

O 65: 2D Materials 2: Growth, Structure and Substrate Interaction

Time: Thursday 10:30–12:30

Location: S052

O 65.1 Thu 10:30 S052

Segregation-enhanced epitaxy of borophene on Ir(111) by thermal decomposition of borazine — ●KARIM OMAMBAC¹, MARKO KRIEGEL¹, MARIN PETROVIC^{1,2}, PANTELIS BAMPOULIS⁴, CHRISTIAN BRAND¹, PASCAL DREHER¹, DAVID JANOSCHKA¹, ULRICH HAGEMANN³, NILS HARTMANN³, PHILIPP VALERIUS⁴, THOMAS MICHELY⁴, FRANK-J. MEYER ZU HERINGDORF^{1,3}, and MICHAEL HORN-VON HOEGEN¹ — ¹Universität Duisburg-Essen, Germany — ²Institute of Physics, 10000 Zagreb, Croatia — ³Interdisciplinary Center for the Analytics on the Nanoscale, Germany — ⁴Universität zu Köln, Germany

While borophene is typically prepared by molecular beam epitaxy [1], we report here on an alternative way of synthesizing large single-phase borophene domains by segregation enhanced epitaxy. X-ray photoelectron spectroscopy shows that borazine dosing at 1100°C onto Ir(111) yields a boron-rich surface without traces of nitrogen. At high temperatures the borazine thermally decomposes, nitrogen desorbs, and boron diffuses into the substrate. Using time-of-flight secondary ion mass spectroscopy we show that during cooldown the sub-surface boron segregates back to the surface where it forms borophene. In this case electron diffraction reveals a (6x2) reconstructed borophene χ_6 -polymorph [1], and scanning tunneling spectroscopy suggests a Dirac-like behavior. Studying the kinetics of borophene formation in low energy electron microscopy shows elongated and extended borophene domains with exceptional structural order. [1] ACS Nano 13 (12), 14511-14518 (2019).

O 65.2 Thu 10:45 S052

Investigation of sub-monolayer Sn phases on Au(111) — ●JULIAN ANDREAS HOCHHAUS^{1,2}, LUKAS KESPER^{1,2}, STEFANIE HILGERS¹, ULF BERGES^{1,2}, and CARSTEN WESTPHAL^{1,2} — ¹Technische Universität Dortmund, Fakultät Physik, Otto-Hahn-Str. 4, D-44227, Dortmund, Germany — ²DELTA, TU Dortmund, Maria-Goeppert-Mayer-Str. 2, D-44227, Dortmund, Germany

In this study we investigate the temperature and layer thickness dependence of sub-monolayer phases of Sn on Au(111). Stanene, the two-dimensional graphene analog of tin, is predicted to exhibit similar exceptional electronic properties. Since tin is one of the heavier elements in the carbon group, stanene exhibits topological properties even at RT due to its strong spin-orbit coupling. Therefore, stanene is a promising material for application in future two-dimensional topological devices.

Since the surface and interface structure of low-dimensional materials often influences their electronic properties, we focus on the structural and chemical analysis of the Sn/Au interface.

Here, we report a structural and chemical investigation of different sub-monolayer Sn phases on Au(111) by means of low energy electron diffraction (LEED) and photoelectron spectroscopy (XPS). Tin layers of different thicknesses were deposited gradually on the Au(111) surface by physical vapor deposition and subsequently heated. A strong dependence of the structural and chemical configuration of the tin atoms on the layer thickness and the post-deposition annealing temperature was observed.

O 65.3 Thu 11:00 S052

On the transition from MoS₂ single-layer to bilayer growth on the Au(111) surface — ●MORITZ EWERT¹, LARS BUSS¹, FRANCESCA GENUZZIO³, TEVFIK ONUR MENTES³, ANDREA LOCATELLI³, JENS FALTA², and JAN INGO FLEGE¹ — ¹Applied Physics and Semiconductor Spectroscopy, Brandenburg University of Technology Cottbus-Senftenberg, Germany — ²Institute of Solid State Physics, University of Bremen, Germany — ³Elettra-Sincrotrone Trieste S.C.p.A., Basovizza, Trieste, Italy

MoS₂ is well known for changing from an indirect to a direct band-gap semiconductor as a single layer. Here, for the model system MoS₂/Au(111), we present in-situ studies of the continued growth of micron-size single-layer MoS₂ islands including the first formation of bilayer patches.

