O 44: Scanning Probe Methods I

Time: Wednesday 10:30–13:15 Location: H33

O 44.1 Wed 10:30 H33

Tuning Fork Sensor Spring Constants and Q-Factors in Experiment and Simulation — •Marvin Stiefermann[1], Jens Falter[2], Harald Fuchs[2], and André Schirmeisen[1] — [1]Universität Gießen — [2]Universität Münster

The increasing application of Tuning Fork (TF) based sensors in non-contact Atomic Force Microscopy (nc-AFM) raised the need for a comprehensive investigation of the two most relevant sensor parameters, the spring constant and Q-factor. Those sensors were primarily designed for the application in watches, and the change of these parameters when mounted in the AFM setups is not well understood. In this work we performed detailed measurements and finite element simulations to understand and determine the TF spring constants as well as Q-factors for different mounting geometries. With a specially developed setup, consisting mainly out of a micrometer caliper and a high sensibility scale, it was possible to apply different forces along arbitrary positions of the prong of the TF, which was attached onto a Macor block holder. Reliable results were achieved only by applying compressive and tensile forces to the TF, allowing us to eliminate the contribution of the tungsten tip deformation to the spring constant. In a second step the complete experimental setup was rebuilt in a finite-element computer model, including the glue points, tip mass and position as well as the Macor holder geometry. This model is in quantitative agreement with the experimental results for the spring constant and allows us to identify the critical parameters to obtain a high Q- factor.

O 44.2 Wed 10:45 H33

Friction induced self-excited cantilever resonance oscillation — •Felix Mertens, Thomas Göddenhenrich, and André Schirmeisen — Institut für Angewandte Physik, Justus-Liebig-Universität Gießen, D-35392 Gießen

The modulation of a sample in the direction of the cantilever long axis leads to bending oscillations of the lever if the tip is in contact with the surface[1]. The lever response oscillation essentially depends on the modulation amplitude and the modulation frequency. Experimental and simulated data indicate that a modulation frequency well below the resonance frequency of the lever and a sufficient modulation amplitude for stick-slip motions of the tip causes a lever response oscillation containing the modulation frequency as well as the self-excited bending resonance frequency of the lever. [1]T. Göddenhenrich, S. Müller, and C.Heiden, Rev. Sci. Instrum. 65, 2870 (1994)

O 44.3 Wed 11:00 H33

Investigations on nanocantilever dynamics in intermittent-contact AFM — •Moid Bhatti, Ivo Knittel, Uwe Schmitt, Andreas Englisch, and Uwe Hartmann — Institute of Experimental Physics, Saarland University, 66041 Saarbruecken, 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) can fulfill this requirement motivating an understanding of the NC-sample interaction.

We are studying contact mechanics of the cantilever-sample system in the dynamic mode AFM using NC of various types: (1) nanowires (NW) grown on a substrate (the dynamic behavior of which is equivalent to a cantilever with a NW attached to it), (2) carbon nanotubes attached to an AFM cantilever, (3) focused-ion-beam-(FIB)-structured NC, (4) a FIB-structured NC at the tip of an optical fiber, whereby the light transmission capability of the fiber can be utilized for the integrated detection of the NC oscillation.

We will present different NC, FEM simulations of NC resonances, a detection mechanism and AFM imaging with NC. The contact stiffness with NC can be very low resulting in a characteristic tip-sample force-distance relation. Distance-dependent resonance curves of an AFM cantilever interacting with a static NW and of a NC tapping on a sample showing the existence of a third state of cantilever dynamics besides the well-known "low- and high-amplitude" states will be presented including the effect of adhesion and dissipation.

O 44.4 Wed 11:15 H33

Development of a Quattro-Cantilever Microscope for topological and electrical measurements — Robert Benzig[1], Marcus Kästner[1], Tzvetan Ivanov[1], Manuel Hofer[1], •Anne-D. Müller[2], Falk Müller[2], and Ivo W. Rangelow[1] — [1]TU Ilmenau, Fakultät für Elektrotechnik und Informationstechnik, Institut für Mikro- und Nano-Elektronik, 98693 Ilmenau, Germany — [2]Anfatec Instruments AG, Melanchthonstr. 28, 08606 Oelsnitz/V., Germany

In the past 15 years, extended developments of AFMs continually have involved multiple cantilever designs that allow the simultaneous operation of more than one AFM tip with the aim to speed up the image acquisition or to use different tips for different purposes [1]. This contribution introduces a thermally driven self-sensing four cantilever array and its application based on an extendable experimental set-up. Each cantilever is operated with an independent dynamic mode feedback while the vertical movement range is about 1.2 μm and connected to dedicated feedback loops. In addition, a master feedback loop operates a standard AFM scanner with 5 μm vertical range. The contribution explains the technical details of the cantilever array, fabrication technology and the experimental set-up. We will demonstrate the simultaneous operation of all four cantilevers (so-called Quattro-Cantilever-Chip).

