O 105: Poster Session VIII: Graphene and beyond II

Time: Thursday 13:30–15:30 Location: P

O 105.1 Thu 13:30 P

Low-energy ion implantation of Cobalt in graphene investigated by scanning tunneling microscopy — •Anna Sinterhauf[1], Benno Harling[1], Manuel Auge[2], Felix Junge[2], Philip Willke[3], Hans Hofsäss[2], and Martin Wenderoth[1] — [1]IV. Physikalisches Institut, Universität Göttingen — [2]II. Physikalisches Institut, Universität Göttingen — [3]Physikalisches Institut, Karlsruher Institut für Technologie (KIT)

To tailor the properties of a graphene sheet by band structure engineering, the issue of doping is decisive to turn graphene into a true device material. For this purpose, a direct incorporation of foreign atoms into the graphene layer by low-energy ion beam implantation has shown to be a versatile method [1] as demonstrated for B and N. Here, we report on the successful implantation of Cobalt atoms into the graphene lattice achieved by low-energy Cobalt implantation at an ion energy of 20eV. After transfer through air, reinsertion into UHV and annealing at 400°C for 30 minutes, the structural and electronic properties of the ion implanted epitaxial graphene are investigated by scanning tunneling microscopy and spectroscopy (STS). Contrary to B and N [2], we find a negligible charge transfer from Co to graphene in agreement with theoretical considerations [2]. In addition, at the topographic position of the defects, STS reveals a pronounced peak in dI/dV-spectra at zero bias voltage. Financial support by the DFG through project We 1889/13-1 is gratefully acknowledged.

[1] P. Willke et al., Nano Lett. 15(8), 5110-5115, 2015

[2] E. J. G. Santos et al., Phys. Rev. B 81, 125433, 2010

O 105.2 Thu 13:30 P

LEEM/PEEM investigation of ambient oxidized g/ge(110) — •Ka Man Yu[1,2], Chanan Euaruksakul[3], Thipusa Wongpinij[3], Robert M. Jacobberger[4], Michael S. Arnold[4], Max G. Lagally[4], and Michael S. Altman[1] — [1]Hong Kong University of Science and Technology, Hong Kong SAR — [2]University of Kaiserslautern, 67663 Kaiserslautern, Germany — [3]Synchrotron Light Research Institute, Nakhon Ratchasima 30000, Thailand — [4]University of Wisconsin-Madison, Wisconsin 53706, United States

Germanium (Ge) is an excellent candidate for MISFET devices due to its high intrinsic charge carrier mobility. However, in contrast to the native oxide on Si, the native oxide on Ge hinders practical applications. The recent finding that a graphene monolayer can diminish the oxidation rates of Ge under ambient conditions identifies a possible scheme for overcoming a key challenge to the development of Ge-based electronic devices. Further knowledge of how oxygen permeates graphene to react with Ge is crucial to achieving this goal. In this work, the oxidation of Ge(110) under a graphene monolayer that is caused by ambient exposure was investigated using LEEM and PEEM. Three oxide domains are identified: a mixed monolayer or dispersed submonolayer comprised of $\mathrm{GeO}_x/\mathrm{GeO}_{1+y}$, thin and thicker GeO_{1+y} over a buried GeO_x interfacial layer in contact with the Ge bulk. The permeability of graphene to oxygen is attributed to defects at boundaries between the prevalent $R0$ and $R30$ graphene grains, within grains and at wrinkles. A statistical treatment for isochromatic correction of energy-resolved PEEM images will also be presented.

O 105.3 Thu 13:30 P

The role of two-dimensional pressure in sulfur intercalation underneath graphene on ruthenium — •Lars Buss[1,2], Jens Falta[2], Moritz Ewert[1], Bin Shao[3], Tim Wehling[4], and Jan Ingo Flege[1] — [1]Applied Physics and Semiconductor Spectroscopy, BTU Cottbus-Senftenberg, Cottbus, Germany — [2]Institute of Solid State Physics, University of Bremen, Bremen, Germany — [3]Beijing Computational Science Research Center (CSRC), Beijing, China — [4]Institute for Theoretical Physics, University of Bremen, Bremen, Germany

