# O 47: Electronic Structure of Surfaces: Spectroscopy, Surface States

Time: Tuesday 18:15–20:30 Location: Poster E

O 47.1 Tue 18:15 Poster E

**Step and terrace conductivity of Ag/Si(111)-($\sqrt{3} \times \sqrt{3}$) and Si(111)-($7 \times 7$) measured by scanning tunneling potentiometry** — •Felix Lüpke, Stefan Korte, Vasily Cherepanov, and Bert Voigtländer — Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany, and JARA-Fundamentals of Future Information Technology

We investigate the local electric potential of Ag($\sqrt{3} \times \sqrt{3}$) and ($7 \times 7$) reconstructed Si(111) surfaces by means of scanning tunneling potentiometry: Two tips of a multi-tip scanning tunneling microscope inject a lateral current into the sample under investigation while a third tip is scanned across the sample surface measuring the topography and local potential simultaneously. From the measured sample geometry and potential distribution on its surface we extract surface and step conductivities.

O 47.2 Tue 18:15 Poster E

**Local Tunneling Decay Length and Kelvin Probe Force Spectroscopy** — •Florian Albrecht[1], Martin Fleischmann[2], Manfred Scheer[2], Leo Gross[3], and Jascha Repp[1] — [1]Institute of Experimental and Applied Physics, University of Regensburg, 93053 Regensburg, Germany — [2]Institute of Inorganic Chemistry, University of Regensburg, 93053 Regensburg, Germany — [3]IBM Research - Zurich, 8803 Rüschlikon, Switzerland

Current-distance spectroscopy has been widely applied to determine variations of the work function at surfaces. While for homogeneous sample areas this technique is commonly accepted to yield at least qualitative results, its applicability to atomic-scale variations has not been proven neither right nor wrong. Here we benchmark current-distance decay constant measurements against the well established Kelvin probe force spectroscopy method for distinctly different cases with atomic-scale variations of the local contact potential. Whereas the maps of the current-distance decay constant are consistent with being topographical artifacts, the Kelvin probe force spectroscopy maps show variations of the local contact potential difference in agreement with expected surface dipoles. This comparison clarifies that maps of the current-distance decay constant are not suited to directly characterize contact potential variations at surfaces on atomic length scales.

O 47.3 Tue 18:15 Poster E

**Force and Kelvin Probe Measurements on Confined Electronic States inside Quantum Resonators** — •Fabian Queck, Florian Albrecht, and Jascha Repp — Institute of Experimental and Applied Physics, University of Regensburg, 93053 Regensburg, Germany

On close-packed surfaces of noble metals such as Cu(111) surface state electrons form a nearly free electron gas in two dimensions. The electrons are scattered from step-edges, point defects and adsorbates giving rise to standing wave patterns, which can be engineered by so-called quantum corrals (1). The standing wave patterns give rise to long range interactions between adsorbates (2) and should therefore be associated with measurable forces between scatterers.

At last year*s DPG meeting we presented preliminary results to directly measure these forces with atomic force microscopy and possible changes of the local contact potential difference arising from the modulation of the surface local density of states associated with the standing wave patterns. Here, we will present much more detailed atomic force microscopy and Kelvin probe spectroscopy data on this topic as well as electron density simulations that confirm our results.

(1) M. F. Crommie, C. P. Lutz, and D. M. Eigler. Confinement of Electrons to Quantum Corrals on a Metal Surface. Science, 262(5131):218*220, 1993.

(2) J. Repp. Rastertunnelmikroskopie und -spektroskopie an Adsorbaten auf Metall und Isolatoroberflaechen. PhD thesis, Freie Universitaet Berlin, 2002.

