O 17: Scanning Probe Techniques: Method Development II

Time: Monday 15:45–18:00 Location: TRE Phy

O 17.1 Mon 15:45 TRE Phy

Imaging adatoms, rest atoms and defects on Si(111)-7x7 with a CO terminated metal tip — •Daniel Meuer and Franz Josef Giessibl — University of Regensburg, D-93055 Regensburg, Germany

The surface of Si(111)-7x7 exposes adatoms at the top surface layer and rest atoms that are approximately 100 pm below the adatom layer [1]. We show that a CO tip of an AFM resolves both adatoms and rest atoms as roughly Gaussian protrusions, which is in agreement with charge density calculations using Slater-type-orbitals. Both the experimental and calculated data do not show apparent artifacts. In this contribution we also present that we can resolve the atomic structure inside surface defects. This is possible due to the fact that the CO molecule at the metal tip apex is a very sharp probe with a thin apex compared to metal cluster tips.

The previous work was done in a force regime, where CO bending artifacts do not occur. For distance regimes with CO bending one would expect a non-Gaussian shape of the adatoms. In 2014 Sweetman et al showed data, where they observe a non-Gaussian shape of the adatoms with a unknown tip termination. They relate this subatomic features of the adatoms of the Si(111)-7x7 surface to the back bonding of the surface atoms [2]. We show data with a CO terminated tip, which clearly show CO bending in preferred directions.

References:

[1] K. D. Brommer et al - Jpn. J. Appl. Phys. 32, 1360 (1993)

[2] A. Sweetman et al.- Nano Lett. 14, 2265-2270 (2014)

O 17.2 Mon 16:00 TRE Phy

Measurement of Nano Particle Adhesion by Atomic Force Microscopy — •Daniel Geiger[1], Irina Schrezenmeier[1], Matthias Roos[3], Tobias Neckernuss[1], Michael Lehn[2], and Othmar Marti[1] — [1]Institute of Experimental Physics, Ulm University, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [2]Institute of Numerical Mathematics, Ulm University, Helmholtzstrasse 20, 89081 Ulm, Germany — [3]Carl Zeiss SMT GmbH, Rudolf-Eber-Strasse 2, 73447 Oberkochen, Germany

The adhesiveness of nanoparticles on surfaces is of interest for many applications. This includes processes that are intended to deposit particles on a surface as well as processes that aim to remove nanoparticles from a surface.

We present a method to measure the adhesiveness of nanoparticles by means of lateral force measurements using an atomic force microscope. The measurement protocol is based on conventional contact, constant force mode scanning of a sample decorated with nano beads. By moving the particles laterally their adhesive forces are given as the lateral force acting on the cantilever. Geometry related measurement errors are compensated by statistical analysis. For that reason a model based on probability theory was derived that allows reconstruction of the actual pushing force distribution acting on the beads. The model is applied to measurement data of 50 nm silica nano beads on a silicon substrate.

O 17.3 Mon 16:15 TRE Phy

Controlled Nanometer Layer Ablation by Diamond AFM tips in a hybrid SEM/AFM — •Frank Hitzel[1] and Jason Kilpatrick[2] — [1]Semilab Germany GmbH, Braunschweig, Germany — [2]Adama Innovations, Dublin, Ireland

Combined Scanning Electron Microscope / Focused Ion Beam (SEM/FIB) systems are nowadays an established and stable technology for precise nanometer manipulation / cutting and in-depth analysis of structures. Nevertheless, the electrical properties of the areas manipulated by FIB strongly change because of implanted Gallium atoms.

In such situations, another technique has been recently evolving, often called "scalpel AFM". Here, typically a diamond tip is scanned with predefined force over a sample surface, removing in a controlled way a few atomic layers of the sample material. Like FIB treatment, this gives access to the layers buried below the surface. But in contrast to FIB treatment, these layers are not contaminated by Ga atoms opening up the possibility for electrical characterization.

The hybrid SEM/AFM enables live imaging of the modified area and gives exceptional control of the ablation process, which is to some extend similar to scratching with a screw driver in a clay layer. Similar to FIB tomography, the combination enables the possibility to switch between SEM imaging and the ablation process, resulting in a 3 dimensional image of the manipulated surface.