Micrometer-sized single-layer graphene can epitaxially be grown on transition-metal substrates with excellent crystalline quality. However, due to strong binding these substrates have a detrimental influence on the intrinsic properties of the graphene. By lifting the interlayer coupling, e. g., via intercalating foreign atoms, its unique electronic properties can be restored. We have investigated the intercalation of sulfur underneath graphene on Ru(0001) with low-energy electron microscopy (LEEM) and micro-diffraction (μLEED). We find that sulfur deposited at elevated temperatures enters through the edge of the island, leading to wrinkle formation in the decoupled graphene. Interestingly, the presence of the graphene limits the possible S/Ru(0001) reconstructions that may form underneath, preventing less dense reconstructions like the p(2×2) and $(\sqrt{3}\times\sqrt{3})$ reconstructions. Based on density functional theory calculations, these findings are explained by a 2D pressure exerted by the overlying graphene, which results from the strong graphene-substrate interaction, only rendering the denser reconstructions of the S/Ru phase diagram energetically favorable.

O 105.4 Thu 13:30 P

Probing Quantum Hall edge channels by scanning tunneling spectroscopy — •Tjorven Johnsen[1], Sayanti Samaddar[1], Astrid Weston[2,3], Matthew J. Hamer[2,3], Kenji Watanabe[4], Takashi Taniguchi[4], Roman Gorbachev[2,3,5], and Markus Morgenstern[1] — [1]II. Institute of Physics B, RWTH Aachen University, Germany. — [2]Department of Physics and Astronomy, University of Manchester, UK. — [3]National Graphene Institute, University of Manchester, UK. — [4]National Institute for Materials Science, Tsukuba, Ibaraki 305-0044, Japan. — [5]Henry Royce Institute for Advanced Materials, University of Manchester, UK.

The topology of the quantum Hall effect is imprinted in the edge channel (EC) transport, but microscopic details of the EC topography at the scale of the magnetic length are largely unknown. Here we use scanning tunneling spectroscopy to probe the quantum Hall ECs at integer fillings along a gate-tunable graphene pn interface. ECs with finite width at the Fermi level become apparent along the continuous potential gradient across the interface. They meander along the interface in width and lateral position due to the inhomogeneous local electrostatic environment. However, the appearance of charging lines testifies the simultaneous presence of a tip-induced quantum dot that is influencing the electrostatics at the interface similarly as in scanning gate experiments and, hence, modifies the measurement results in detail. To disentangle the contributions from ECs and quantum dot, we employed electrostatic model simulations that explain multiple details of the observed charging lines and the local density of states features.

O 105.5 Thu 13:30 P

Local spots of viscous electron flow in graphene at room temperature and moderate mobility — •Sayanti Samaddar[1], Jeff Strassdas[1], Kevin Janssen[2], Tjorven Johnsen[1], Zhenxing Wang[3], Daniel Nuemaier[3,4], Marcus Liebmann[1], and Markus Morgenstern[1] — [1]II. Institute of Physics B, RWTH Aachen University and JARA-FIT, Otto-Blumenthal-Str., 52074 Aachen, Germany — [2]Research Centre Jülich, Peter Grünberg Institute, 52425 Jülich, Germany, — [3]Advanced Microelectronic Center Aachen (AMICA), AMO GmbH, Otto-Blumenthal-Str. 25, 52074 Aachen — [4]University of Wuppertal, 42285 Wuppertal, Germany,

Dominating electron-electron scattering enables viscous electron flow exhibiting hydrodynamic current density patterns such as Poiseuille profiles or vortices. The viscous regime has recently been observed in graphene by non-local transport experiments and mapping of Poiseuille profiles up to room temperature. Here, we probe the current-induced surface potential maps of graphene field effect transistors using scanning probe microscopy at room temperature. We discover the appearance of μm large areas close to charge neutrality, where the current induced electric field opposes the externally applied field. By estimating the scattering lengths from the gate dependence of local electric fields, we find that these areas exhibit a dominating electron-electron scattering as expected for viscous flow. We map the respective meandering electric fields and carefully rule out artifacts such as by source-drain voltage induced local doping. Our results imply that viscous electron flow is omnipresent in graphene devices, even at moderate mobility.