We have used angle-resolved photoemission spectroscopy from micrometer sized regions to investigate the local band structure of the islands' rims and centers, showing a prevalence for bilayer and single-layer formation at the rims and centers, respectively. The bilayer

patches can clearly be identified locally on the few nanometer scale employing intensity-voltage low-energy electron microscopy as a fingerprinting method. Astonishingly, micro-spot low-energy electron diffraction hints toward the nucleation of the second layer of the MoS₂ between the single layer MoS₂ and the Au(111) substrate when the step bunches formed by the single-terrace growth mechanism become sufficiently high.

O 65.4 Thu 11:15 S052

Structural and electronic investigations of CVD-grown TMDs on Au(111) — ●JULIAN PICKER¹, MAXIMILIAN SCHAAL², ZIYANG GAN¹, MARCO GRUENEWALD², CHRISTOF NEUMANN¹, ANTONY GEORGE¹, FELIX OTTO², TORSTEN FRITZ², and ANDREY TURCHANIN¹ — ¹Institute of Physical Chemistry, Friedrich Schiller University Jena, Lessingstraße 10, 07743 Jena, Germany — ²Institute of Solid State Physics, Friedrich Schiller University Jena, Helmholtzweg 5, 07743 Jena, Germany

Transition metal dichalcogenides (TMDs) are layered two-dimensional (2D) materials which have come into the focus of research in recent years. Especially, the exciting change of properties when going from bulk to monolayer make them interesting for novel electronic applications. Here, we demonstrate the *ex-situ* growth of MoS₂ and MoSe₂ monolayers on Au(111) by chemical vapor deposition (CVD) in a two-zone furnace. Afterwards, the samples were analyzed in ultra-high vacuum (UHV) with the help of surface sensitive methods, including (low-temperature) scanning tunneling microscopy and spectroscopy (STM/STS), low-energy electron diffraction (LEED) as well as X-ray and angle-resolved ultra-violet photoelectron spectroscopy (XPS/ARPES). While we could confirm the growth of high-quality single crystalline TMDs, we also accessed the structural and electronic properties of these samples down to the atomic scale. Finally, the impact of annealing on the structure and properties of the TMDs was studied.

O 65.5 Thu 11:30 S052

Spectroscopic and microscopic study of carborane based 2D materials — ●MARTHA FREY¹, JULIAN PICKER¹, JAKUB VIŠŇÁK², CHRISTOF NEUMANN¹, TOMÁŠ BAŠE², and ANDREY TURCHANIN¹ — ¹Friedrich Schiller University Jena, Institute of Physical Chemistry, Lessingstraße 10, 07743 Jena, Germany — ²The Czech Academy of Sciences, Institute of Inorganic Chemistry, 250 68 Husinec-Rez, c.p. 1001, Czech Republic

Carboranes are electron-delocalized molecular clusters containing boron, carbon and hydrogen. Because of their high stability and structural variability, they are interesting for a wide range of applications including nanoscale engineering, catalysis and boron neutron capture therapy. Here, we present the fabrication of a novel boron-based two-dimensional (2D) material *via* electron irradiation induced cross-linking of carborane self-assembled monolayers (SAMs) on silver or gold substrates. The SAMs, the cross-linking process and the resulting 2D nanosheets have been characterized with different complementary surface sensitive techniques including X-ray photoelectron spectroscopy (XPS), low-energy electron diffraction (LEED), scanning tunneling microscopy (STM) and scanning electron microscopy (SEM).

O 65.6 Thu 11:45 S052

Growth and Structural Properties of 2D Blue Phosphorene on Au(111) and on Au(100) — ●MAXIMILIAN SCHAAL¹, JULIAN PICKER², FELIX OTTO¹, MARCO GRUENEWALD¹, ROMAN FORKER¹, and TORSTEN FRITZ¹ — ¹Institute of Solid State Physics, Friedrich Schiller University Jena, Helmholtzweg 5, 07743 Jena, Germany — ²Institute of Physical Chemistry, Friedrich Schiller University Jena, Lessingstraße 10, 07743 Jena, Germany

Blue phosphorene (BlueP) is a novel two-dimensional material that shares properties with black phosphorene and is potentially even more interesting for optoelectronic applications because of its layer dependent band gap of approx. 2 to 3 eV and superior charge carrier mobility [1]. Despite these promising properties, the growth of quasi-freestanding BlueP is still challenging.

