O 63: Focus Session: Charge Transport at Surfaces and Nanostructures with Multi-probe Techniques

Time: Tuesday 18:30–20:30 Location: P2-OG3

O 63.1 Tue 18:30 P2-OG3

Multiprobe measurements on a stepped Bi_2Se_3 surface — •Sebastian Bauer, Mandana Soleimani-Esfahani, Stephanie Hoepken, and Christian A. Bobisch — Faculty of Physics, Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Lotharstraße 1-21, 47057 Duisburg

Bi_2Se_3 is a well-known representative of the new material class of 3D topological insulators (TI). TIs have a spinpolarized surface state for which direct backscattering of electrons is forbidden. Therefore, they are discussed for future spintronic devices [1]. We present a detailed multiprobe analysis of a 15 QL thick stepped Bi_2Se_3 film which was grown in situ on an inclined Si(111) surface. Scanning tunneling potentiometry [2] gives us a direct view into the nanoscale electron transport on the Bi_2Se_3 surface. While a lateral current flows along the surface, an STM tip records simultaneously the local electrochemical potential and the topography on the Bi_2Se_3 surface. We found that beside surface steps [3], also grain boundaries scatter the conducting electrons in the film. An additional rotational four point probe measurement shows an electronic anisotropy of the sheet conductivity due to the anisotropic arrangement of the Bi_2Se_3 steps on the surface. The computed step conductivity of about 1000 S/cm confirms former STP results [4] and reveals the contribution of step edges as electron scatterer.

[1] M. Z. Hasan, C. L. Kane, Rev. Mod. Phys. 82, 3045 (2010). [2] C. A. Bobisch and R. Möller, CHIMIA 66, 23-30 (2012). [3] S. Bauer, C. A. Bobisch, Nat. Com. 7, 11381 (2016). [4] T. Kanagawa et al., Phys. Rev. Lett. 91, 036805 (2003).

O 63.2 Tue 18:30 P2-OG3

Molecular manipulation of acetylbiphenyl with a four-probe-STM — •Frank Eisenhut[1], Corentin Durand[2], Francesca Moresco[1], Jean Pierre Launay[2], and Christian Joachim[2,3] — [1]Institute for Materials Science, Max Bergmann Center of Biomaterials, and Center for Advancing Electronics Dresden, TU Dresden, Dresden, Germany — [2]GNS & MANA Satellite, CEMES, CNRS, Toulouse, France — [3]International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS), Namiki Tsukuba, Ibaraki, Japan

A low temperature ultrahigh vacuum four-probe scanning tunneling microscope has been used to study acetylbiphenyl (ABP) molecules on Au(111). Supramolecular assemblies of ABP interacting via hydrogen bonds were investigated and the tetrameric structure were controllably moved several nanometers by voltage pulses along the fcc domain of the Au(111) herringbone reconstruction. Meanwhile, scanning with another tip was possible without influencing the manipulation. The investigation is an important step towards the preparation of the first international nano-car race [1].

[1] F. Eisenhut et. al., Training for the 1st international nano-car race: the Dresden molecule-vehicle. Eur. Phys. J. Appl. Phys. (2016) 76: 10001.

O 63.3 Tue 18:30 P2-OG3

Polycyclic aromatic hydrocarbon-based nanocars equiped with triptycene wheels — Henri-Pierre Jacquot de Rouville[1,2,4], Claire Kammerer[1,2], Corentin Durand[1,2], •Christian Joachim[1,2,3], and Gwénaël Rapenne[1,2] — [1]Université Paul Sabatier, Toulouse, France — [2]GNS, CEMES-CNRS, Toulouse, France — [3]International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS), Namiki Tsukuba, Ibaraki, Japan — [4]Present adress : ITODYS-CNRS, Université Paris Diderot, Paris, France

Technomimetic molecules[1] are molecules designed to imitate macroscopic objects at the molecular level, also transposing the motions that these objects are able to undergo. We designed and synthesized two nanocars including triptycene wheels in an extended aromatic platform as a cargo zone[3].

