O 54: Poster Wednesday: 2D Materials 2

Time: Wednesday 18:00–20:00 Location: P4

O 54.1 Wed 18:00 P4

Mapping angle- and doping-dependent dispersion of bending graphene — •Zhihao Jiang[1], Paulina Majchrzak[1], Bjarke Jessen[2], Maëlle Kapfer[2], Deepnarayan Biswas[1], Jose Avila[3], Pavel Dudin[3], Cory Dean[2], and Søren Ulstrup[1] — [1]Aarhus University — [2]Columbia University — [3]Synchrotron SOLEIL

The possibility to systematically engineer the interlayer rotation angle (θ) between two-dimensional (2D) materials stacked in heterostructures offers an intriguing means to tailor superlattices, electronic band structures and interactions. Here, we set out to perform a proof-of-principle nanoARPES experiment demonstrating the ability to continuously twist a graphene flake stacked on hexagonal boron nitride by tuning θ using a nano-rotation device engaged by the tip of an atomic force microscope (AFM). The overarching objective is thereby to capture the evolution of the θ-dependent electronic dispersion of graphene. Ultimately, these experiments are expected to pave the way for band structure measurements of systematically twisted heterostructures composed of bilayer graphene and monolayer dichalcogenides.

O 54.2 Wed 18:00 P4

Growth and characterization of WSe_2 on epitaxial graphene on SiC(0001) — •Adrian Schütze, Philip Schädlich, and Thomas Seyller — Institute of Physics, TU Chemnitz, Chemnitz, Germany

2D materials such as, for example, graphene, hexagonal boron nitride or transition metal dichalcogenides have recently received much interest as building blocks for electronic devices. For a successful integration of these materials, scalable growth methods are essential. In this work we investigate the growth of WSe_2 by metal organic molecular beam epitaxy (MOMBE) [1] on epitaxial graphene on SiC(0001). In that process $W(CO)_6$ is used as a precursor in conjunction with selenium vapor produced by decomposition of $SnSe_2$ in a thermal evaporator. Using MOMBE we were able to grow ultra-thin films of WSe_2 on epitaxial graphene which were characterized by a combination of X-ray photoelectron spectroscopy (XPS), angle resolved photoemission spectroscopy (ARPES), low-energy electron diffraction and microscopy (LEED, LEEM) and atomic force microscopy (AFM). The films were observed to consist of triangular domains. We discuss the influence of the growth parameters such as the substrate temperature on the structural and electronic properties of the layers.

[1] S. Tiefenbacher et al., Surf. Sci. 318 (1994) L1161

O 54.3 Wed 18:00 P4

Vanadyl phthalocyanine: study of the formation of a characteristic molecular spin pattern on a diamagnetic template — •Corina Urdaniz, Kyungju Noh, Luciano Colazzo, Jaehyun Lee, Andreas Heinrich, Christoph Wolf, Fabio Donati, and Yujeong Bae — Center for Quantum Nanoscience (QNS), IBS, Ewha Womans University, Seoul, Republic of korea

Achieving quantum coherent control of spins on surfaces at the atomic scale is the goal for quantum coherent nanoscience. A good surface spin system requires two components: a localized spin and a buffer layer to isolate that spin from the metallic substrate. The use of magnetic molecules as hosts for spin qubits is a promising pathway towards quantum information processing.

In this work, we used Vanadyl phthalocyanine (VOPc), a well-known spin = 1/2 molecule with long coherence times up to one microsecond in its crystalline form, and the non-magnetic Titanyl phthalocyanine (TiOPc) as a buffer layer from the metal. We found that TiOPc is an effective buffer layer, preserving vacuum-like electronic structure of VOPc. We present compelling arguments for using TiOPc as self-assembling templates with long-range order for adsorbed VOPc molecules. Our results suggest that the TiOPc/VOPc system is a potential candidate for long-lived molecular spin states on surfaces for the study of quantum information processing.