In our contribution we will report on the structural and electronic properties of epitaxial BlueP on Au(111) and on Au(100) by means of scanning tunneling [hydrogen] microscopy (ST[H]M), distortion-corrected

low-energy electron diffraction (LEED) as well as X-ray photoelectron spectroscopy and diffraction (XPS and XPD). It is already known that on Au(111) a network consisting of BlueP islands, which are connected by Au linker atoms, is formed [2]. In contrast, we demonstrate that on Au(100) quasi-free standing BlueP domains grow [3].

[1] Z. Zhu and D. Tománek, Phys. Rev. Lett. 112, 176802 (2014).

[2] H. Tian et al., Matter 2, 111 (2020).

[3] M. Schaal, J. Phys.: Condens. Matter 33, 485002 (2021).

O 65.7 Thu 12:00 S052

How the supple Pt(110) surface paves the way to single-domain h-BN growth. — ●MARCO THALER¹, DOMINIK STEINER¹, FLORIAN MITTENDORFER², and ERMALD BERTEL¹ — ¹Department of Physical Chemistry, University of Innsbruck, Austria — ²Institute of Applied Physics and Center for Computational Materials Science, Vienna University of Technology, Austria

Its structural flexibility renders Pt(110) an extraordinary substrate for hexagonal boron nitride (h-BN) growth. Borazine-exposure at high temperature yields either an extended film or empty terraces depending on dosage. Annealing preadsorbed Borazine, in contrast, yields nuclei with a structure differing from the extended film. DFT modelling of the latter was carried out by starting with a stretched film, which ruptured upon relaxation into smaller h-BN islands. The Pt surface layer below them is severely disordered. Only after high-T annealing the islands relax into the final h-BN/Pt(110)-(1xn) missing-row configuration. Thus, this non-classical, two-step nucleation proceeds via a metastable transition structure. Under the conditions of high-T exposure the metastable nuclei are continuously dissolved by desorption and H-induced etching. Stochastic formation of a critical island size with the more stable (1xn)m.r. structure requires a high supersaturation, but once formed, such an island grows explosively into an

extended film. Hence, single-domain growth of h-BN on Pt(110) differs significantly from that on vicinal Cu(110), where (1-12) step edges act as nucleation sites giving rise to uniform nuclei capable of seamless coalescence.

O 65.8 Thu 12:15 S052

Development of strain- and gate-controllable STM sample holder — ●JZ-YUAN JUO¹, BONG GYU SHIN¹, SOON JUNG JUNG¹, and KLAUS KERN^{1,2} — ¹Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, DE-70569 Stuttgart, Germany — ²Institut de Physique, École Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

An atomic-scale understanding of strain effects on electronic properties is essential for implementing two-dimensional materials into flexible electronics. The scanning tunneling microscopy (STM) is an ideal method to advance this understanding. However, the combination of STM and strain-controllable devices remains challenging due to the high demand for compatibilities with limited STM space, ultrahigh vacuum, and mechanical stability. We have developed an indentation-based sample holder for STM measurements. A gearbox and a piezo stack were used to control the distance between the indenter and 2D materials transferred on the suspended polyimide. The gearbox has a travel range of $\sim 120 \mu\text{m}$ and precision of $\sim 1.4 \mu\text{m}$; the piezo stack has a travel range of $\sim 1.8 \mu\text{m}$ and precision of $< 1 \text{ nm}$. The combination of gearbox and piezo stack allowed us to tune the distance between indenter and sample continuously with nanometer precision, characterized by atomic force microscopy. Raman spectroscopy was used to measure strain distribution in monolayer MoS₂ at the indented area. The strain controllability is characterized by calculating graphene lattice constant changes in STM atomic-resolution images. Spectroscopic studies confirm the gate tunability by observing Dirac point shifts.