O 17.4 Mon 16:30 TRE Phy

Atomic Force Microscopy with stiff qPlus sensors in liquid environments — •Korbinian Pürckhauer, Alfred J. Weymouth, and Franz J. Giessibl — University of Regensburg, Germany

We set up a custom-built AFM with qPlus sensors to operate in ambient conditions as well as in liquid environments [1]. For measurements in liquids we immerse the sample in liquid and use long tips, only submerging the tip apex. We discuss the decrease of the Q-factor as a function of the penetration depth of the tip in liquid. The high stiffness of our qPlus sensors ($k \geq 1800$ N/m) allows us to keep this Q value above 140 during measurements.

Atomic resolution of muscovite mica was achieved both in ambient conditions and in liquid. Beside H_2O we used Tris-HCl buffer and a culture medium, which contains salts, a mineral solution, Resazurin, Na_2S and other solutes.

[1] Wastl, D. S., Weymouth, A. J., & Giessibl, F. J. (2013). Optimizing atomic resolution of force microscopy in ambient conditions. Physical Review B, 87(24), 245415.

O 17.5 Mon 16:45 TRE Phy

Imaging successive intermediate states of the on-surface Ullmann reaction — •Daniel Ebeling[1], Sören Zint[1], Tobias Schlöder[2], Sebastian Ahles[3], Doreen Mollenhauer[2], Hermann A. Wegner[3], and Andre Schirmeisen[1] — [1]Institute of Applied Physics, Justus Liebig University Giessen, Germany — [2]Institute of Physical Chemistry, Justus Liebig University Giessen, Germany — [3]Institute of Organic Chemistry, Justus Liebig University Giessen, Germany

Recently, different bottom-up approaches have been developed for the on-surface synthesis of covalently bonded organic frameworks. In order to use these structures for future applications, such as nanoelectronic or -optical devices, in-depth knowledge about the underlying reaction mechanisms has to be gained. This is crucial for establishing a basis for the design of new functional devices with tailor-made properties. Here, we are using low temperature atomic force microscopy (AFM) with CO functionalized tips together with density functional theory (DFT) calculations with dispersion correction to study the complete reaction pathway of the on-surface Ullmann-type coupling between bromotriphenylene molecules on a Cu(111) surface. All steps of the Ullmann reaction, i.e., bromotriphenylenes, triphenylene radicals, organometallic intermediates, and bitriphenylenes could be imaged with submolecular resolution. We can unambiguously identify the chemical structure and the adsorption geometry of each individual species and therewith provide deeper insight into the reaction process.

O 17.6 Mon 17:00 TRE Phy

AFM investigation on CaF2(111) with atomically characterized tips — •Alexander Liebig, Angelo Peronio, Daniel Meuer, Alfred J. Weymouth, and Franz J. Giessibl — Universität Regensburg, Germany

In contrast to ionic crystals of the rock salt structure, the surface ions of CaF2(111) are all charged negatively, and AFM measurements on this surface had previously been used to identify positively- and negatively-terminated tips [1]. Similar to previous experiments on Cu2N [2], we imaged this surface with both metal- and CO-terminated tips that were characterized using the COFI method, where an adsorbed CO molecule is used to image the tip apex [3]. We simulated the AFM data with a simple electrostatic model, in which the surface atoms are represented as point charges and the tip as a dipole. For measurements acquired relatively far from the surface the electrostatic force is the dominant contribution to the AFM contrast and the model allows us to determine the sign of the net charge at the tip apex. However, this point-charge model fails to reproduce the data closer to the surface, where the bending of the CO molecule and Pauli repulsion become important [4,5]. These effects lead to a contrast inversion in the AFM images acquired with a CO-terminated tip at very close tip-sample distances.

[1] A.S. Foster et al., Phys. Rev. Lett. 86, 2373 (2001). [2] M. Schneiderbauer et al., Phys. Rev. Lett. 112, 166102 (2014). [3] J. Welker and F.J. Giessibl, Science 336, 6080 (2012). [4] L. Gross et al., Science 337, 6100 (2012). [5] M. Ellner et al., ACS Nano Letters 16, 3 (2016).