O 54.4 Wed 18:00 P4

Competing Processes as Quality Limitation: New Insights into Microscopic Growth Mechanism of hexagonal Boron Nitride on Ir(111) — •Marko Kriegel[1], Karim Omambac[1], Marin Petrovic[2], Birk Finke[1], Frank Meyer zu Heringdorf[1,3], and Michael Horn-von Hoegen[1] — [1]Faculty of Physics, University of Duisburg-Essen, D-47057 Duisburg, Germany — [2]Center of Cxcellence for Advanced Materials and Sensing Devices, Institude of Physics, HR-10000 Zagreb, Croatia — [3]Interdisciplinary Center for Analytics on the Nanoscale (ICAN), D-47057 Duisburg, Germany

Despite the tremendous research effort targeting industrial growth of two-dimensional hexagonal boron nitride (hBN), especially on transition metal surfaces, until today no superior growth recipe was developed, promising large domain sizes, homogeneous lattice constants and a matching orientation of layer and substrate. Here we study single layer hBN grown on Ir(111) via conventional chemical vapor deposition (CVD) using borazine as precursor. We found two competing processes governing the density of hBN domains on a microscopic scale: Kinetic limitations at low T and the disintegration of B_3N_3 rings as well as the grown layer at high T. The interplay of both processes sets a fundamental limit to the achievable quality in this and other 2D material systems. Our study combines data from high-resolution reciprocal space mapping, using Spot Profile Analyzing Low Energy Electron Diffraction (SPA-LEED), allowing us to determine the complete distribution of domain orientations, and Low Energy Electron Microscopy (LEEM), for the measure of domain densities.

O 54.5 Wed 18:00 P4

Tuning MoS_2 doping by switching its support material — •Marco Bianchi[1], Daniel Lizzit[4], Paolo Lacovig[2], Charlotte Sanders[3], Davide Curcio[1], Ezequiel Tosi[2], Monika T. Schied[2], Jill Miwa[1], Silvano Lizzit[2], and Philip Hofmann[1] — [1]Dep. of Physics and Astronomy, ASTRID2, iNANO, Aarhus University, DK. — [2]Elettra Sincrotrone Trieste S.C.p.A., Trieste, IT — [3]Artemis Program, UK Central Laser Facility, Harwell, STFC, UK — [4]DPIA - University of Udine, IT

Tuning the electronic properties of a 2D crystal by the interaction with its support is the key to design well-controlled nanoelectronic devices based on transition metal dichalcogenides (TMDCs). In particular, the establishing of a low resistance between a metallic contact and the TMDC has been challenging and different strategies for this have been introduced. It was suggested that a low Schottky barrier could be achieved not only by choosing contact materials with the suitable work function but also by introducing interface defects that can contribute independent of the metal contact work function.

Here we present a combined ARPES, STM, LEED and XPS study of MoS_2 grown on Au(111) using well established methods. After intercalation of Bi, which is semimetallic, and its further treatment we observe a doping consistent with what was inferred from recent transport measurements. The results shown here sheds light on a potential way for tuning the effects of contacts of a 2D layer and their influence on the TMDC electronic structure.

O 54.6 Wed 18:00 P4

Subnanoscale Engineering of 2D Magnetism in van der Waals Heterostructures — •Keda Jin[1,2], Jose Martinez-Castro[1,2], Stefan F. Tautz[1,3], and Markus Ternes[1,2] — [1]Institute of Physics II B, RWTH Aachen University, 52074 Aachen, Germany — [2]Peter Grünberg Institute (PGI-3), Forschungszentrum Jülich and Jülich-Aachen Research Alliance (JARA), Fundamentals of Future Information Technology, 52425 Jülich, Germany — [3]Institute of Physics IV A, RWTH Aachen University, 52074 Aachen, Germany

The dry transferred method paves a way to investigate exotic properties and emerging new phenomena in van der Waals heterostructures. Polycarbonate (PC) is commonly used as a polymer for the dry transfer of 2D materials. A limitation of PC is the contamination of chemical residues on the surface and the difficulty to fabricate complex heterostructures. Here, we show the study of different polymers, including polyvinyl chloride (PVC) and nitrocellulose for an effective and clean way to assemble 2D heterostructures. In addition, based on our previous method of studying encapsulated air-sensitive 2D materials (Nano Lett. 18, 6696 (2018)), we show our current development in a new technique to study air-sensitive materials in heterostructures compatible with ultra-high vacuum: in-situ de-encapsulation. This technique aims to provide the required cleanliness of mechanical assembled air-sensitive van der Waals heterostructures for their study by scanning tunneling microscopy at ultra-high vacuum and low temperature.

