O 47: Poster Tuesday: Scanning Probe Techniques

Time: Tuesday 18:00–20:00 Location: Poster D

O 47.1 Tue 18:00 Poster D

Simulation of STM images and spectroscopy of single nitrogen-doped molecules with 5-7 membered rings on Au(111) surfaces — •Seddigheh Nikipar[1,3,4], Dmitry A. Ryndyk[1,2], Sibylle Gemming[3,4], Francesca Moresco[1,4], Gianaurelio Cuniberti[1,4], and Thomas Frauenheim[2] — [1]Institute for Materials Science, TU Dresden — [2]BCCMS, Department of Physics, Universität Bremen — [3]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf — [4]Center for Advancing Electronics Dresden, TU Dresden

We consider STM images and spectroscopy (STS) of molecules on metal surfaces. We combine DFT based atomistic tight-binding model (DFTB approach) with Green function technique, which offers a framework to consider tip, molecule and surface as one integrated system and taking into account the tip geometry. Besides, it captures the interference and interaction effects. This approach can be applied for the investigation of finite-voltage effects and describe the high-energy molecular transport states. It allows to simulate quantitatively the I(V) current-voltage spectroscopy curves and dI/dV maps in both constant current and constant height modes. We applied our methods to nitrogen-doped molecules with 5-7 membered rings on Au(111) surface and showed that the electronic properties of molecules are strongly influenced by formation of azulene-motifs. We developed the integrated open software suite for quantum nanoscale modeling (TraNaS OpenSuite, tranas.org/opensuite) for convenient calculations of large-scale molecular nanosystems on metal surfaces.

O 47.2 Tue 18:00 Poster D

Nano-manipulation on the polymer surfaces using functionalized AFM probes — •Tunç Çiftçi[1], Laurent Pham Van[2], Oleg Kurnosikov[1], and Bert Koopmans[1] — [1]Eindhoven University of Technology, Eindhoven, the Netherlands — [2]Centre CEA de Saclay, Gif-sur-Yvette, France

We demonstrate a new approach to manipulate various polymer surfaces by an AFM using specifically designed probes. By this new method, the submicrometer protrusions can be formed on the surface in any selected positions. In contrast to the earlier approaches based on deforming thick organic materials by pressing with a probe, we form protrusions without any tip-surface contact. These functionalized probes can generate an instant temperature gradient at the tip while remaining in the non-contact regime close the surface. The high temperature gradient at the tip end can be switched on and off sharply. The organic material is heated up to its melting point quickly and locally pulled up towards to the hot tip by the van der Waals forces. With a sharp drop in the temperature, this fluidic-protrusion solidifies maintaining its shape. To realize this functionality, we implemented a new type of conducting planar probes, which provide high current density close to the tip end for controlling the local temperature. With this design we can manipulate a broad class of organic materials with melting temperature from 20 up to 400 degrees of Celsius. Our approach is also could be challenging for study and selective manipulation of biological systems.

O 47.3 Tue 18:00 Poster D

High resolution imaging of organic molecules using Q-controlled amplitude modulation atomic force microscopy with CO-functionalized tips — •Daniel Martin-Jimenez[1], Alexander Ihle[1], Sebastian Ahles[2], Hermann A. Wegner[2], Andre Schirmeisen[1], and Daniel Ebeling[1] — [1]Institute of Applied Physics (IAP), Justus Liebig University Giessen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany — [2]Institute of Organic Chemistry, Justus Liebig University Giessen, Heinrich-Buff-Ring 17, 35392 Giessen, Germany

The so-called bond imaging atomic force microscopy (AFM) technique has become an invaluable tool for studying organic molecules on surfaces. The key feature of this technique is to functionalize the AFM-tip with a single molecule, e.g., CO. Hereby, the imaging capabilities of dynamic mode AFM are improved, which allows to determine the precise orientation and internal structure of adsorbed organic molecules. Usually, these measurements are performed by operating tuning fork sensors in frequency modulation mode at low temperatures in ultra-high vacuum conditions. The high quality factors of the tuning fork sensors under these conditions typically prohibit operation in amplitude modulation mode due to the slow response time caused by the low damping environment. Here, we use the Q-control technique to reduce the effective quality factor of the sensor from about 30000 to 3000. This enables submolecular amplitude modulation imaging with a lateral resolution and signal to noise performance comparable to frequency modulation mode.

