace conductivity (600 kS/m) repeated optimization provide best agreement for $R(s)$ for $\sigma_{\text{terrace}} = 500$ kS/m and $\sigma_{\text{barrier}} = 200$ S/m. Applied in a square angle dependent setup the model also recreates the discrete anisotropy behavior. On larger scale, barrier defects yield a continuous but smaller anisotropy. Finally, we explore the separation of two T-dependent phases by varying the conductivity levels in the model based on reference measurements at 30 K and RT. [1] Adv. Mater. Interfaces 10, 2300471 (2023); [2] Materials 14, 7706 (2021)

O 30.6 Tue 12:30 Poster A

Intercalation of Sn beneath the Buffer Layer on SiC(0001) studied by SPA-LEED — •Kurt Hered, Zamin Mamiyev, and Christoph Tegenkamp — Technische Universität Chemnitz, Institut für Physik, Reichenhainer Straße 70R

The intercalation of atomically flat metallic structures beneath epitaxial graphene is interesting for realizing proximity-coupled 2D systems. In this context, carbon group elements are noteworthy due to their well-known correlated electronic properties. In this work, we have investigated the intercalation of Sn beneath the buffer layer (BL)

on 4H-SiC(0001) by means of high-resolution SPA-LEED. Superior to conventional LEED, SPA-LEED with its high k-space resolution and capability to investigate vertical and lateral roughness, enables control over the intercalation process. To optimize high-quality Sn-induced interface, we explore different routes, including varying Sn coverages, intercalation temperatures and time. It turns out that in all approaches, Sn intercalation progresses through intercalated disordered interface, an ordered 1×1 phase, and finally $(\sqrt{3} \times \sqrt{3})R30^\circ$ periodicity w.r.t the SiC latticce, achieved above 1000 °C. [1] Quantitative H(S) and G(S) analyses show for the clean system a mosaic two-level BL surface, with >97% BL with 2.5 Å step heights, revealing a flat SiC surface at a 0.01° inclination. After forming the Sn(1×1) interface layer, 95% transforms into QFMLG, with a slightly increased 2.64 Å step height while preserving macroscopic surface orientation. Annealing above 1000 °C results in surface roughening due to deintercalation.
[1] Z. Mamiyev et al. Surf. Interfaces 34, 102304 (2022)

O 30.7 Tue 12:30 Poster A

Sn intercalated epitaxial graphene studied by scanning tunneling microscopy — •Dorothee Hennig, Chitran Ghosal, Zamin Mamiyev, and Christoph Tegenkamp — Institute of Physics, Technische Universität Chemnitz, Reichenhainer Str. 70, Germany

Electronically correlated 2D systems can be realized, for example, by adsorption of Sn on SiC(0001) [1]. The generation of such or similar phases as interfacial phases in the vicinity of epitaxial graphene (EG) promises the realization of novel quantum phases. Here we have investigated the intercalation of Sn on buffer layers (BL) on SiC(0001) using low temperature STM. We know from previous LEED investigations that a (1×1) phase forms first after deposition and subsequent heating. Further heating thins this phase further and $(\sqrt{3} \times \sqrt{3})$-reflexes appear [2]. The Sn(1×1)-phase below epitaxial graphene was found only locally with typical sizes of 2-3nm. Between these crystalline areas with distances of 5-10nm. In between, rather disordered Sn phases are formed, probably formed due to lateral strain effects or triggered by selective reactions at the interface due to the former BL. These centers also act as defects for EG, e.g. es seen by the $(\sqrt{3}\times\sqrt{3})$-reconstruction w.r.t. to EG imaged at bias voltage conditions close to Fermi energy. For the deluted phase, showing $\sqrt{3}$-reflexes, large islands (100nm) with a 6x6 periodicity similar to the BL reconstruction were found. Again, this finding suggests that the interface adsorption sites are defined by the former bonds of the BL with the SiC(0001) substrate.

[1] S. Glass et al., PRL 114, 247602 (2015). [2] Z. Mamiyev et al. Suf. Int. 34, 102304 (2022)