O 47.4 Tue 18:15 Poster E

**Long-Lived Excited States in Porphyrin Nanostructures** — •Hannes Hartmann[1], Ingo Barke[1], Alexej Friedrich[1], Per-Arno Plötz[1], Kevin Oldenburg[1], Johannes A.A.W. Elemans[2], Mohammadreza Bahrami[1], Karl-Heinz Meiwes-Broer[1], Oliver Kühn[1], Stefan Lochbrunner[1], and Sylvia Speller[1] — [1]University of Rostock, Institute of Physics, 18059 Rostock, Germany — [2]Radboud University Nijmegen, Institute for Molecules and Materials, 6525 AJ Nijmegen, The Netherlands

Long-lived excitons are a promising pathway for energy transfer over long distances. Here we show that self-organized porphyrin nanostructures host excited states with surprisingly long lifetimes. The molecule aggregates are investigated by spatially and time-resolved photoemission electron microscopy (PEEM). While time-resolved fluorescence spectroscopy reveals lifetimes in the nanosecond range, additional decay processes are observed by PEEM with substantially longer time constants. These optically dark states may enable an efficient energy transport channel within the aggregates.

O 47.5 Tue 18:15 Poster E

**Towards ToF Momentum Microscopy With CW Sources Using an Ultrafast Chopper Scheme** — •Anna Zaporozhchenko[1,2], Olena Fedchenko[1], Katerina Medjanik[3,1], Sergej Chernov[1], Andreas Oelsner[4], Hans-Joachim Elmers[1,2], and Gerd Schönhense[1,2] — [1]Institut für Physik, JOGU, 55099 Mainz, Germany — [2]Graduate School of Excellence MAINZ, 55128 Mainz, Germany — [3]Lund University, MAX IV Laboratory, 22100 Lund, Sweden — [4]Surface Concept GmbH, 55124 Mainz, Germany

The use of time-of-flight techniques for high-resolution spectroscopy and momentum microscopy requires a defined time structure of the photon beam. The time resolution of 3D (x,y,t)-resolving detectors, e.g. the delay-line detector, is typically 150 ps [1]. Thus a period of the exciting photon pulses of 200 ns (pulse rate of 5 MHz) yields more than 1000 time slices, sufficient for high-resolution spectroscopy. We developed an ultrafast electron-optical deflector system capable of chopping the desired pulse repetition rate out of a faster pulse train or even out of a continuous-wave signal. A first experiment with a laboratory He source was performed. In the first prototype pulse profiles of 2 ns width have been achieved. One goal is to chop lower pulse rates from the 100 or 500 MHz multibunch signal of storage rings. The current status of this development will be shown. Funded by BMBF (05K13UM1)

O 47.6 Tue 18:15 Poster E

**Investigation of Coronene Thin-Films on Ag(111) Using Photoelectron Spectroscopy** — •Christian Udhardt, Felix Otto, Tino Kirchhübel, Falko Sojka, Tobias Hümpfner, Bernd Schröter, Roman Forker, and Torsten Fritz — Institute of Solid State Physics, Friedrich Schiller University Jena, Helmholtzweg 5, 07743 Jena, Germany

Several metal-intercalated aromatic hydrocarbons, including potassium intercalated coronene, were found to have superconductive properties [Kubozono et. al, Phys. Chem. Chem. Phys. **13**, 16476 (2011)]. Preparing and investigating the organic materials as thin films on various substrates can give access to the underlying mechanisms of the observed superconductivity and make the materials available for a potential use in electronic devices. Here we characterized the electronic structure of the coronene molecules prepared as thin films in the monolayer range on Ag(111) using ultraviolet and X-ray photoelectron spectroscopy (UPS and XPS). Comparing the results of $k_x$, $k_y$ -dependent UPS measurements with those from low-energy electron diffraction (LEED) and density functional theory (DFT) calculations we were able to reconstruct the alignment of the coronene molecules with respect to the Ag(111) surface. Results after doping the films with potassium are presented as well.

O 47.7 Tue 18:15 Poster E

**Low temperature scanning tunneling microscopy investigation of the phase change material $Ge_2Sb_2Te_5$** — •Daniel Montag[1], Jens Kellner[1], Christian Pauly[1], Marcus Liebmann[1], Alessandro Giussani[2], Volker Deringer[3], Raffaella Calarco[2], Richard Dronskowski[3], and Markus Morgenstern[1] — [1]II. Physikalisches Institut B, RWTH Aachen University, Germany — [2]Paul Drude Institut für Festkörperelektronik, Berlin, Germany — [3]Institute of Inorganic Chemistry, RWTH Aachen University, Germany