However, the manipulation of the planar one on metallic surfaces proved to be difficult due to a strong molecule-surface interaction, the curved nanocar adress this problem by decreasing the interaction between the aromatic system and the surface. STM experiments are currently underway to test the molecule before the nanocar race organized next spring in Toulouse, France.

[1] G. Rapenne, Org. Biomol. Chem. 2005, 3, 1165. [2] (a) H.P. Jacquot de Rouville, R. Garbage, R.E. Cook, A.R. Pujol, A.M. Sirven, G. Rapenne, Chem. Eur. J. 2012, 18, 3023; (b) C. Joachim, G. Rapenne, ACS Nano, 2013, 7, 11.

O 63.4 Tue 18:30 P2-OG3

Disentangling *in situ* top and bottom conductance of a topological insulator thin film — •Felix Lüpke, Markus Eschbach, Tristan Heider, Martin Lanius, Peter Schüffelgen, Daniel Rosenbach, Nils von den Driesch, Vasily Cherepanov, Gregor Mussler, Lukasz Plucinski, Detlev Grützmacher, Claus M. Schneider, and Bert Voigtländer — Peter Grünberg Institute and JARA-FIT, Forschungszentrum Jülich GmbH, D-52425 Jülich, Germany

Charge transport in thin films of 3D topological insulator materials can be through the top and the bottom topological surface state as well as through the interior of the film. The latter undesirable conductivity can be minimized by the use of thin films (10 nm) and the use of MBE grown ternary material systems with reduced bulk conductivity. However, it is still difficult to separate the contributions of the three channels to the conduction. Using a multi-tip STM we performed *in situ* gate-dependent four-probe conductivity measurements of $(Bi_{0.53}Sb_{0.47})_2Te_3$ thin films. Combining the information from these measurements with the band structure obtained from subsequent ARPES measurements, we determine the carrier densities as well as the mobilities in the top and bottom topological surface state channels.

O 63.5 Tue 18:30 P2-OG3

Quasi-free-standing bilayer graphene nanoribbons probed by electronic transport — •Johannes Aprojanz[1], Ilio Miccoli[1], Jens Baringhaus[1], Timo Lichtenstein[1], Lauren A. Galves[2], Joao Marcelo J. Lopes[2], and Christoph Tegenkamp[1] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany

Graphene nanoribbons (GNR), directly grown on insulating SiC-templates, have attracted much intention due to their unique electronic properties. The growth of armchair and zig-zag orientated GNR with tunable band gaps and topologically protected metallic edge states was recently demonstrated [1,2]. Here, we present a detailed study of the structural and electronic transport properties of novel oxygen-intercalated bilayer graphene nanoribbons grown along step edges of SiC(0001) substrates [3]. The local transport properties as well as the microscopic structure have been investigated using a 4-tip STM/SEM system. Probe spacing dependent measurements combined with spectroscopic analyses reveal a hole concentration of $1 \times 10^{13}cm^{-2}$ and mobilities up to 700 cm^2/Vs of as-grown GNR at room temperature, which we attribute to an interlayer charge hopping mechanism.

[1] Baringhaus et al., Nature **506**, 349 (2014)
[2] Palacio et al., Nano Letters **15**, 182 (2015)
[3] Oliveira et al., Nat. Comm. **6**, 7632 (2015)

O 63.6 Tue 18:30 P2-OG3

Electronic Transport Measurements of 2-Dimensional Systems with a 4-Probe STM — •Tim Flatten[1], Sven Borghardt[2], Frank Matthes[1], Beata Kardynal[2], Daniel E. Bürgler[1], and Claus M. Schneider[1] — [1]Peter Grünberg Institut, Electronic Properties (PGI-6), Forschungszentrum Jülich — [2]Peter Grünberg Institut, Semiconductor Nanoelectronics (PGI-9), Forschungszentrum Jülich

The recent emergence of 2-dimensional materials such as the transition metal dichalcogenides (TMD) requires new measurement techniques for exploring their physical properties. TMDs are interesting due to their large variety of electric properties ranging from insulating and semiconducting with direct or indirect band gap to metallic behavior depending on their composition and thickness. We employ a 4-probe scanning tunneling microscope (4-probe STM) operating in ultra-high vacuum (UHV) and at temperatures down to 5 K to combine STM with lateral 4-probe transport measurements. A top-mounted scan-

ning electron microscope (SEM) enables positioning of the 4 independently driven STM tips on a sub-micrometer scale. We investigate the influence of ex-situ sample preparation and in-situ treatment on the surface morphology and cleanness by STM imaging and measure their effect on the electronic transport properties of single TMD flakes. In first steps, we perform scanning tunneling spectroscopy (STS) on single monolayer $MoSe_2$ flakes adsorbed on various insulating substrates to measure the dependence of their electronic band gap on the substrate properties.

