O 97: Scanning probe techniques: Method development II

Time: Thursday 15:00–18:30 Location: MA 005

O 97.1 Thu 15:00 MA 005

Nanosecond time resolution in Electrostatic Force Microscopy — •Riccardo Borgani, Daniel Forchheimer, Per-Anders Thorén, and David B. Haviland — Nanostructure Physics, KTH Royal Institute of Technology, Stockholm, Sweden

We introduce a scanning probe microscopy technique based on nonlinear electrostatic interaction to map the fast response of a surface to an electric or luminous stimulus. The technique allows for investigation of the fast generation and recombination of charge, e.g. in photo-voltaic materials.

We excite the probe at its resonance frequency, and the material under study with a periodic train of sharp pulses. We drive the cantilever and monitor its deflection near its mechanical resonance frequency, where a high SNR measurement of intermodulation between the drive and the material response to the pulses is possible. The proposed technique is able to reconstruct the rise and fall time of the material response from hundreds of milliseconds to the nanosecond regime.

We show experimental data demonstrating this time resolution, and we discuss the theory and simulations that suggest a even faster time resolution is achievable at the expense of the measurement time. Our work demonstrates how the intermodulation spectral technique, where phase-coherent down-conversion is measured at many frequencies, is an attractive alternative to pump-probe measurements for probing fast dynamics.

O 97.2 Thu 15:15 MA 005

Two-degree-of-freedom control combining machine learning and extremum seeking for fast scanning quantum dot microscopy — •Michael Maiworm[1], Christian Wagner[2,3], Ruslan Temirov[2,3], F. Stefan Tautz[2,3], and Rolf Findeisen[1] — [1]Institute for Automation Engineering (IFAT), Otto-von-Guericke Universität Magdeburg, Germany — [2]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — [3]JARA-Fundamentals of Future Information Technology, Jülich, Germany

Scanning Quantum Dot Microscopy (SQDM) is a novel technique for the quantitative imaging of surface potential distributions with nanometer resolution[1,2]. The SQDM sensor is a molecular quantum dot (QD) attached to the tip of a non-contact AFM by molecular manipulation. Surface potential variations can change the QD charge state via gating which causes sharp dips in NC-AFM $\Delta f(V_{bias})$ spectra. Mapping of the surface potential is thus possible via mapping of the V_{bias} values at which the respective dips appear. For this purpose we present a two-degree-of-freedom control approach, consisting of an extremum seeking controller and a feedforward control. The feedforward signal is based on a machine learning approach where a Gaussian process is used to capture the already scanned part of the image and compute a prediction for the next scan lines. The proposed control approach speeds up the scanning process by one order of magnitude and enables to scan large areas and strong potential variations. [1] C. Wagner et al. Phys. Rev. Lett. 115, 026101 (2015) [2] M. Green et al. Japan. J. Appl. Phys. 55, 08NA04-7 (2016)

O 97.3 Thu 15:30 MA 005

Mapping Light-Induced Cantilever dynamics by Scanned Laser Radiation — •Sven Kraft, Dieter Schick, Semjon Köhnke, Boris Hage, Ingo Barke, and Sylvia Speller — University of Rostock, Institute of Physics, 18051 Rostock, Germany

Direct actuation of Atomic Force Microscopy (AFM) cantilevers by a laser beam is an alternative method to the widely used dither piezo actuator. In particular in the case of liquid environments laser actuation is beneficial because spurious oscillation modes, visible as the so called "Forest of peaks" [1], are avoided. Our aim is to better understand the mechanisms leading to the laser-induced oscillation, by revealing the dependence of the location of the laser spot on the cantilever. Analysis of spatially and frequency resolved data of different cantilevers indicate that a combination of mechanisms contributes to the total motion. Among them are thermal effects [2,3] and instantaneous forces from radiation pressure [4]. Besides these two we observe quasi-instantaneous thermal actuation forces for coated as well as uncoated cantilevers. The results may allow improved actuation schemes, reducing undesired effects such as cantilever heating.