O 54.7 Wed 18:00 P4

Growth and characterization of monolayer $MnSe_2$ on Au(111) — •Sebastien Elie Hadjadj[1], Evangelos Golias[2], Jack Hayes[1], Marcel Walter[1], Christian Lotze[1], Sangeeta Thakur[1], Ivar Kumberg[1], Ismet Gelen[1], Jorge Torres[1], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]MAX IV Laboratory, Lund University, Fotongatan 2, Lund, Sweden

During the last couple of years, there has been a rising interest in novel two-dimensional magnetic materials. Most recently, several groups have shown that magnetic order in two-dimensional materials can be stable. Among them, $MnSe_2$ is interesting, since it has shown magnetic properties at room temperature [1], making it an ideal candidate for applications. However, magnetic order so far has been reported for $MnSe_2$ grown on GaSe or $SnSe_2$, and the role of the interface in the stabilization of magnetic order is not yet clear. We use molecular beam epitaxy to co-deposit Se and Mn on Au(111) to ascertain if the magnetic ordering of monolayer $MnSe_2$ is an intrinsic effect of the material or an interface-induced phenomenon. We examine the films chemically by X-ray photoelectron spectroscopy (XPS) and X-ray absorption spectroscopy (XAS) as well as structurally by scanning tunneling microscopy (STM) and low-energy electron diffraction (LEED). The latter shows a near - 3×3 pattern. The XPS measurements show chemical shifts in the Mn and Se binding energies for the $MnSe_2$ sample in comparison to pure Mn and Se that confirm that the Mn has bonded to Se. [1] D. J. O'Hara et al., Nano Letters 18, 3125 (2018).

O 54.8 Wed 18:00 P4

Towards Shot-Noise Spectroscopy of Majorana Modes in 2D Systems — •Jan Cuperus, Floris Kooij, and Ingmar Swart — Condensed Matter & Interfaces, Utrecht University, Utrecht, The Netherlands

The quasiparticles known as Majorana zero modes (MZMs) are particles that have the peculiar properties to be their own antiparticle and to obey non-Abelian statistics. Because of the latter, MZMs are predicted to be the building blocks of topological quantum computing. Over the past years, many signatures of what could be MZMs have been reported. Examples are the end modes of 1D atomic line defects in ML FeSe [1], or the edge modes found on CrBr3 island grown on NbSe2 [2]. Conclusive observations are however, still to be made. One reason for this is the similarity of MZMs to other (close-to-)zero-energy states, e.g. Yu-Shiba-Rusinov states or Andreev bound states. Scanning tunnelling microscopy (STM) has already shown to be a key tool in the field of condensed matter physics because of its extreme spatial resolution and spectroscopic abilities. Via a new STM-based tool, namely shot-noise spectroscopy, we aim to provide a new point of view onto the matter of MZMs.

References: [1]Chen et al., Nat. Phys., 16, 536-540 (2018) [2]Kezilebieke et al., Nature, 588, 424-428 (2020)

O 54.9 Wed 18:00 P4

The tellurization of Cu(111): From incorporated Te atoms via 1D-like surface reconstructions to closed films — •Andreas Raabgrund, Tilman Kisslinger, Maximilian Ammon, Lutz Hammer, and M. Alexander Schneider — Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

