O 48: Scanning Probe Methods I

Time: Wednesday 10:30–13:15 Location: GER 38

O 48.1 Wed 10:30 GER 38

Correction of non linear lateral distortions of scanning probe microscopy images — •Michael Schnedler, Phillip Weidlich, Verena Portz, Dieter Weber, Rafal E. Dunin-Borkowski, and Philipp Ebert — Peter Grünberg Institut, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

The inverse piezo electric effect is commonly utilized to position the tip or cantilever with atomic precision in scanning probe microscopes (SPM). Although the properties of modern piezo electric materials are well known, their application in SPMs requires a calibration of their lateral and vertical positioning, which is usually achieved by acquiring images of atomic lattices and comparing them with the perfect periodical arrangement of the atoms of a crystalline surface. Hence, the calibration is optimized for a nanometer scan range. However, sometimes the measurement requires scanning parameters that exceed the designated linear range of the calibration. Then, nonlinear effects of the piezoceramic actuators, like hysteresis creep, drift, and a nonlinear dependence of the displacement on the applied voltage often result in image distortions. Therefore, a methodology for the correction of scanning probe microscopy image distortions occuring in large scanning ranges is demonstrated. It is based on the determination of displacement vectors from the measurement of a calibration sample. By moving the pixels of the distorted scanning probe microscopy image along the displacement vectors an almost complete correction of the nonlinear, time independent distortions is achieved.

O 48.2 Wed 10:45 GER 38

Detecting the Dipole Moment of a Molecule with Atomic Force Microscopy — •Alexander Schwarz, Arne Köhler, Josef Grenz, and Roland Wiesendanger — Institute of Applied Physics, University of Hamburg, Jungiusstrasse 11, 20355 Hamburg, Germany

Using non-contact atomic force microscopy (NC-AFM) in the constant Δf mode with metallic tips enabled us to detect the permanent electrostatic dipole moment of single CO molecules adsorbed on three very different substrates, i.e., Cu(111), NiO(001) and Mn/W(001). The observed characteristic distance dependent contrast, which changes from a simple protrusion to a donut-shape for decreasing tip-sample separations, can be explained by an interplay between the attractive van der Waals interaction and a repulsive electrostatic interaction. The latter stems from antiparallel aligned dipoles present in CO as well as at the tip apex [1]. Our results suggest that the dipole-dipole interaction has to be considered when using metallic or CO functionalized tips to study polar molecules. They can also be responsible for complex and tip-dependent contrast patterns reported recently, which have been interpreted in terms of so-called *subatomic* features [2].

[1] G. Teobaldi, et al., Phys. Rev. Lett. **106**, 216102 (2011).
[2] J. Welker and F. J. Giessibl, Science **336**, 444, (2012).

O 48.3 Wed 11:00 GER 38

Tuning Fork Force Sensor: Spring Constant and Q-Factor in Experiment and Simulation — •Marvin Stiefermann[1], Jens Falter[1], Harald Fuchs[2], Henrik Hölscher[3], and André Schirmeisen[1] — [1]Institute of Applied Physics (IAP), Justus-Liebig-University Giessen, Germany — [2]Center for Nanotechnology (CeNTech) and Institute of Physics, University of Münster (WWU), Münster, Germany — [3]Institute of Microstructure Technology (IMT), Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany

Force spectroscopy in non contact-atomic force microscopy (nc-AFM) has recently been used to determine absolute forces on individual atoms and molecules. Particular impressive results at cryogenic temperatures have been achieved using tuning fork based sensors in the "qPlus" design. However, reliable interpretation of force spectroscopy results require a precise calibration of the tuning fork spring constant. Here we present a comprehensive and straightforward calibration analysis based on experimental determination and FEM simulation of the tuning fork spring constant. We find that the beam formula widely used in the literature systematically overestimates the spring constant. However, we show that a origin shift of the beam can be used to correct this effect for most cases. Further, we find that already a small tilt angle of the tip glued to the prong strongly influences the spring constant, explaining the large scatter of our experimental calibration values. Further we present FEM simulations monitoring the influence of different tuning fork setups, adhesives and tip positions on the Q-Factor.

O 48.4 Wed 11:15 GER 38

Reconstruction of field ion microscopy characterized tungsten tips of AFM tuning fork sensors at the atomic level — •Sören Zint[1], Jens Falter[2,1], Dirk Dietzel[1], and André Schirmeisen[1] — [1]Institute of Applied Physics (IAP), Justus-Liebig-University Giessen — [2]TransMIT-Center for Adaptive Cryotechnology and Sensors

Non-contact atomic force microscopy (ncAFM) has proven to be a valuable tool for surface characterization with atomic-resolution. For a quantitative comparison between force spectroscopy experiments and corresponding analytical models, knowledge of the true tip geometry is required. One method for gaining information about the geometry of metallic tips is the field ion microscopy (FIM) technique. In order to determine the tip geometry with FIM we employ the reconstruction of ball models based on the field ion micrograph. For this purpose we developed specific software which allows for the creation of hemispherical ball models, the determination of atoms imaged brightly in FIM and the possibility of both the addition and removal of tip atoms. In order to ascertain the tip geometry of a FIM characterized tip we compare the field ion micrograph and the projection of the tip model at the atomic level. This new approach allows us to precisely determine the tip radius with an error of less than two lattice constants.