O 47.4 Tue 18:00 Poster D

Quantitative Kelvin probe force microscopy on nanoscale devices — Amelie Axt[1], Ilka M Hermes[1], Rüdiger Berger[1], and •Stefan A.L. Weber[1,2] — [1]MPI for Polymer Research Mainz, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, Germany

We investigate the influence of the operation method in Kelvin probe force microscopy (KPFM) on the measured potential distribution. KPFM is widely used to map the nanoscale potential distribution in operating devices, e.g. in thin film transistors or on cross sections of functional solar cells [1]. Quantitative surface potential measurements are crucial for understanding the operation principles of functional nanostructures in these electronic devices. Nevertheless, KPFM is prone to certain imaging artifacts, such as crosstalk from topography or stray electric fields. Here, we compare different Amplitude Modulation (AM) and Frequency Modulation (FM) KPFM methods on a reference structure with a defined potential difference [2]. In particular, we investigate how quantitative the externally applied voltage is measured. We found that even in the presence of a strong stray field, the FM KPFM methods measured more than 95% of the external bias, whereas the commonly used lift-mode AM KPFM measured less than 70% of the external bias. [1] Energy Environ. Sci., 2018,11, 2404; J. Phys. Chem. Lett., 2018, 9, 6249. [2] Beilstein J. Nanotechnol. 2018, 9, 1809.

O 47.5 Tue 18:00 Poster D

Optimization of the energy resolution and RF capability of a 30 mK dilution refrigerator scanning tunneling microscope — •Manuel Steinbrecher[1], Henning von Allwörden[1], Andreas Eich[1], Jan Gerritsen[1], Fabian D. Natterer[2], Daniel Wegner[1], and Alexander A. Khajetoorians[1] — [1]IMM, Radboud University Nijmegen, The Netherlands — [2]University of Zurich, Switzerland

For a scanning tunneling microscope (STM) operated with a metallic tip the energy resolution of the spectroscopic measurements typically is given by the effective temperature of the tunneling electrons, namely $3.5k_BT$. However, for temperatures below $\approx 100\,\mathrm{mK}$, contributions like the electromagnetic noise inside the system and capacitive noise become more dominant [1-2].
We use a home-made dilution refrigerator ($T = 30\,\mathrm{mK}$) based STM [3], with a vector magnet established in Nijmegen to test the energy resolution of our setup. We report on superconducting measurements of Al-Al junctions. We perform measurements in different tunneling regimes and with a variety of tips, testing both tip diameters and materials and report on their significance. In this course, the system was upgraded to RF capability for electron spin resonance (ESR) experiments [4]. Results and performance will be shown for a dilution fridge STM for the first time.
[1]D. Vion *et al.*,JoAP **77**, 2519 (1995)
[2] C. R. Ast *et al.*, Nat. Commun. **7**:13009 (2016)
[3] H. v. Allwörden *et al.*, RSI **89**, 033902 (2018)
[4] S. Baumann *et al.*, Science **350**, 417-420 (2015)

O 47.6 Tue 18:00 Poster D

Automated Laboratory Monitoring based on the Internet of Things — •Nicolaj Betz[1], Max Hänze[1,2,3], Luigi Malavolti[1,2,3], Gregory McMurtrie[1,2,3], and Sebastian Loth[1,2,3] — [1]University of Stuttgart, 70569 Stuttgart, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, 22761 Hamburg, Germany — [3]Max Planck Institute for Solid State Research, 70569 Stuttgart, Germany

Precise environment control is a crucial factor for reliable scanning tunneling microscopy. The Internet of things is a network of devices and appliances that combine measurement and control features with a connectivity framework, thereby introducing the possibility of re-

motely monitor and control laboratory setups [1]. Here we present an implementation that is based on battery-powered microcontrollers and Wifi connectivity to enable the use of conventional lab equipment in a cloud-based measurement system. Our approach enables precise process monitoring and control of a sub-Kelvin high magnetic field scanning tunneling microscopy laboratory with a small budget.

[1] Jeffrey M. Perkel, Nature 542, 125 (2017).

O 47.7 Tue 18:00 Poster D

Modelling Photo-Assisted Scanning Tunneling Microscopy — •Ole Bunjes, Benjamin Schröder, Lara Wimmer, Claus Ropers, and Martin Wenderoth — Georg-August-Universität, IV. Physikalisches Institut, Friedrich-Hund-Platz 1, 37077 Göttingen

Scanning Tunneling Microscopy (STM) offers unique capabilities in imaging and spectroscopy on the atomic scale. A promising approach to observe surface dynamics faster than electronic sampling speeds is the combination of STM with pulsed laser excitation.