O 63.7 Tue 18:30 P2-OG3

Imaging the local voltage landscape of a Bi_2Te_3 surface — •Mandana Soleimani Esfahani, Stephanie Hoepken, Sebastian Bauer, and Christian A. Bobisch — Faculty of Physics, Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Lotharstraße 1-21, 47057 Duisburg, Germany.

Bi_2Te_3 is a prominent prototype system for the new material class of topological insulators (TI) [1]. Compared to other TI materials like Bi_2Se_3 the bulk conductivity in Bi_2Te_3 is lower and the electron transport through the surface state should be enhanced. For Bi_2Se_3 we have already shown that surface defects like step edges and grain boundaries have an impact on the local transport field [2]. Now, we study the local electron transport on a Bi_2Te_3 surface by scanning tunneling potentiometry (STP, [3]). During the STP measurement a lateral current flows along the Bi_2Te_3 surface, resulting in a lateral variation of the electrochemical potential. The latter is probed by a STM tip simultaneously mapping the potential as well as the topography of the Bi_2Te_3 surface with nanometer lateral resolution. This allows for a detailed study of the electron transport field on the surface of Bi_2Te_3 on the atomic scale.

[1] M. Z. Hasan, C. L. Kane, Rev. Mod. Phys. 82, 3045 (2010).
[2] S. Bauer, C. A. Bobisch, Nat. Com. 7, 11381 (2016).
[3] C. A. Bobisch and R. Möller, CHIMIA 66, 23-30 (2012).

O 63.8 Tue 18:30 P2-OG3

A six-tip AFM - SEM combination for semiconductor chip failure analysis — •Stefan Korte, Vasily Cherepanov, Richard Spiegelberg, Peter Coenen, and Bert Voigtländer — Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany, and JARA-Fundamentals of Future Information Technology

The structure size of modern semiconductor electronics is shrinking to dimensions where the electrical failure analysis of single components like transistors on a chip is hard to conduct. We developed a six-tip AFM combined with an SEM to contact single transistors on a chip with multiple tips. Its compact size reduces probe drifts to below 0.1 nm/min. This is necessary to create contacts stable enough for electrical measurements even on state-of-the-art semiconductor chips. Fast AFM scanning with FM-AFM using needle sensors and home-built fast PLL detection electronics is used to position the tips exactly on the contacts. In first trials we contacted single transistors of an SRAM cell on a chip built with 65 nm structure size for electrical characterization.

O 63.9 Tue 18:30 P2-OG3

Manipulation of tolyl-terpy molecules along the Au(111) reconstruction — •Rémy Pawlak[1], Tobias Meier[1], Marcin Kisiel[1], Antoine Hinaut[1], Thilo Glatzel[1], Catherine Housecroft[2], and Ernst Meyer[1] — [1]University of Basel, Department of Physics, Klingelbergstr. 82, CH-4056, Basel, Switzerland — [2]University of Basel, Department of Chemistry, Spitalstrasse 51, CH-4056, Basel, Switzerland

In spring 2017, the first international "NanoCar Race" will be held in Toulouse (France) in a unique low-temperature ultra high vacuum four-probe scanning tunneling microscope. During the competition, the participants will have to simultaneously drive their vehicles over 100 nm along the Au(111) herringbone structure, only using electron injections from one of the STM tips. Here, we report on the adsorption characteristics and first driving experiences of the 4'-(4-Tolyl)-2,2':6',2"-terpyridine, so-called Swiss Nano Dragster on gold [1]. We show that our molecule is translated in a controlled way and high directionality through appropriate electrical excitation. We also find that peculiarities of the gold reconstruction can irremediably trap the molecules and reached a maximum speed of about 20 nm/hour.