O 48.5 Wed 11:30 GER 38

Advances in Scan Movement Linearization for High-Speed AFM Imaging — •Anne-D. Müller and Falk Müller — Anfatec Instruments AG, Melanchthonstr. 28, 08606 Oelsnitz

In the past decade, several approaches have been undertaken to speed up the raster scan of an Atomic Force Microscope into the 100 Hz range or even higher with the aim to produce artifact free images. From the hardware side, specialized stiff scanner designs with very high resonance frequencies have been developed, some of them even using a push-pull technique. The most promising method, however, is the resonance compensation by a dedicated shaping of the scan ramp output first realized by a simple notch filter, whose parameters are adapted to the scanner [1].

This contribution presents a smarter and more flexible design method for a filtered and linearized scan control of high-speed AFMs, that works for all kind of scanners, even if they have strong nonlinearities, large hysteresis and multiple resonances. Moreover, a first approach for the reduction of resonances in z-direction is presented.

[1] DJ Burns, K Youcef-Toumi, and GE Fantner. Nanotechnology. 22.31 (2011).

O 48.6 Wed 11:45 GER 38

SubSurface-AFM: unravelling the contrast formation mechanism — Gerard J. Verbiest[1] and •Marcel J. Rost[2] — [1]JARA-FIT and II. Institute of Physics, RWTH Aachen University, 52074 Aachen, Germany — [2]Kamerlingh Onnes Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands

Subsurface-AFM is realized by Heterodyne Force Microscopy (HFM), in which two ultrasonic signals of slightly different frequencies are sent through the sample and the cantilever, respectively. The sound wave through the sample contains subsurface information. The nonlinear interaction between the cantilever's tip and the sample generates a low-frequency heterodyne force that is detected in the cantilever's motion, if one tunes this force below its fundamental resonance frequency.

Despite some reported subsurface observations that clearly demonstrate the power of this technique, a decent quantitative understanding of the physical contrast mechanism was (until now) still missing.

Our recent insight in the working principles of HFM [1-3] enabled us to perform a quantitative analysis of our measurements on a well-characterized sample and to determine the physical contrast mechanism. Totally unexpected, the contrast is neither related to ultrasonic Rayleigh scattering nor elasticity variations in the sample, but to the *rattling* motion (and the involved friction) of *shaking* nanoparticles [4].

[1] G.J. Verbiest et al., Ultramicroscopy 135, 113 (2013)
[2] G.J. Verbiest et al., Nanotechnology 24, 365701 (2013)
[3] G.J. Verbiest, and M.J. Rost, Nature Physics submitted
[4] G.J. Verbiest and M.J. Rost, http://arXiv/abs/1307.1292

O 48.7 Wed 12:00 GER 38

Visualizing the Subsurface of Soft Matter: Simultaneous Topographical Imaging, Depth Modulation, and Compositional Mapping with Triple Frequency Atomic Force Microscopy — •Daniel Ebeling[1,2], Babak Eslami[2], and Santiago D. Solares[2] — [1]Institute of Applied Physics, Justus Liebig University Giessen, Giessen, Germany — [2]Department of Mechanical Engineering, University of Maryland, College Park, Maryland, United States

Characterization of subsurface morphology and mechanical properties with nanoscale resolution and depth control is of significant interest in soft matter fields like biology, polymer science, where buried structural and compositional features can be important. However, controllably "feeling" the subsurface is a challenging task for which the available imaging tools are relatively limited. In this paper, we propose a trimodal atomic force microscopy (AFM) imaging scheme, whereby three eigenmodes of the microcantilever probe are used as separate control "knobs" to simultaneously measure the topography, modulate sample indentation by the tip during tip-sample impact, and map compositional contrast, respectively. We illustrate this multifrequency imaging approach through computational simulation and experiments conducted on ultrathin polymer films with embedded glass nanoparticles in ambient air. By actively increasing the tip*sample indentation using a higher eigenmode of the cantilever, we are able to gradually and controllably reveal glass nanoparticles which are buried tens of nanometers deep under the surface, while still being able to refocus on the surface.