Typically, the tunnel current $I(z)$ depends mono-exponentially on the tip-sample distance z. In recent experiments, we found a strong deviation from this typical exponential decay upon femtosecond laser illumination of the tunnel junction.

We explain this observation by modelling the vacuum barrier including a one-dimensional image potential and an effective electron energy distribution. We simulate the energy-, distance- and bias-voltage-dependent transmission probabilities. In combination with a series of fermionic distributions of different amplitudes, temperatures and energy intervals, we model the measured $I(z)$ curves. This approach allows us to quantify the contributions of hot electrons as well as multi-photon excited electrons to the tunneling current. We provide a comprehensive picture including voltage- and laser-power-dependent data.

This project is financially supported by the DFG in the SFB 1073 (project C4).

O 47.8 Tue 18:00 Poster D

Atomic Manipulation in NC-AFM Experiments: The Influence of the Chemical Tip Termination — •Damla Yesilpinar, Alexander Timmer, Bertram Schulze Lammers, Harald Fuchs, and Harry Mönig — Physikalisches Institut, WestfälischeWilhelms-Universität Münster

Controlled manipulation of atoms and molecules on the surface by an NC-AFM tip allows measuring the forces during the manipulation. The underlying mechanism has previously been attributed to lowering of the diffusion barrier due to the interaction between the tip and the manipulated particle. In this study, we have examined the effect of different chemical tip terminations on the manipulation processes. As a model system, we have chosen Xe atoms on a partially oxidized Cu(110) surface. This surface exhibits the typical p(2x1)O-reconstructed oxide stripes alternating with pure Cu domains. STM images showed that Xe atoms were preferentially adsorbed at the metal/metal-oxide boundaries. The manipulation experiments were carried out along and perpendicular to the oxide rows with metallic-, Xe-terminated and CuOx-functionalized [1] tips. While each tip was able to manipulate the Xe atoms along the oxide row, only CuOx tips allowed successful manipulations above the pure Cu domains. This work sheds light on the pronounced influence of the chemical tip termination in such experiments and provides insights on the mechanisms of the preferential adsorption at the metal/metal-oxide boundaries [2].

[1]ACS Nano 2016, 10, 1, 1201-1209 [2]Nano Lett. 2018, 18, 7, 4123-4129

O 47.9 Tue 18:00 Poster D

dS11/dV spectroscopy and imaging of buried nanostructures — •Alexander Kölker[1,3], Georg Gramse[2,4], Matthias Koch[3], Ferry Kienberger[4], and Neil Curson[1] — [1]London Centre of Nanotechnology, UCL, London, UK — [2]Johannes Kepler University, Biophysics Institute, Linz, Austria — [3]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [4]Keysight Laboratories, Keysight Technologies, Inc.,Linz, Austria

Non-destructive device characterization is especially of interest when including newly emerging materials like δ-layers, nanowires, graphene or spintronics in the fabrication processes. Scanning microwave microscopy (SMM) is a non-destructive technique that allows advanced characterization of electrical properties, such as carrier concentration, capacitance and conductivity, by measuring the reflected signal power (S11) of an electro magnetic wave guided to the AFM tip [1].

Further information, such as capacitance and conductance derivative (dC/dV and dG/dV) can be extracted by exploiting the field effect of a DC bias, applied in addition to the low RF signal to the tip.

Here we demonstrate for buried δ-layer nanostructures how dS11/dV spectroscopy in conjunction with FEM-modelling can be employed to identify contributions to the admittance that originate from the substrate, the patterned δ-layer region and its 2D nature. In the outlook we report on the development of a novel SPM sample that hosts an integrated circuit for in-situ single-molecule charge transport measurements. [1] G. Gramse, A. Kölker et al. Science Advances, vol. 3, no. 6, p. e1602586, 2017.

O 47.10 Tue 18:00 Poster D

A cryogen-free low-temperature scanning tunneling microscope — •Lukas Arnhold[1], Gregory McMurtrie[1], Stephan Spieker[1], Luigi Malavolti[1,2], and Sebastian Loth[1] — [1]Universität Stuttgart — [2]Max-Planck-Institut für Festkörperforschung

State of the art Scanning Tunneling Microscopes (STM) are inherently limited in their continuous measurement time by their cryocooling systems, making the acquisition of high resolution differential conductivity maps and other time consuming experiments challenging.