We present a scanning tunneling microscopy (STM) study of the phase change material $Ge_2Sb_2Te_5$ (GST), epitaxially grown on Si(111) in the

metastable cubic phase and transferred in-situ in ultrahigh vacuum from the molecular beam epitaxy system to the STM. Despite the fact that GST is already commercially used, there is still no complete understanding of the ultra fast switching speed, the strong resistance change, and the high endurance of the Ge-Sb-Te alloys. One contribution to such a theory is an atomic scale understanding of the electronic properties of GST including the disorder caused by the relatively high vacancy content in the GeSb layers. We present $\frac{dI}{dV}$-field measurement on the atomic scale conducted at 8K. The analysis shows spatial fluctuations of the valence band onset and the gap width, wich is probably related to a random distribution of the Ge and Sb atoms. Moreover, particular structures within the STM images probing mainly the surface Te layer are compared with density functional theory calculations.

O 47.8 Tue 18:15 Poster E

**Fermi surface mapping of the phase change material $Ge_2Sb_2Te_5$ by photoelectron spectroscopy** — •Jens Kellner[1], Marcus Liebmann[1], Christian Pauly[1], Jos Boschker[2], Rui Ning Wang[2], Evangelos Golias[3], Jaime Sanchez-Barriga[3], Oliver Rader[3], Raffaella Calarco[2], and Markus Morgenstern[1] — [1]II. Physikalisches Institut B, RWTH Aachen — [2]Paul Drude Institut für Festkörpelektronik, Berlin — [3]Helmholtz-Zentrum, BESSY, Berlin

Phase change materials (PCM) have become essential components of optical memories (DVD-RW, Blu-ray Disc, ...) and they are important candidates for future non-volatile computer memories. Understanding the fundamental electronic properties would thus be important to improve the phase change characteristics. We present an angle-resolved photoemission (ARPES) study of the ternary PCM $Ge_2Sb_2Te_5$, epitaxially grown on Si(111) in the metastable cubic phase. The sample was transferred in-situ in ultrahigh vacuum from the molecular beam epitaxy system to the analysis chamber, where we performed a three-dimensional mapping of the band structure by variation of the photon energy (15-31 eV). The states close to the Fermi energy, which are contributing to the transport, are used to construct three-dimensional constant energy surfaces mimicking the Fermi surface relevant for the metallic conductivity of the crystalline phase. Additional spin-polarized ARPES measurements identify a surface state close to the Fermi level with a spin polarization of nearly 100%.

O 47.9 Tue 18:15 Poster E

**Investigation of the Potassium-Doping of Tetraphenyldibenzoperiflanthene (DBP) on Ag(111) by Photoelectron Spectroscopy** — •Felix Otto, Christian Udhardt, Tino Kirchhuebel, Bernd Schroeter, Roman Forker, and Torsten Fritz — Institute of Solid State Physics, Friedrich Schiller University Jena, Helmholtzweg 5, 07743 Jena, Germany

Tetraphenyldibenzoperiflanthene (DBP, $C_{64}H_{36}$) has been explored for some years because of its possible use in organic electronics [1]. DBP consists of an aromatic backbone with four phenyl rings attached nearly perpendicular to the molecular plane. We analysed the change of electronic properties due to the doping process of this organic dye with potassium. Special attention is paid to the possible adsorption sites of the potassium atoms in the organic/inorganic heterosystem. We used *in situ* differential reflectance spectroscopy (DRS) to determine changes of the optical properties due to the potassium deposition [2, 3]. These results are compared with x-ray (XPS) and ultraviolet photoelectron spectroscopic (UPS) measurements to elucidate the charge transfer between the alkali metal and DBP. Furthermore effects on the electronic structure are discussed in terms of lowest unoccupied molecular orbital (LUMO) filling and the evolution of an interface dipole.

[1] J. D. Debad *et al.*, J. Am. Chem. Soc. **118**, 2374 (1996).

[2] R. Forker and T. Fritz, Phys. Chem. Chem. Phys. **11**, 2142 (2009).

[3] R. Forker *et al.*, Annu. Rep. Prog. Chem., Sect. C: Phys. Chem. **108**, 34 (2012).