O 48.8 Wed 12:15 GER 38

Origin of sharp apparent intermolecular bonds in AFM and STM experiments — •Prokop Hapala[1], Georgy Kichin[2], Stefan Tautz[2], Ruslan Temirov[2], and Pavel Jelinek[1] — [1]Institute of Physics , Academy of Sciences of the Czech Republic, Cukrovarnická 10, Prague, 16253, Czech Republic — [2]Institut fur Bio- und Nanosysteme 3, Forschungszentrum Julich, 52425 Julich, Germany

In recent years sub-molecular resolution in STM and AFM was achieved and enabled visualization of individual bonds between atoms. These techniques are based on usage of functionalized probe consisting a simple molecule or atom (such as CO, CH3, Xe, H2, Cl-) attached to the tip apex. Recently, several groups also reported direct observation of intermolecular bonds between molecules by the same technique [1],[2],[3]. In literature this observations used to be explained as visualization of electron density in the bond due to Pauli repulsion. It was already shown, that the measured images are strongly distorted and sharpened by relaxation of molecular probe [4]. Here we show, that sharp features measured in these experiments, especially apparent intermolecular bonds, can be explained almost exclusively by simple geometrical model using pairwise potential (Lennard-Jones, Morse) when relaxation of probe position is considered.

1. J.Zhang, et al., Science 342, 611-4 (2013).
2. C.Weiss, et al., J. Am. Chem. Soc. 132, 11864-5 (2010).
3. G.Kichin, et al., J. Am. Chem. Soc. 133, 16847-51 (2011).
4. L.Gross, et al., Science 337, 1326-9 (2012).

O 48.9 Wed 12:30 GER 38

The influence of the tip geometry on picking up a CO molecule — •Daniel Meuer and Franz J. Giessibl — Institute of Experimental and Applied Physics, University of Regensburg, D-93053 Regensburg, Germany

CO tip termination allows increased AFM resolution of carbon based molecules and structures by imaging, for instance, carbon back bonds [1,2]. Furthermore it has been shown that a measure of the bond order and the length of covalent bonds is possible with CO functionalized tips [2]. Our group has shown that it is possible to identify the orientation of the front most tip atom, using a CO molecule chemisorbed to a Cu(111) surface [3]. This allows us to investigate the influence of the metal tip geometry on the likelihood of picking up a CO molecule.

References

[1] L. Gross et al., Science 325, 1110 (2009)
[2] L. Gross et. al., Science 337, 1329 (2012)
[3] J. Welker and F. J. Giessibl, Science 336, 444 (2012)

O 48.10 Wed 12:45 GER 38

Looking for the Origin of Power Laws in Electric Field Assisted Tunneling — •H. Cabrera, D.A. Zanin, L.G. De Pietro, A. Vindigni, U. Ramsperger, and D. Pescia — Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland

We have measured the voltage vs distance characteristics at constant current I of a tunnel diodelike junction consisting of an electron emitting sharp tip placed at a variable distance d from a planar anode. Such a junction is used e.g. in Scanning Tunneling Microscopy (STM) and in the topografiner technology. By mounting the tip onto a piezocrystal, which can move the tip perpendicularly to the surface, the distance d can be varied, its value can be also double checked by an optical sensor device. At sufficiently large distances, i.e. in the regime of electric field assisted quantum tunneling, the $V - d$ characteristic curves for different currents follow approximately a power law, the exponent λ being independent of the current. Here we compare and discuss the origin of the observed power law and the measured value of it in terms of electrostatic properties of the tip-plane junction, taking the geometry of the tip as a hyperboloid of revolution.

O 48.11 Wed 13:00 GER 38

Investigations on the imaging dynamics of carbon nanotube based probes in intermittent-contact AFM — •Moid Bhatti — Institut für Experimentalphysik, Universität des Saarlandes, 66041 Saarbrücken, Germany

High speed (video rate and beyond) atomic force microscopy (AFM) requires not only fast feedback with a bandwidth exceeding 100 kHz – for which solutions are emerging – but also cantilever resonant frequencies in the MHz range. Nanocantilevers (NC) or nanowires (NW) can fulfill this requirement motivating an understanding of their interaction with the sample.

We are studying contact mechanics of the cantilever-sample system in the dynamic mode AFM using: (1) nanowires (NW) grown on a substrate whose dynamic behavior is equivalent to an AFM cantilever with a NW attached to it (AFM-NW), (2) carbon nanotubes (CNT) attached to an AFM cantilever (AFM-CNT), and (3) focused-ion-beam-(FIB)-structured NC (AFM-NC).

Single-walled AFM-CNT have been in use as a super tip. A CNT adds to the complexity of the contact mechanics of the probe-sample system because it can stick, slip, adhere, kink, and buckle as it interacts with the sample surface leading to imaging artifacts. We describe here the imaging dynamics of AFM-NW by using a long and shortened multi-walled CNT and explain the interaction dynamics using cantilever trajectories, distance-dependent resonance curves, and amplitude-distance curves which differ from those of the conventional AFM tips in a marked way.