O 17.7 Mon 17:15 TRE Phy

HR-LC-AFM for detection of current paths on oxides with atomic resolution — •Christian Rodenbücher, Gustav Bihlmayer, Marcin Wojtyniak, Wolfgang Speier, and Kristof Szot — Peter-Grünberg-Institut and JARA-FIT, Forschungszentrum Jülich, 52425 Jülich

The ongoing miniaturization of electronic devices and the introduction of novel materials such as metal oxides for memristive applications is accompanied with new challenges since the electronic transport phenomena have to be analyzed on the atomic scale. Typically, the STM method is used to obtain information about the electronic properties in nanoscale, however it cannot be successfully applied on all surfaces. For example, on surfaces with inhomogeneous conductivity any changes in the electrical properties of the surface are inseparable from changes in the sample topography. Hence, we implemented the technique of high-resolution local-conductivity atomic force microscopy (HR-LC-AFM) for the investigation of oxide surfaces and achieved, for a first time, a direct current mapping with atomic resolution. We revealed that the surface conductivity of the prototypical transition metal oxides $SrTiO_3$ and TiO_2 is confined to conducting areas on the nanoscale. Assisted by *ab initio* theory we argue that a clustering of oxygen vacancies in the surface of transition metal oxides could be responsible for the observed localization. This way we introduced LC-AFM as next scanning probe tool with true atomic resolution complementing the well-established techniques of (NC-)AFM, FFM, SKPM, and STM which may help to open up a new chapter on surface science.

O 17.8 Mon 17:30 TRE Phy

Scanning tunneling microscopy and potentiometry using a cooled JFET electrometer — •Paul Graf, Meike Flebbe, Christian A. Bobisch, Hermann Nienhaus, and Rolf Möller — Faculty of Physics, Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, 47048 Duisburg, Germany

We show that a liquid nitrogen cooled junction field effect transistor can be used to measure either small electric charges or ultra low currents in the range of 10^{-18} A [1]. The leakage current between the gate electrode and the source-drain channel of the JFET drops to several 10^{-20} A at a temperature of 80 K, so that the gate can store charge for a time of several days. The gate voltage, hence the charge, can be easily measured by the source-drain current. Here, we combine this cooled JFET electrometer with a scanning tunneling microscope connecting the gate electrode of the JFET directly to the tunneling tip. Using an AC-bias voltage, STM imaging at low current becomes possible. Since the gate voltage automatically adjust to zero average current, the dc component directly yields the electrochemical potential. Laterally resolved images show topographic features such as atomic step edges and terraces but also lateral oscillations in the electrochemical potential, i.e. thermovoltage, which can be attributed to standing electron wave patterns, e.g., of the surface state of Cu(111).

[1] Rolf Möller and Hermann Nienhaus, patent pending, *Open FET Sensor*, Provendis Ref.-Nr. 4817

O 17.9 Mon 17:45 TRE Phy

Imaging and quantification of work function variations on a nanostructured surface with scanning quantum dot microscopy — •Christian Wagner[1,2], Matthew F. B. Green[1,2], Philipp Leinen[1,2], Michael Maiworm[3], Taner Esat[1,2], Rolf Findeisen[3], Ruslan Temirov[1,2], and F. Stefan Tautz[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology — [3]Institute for Automation Engineering (IFAT), Otto-von-Guericke Universität Magdeburg, Germany

The properties of a surface are crucially influenced by its electrostatic potential landscape. This landscape is formed by work function variations, e.g., due to adsorbate layers and by the local fields of edges and point-like impurities. When imaging the surface potential it is desirable to observe all these effects on equal footing. We demonstrate that scanning quantum dot microscopy (SQDM) enables precise quantification of work function variations for structures down to 10 nm in diameter and simultaneous imaging of individual atomic-scale defects. This is possible since SQDM is essentially based on a point-like probe, a molecular quantum dot, and thus avoids the averaging effects which are intrinsic to Kelvin probe force microscopy (KPFM) and which depend on tip size, shape and height. Paradoxically, in SQDM a blunter AFM tip yields sharper images due to electrostatic screening. We exemplify our method by imaging the interface dipole of islands of perylene-tetracarboxylic dianhydride (PTCDA) on Ag(111) and determining its value to be $\Delta\phi = 145 \pm 10$ mV.