[1] T. E. Schäffer, J. P. Cleveland, F. Ohnesorge, D. A. Walters, and P. K. Hansma, J Appl Phys 80, 3622 (1996)

[2] D. Ramos, J. Tamayo, J. Mertens, and M. Calleja, J Appl Phys 99, 124904 (2006)

[3] D. Kiracofe, K. Kabayashi, A. Labuda, A. Raman, H. Yamada, Review of Scientific Instruments 82, 013702 (2011)

[4] D. Kleckner, D.Bouwmeester, Nature 444(7115) (2006)

O 97.4 Thu 15:45 MA 005

Molecular model of a quantum dot junction beyond the constant interaction approximation — •Ruslan Temirov[1,2], Niklas Friedrich[1,2], Taner Esat[1,2], Philipp Leinen[1,2], Matthew F. B. Green[1,2], Christian Wagner[1,2], Pawel Chmielniak[3,4,2], Jeffrey Rawson[3,4,2], Paul Kögerler[3,4,2], Michael Rohlfing[5], and F. Stefan Tautz[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA)–Fundamentals of Future Information Technology, Jülich, Germany — [3]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich, Germany — [4]Institute of Inorganic Chemistry, RWTH Aachen, Germany — [5]Institute for Solid-state Theory, University of Münster, Germany

We present a physically intuitive model of molecular quantum dots beyond the constant interaction approximation. It accurately describes their charging behaviour and allows the extraction of important molecular properties that are otherwise experimentally inaccessible. The model is applied to data recorded with a non-contact atomic force microscope (AFM) on three different molecules that act as a quantum dot when attached to the microscope tip [1-2]. Results are in excellent agreement with first principle simulations.

[1] C. Wagner et al. Phys. Rev. Lett. 115, 026101 (2015) [2] M. Green et al. Japan. J. Appl. Phys. 55, 08NA04-7 (2016)

O 97.5 Thu 16:00 MA 005

Intermodulation gain and noise squeezing in dynamic AFM — •David Haviland, Alexander Revera-Ahlin, Daniel Forchheimer, Riccardo Borgani, Thomas Weissl, and Shan Jolin — Nanostructure Physics, KTH, Stockholm, Sweden

When driven by a strong pump, a nonlinear oscillator will create correlations in the frequency domain between signal and idler pairs symmetrically placed about the pump frequency. These correlations result in two-mode squeezing, giving power gain to a weak signal by amplifying one quadrature while the other quadrature is de-amplified. Not only signals but also noise can be squeezed, resulting in measurement sensitivity below the standard limits imposed by thermal or quantum fluctuations. There is currently numerous experiments demonstrating these effects at the quantum limit, but much less attention has been paid to the squeezing of thermal noise where there is in fact great potential for practical applications. We demonstrate parametric gain and thermal noise squeezing in a room-temperature dynamic Atomic Force Microscopy, where the limiting noise is thermal Brownian motion of the cantilever. Unlike previous work on the mechanical amplification of force, we do not use an 'external' nonlinearity to realize gain, but rather the sample itself is used as the 'gain medium'. We show how parametric gain results in a widening of the measurement bandwidth over which dynamic AFM is limited by thermal noise.

O 97.6 Thu 16:15 MA 005

Application of machine learning techniques to multifrequency AFM — •Daniel Forchheimer[1,2], Per-Anders Thoren[1], Riccardo Borgani[1], and David Haviland[1,2] — [1]The Royal Institute of Technology (KTH), Stockholm Sweden — [2]Intermodulation Products AB, Segersta, Sweden

Thanks to the development of multifrequency AFM techniques datasets obtain with scanning probe microscopy are becoming increasingly high-dimensional. With Intermodulation AFM for example, one is able to measure at over 40 frequencies simultaneously, to obtain over 80 "observables" for each image pixel. We have developed extensive analysis methods based on careful modeling and calibration of the AFM system, to convert these raw observables to interpretable physical properties.