[1] R. Pawlak, T Meier et al. Driving experiences on the gold racetrack with the Swiss Nano-Dragster. In preparation.

O 63.10 Tue 18:30 P2-OG3

Scanning tunneling potentiometry using a triangular geometry of the electric contacts — •Hüseyin Azazoglu, Sebastian Bauer, Rolf Möller, and Christian A. Bobisch — Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

Scanning tunneling potentiometry (STP) [1] is used to study the microscopic resistivity in an electric conductor. The direction of the electric current is varied on the nanometer scale by applying three point contacts in an equilateral triangle using different relative voltages at the tips. Thereby, we can rotate the global current direction by any angle up to 360° during the STP measurements. The Si(111)-$\sqrt{3}\times\sqrt{3}$:Ag surface reconstruction [2] was studied. We find that the measured local potential varies as a function of the global current direction. This demonstrates the ability to manipulate the electric transport on the nanoscale with the help of the three-point-geometry, e.g., this technique can be used to study scattering at an individual defect as a function of the angle of incidence.

[1] P. Muralt et. al., Appl. Phys. Lett. 48, p. 514, (1986). [2] J. Homoth et al, Nano Letters 9,1589, (2009).

O 63.11 Tue 18:30 P2-OG3

Transport on Si(553)-Au and Si(557)-Au atomic chains: The effect of oxygen adsorption — Frederik Edler[1], Ilio Miccoli[1], •Jan P. Stöckmann[1], Herbert Pfnür[1], Christian Braun[2], Simone Sanna[2], Wolf G. Schmidt[2], and Christoph Tegenkamp[1] — [1]Universität Hannover, 30167 Hannover — [2]Universität Paderborn, 33098 Paderborn

Atomic chain ensembles grown by self-assembly are prototype 1D systems with partly outstanding electronic properties such as Peierls instabilities or dimensional crossover from Fermi to Luttinger liquid behavior. Recently [1], the Au-induced atomic chain structures on Si(hhk) attracted a lot of attention. The strong spin-orbit coupling gives rise to spin polarized surface bands and in case of Si(553)-Au even quantum spin liquid behavior. However, such properties can strongly be altered by imperfections, e.g. defects induced by adsorbates. In this contribution, we present a systematic study of the transport properties of Si(553)-Au and Si(557)-Au system by means of a 4-tip STM system in combination with SPALEED tuned by adsorption of molecular oxygen. Our DFT calculations show that the origin of metallic surface bands along the wires of similar Si(hhk)-Au surfaces are strongly dependent on the structure of Au chains, Si-adatom chains and Si edges. Here we see an inert behavior for the Si(553)-Au surface while a strong decrease in the conduction along the chains is present for the Si(557)-Au.

[1] B. Hafke et al., Phys. Rev. B **94** (2016) p. 161403

O 63.12 Tue 18:30 P2-OG3

Metal-to-insulator transition in a quantum spin system — •Ilio Miccoli[1], Frederik Edler[1], Jan P. Stöckmann[1], Bernd Hafke[3], Michael Horn-von Hoegen[3], Herbert Pfnür[1,2], and Christoph Tegenkamp[1,2] — [1]Institut für Festkörperphysik, Hannover Uni., 30167-DE — [2]Laboratory of Nano Quantum Engineering, Hannover, 30167-DE — [3]CENIDE, Duisburg-Essen Uni., 47048-DE

Atomic wires on surfaces are prototype 1D systems for studying fundamental aspects, e.g. charge density waves (CDW) or dimensional crossover from a Fermi to a Luttinger liquid behavior. Among others, Au-induced wire structures on Si(553) substrates revealed a lot of attention because of their quasi-1D metallic structures with a pronounced magnetic order, which mimics a 2D quantum spin liquid state.[1] By means of low energy electron diffraction (LEED) and 4-tip STM, we investigated the surface structure and transport properties of Si(553)-Au as a function of temperature. LEED revealed an isotropic order-disorder transition at 90 K, i.e. both the $\times 3$ periodicity along and the magnetic ordering in between the wires vanishes simultaneously. In transport the system undergoes a metal-insulator transition (MIT). Thereby, while heating the resistance across the wires decreases sharply at 90K by 2-3 order of magnitude. Interestingly, we found also a MIT along the wires, which occurs at the same temperature. This combined study gives direct evidence also for a CDW formation along the wires. Moreover, the magnetic ordering stemming from localized electrons fed back to the 1D electronic states at Fermi energy.