Gifford-McMahom (GM) cryocoolers [1] feature an extremely long hold time [2], but tend to introduce a degree of vibration which aggravates their use in scanning probe techniques.

In this homebuilt STM, we decouple a GM crycooler from the microscope head using a two-frame support system.

Performance tests indicate sufficient vibration suppression to perform high-quality STM measurements that can last as long as the cryocooler can operate.

Such extended hold-time STM's open the possiblity of investigating novel surfaces with unprecedented resolution and extended parameter spaces.

[1] J. Hacklez, High-stability cryogenic scanning tunneling microscope based on a closed-cycle cryostat, Review of Scientific Instruments 85, 103704 (2014) [2] S. Zhang, A cryogen-free low temperature scanning tunneling microscope capable of inelastic electron tunneling spectroscopy, Review of Scientific Instruments 87, 063701 (2016)

O 47.11 Tue 18:00 Poster D

Temperature dependence of directional nanofriction on NaCl — •Jennifer Konrad, Dirk Dietzel, and Andre Schirmeisen — Institute of Applied Physics, Justus-Liebig University Giessen, 35392 Giessen, Germany

On the nanometer scale, the directional dependence of friction is a well known phenomenon [1] that is typically related to the lattice structure of the sample with different energy barrier heights related to different sliding directions. Consequently, temperature should influence the friction pattern with more defined structures expected at low temperatures according to the concept of thermally activated friction. In this work, this fundamental assumption is analyzed by temperature dependent friction force microscopy on NaCl under UHV conditions. As a result, our measurements do not only document the general effect of temperature, but also highlight the additional influences of parameters like wear and tip shape on the effective friction pattern.

[1] S. G. Balakrishna, A. S. de Wijn, and R. Bennewitz, Physical Review B 89, (2014).

O 47.12 Tue 18:00 Poster D

Three dimensional tracing of the trajectory of a charged particle by electrostatic detection — •Erdem Genc, Doris Tarasevitch, Tobias Roos, Detlef Utzat, Hermann Nienhaus, and Rolf Möller — Fakultät für Physik/Cenide, Universität Duisburg-Essen, Germany

The position of a moving charged particle in free space is determined by using a configuration of electrodes in a parallel plate capacitor geometry. The electrodes are connected to ultra-sensitive and fast charge amplifiers [1] which measure the time-dependent displaced charge in the electrodes. In the experiment we trace the trajectory of a steel sphere of 1mm in diameter which falls freely and bounces off a surface. The initial charge on the sphere is 0.1pC. A spatial resolution of approximately 0.1mm perpendicular and 1mm parallel to the electrodes is achieved combined with a temporal resolution of better than 10 microseconds. In addition, the transfer of electric charge between the sphere and the electrodes during contact is evalutated for every collision. The experimental results are in excellent agreement with calculations applying classical electrodynamics. The method allows the

access to charge transfer processes between colliding particles which is of high relevance in technology and fundamental research. [1] P. Graf. et al., Rev. Sci. Instrum. 88, 084702 (2017).

O 47.13 Tue 18:00 Poster D

Space and time-resolved unidirectional switching of single molecules — •Thomas Buchner, Dominik Peller, Lukas Kastner, Rupert Huber, and Jascha Repp — Department of Physics, University of Regensburg, 93040 Regensburg, Germany

Combining low-temperature scanning tunneling microscopy (STM) and ultrafast lightwave electronics has paved the way for tracking single molecule dynamics with combined atomic resolution and femtosecond temporal precision [1]. Here, we introduce single-shot detection in lightwave STM with single-electron control, opening the door to path-selective studies of unidirectional quantum events. We examine a magnesium phthalocyanine molecule, which adsorbs on sodium chloride in a bistable geometry. By means of single light pulses, single electrons can be deliberately injected into an unoccupied orbital, triggering the molecule to rearrange on the surface, eventually leading to a switching of its adsorption geometry. Monitoring a non-resonant cotunneling current allows one to detect every single switching event. In pump-probe experiments, the quantum yield for switching is measured for various parameters with combined sub-Å spatial and femtosecond temporal precision, which exhibits a distinct behavior for each reaction path. These multi-dimensional experimental data show marked oscillations in time and provide a fingerprint of the atomistic details of the molecular dynamics, at the sub-picosecond time scale.

[1] T. L. Cocker, D. Peller et al., Nature 539, 263-267 (2016)