O 47.10 Tue 18:15 Poster E

**Thickness dependent electronic structure and Kondo resonance of $CePt_5$ on Pt(111)** — •Katharina Treiber, Henriette Maass, Holger Schwab, Hendrik Bentmann, and Friedrich Reinert — Experimentelle Physik VII, Universität Würzburg, 97074 Würzburg

At low temperatures local interactions between Ce *4f*— and conduction electrons in thin films of $CePt_5$ on Pt(111) lead to a spectral feature at the Fermi surface — the Kondo resonance [1]. At even lower temperatures heavy quasiparticles interact and form coherent heavy fermion bands at the Fermi-level [2]. Whereas previous studies showed that the $CePt_5$ surface alloy appears in a variety of different phases depending on Ce coverage and post annealing procedure [3], most photoemission studies have been carried out on a phase occurring at a surface coverage of four unit cells $CePt_5$ on Pt(111).

In this contribution we examine the electronic structure of the different surface phases by angle-resolved photoemission (ARPES) at low temperatures considering Fermi surface, Kondo resonance and bandstructure. Furthermore, we explore the Kondo temperature which recently has been suggested to show a dependency on the $CePt_5$ film thickness on the basis of x-ray absorption spectroscopy and x-ray magnetic circular dichroism studies [4].

[1] M. Garnier *et al.*, Phys. Rev. B **56**, R11399(R), (1997)

[2] M. Klein *et al.*, Phys. Rev. Lett. **106**, 186407, (2011)

[3] J. Tang *et al.*, Phys. Rev. B **15**, 15342, (1993)

[4] C. Praetorius *et al.*, Phys. Rev. B **92**, 045116, (2015)

O 47.11 Tue 18:15 Poster E

**Spin-orbit interaction in Pb monolayers on Si(111)** — •Christian Brand[1], Haiyue Liu[1], Philipp Kröger[1], Herbert Pfnür[1], Gabriel Landolt[2,3], Jan-Hugo Dil[2,4], Stefan Muff[2,4], Michael C. Tringides[5], and Christoph Tegenkamp[1] — [1]Leibniz Universität Hannover, Germany — [2]Swiss Light Source, Villigen, Switzerland — [3]Universität Zürich, Switzerland — [4]École Polytechnique Fédérale de Lausanne, Switzerland — [5]Ames Laboratory & Iowa State University, Ames, USA

Atomic monolayers (ML) of Pb/Si(111) have recently been found to be superconducting below $T_C \approx 1.6\,K$, but the mechanism behind the evolution of these 2d states is yet not understood. In the range from $6/5\,ML$ to $4/3\,ML$ supercells consisting of linear combinations of $\sqrt{7}\times\sqrt{3}$ and $\sqrt{3}\times\sqrt{3}$ unit cells are formed (so-called Devil's staircase regime). This allows us to the tune spin-orbit interaction (SOI), the electronic and atomic structure via adsorption of minute amounts of Pb. In this study we present (SR)-ARPES, DC-, and magneto-transport measurements at low $T$ ($> T_C$) to evaluate the influence of SOI on the Pb surface states. As derived from magneto-transport weak-antilocaization occurs indicating strong SOI, while Hall resistance slopes shows pure $n$-type conductivity. The carrier concentrations agree well with EDCs from ARPES, while SR-MDCs reveal a complex spin-texture at $E_F$ in Pb surface states around the surface high symmetry points. Moreover, Pb induced high Schottky barriers at highly $n$-doped substrates reveal new insights into hybridization of Si bulk states in valence band by confinement effects near the surface.