[1] B. Hafke et al., Phys. Rev. B **94** (2016) p. 161403

O 63.13 Tue 18:30 P2-OG3

A frame suspended into four Cucurbituril wheels: meet the Ohio Bobcat Nanowagon — •Eric Masson[1] and Saw Wai Hla[1,2] — [1]Dept of Chemistry and Biochemistry and Dept of Physics and Astronomy, Ohio University, Athens, OH 45701, USA — [2]Center for

Nanoscale Materials, Argonne National Laboratory, Argonne, IL 60439 USA

We present the design, synthesis and characterization of the Ohio Bobcat Nanowagon, a [5]pseudorotaxane assembly bearing an H-shaped frame threaded into four Cucurbit[7]uril (CB[7]) wheels. The key motifs in the frame are two benzimidazolium groups, which link a terphenyl drive shaft (the horizontal bar of the "H" frame) to the axle shafts (the vertical bars of the "H" frame). Four pyridinium units terminate the latter. Positive charges at the pyridinium and benzimidazolium units allow the frame and the CB[7] wheels to assemble into the final nanowagon in water. The white solid obtained upon freeze-drying was used for STM analysis.

O 63.14 Tue 18:30 P2-OG3

Conformation manipulation of binaphthyl-dimer with a low temperature STM — •We-Hyo Soe[1], Marek Kolmer[2], Xavier Bouju[1], Yasuhiro Shirai[3], Kosuke Minami[3], Katsuhiko Ariga[3], and Waka Nakanishi[3] — [1]GNS & MANA Satellite, CEMES, CNRS, Toulouse, France — [2]Centre for Nanometer-Scale Science and Advanced Materials (NANOSAM), Jagiellonian University, Krakow, Poland — [3]International Center for Materials Nanoarchitectonics (MANA), National Institute for Materials Science (NIMS), Tsukuba, Ibaraki, Japan

One of the low temperature ultrahigh vacuum scanning tunneling microscope (STM) of the LT-UHV 4-STM has been used to study binaphthyl-dimer molecules on Au(111) [1],[2]. The molecule has three C2 symmetry conformations energetically possible, namely, cis, trans, and planar-like conformations. Right after the molecules deposition on a clean gold surface, only cis conformation molecules forming small 2D islands have been observed. Using a STM tip single molecule mechanical manipulation protocol, single planar conformation molecules have been produced one by one corresponding to our registered nanocar. This confirms that on an Au(111) surface, single and isolated binaphthyl-dimer molecules equipped with 2 paddles are ready to compete for the first international nano-car race in Toulouse, spring 2017.

[1] Y. Shirai, K. Minami, W. Nakanishi, Y. Yonamine, C. Joachim and K. Ariga, Jap. Journ. Appl. Phys., 55 (2016) 1102A2. [2] S. Fujiyoshi, S. Takeuchi, T. Tahara, J. Phys. Chem. A, 108 (2004) 5938.

O 63.15 Tue 18:30 P2-OG3

Koala TetraProbe Multi-Tip STM - Charge Transport Measured at the Nanoscale by a Multi-Tip STM — •Bert Voigtländer, Vasily Cherepanov, and Peter Coenen — mProbes GmbH Jülich, Germany

The ultra-compact Koala TetraProbe STM integrates four independent STM units within a diameter of 50 mm resulting in an unsurpassed mechanical stability, enabling atomic resolution imaging with each tip [1,2]. Each tip and the sample can be positioned independently under control of an optical microscope or an SEM. Software controlled switching between current probe and voltage probe for each tip allows virtually any possible "concerted" spectroscopic measurements involving the four tips and the sample. A four tip STM/AFM combination and a low temperature version are available. Applications include: Local potential measurements on the nanoscale [3], controlled nondestructive measurements in spectroscopy mode, four point measurements with free positionable local probes on structured samples [4], and measurements of the surface conductivity [5].