O 44.5 Wed 11:30 H33

Technical limitations in dynamic mode high-speed AFM imaging — •Anne-D. Müller and Falk Müller — Anfatec Instruments AG, Melanchthonstr. 28, 08606 Oelsnitz, Germany

As the availability of AFM probes and digital control technology have improved substantially within the past decade, high-speed imaging in contact and dynamic mode AFM became an achievable goal for current instrumentation development. In order to reasonably track the topology of the surface, the most important target of current investigations is the response time of the digital feedback loop. This contribution presents a technical solution for the direct determination of the frequency dependent disturbance rejection of digital feedback loops considering the whole system including the cantilever, the lockin amplification and all required A/D and D/A converters. It will be shown that the cantilever itself remains as bottleneck for the further increase of the imaging speed in dynamic mode. Results acquired with different commercially available high-speed cantilevers will be compared.

O 44.6 Wed 11:45 H33

Conductive AFM for characterization of MW-CNT-based via interconnect systems — •Marius Toader[1], Holger Fiedler[2], Sascha Hermann[2], Stefan E. Schulz[2,3], Thomas Gessner[2,3], and Michael Hietschold[1] — [1]Chemnitz University of Technology, Institute of Physics, Solid Surfaces Analysis Group, D-09107 Chemnitz, Germany — [2]Chemnitz University of Technology, Center for Microtechnologies, D-09126 Chemnitz, Germany — [3]Fraunhofer Institute for Electronic Nano Systems (ENAS), D-09126 Chemnitz, Germany

Advanced hybrid interconnects where copper will be replaced using carbon nanotubes (CNTs) will represent the breakthrough in overcoming the actual limitations of interconnect industry strongly constrained by the shrinking issues. To successfully proceed with the development and improvement of such systems, a comprehensive understanding is required and therefore a detailed characterization should be addressed. We report on and emphasize the versatility of conductive AFM (c-AFM) in characterizing vertically aligned CNTs aimed to be used in via interconnect technology. The study is conducted on multi-walled CNT (MW-CNT) arrays vertically grown on a copper-based metal line [1]. The advantages of the c-AFM with respect to the classical electrical measurements are discussed. A detailed insight into the internal performance is achieved via current-voltage spectroscopy. [1] Fiedler H, Toader M, Hermann S, Rodriguez R, Sheremet E, Rennau M, Schulze S, Waechtler T, Hietschold M, Zahn D, Schulz S, Gessner T: ECS Journal of Solid State Science and Technology 2012, 1(6) M47-M51.

O 44.7 Wed 12:00 H33

Passing current through molecular wires of different length — •Norman Fournier[1,2], Christian Wagner[1,2], Ruslan Temirov[1,2], and Stefan Tautz[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich — [2]JARA-Fundamentals of Future Information Technology

Recently we developed a method to contact a single molecule on a metal substrate and lift it up with the tip of a combined AFM/STM based on the qPlus sensor [1]. While lifting, we pass the current through the molecule and measure the conductance. The geometry of the junction is controlled by measuring the frequency shift of the qPlus sensor [2].

We applied this method to a set of π-conjugated molecules of different length which all have the same anchoring group. By doing this systematically we probed the transport properties of the wire depending on its length. We also investigated how the transport through the molecule depends on its contacts by using two differnet types of electrodes (Ag and Au).

References
[1] N. Fournier et al. Physical Review B 84, 035435 (2011)
[2] C. Wagner et al. Physical Review Letters 109, 076102 (2012)

O 44.8 Wed 12:15 H33

Calibrating atomic-scale force sensors installed at the scanning tunneling microscope tip apex — Georgy Kichin[1,2], Christian Wagner[1,2], Stefan Tautz[1,2], and •Ruslan Temirov[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich — [2]JARA-Fundamentals of Future Information Technology

Using the combined low-temperature atomic force and scanning tunneling microscope (LT AFM/STM) we perform simultaneous force and conductance measurements on STM tips decorated with either a single carbonmonoxide molecule or an individual xenon atom. Our results show that both tips act as force sensors coupling the tunneling conductance of the junction to the force acting on the tip. On the basis of the obtained data we attempt the quantitative calibration of the observed sensor function.