O 105.6 Thu 13:30 P

Control of interface alloying between silicene and a silver substrate — •Johannes Küchle[1], Aleksandr Baklanov[1], Felix Haag[1], David Duncan[2], Paul Ryan[2,3], Ari Seitsonen[4], Willi Auwärter[1], and Francesco Allegretti[1] — [1]Physics Department E20, Technical University of Munich, 85748 Garching, Germany — [2]Diamond Light Source, OX11 0DE Didcot, UK — [3]Imperial College London, SW7 2AZ London, UK — [4]Département de Chimie, École Normale Supérieure, 75005 Paris, France

Silicene, the silicon analogue of graphene, is a promising material with unique structural and electronic properties, which has been in the focus of intense research during the past decade. With the epitaxial fabrication via deposition of silicon on solid substrates being the best-established growth method, silicene is susceptible to strong interfacial interactions that may drastically alter its functional properties. However, these interactions are still largely unexplored. Here, we present our recent experiments with soft X-ray photoelectron spectroscopy (SXPS) at various Si coverages in combination with X-ray standing waves, indicating that during the growth of the most commonly studied (4 x 4) superstructure of silicene on Ag(111) Si-Ag surface alloying occurs. Accordingly, our scanning tunneling microscopy (STM) studies resolve a yet unreported phase, which we interpret as a Si-Ag alloy structure, extending underneath the silicene layer. Moreover, we show that growing silicene on a sacrificial Ag$_2$Ge surface alloy strongly suppresses the Si-Ag alloy component in SXPS, resulting in new, distinct phases, as detected by low energy electron diffraction and STM.

O 105.7 Thu 13:30 P

Two phases of monolayer tantalum sulfide on Au(111) — Daniela Dombrowski[1,2], Abdus Samad[3], Clifford Murray[4], Marin Petrović[5], Pascal Ewen[1], Thomas Michely[4], Marko Kralj[5], Udo Schwingenschlögl[3], and •Carsten Busse[1,2] — [1]Institut für Materialphysik, Westfälische Wilhelms-Universität Münster, Germany — [2]Department Physik, Universität Siegen, Germany — [3]KAUST, Physical Science and Engineering Division, Thuwal, Saudi Arabia — [4]II. Physikalisches Institut, Universität zu Köln, Germany — [5]Center of Excellence for Advanced Materials and Sensing Devices, Institute of Physics, Zagreb, Croatia

Transition metal chalcogenides (TMCs) are 2d materials with a broad variety of electrical properties and phenomena like charge density waves, superconductivity and Mott transitions. Like their bulk parent materials, 2d-TMCs exhibit polymorphism. This includes the well-known 2H- and 1T-MX$_2$ phases but also more complex structures such as self-intercalated bilayers or chalcogene-poor compounds with sulfur vacancies. The structure has a strong influence on the properties. For example, group 6 TMCs in the 2H-phase are semiconducting, while they are metallic in the 1T-phase.

We use a combination of physical and chemical vapor deposition to grow two different phases of tantalum sulfide on Au(111). STM, STS and ARPES results corroborated by DFT allow us to identify the phases as 2H-TaS$_2$ and a novel phase found for sulfur-poor conditions where the bottom sulfur layer is missing.

O 105.8 Thu 13:30 P

Single-domain h-BN monolayer growth on an incommensurable surface: Pt(110) — •Dominik Steiner[1], Marco Thaler[1], Florian Mittendorfer[2], and Erminald Bertel[1] — [1]Institute of Physical Chemistry, University of Innsbruck, Innsbruck, Austria — [2]Institute of Applied Physics and Center of Computational Material Science, University of Technology, Vienna, Austria

Lattice matching has been widely considered to be a prerequisite for perfect epitaxial growth. In contrast, we demonstrate by LEED, STM and DFT calculations large-scale, single-domain hexagonal Boron Nitride (h-BN) growth on the incommensurable Pt(110) surface [1]. In a competition between the h-BN and the Pt bulk geometry the former dominates the arrangement of the Pt(110) surface atoms. This adaptivity of the Pt(110) surface is key to the perfect film growth.

STM and LEED studies show that single-domain growth occurs only above a threshold temperature of ~1120 K. At T<1120 K, a defective multi-domain film on a rough Pt-surface is obtained. Referring to the results of Lee et al. for h-BN growth on liquid Au [2] we proposed that the Pt surface atoms form a quasi-liquid layer above the threshold temperature, thus enabling the alignment of h-BN nuclei. Our recent studies of the growth mechanism, however, indicate a more complex mechanism leading to single-domain growth.