[1] www.mprobes.com; [2] V. Cherepanov, E. Zubkov, H. Junker, S. Korte, M. Blab, P. Coenen, B. Voigtländer, Rev. Sci. Instrum. 83 (2012) 033707; [3] F. Lüpke, S. Korte, V. Cherepanov, B. Voigtländer, Rev. Sci. Instrum. 86 (2015) 123701; [4] S. Korte, M. Steidl, W. Prost, V. Cherepanov, B. Voigtländer, W. Zhao, P. Kleinschmidt, .T. Hannappel, Appl. Phys. Lett. 103 (2013) 143104; [5] S. Just, M. Blab, S. Korte, V. Cherepanov, H. Soltner, B. Voigtländer, Phys. Rev. Lett. 115 (2015) 066801.

O 63.16 Tue 18:30 P2-OG3

Recent technology advancements in SPM based electrical probing at low temperatures — •Markus Maier, J Köbele, R Thiel, A. Priou, D. Stahl, M. Fenner, and T. Roth — Scienta Omicron GmbH, Limburger Straße 75, 65232 Taunusstein, Germany

A major challenge in the development of novel devices in nano- and molecular electronics is their interconnection with larger scaled electrical circuits. Local electrical transport measurements by multiple atomic scale precision probes can significantly improve the analysis of individual nano-scaled structures without the need of a full electrical integration. The LT NANOPROBE is a sophisticated instrument that merges the requirements of a 4-probe system, efficiently and precisely navigated by a scanning electron microscope (SEM) and at the same time satisfies the needs for high performance SPM. The excellent stability in the pm range allows for atomic resolution in STM and nc-AFM (QPlus) and expands applications from electrical nano-probing towards tunnelling and force spectroscopy and even the creation of atomically precise structures. The system is operated at temperatures below 5K, specifically also during SEM operation. The microscope stage works at very low thermal drift in the range of 100pm/h. We will present measurements that prove the instrument's performance level, specifically thermal drift, stability and QPlus AFM measurements. We will also show the newest technology improvements, such as high frequency capabilities and optical access for pumped probe experiment. Future challenges as well as applications and scientific drivers for this type of scientific instrumentation will be discussed.

O 63.17 Tue 18:30 P2-OG3

4-Point Nano Probing: Comparison of Single-Chip 4-Point Micro Probes as exposed to Multi Probe STM Heads — •T. Berghaus[1], T. Richter[1], and Y. Miyatake[2] — [1]nanoscore gmbh, Maisebachstr. 3, 61479 Glashütten, Germany — [2]UNISOKU Co. Ltd., 2-4-3 Kasugano Hirakata, OSAKA 573-0131, Japan

STM-based nano probing has become of increasing interest as tool for characterising the properties of layered tructures, 2D materials like graphene, one-dimensional conductors, as well as for the investigation of topological insulators. Two fundamentally different instrumental implementations have evolved:(i) 2-Probe or 4-probe STMs using conventional macro-fabricated STM tips and having independent positioning, scan, and imaging means for each of the tips as proposed by Aono et al.[1]. (ii) STMs with single channel means for positioning, scan, and imaging, but using micro fabricated multi-tip chips - such as micro 4-point probe chips (micro 4PP)[2]. Here we compare the two approaches. The multi STM approach appears to be more flexible because of the independent tip positioning. On the other hand it is more expensive and difficult to control. Whereas the micro 4-PP approach offers many more possibilities for integration into demanding environments such as ultra low temperature or high magnetic fields as recently presented by Jian-Feng Ge et al. [3]. Further throughput and reproducibility can be enhanced by using commercially available micro-4PP chips [4].

[1] M.Aono et al.Oyo Buturi 67, 1361 (1998) [2] S. Hasegawa et al.Surf. Sci. 500, 84 (2002) [3] Jian-Feng Ge et al. Rev. Sci. Inst. 86, 053903 (2015). [4] Capres A/S, DK-2800 Kgs. Lyngby