However, this analysis can be quite computationally intense, and in some situations not even possible, as for example the case of broad band interaction where multiple eigenmodes are excited where calibration is lacking. Therefore it is also of interest to apply tools from "big data analysis", i.e. machine learning tools such as clustering and dimensionality reduction where analysis is performed on the raw observables, agnostic to the physical system. We have applied some machine learning algorithms to multifrequency AFM to investigate its utility and to compare with an the results of physical modeling.

15 min. break

O 97.7 Thu 16:45 MA 005

Low temperature scanning tunneling microscope with optical access — •Lars Wilmes[2], Kevin Edelmann[1,2], Moritz Winkler[2], Lukas Gerhard[2], and Wulf Wulfhekel[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Institut für Nanotechnologie, Karlsruher Institut für Technologie, 76344 Eggenstein-Leopoldshafen, Germany

Exploring the conversion of electric power to light and the relevant processes at a molecular level is key for the further development and miniaturization of high efficient light emitting devices. Systematic investigations with a reduced number of degrees of freedom can be achieved in single molecule junctions in a scanning tunneling microscope (STM). A new ultra high vacuum low temperature (1.5 K) STM featuring an optical access with high collection efficiency gives experimental access to plasmons within the tunnel junction and electroluminescence from single molecules. A silver coated tip within a microscopic parabolic mirror is used to focus light directly into an optical fiber. With a single fiber to guide the collected light into a spectrometer the STM provides a combination of optical and electrical spectroscopy. Preliminary results show promising photon yield with atomic-scale spatial resolution.

O 97.8 Thu 17:00 MA 005

Evaluating the potential energy above a single molecule at room temperature with lateral force microscopy — •Alfred J. Weymouth, Elisabeth Riegel, Sonia Matencio, and Franz J. Giessibl — Universität Regensburg, Regensburg, Germany

One of the challenges of AFM, in contrast to STM, is that the measured signal includes both long-range and short-range components. The most accurate method for removing long-range components is to measure both on and off an adsorbate and to subtract the difference. [1] This on-off method, however, is challenging at room temperature due to thermal drift. By moving to a non-contact scheme in which the lateral component of the force interaction is probed, the measurement is dominated by short-range interactions. [2] We use non-contact lateral force microscopy (LFM) in the frequency-modulation mode and measure the local interaction above a PTCDA island grown on Ag/Si(111)-($\sqrt{3}\times\sqrt{3}$). Each molecule appears as a single feature. By fitting this feature to a model potential, we can extract the depth and width of the potential. As we move closer to the sample, we reach the range in which Pauli repulsion plays a role in our tip-sample interaction.

[1] Ternes et al., Phys. Rev. Lett. 106, 016802 (2011)
[2] Weymouth, J. Phys. Condens. Matter. 29, 323001 (2017)

O 97.9 Thu 17:15 MA 005

Unexpected lateral contrast in Topografiner imaging on sub-Angström corrugations — •Gabriele Bertolini[1], Robin Pröbsting[1], Danilo Andrea Zanin[1], Hugo Cabrera[1], Urs Ramsperger[1], Danilo Pescia[1], and Oguzhan Gürlü[1,2] — [1]Laboratory for Solid State Physics, ETH Zurich, 8093 Zurich, Switzerland — [2]Auguste-Piccard-Hof 1, HPT C5.3 ETH Hoenggerberg

By running the Scanning Tunnelling Microscope (STM) in the Fowler-Nordheim regime, i.e. going back to Topografiner from STM, we were able to attain lateral resolution with several nanometers on structures embedded in W(110) terraces, which have less than 20 pm corrugation. Our results showed that local work function on the surface is modified at the atomic level due to contaminants as expected, and this is reflected in the imaging capability of Topografiner with such unexpected lateral resolution. The secondary electron (SE) images and absorbed current images present complementary information. This in itself showed the extreme sensitivity of this imaging technique to local chemical environment. Furthermore our results showed that SEs dominate the signal reaching to the detector from the tip-sample junction rather than elastically back scattered electrons.