[1] Steiner et al., ACS Nano 2019, 13 (6), 7083-7090.

[2] Lee at al., Science 2018, 362 (6416), 817.

O 105.9 Thu 13:30 P

Moiré-driven charge accumulation in few-layer antimony films on InSb(111)A — Bing Liu[1,3], •Tim Wagner[1,3], Martin Kamp[1,3], Stefan Enzner[2,3], Philipp Eck[2,3], Giorgio Sangiovanni[2,3], and Ralph Claessen[1,3] — [1]Physikalisches Institut, Universität Würzburg, D-97074 Würzburg, Germany — [2]Institut für Theoretische Physik und Astrophysik, Universität Würzburg, D-97074 Würzburg, Germany — [3]Würzburg-Dresden Cluster of Excellence ct.qmat, Universität Würzburg, D-97074 Würzburg, Germany

Few-layer antimony films are a promising topological material which has been widely investigated on various substrates. Here we show few-layer films which have been successfully synthesized on a InSb(111)A substrate. The epitaxially grown antimony layers keep the bulk Sb lattice constant, i.e., do not adapt to that of the substrate. According to density functional theory calculations considering this Moiré situation in a simplified unit cell, the lattice mismatch at the interface gives rise to charge accumulations at positions where the atoms of film and substrate are in phase. Although situated at the interface, these charge localizations are predicted to extend perpendicular to the interface over several antimony layers. Experimentally, this can be confirmed in scanning tunneling microscopy with a Moiré pattern visible up to the seventh layer. Spectroscopy measurements of antimony films with various thicknesses show Sb bulk behavior, i.e., the scattering of the topological surface state, down to five film layers. At lower thicknesses, this scattering is suppressed, which may be attributed to the increased influence of the Moiré-driven charge accumulations at the interface.

O 105.10 Thu 13:30 P

Proximity effects in the charge density wave order and superconductivity in single-layer NbSe2 — •Wen Wan[1], Paul Dreher[1], Alla Chikina[2], Haojie Guo[3], Rishav Harsh[1], Marco Bianchi[2], Marco Gobbi[4], Jose-Maria Gomez-Rodriguez[3], Antonio Javier Martinez-Galera[3], Philip Hofmann[2], Jill A. Miwa[2], and Miguel Ugeda[1] — [1]Donostia International Physics Center, San Sebastián-Donostia, Spain — [2]Department of Physics and Astronomy, Aarhus University — [3]Dpto. Física de la Materia Condensada, Universidad Autónoma de Madrid — [4]CIC Nanogune

Collective electronic states such as the charge density wave (CDW) order and superconductivity respond dramatically to external perturbations. In two-dimensional materials hosting such states, the closeness to unavoidable supporting substrates may lead to significant changes in their properties. Here we explore the impact of proximity effects on the CDW and superconducting states in single-layer NbSe2. We performed the electronic characterization of single-layer NbSe2 on several substrates of opposite metallicity by means of STM/STS at 350 mK, ARPES and 4-point probe transport measurements. In particular, we have epitaxially grown single-layer NbSe2 by MBE on two different metals, Au(111) and BLG/SiC(0001), and two insulators, bulk WSe2 and monolayer h-BN/Ir(111). While both phases disappear on Au(111), they persist on BLG/SiC. The fate of the CDW and superconducting phases is more intricate on insulating substrates, which are largely affected, however, despite of the electronic decoupling of the 2D superconductor with the substrate states.

O 105.11 Thu 13:30 P

The true corrugation of monolayer h-BN on Rh(111) — Luis Henrique de Lima[1,2], Thomas Greber[3], and •Matthias Muntwiler[2] — [1]Universidade Federal do ABC, Santo Andre, Brazil — [2]Paul Scherrer Institut, Villigen, Switzerland — [3]Universität Zürich, Zürich, Switzerland

Monolayer hexagonal boron nitride (h-BN) grown on the (111) surface of rhodium exhibits an intriguing corrugation pattern called "nanomesh" with a lattice constant of 3.2 nm. Despite numerous experimental and theoretical studies, structural details such as the corrugation amplitude have been difficult to determine quantitatively due to the differences in chemical and electronic environments in the strongly bound pore regions and the weakly bound wire regions of the corrugated structure. For reliable results it is important to probe the structure with a method that is inherently sensitive to the positions of the atomic cores rather than electron density.