O 47.12 Tue 18:15 Poster E

**Scanning Tunneling Microscopy study of a newly proposed Topological Insulator $ZrTe_5$** — •Timo Kuhn[1], Luca Gragnaniello[1], Gabriel Autès[2], Giulia Manzoni[4], Alberto Crepaldi[3], Fulvio Parmigiani[3], Helmuth Berger[2], Oleg Yazyev[2], and Mikhail Fonin[1] — [1]Universität Konstanz, Universitätsstraße 10, 78464 Konstanz, Germany — [2]Institute of Condensed Matter Physics, Ecole Polytechnique Fédérale de Lausanne (EPFL), CH-1015 Lausanne, Switzerland — [3]Elettra-Sincrotrone Trieste, Strada Statale 14, 34149 Basovizza, Trieste, Italy — [4]Universitá degli Studi di Trieste, Via A. Valerio 2, Trieste 34127, Italy

Topological insulators belong to a new kind of material class that posses robust gapless states inside the insulating bulk gap, which makes them promising candidates for achieving dissipationless transport devices. We present a Scanning tunneling microscopy (STM) and spectroscopy (STS) study on a layered material $ZrTe_5$, a promising candidate for a new topological insulator. The crystal structure could clearly be identified in topography images. STM measurements enabled direct imaging of standing waves at steps and defects. The standing waves show a clearly dispersive character. Furthermore STS measurements are in good agreement with density functional theory calculations and reveal Landau quantization with applied magnetic field. Comparison with data obtained by angle resolved photoemission spectroscopy allows for detailed insights into the electronic properties of this material.

O 47.13 Tue 18:15 Poster E

**Probing the electronic structure of epitaxially grown topological insulators with varying magnetic doping** — •Sonja Schatz[1], Mohammed Al-Baidhani[1], Thiago R. F. Peixoto[1], Henriette Maass[1], Christoph Seibel[1], Hendrik Bentmann[1], Grzegorz Karczewski[2,3], Steffen Schreyeck[2], Martin Winnerlein[2], Charles Gould[2], Karl Brunner[2], Laurens Molenkamp[2], and Friedrich Reinert[1] — [1]Experimentelle Physik

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We will present an overview of recent photoelectron spectroscopy (PES) studies of epitaxial topological insulator (TI) thin films. In particular, we investigated $(BiSb)_2Te_3$ layers with a particular focus on magnetic doping with V and Cr impurities. X-ray photoemission (XPS) and absorption measurements of the $2p$ core level lines provide information on the incorporation of the impurities in the TI host material. Resonant PES allows us to address the V $3d$ states in the valence band which are expected to play a crucial role for the exotic magnetic and transport properties of these systems. Furthermore, angle-resolved PES of the topological surface state in $Bi_2Se_2Te$ films will be presented, focusing on anisotropy effects in the Fermi surface [1]. The strength of the anisotropy lies between $Bi_2Se_3$ and $Bi_2Te_3$. Angle-dependent XPS is used to characterize chemical shifts in the core level lines and to obtain information of the chemical composition near the surface [1].

[1] H. Maaß *et al.*, J. Appl. Phys. **116**, 193708, (2014)

O 47.14 Tue 18:15 Poster E

**Alpha-Sn: doping and Te coating study** — •Caroline von Andrian-Werburg, Markus Scholz, Felix Reis, Victor Rogalev, Ralph Claessen, and Jörg Schäfer — Physikalisches Institut, Universität Würzburg, 97074 Würzburg, Germany

Topological insulators (TIs) promise an outstanding progress in transformation of conventional electronics to spintronics. In that scope mono-elemental 3D TIs would have a significant advantage due to the simplicity of growth and defect control. However, the only example described so far is the low temperature phase of Sn ($\alpha$-Sn) [1]. Recently it was found that using Molecular Beam Epitaxy one can stabilize the low-T phase of Sn with topological character on a substrate with a slightly mismatched lattice (0, 14%)[2]. This compressive strain induces a gap at the Fermi level of the otherwise gapless $\alpha$-Sn with band inversion, thus enabling the occurrence of the topological surface states. In the current study we explore further important steps towards the technological application of $\alpha$-Sn, namely, the possibility of doping to vary the position of the Fermi level and protective capping of the film. The protective layer is required in case of ex-situ transfer operations. For both purposes we find elemental Te to be a suitable candidate. A small amount of the Te during the co-deposition with Sn allows to introduce a n-doping of the material, while the amorphous Te overlayer protects the surface from the unnecessary contamination and can be removed by moderate annealing.

[1] L. Fu and C. L. Kane, Phys. Rev. B. 76, 045302 (2007).
[2] A. Barfuss et al., Phys. Rev. Lett. 111, 157205 (2013).