O 44.9 Wed 12:30 H33

Capillary forces between a rigid sphere and an elastic half -space: the role of Young's modulus and equilibrium vapor adsorption — Marjan Zakerin[1], •Michael Kappl[1], Ellen Backus[1], Hans-Jürgen Butt[1], and Friedhelm Schönfeld[2] — [1]Max Planck Institute for Polymer Research, Ackermannweg 10, 55128 Mainz — [2]Hochschule RheinMain, Faculty of Engineering, Am Brückweg 10, 65428 Rüsselsheim

Capillary adhesion of microparticles to a deformable substrate was analytically calculated, simulated by finite element simulations and measured with an atomic force microscope. The effects of elastic deformation and liquid adsorption were analyzed. Using an atomic force microscope, we measured the force between a silica bead of 2 μm radius and a silicon wafer (Young's modulus E = 170 GPa) and polydimethylsiloxane (PDMS, E = 1 MPa) in the presence of ethanol at different vapor pressures. Adhesion forces on soft surface were much stronger than on rigid samples. In order to fully explain the experimental results, the previous developed theory by Butt et al. (1) was extended to take into account vapor adsorption of ethanol. Calculations were compared to results of finite element (FEM) simulations taking the detailed deformation of the elastic support close the meniscus explicitly into account.

(1) H.-J. Butt, W. J. P. Barnes, A. del Campo, M. Kappl and F. Schönfeld, Soft Matter, 2010, 6, 5930

O 44.10 Wed 12:45 H33

Efficient orbital dependent STM simulation model — •Gabor Mandi, Laszlo Szunyogh, and Krisztian Palotas — Budapest University of Technology and Economics, Department of Theoretical Physics, Budapest, Hungary

The interplay of experiment and theory is essential for the correct interpretation of experimental scanning tunneling microscopy (STM) results. We propose an orbital dependent tunneling model and implement it within an atom superposition approach for simulating STM [1].

In order to demonstrate the applicability of this method we consider a W(110) surface, and analyze the orbital contributions to the tunneling current and the corrugation of constant current STM images. In accordance with a previous study [2] we find atomic contrast reversal depending on the bias voltage. We analyze this effect depending on the tip-sample distance using different tip models and find two qualitatively different behaviors. As an explanation we highlight the role of the real space shape of the orbitals involved in the tunneling. STM images calculated by our model agree well with Tersoff-Hamann and Bardeen results. The computational efficiency of our model is remarkable as the k-point samplings of the surface and tip Brillouin zones do not affect the computation time, in contrast to the Bardeen method.

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[1] Palotas et al., arXiv:1206.6628 (2012).
[2] Heinze et al., Phys. Rev. B 58, 16432 (1998).

O 44.11 Wed 13:00 H33

Fundamental relation between chemical force and tunneling current driven by quantum degeneracy — Yoshiaki Sugimoto[1], Martin Ondráček[3], Masayuki Abe[1], Seizo Morita[1], Pablo Pou[2], Rubén Pérez[2], Fernando Flores[2], and •Pavel Jelínek[3] — [1]Graduate School of Engineering, Osaka University 2-1, Yamada-Oka, Suita, Osaka 565-0871, Japan — [2]Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049, Spain — [3]Institute of Physics, Academy of Sciences of the Czech Republic, Cukrovarnická 10/112, Prague, 162 00, Czech Republic

Both the tunneling current I and the short-range component of the force F, induced by the formation of the chemical bond, exhibit in atomic contacts an exponential decay with similar characteristic decay length. Consequently, the relation between F and I follows the relation F^n I, where n is an integer number. Over the last 10 years, several different factors n have been proposed by different groups based on both theoretical analysis and experimental measurements; still there is no consensus on the relation between F and I.

We explain origin of two characteristic scaling regimes, where the current is either proportional to the force I$\sim$F or to the square of the chemical force, i.e. $I \sim F^2$, as consequence of the quantum degeneracy. We will collate our theoretical prediction with experimental AFM/STM measurements of single atom point contacts and complex DFT simulations to unambiguously prove the existence of these two characteristic regimes.