In this contribution, we determine the corrugation of h-BN nanomesh from synchrotron based angle- and energy-resolved photoelectron diffraction measurements with chemical state resolution. By comparing measured data to multiple-scattering simulations true adsorbate-substrate distance can be measured with high precision, avoiding pitfalls of apparent topography observed in scanning probe techniques.

L. H. de Lima et al., 2D Mater. 7, 035006 (2020)

O 105.12 Thu 13:30 P

Transitions from single-layer MoS$_2$ to bilayer growth: A LEEM study — •Moritz Ewert[1,2,3], Lars Buss[1,2], Francesca Genuzio[4], Tevfik Onur Menteş[4], Andrea Locatelli[4], Jens Falta[2,3], and Jan Ingo Flege[1,2,3] — [1]Applied Physics and Semiconductor Spectroscopy, Brandenburg University of Technology Cottbus-

Senftenberg, Germany — [2]Institute of Solid State Physics, University of Bremen, Germany — [3]MAPEX Center for Materials and Processes, University of Bremen, Germany — [4]Elettra-Sincrotrone Trieste S.C.p.A., Basovizza, Trieste, Italy

Molybdenum disulfide (MoS_2) is well-known to change from an indirect to a direct semiconductor as a single layer.
We present insights from in-situ low-energy electron microscopy (LEEM) on the extended growth of MoS_2 on the Au(111) surface at elevated temperatures of 720°C. Our continuous growth method leads to the formation of micron-sized single-layer MoS_2 islands. The single-domain character of these islands is confirmed by employing dark-field imaging and micro-diffraction (LEED). This also reveals the distribution of 90:10 of the two expected MoS_2 mirror domains on Au(111). Selected-area angle-resolved photoelectron spectroscopy (ARPES) measurements of these mirror domains underline the threefold symmetry of the two mirror domains and indicate the presence of MoS_2 bilayer. Using X-ray photoemission electron microscopy (XPEEM) and intensity-voltage LEEM (I(V))-LEEM we identify the bilayer nucleation areas at nearly full surface coverage and propose a model pathway for their formation.

O 105.13 Thu 13:30 P

1H-MoS_2 edge reconstructions and functionalization — •Yuman Sayed-Ahmad-Baraza[1], Ruben Canton-Vitoria[2], Mario Pelaez-Fernandez[3], Carla Bittencourt[4], Raul Arenal[3], Nikos Tagmatarchis[2], and Chris Ewels[1] — [1]Institut des Matériaux Jean Rouxel (IMN), Université de Nantes, CNRS, 2 rue de la Houssinière, BP 32229, 44322 Nantes, cedex 3, France — [2]Theoretical and Physical Chemistry Institute, National Hellenic Research Foundation, 48 Vassileos Constantinou Avenue, 11635 3 Athens, Greece — [3]Laboratorio de Microscopias Avanzadas, Instituto de Nanociencia de Aragon, Universidad de Zaragoza, 50018 Zaragoza, Spain — [4]Chimie des Interactions Plasma-Surface, University of Mons, 20 Place du Parc, 7000 Mons, Belgium

Single-layer 1H-MoS_2 presents a rich variability of edges. We present DFT studies of the structure and stability of reconstructed Mo-100%S and Mo-50%S zigzag edges [1]. For Mo-100%S we identify a family of metastable edges consisting in Mo atoms linked by disulfide ligands. For Mo-50%S, we find a lattice distortion with 3x periodicity, compatible with a Peierls' distortion and the formation of 3-centre local bonds. Additionally, we present DFT studies of the covalent functionalization of MoS_2 with 1,2-dithiolanes. We find preferential functionalisation at the edges, stable against a vacancy healing reaction; consistent with our experimental results [2]. 1. Y. Sayed-Ahmad-Baraza and C. P. Ewels, Chem. - Eur. J. 26, 6686 (2020). 2. Y. Sayed-Ahmad-Baraza, R. Canton-Vitoria, M. Pelaez-Fernandez, R. Arenal, C. Bittencourt, C. P. Ewels, and N. Tagmatarchis, Npj 2D Mater. Appl. 1, (2017).