We investigated the tellurization of Cu(111) from low Te coverages up to thick films both structurally and electronically by STM, STS, LEED-IV structural analysis, and DFT. For $\Theta < 0.14$ ML Te forms a substitutional surface alloy with short-range ordered patches of a $(\sqrt{7} \times \sqrt{7})$R19.1° structure. Increasing the Te coverage leads to coexisting islands of a $(3 \times \sqrt{3})_{\mathrm{rect}}$ superstructure which is well-ordered and fully developed at $\Theta = 0.33$ ML [1]. In the range $0.33\,\mathrm{ML} < \Theta < 0.40\,\mathrm{ML}$, the $(3 \times \sqrt{3})_{\mathrm{rect}}$ structure coexists next to a well-ordered $(5 \times \sqrt{3})_{\mathrm{rect}}$ phase which is completely developed at $\Theta = 0.40$ ML [2]. Our LEED-IV analyses reveal arrangements of Cu_2Te_2 chains, whereby for the $(5 \times \sqrt{3})_{\mathrm{rect}}$ phase a substantial reorganization of the surface into troughs allows to incorporate more Te. STS finds an unoccupied chain state, that has lower energy on the $(3 \times \sqrt{3})_{\mathrm{rect}}$ which we interpret as an indication of delocalization with decreasing interchain distance. By further tellurization beyond $\Theta = 1.1$ ML closed $Cu_{2-x}Te$ films develop. For $\Theta > 4$ ML, a phase transition takes place below 300 K that results in a wrinkled appearance at low temperatures. On the surface two different reconstructions with distinct electronic fingerprint occur side-by-side. [1] T. Kißlinger et al., Phys. Rev. B **102**, 155422 (2020)

[2] T. Kißlinger et al., Phys. Rev. B **104**, 155426 (2021)

O 54.10 Wed 18:00 P4

Fabrication of nanostructured van der Waals heterostructures — •Khairi F. Elyas[1], Johanna Richter[3], Kirill Bolotin[3], Hannah C. Nerl[2], and Katja Höflich[1] — [1]Ferdinand Braun Institut gGmbH, Berlin, Germany — [2]Humboldt Universität zu Berlin, Institute of Physics, Berlin, Germany — [3]Freie Universität Berlin, Institute of Experimental Physics, Berlin, Germany

Two-dimensional (2D) materials can exhibit a significantly enhanced light-matter interaction making them interesting for highly-confined and low-loss light transport. When combining different 2D materials, the different polaritonic modes may hybridize to combine the strong localization of plasmonic excitations with the long propagation distances of phonon modes. Here we report on the fabrication of heterostructures of the (semi)metallic graphene and the wide-bandgap material hexagonal boron (hBN) nitride. The dry-release transfer of graphene and hBN makes use of polydimethylsiloxane(PDMS) and poly(propylene) carbonate (PPC) films. Due to the strong adhesion between PPC and 2D materials at room temperature, we show that single-layer to few-layer graphene as well as few-layer hBN can be produced on a spin coated PPC film/SiO2/Si substrates by mechanical exfoliation. Using He ion beam patterning we further modify the geometry of the heterostructures on the nanoscale with the specific aim to tune hybrid polaritonic modes. The optical properties of the fabricated heterostructures are then mapped using monochromated low-loss scanning transmission electron microscopy (STEM) electron energy-loss spectroscopy (EELS)and outcomes compared to optical methods.

O 54.11 Wed 18:00 P4

Interlayer charge transport anomalies in 1T-TaS_2 and 2H-NbS_2 — Edoardo Martino, László Forró, and •Konstantin Semeniuk — Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland

Layered van der Waals materials, such as transition metal dichalcogenides, have emerged as promising platforms for realising functional materials for practical applications. Tuning interlayer coupling in these systems via twist, intercalation, exfoliation, etc. opens up a vast parameter space for inducing exploitable properties. Probing of the out-of-plane conduction is a useful tool for gauging the subtle interactions between the atomic planes, particularly in bulk crystals of TMDs.

We present comprehensive studies of charge transport anisotropies of bulk 1T-TaS_2 and 2H-NbS_2. The samples were tailored using focused ion beam in order to ensure homogeneous current flow across the principal crystallographic directions. We find that resistivity anisotropy of 1T-TaS_2 is, paradoxically, of the order of unity, with the out-of-plane conduction becoming more preferred at lower temperatures due to a formation of c-axis-oriented quasi-one-dimensional orbital chains. In 2H-NbS_2, we observe a pronounced upturn of the out-of-plane resistivity upon cooling. We attribute the anomaly to a unidirectional Kondo scattering, caused by inherent inclusions of 1T-NbS_2 layers, which host a lattice of singly occupied orbitals.