O 97.10 Thu 17:30 MA 005

Coherent single electron field emitter assembled with SPM — •Taner Esat[1,2], Niklas Friedrich[1,2], Ruslan Temirov[1,2], and F. Stefan Tautz[1,2] — [1]Peter Grünberg Institute (PGI-3), Forschungszentrum Jülich, Germany — [2]Jülich Aachen Research Alliance (JARA), Fundamentals of Future Information Technology, Germany

In this work we demonstrate the assembly of a coherent single electron field emitter by controlled manipulation of individual atoms and a molecule with the tip of a combined NC-AFM/STM.

O 97.11 Thu 17:45 MA 005

Investigation of the significance of higher harmonics in non-contact atomic force microscopy — •Daniel Heile, Alexander von Schmidsfeld, and Michael Reichling — Universität Osnabrück, Barbarastraße 7, 49076 Osnabrück

In the non-contact atomic force microscopy the prevalent theoretical approach to force sensor oscillations is the harmonic approximation. Hence, the complex cantilever oscillations are simplified to a harmonic oscillator at its tip position. This is a sufficient approximation for a cantilever in the freely oscillating case. However, for applied loads on the cantilever, for example due to tip-sample interactions, higher harmonic cantilever modes occur. To describe the dynamics of the cantilever we introduce the finite differences method (FDM) on the basis of the Euler-Bernoulli beam theory. This numerical approach allows the detailed description of the cantilever dynamics under applied loads and hence provides information on the modal structure and frequency spectrum. With that approach the deviation of the tip movement from the sinusoidal harmonic oscillation can be investigated in detail.

O 97.12 Thu 18:00 MA 005

Information content comparison of mulitfrequency afm methods — •Daniel Platz[1], Daniel Forchheimer[2], Erik Tholén[3], and David B. Haviland[2] — [1]TU Wien, Gußhausstraße 27-29, A-1040 Vienna, Austria — [2]KTH Royal Institute of Technology, Albanova University Center, SE-106 91 Stockholm, Sweden — [3]Intermodulation Products AB, Landa Landavägen 4193, SE-823 93 Segersta, Sweden

Dynamic atomic force microscopy (AFM) is one of the key tools for imaging and measuring matter at the nanoscale. In conventional dynamic AFM a small tip at the end of a micro-cantilever oscillates at one frequency above a sample surface. In recent years, several multifrequency methods have been developed to increase the information content of AFM measurements. All these multifrequency methods allow for tip motion comprising multiple frequency components but they are based on different principles like the excitation of multiple cantilever eigenmodes, measurement of higher harmonics of the tip motion or creation of spectral mixing products. Although multifrequency methods have been extensively studied experimentally, it is not well understood how different methods compare. We developed a framework for the consistent comparison of multifrequency AFM methods. The framework is based on the numerical kernel estimation method which allows for an easily understandable interpretation of spectral frequency components. Using this approach, we are able to quantify the information content of different multifrequency AFM methods and to study their robustness to noise.

O 97.13 Thu 18:15 MA 005

Characterising NC-AFM cantilevers by opto-mechanical forces — •Alexander von Schmidsfeld and Michael Reichling — Universität Osnabrück

Cantilevers are harmonic oscillators that are designed to have a high sensitivity for the detection of minute external forces typically used in non-contact force microscopy (NC-AFM) to detect forces originating from the tip-sample interaction.

We use opto-mechanical forces acting in the light field of an interferometer for measuring the displacement of an oscillating cantilever for a complete characterization to derive the eigen-frequency (f_0), Quality-factor (Q) oscillation amplitude (A) and cantilever stiffness (k_0) of the cantilever.

As the radiation pressure acting on the cantilever can be determined and the interferometer provides a precise, intrinsically calibrated displacement measurement, these for the interpretation of NC-AFM images crucial properties can be determined with remarkable precision. Due to the sinusoidal intensity modulation of the light intensity an amplitude dependent frequency shift is observed enabling the comparison of the opto-mechanical force to the restoring force. By exactly characterizing the interferometer the light intensity inside the cavity formed by fiber and cantilever and thus the opto-mechanical force can be determined with high precision.