[1] E. Martino et al., npj 2D Mater. Appl., **4**, 7 (2020).
[1] E. Martino et al., npj 2D Mater. Appl., **5**, 86 (2021).

O 54.12 Wed 18:00 P4

STM studies of graphene encapsulated Fe3GeTe2 — •Tobias Wichmann[1,2,3], Felix Lüpke[1,2], and F. Stefan Tautz[1,2,3] — [1]Peter-Grünberg-Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA) - Fundamentals of Future Information Technology, Germany — [3]Institut für Experimentalphysik IV, RWTH Aachen, Germany

Fe_3GeTe_2 is a metallic 2D ferromagnet with a Curie Temperature of 130K, in which Kondo effect and skyrmions have been observed. These properties make it a promising candidate as a source of magnetic proximity effect in van der Waals heterostructures.

To examine its potential use in in van der Waals heterostructures we investigated the influence on adjacent layers of 2D materials through encapsulation with graphene. The resulting structure was characterized in a low temperature STM.

O 54.13 Wed 18:00 P4

Fabrication of nanostructured van der Waals heterostructures — •Khairi F. Elyas[1], Johanna Richter[3], Kirill Bolotin[3], Hannah C. Nerl[2], and Katja Höflich[1] — [1]Ferdinand Braun Institut gGmbH, Berlin, Germany — [2]Humboldt Universität zu Berlin, Institute of Physics, Berlin, Germany — [3]Freie Universität Berlin, In-

stitute of Experimental Physics, Berlin, Germany

Two-dimensional (2D) materials can exhibit a significantly enhanced light-matter interaction making them interesting for highly-confined and low-loss light transport. When combining different 2D materials, the different polaritonic modes may hybridize to combine the strong localization of plasmonic excitations with the long propagation distances of phonon modes. Here we report on the fabrication of heterostructures of the singlecrystalline gold flakes or graphene and the wide-bandgap material hexagonal boron (hBN) nitride. Polydimethylsiloxane(PDMS) and poly(propylene) carbonate (PPC) films were used for the dry transfer of gold and hBN due to the strong adhesion between PPC and 2D materials at room temperature. Using this method, single-layer to few-layer hBN were successfully transferred. Using He ion beam patterning we further modify the geometry of the heterostructures on the nanoscale with the specific aim to tune hybrid polaritonic modes. The optical properties of the fabricated heterostructures are then mapped using monochromated low-loss scanning transmission electron microscopy (STEM) electron energy-loss spectroscopy (EELS)and outcomes compared to optical methods.

O 54.14 Wed 18:00 P4

Carbon Embedding of Pt Cluster Superlattices Templated by Hexagonal Boron Nitride on Ir(111) — •Tobias Hartl[1], Moritz Will[1], Pantelis Bampoulis[1,2], Virginia Boix de la Cruz[3], Paolo Lacovig[4], Vedran Vonk[5], Simon Chung[5], Andreas Stierle[5], Jan Knudsen[3], Silvano Lizzit[4], and Thomas Michely[1] — [1]Universität zu Köln — [2]University of Twente — [3]MAX IV Laboratory and Division of Synchrotron Radiation Research — [4]Elettra-Sincrotrone Trieste S.C.p.A — [5]DESY Hamburg

With the goal to delevop the fabrication of a new type of Pt-nanoparticle carbon support electrocatalyst, we investigate the carbon embedding of Pt cluster superlattices grown on the moiré of a monolayer of h-BN on Ir(111). Using STM and XPS we find that carbon embedding is conformal and does not deteriorate the excellent order of the clusters. The thermal and mechanical stability of the embedded clusters is greatly enhanced by the C forming a strong binding to the Pt clusters. Sintering as well as single cluster pick-up by the STM tip, are both suppressed. (Hartl, T. et al., J. Phys. Chem. C, 2021)

The only cluster decay path left takes place at an elevated temperature above 850 K. Cluster material penetrates through the h-BN sheet, whereby it becomes bound to the underlying metal. There are indications that while the a-C matrix and the Pt clusters bind strongly to each other, upon annealing both weaken their binding to h-BN.

We discuss how the binding between the membrane and the substrate can be weakened, such that it is possible to be split-off via a combination of hydrogen bubbling and dry transfer approaches.