O 84: Scanning Probe Techniques: Method Developments

Time: Thursday 15:00–18:15 Location: S054

Invited Talk O 84.1 Thu 15:00 S054

Radio frequency STM on molecular resonators — •Stefan Müllegger — Johannes Kepler University Linz, Institute of Semiconductor and Solid State Physics, Linz, Austria.

To benefit from both, the superior spatial resolution of scanning tunneling microscopy (STM) and the exceptional energy resolution of magnetic resonance techniques, we developed a spectroscopic radio frequency (rf) STM system [1,2]. It enables the detection [1] and excitation [2] of mechanical vibrations of a new type of nano-mechanical resonator system based on one-dimensional chains of only 4 to 7 weakly coupled small molecules on a Au(111) surface. Rf-STM reveals concerted mechanical oscillations at 51–127 MHz with a chain-length dependence in reasonable agreement with a coupled-oscillator model. Moreover, I discuss the resonant excitation of single nuclear (I) and electronic (J) spins by rf tunneling in individual molecular quantum dots by a novel technique denoted as rf scanning tunneling spectroscopy (rf-STS) [3], enabling single-spin spectroscopy unbound from electromagnetic dipole selection rules [4]. Our rf-STS experiments on magnetic molecular quantum dots have revealed nuclear and electronic spin transitions of individual quantum spins of up to $\Delta I_z = \pm 3$ and $\Delta J_z = \pm 12$ with sub-nanometer spatial resolution. The molecular quantum dots are formed by molecules of the single-molecule magnet bis-phthalocyanato terbium (III) on Au(111) at 5 K.

[1] Phys. Rev. Lett. 112, 117201 (2014). [2] Nanotechn. 25, 135705 (2014). [3] Phys. Rev. Lett. 113, 133001 (2014). [4] arXiv:1510.04804.

O 84.2 Thu 15:30 S054

Co-resonant scanning force microscopy sensors — •Christopher F. Reiche[1], Julia Körner[1], Bernd Büchner[1,2], and Thomas Mühl[1] — [1]Leibniz-Institut für Festkörper- und Werkstoffforschung IFW Dresden — [2]Institut für Festkörperphysik, Technische Universität Dresden

A possible route to enable the detection of very small interaction forces in dynamic mode scanning force microscopy (SFM) is to decrease the spatial dimensions of the cantilever force sensor to reduce its effective spring constant and increase its resonance frequency. However, this approach is limited by the required operational stability of the sensor to avoid snap-ins and the capability of the equipment to still reliably detect the sensor's oscillatory state. By applying a recently developed co-resonant sensor concept [1] to bidirectional scanning force microscopy sensors [2], it is possible to combine the stability and ease-of-detection of a standard SFM cantilever with the high sensitivity of a nanocantilever. Since the measurement signal is still generated by observing changes in the oscillatory state of the standard cantilever, these novel sensors for dynamic mode SFM are still compatible with common SFM equipment. To demonstrate the performance of these sensors, we employed iron filled carbon nanotubes as nanocantilevers to achieve sensitivity to magnetic stray fields. A comparison of experimental results to calculated data reveal a signal increase by three orders of magnitude compared to standard force sensors.

[1] C.F. Reiche, J. Körner et al., Nanotechnology 26 (2015) 335501
[2] C.F. Reiche et al., New J. Phys. 17 (2015) 13014

O 84.3 Thu 15:45 S054

Effect of amplitude on bimodal frequency modulation atomic force microscopy with small amplitudes in ambient conditions — •Dominik Kirpal[1], Hiroaki Ooe[2], Daniel Wastl[1], Alfred J. Weymouth[1], Toyoko Arai[2], and Franz J. Giessibl[1] — [1]Department of Physics, University of Regensburg, Regensburg, Germany — [2]Natural Science and Technology, Kanazawa University, Kanazawa, Japan

Bimodal atomic force microscopy (AFM) is usually performed with the first flexural mode excited at a large amplitude to maintain a stable oscillation, and the second mode excited at a small amplitude to be sensitive to short-range interactions. A stiff cantilever, such as the one provided by a qPlus sensor, can be used to perform bimodal AFM with small amplitudes in both flexural modes. We calculated the piezoelectric sensitivity of the qPlus sensor in the second flexural mode and imaged KBr(100) in ambient conditions to determine the ideal amplitudes for atomic resolution with bimodal AFM. The highest signal-to-noise ratio is achieved if the total vertical displacement of the tip in each cycle is less than the thickness of a single hydration layer.

O 84.4 Thu 16:00 S054

Force reconstruction with multifrequency kernel spectroscopy — •Daniel Platz[1,2], Daniel Forchheimer[2,3], Erik A. Tholen[3], John E. Sader[4], and David B. Haviland[2] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, D-01187 Dresden, Germany — [2]KTH Royal Institute of Technology, Albanova University Center, SE-114 19 Stockholm, Sweden — [3]Intermodulation Products AB, Landa Landavägen 4193, SE-823 93 Segersta, Sweden — [4]The University of Melbourne, Victoria 3010, Australia

The object of interest in dynamic atomic force microscopy (AFM) is the interaction force between a sample surface and the tip of an oscillating cantilever. However, the measured data in AFM do not describe this interaction force directly but rather describe properties of the cantilever motion like amplitudes, phase or frequency shifts. Each AFM mode requires extensive modeling to link the measured data and physical properties of the interaction force. Here, we present a general method, called multifrequency kernel spectroscopy (MKS), for interpreting measured AFM data. The method allows for a clear measurement of the "amount of information" in AFM data and a quantitative reconstruction of the interaction force for any AFM mode. To demonstrate the capabilities of MKS we use it to unambiguously separate long and short range forces in multifrequency magnetic force microscopy and reconstruct the tip-sample interaction force from amplitude-modulated AFM measurements.

O 84.5 Thu 16:15 S054

The effect of non-ideal tunneling current amplifiers on force measurements — •Nirmalesh Kumar Sampath Kumar, A. J. Weymouth, V. Junk, F. Huber, and F. J. Giessibl — University of Regensburg, Regensburg, 93053, Germany

Measurements of the tunneling current are performed with a current-to-voltage converter typically implemented by returning the output of an operational amplifier with a resistor in the Mega- to Giga-Ohm range to the inverting input. With the sample is attached to inverting input, and the non inverting input at ground, an ideal operational amplifier would maintain the sample at ground. A real operational amplifier, however, has finite internal impedance and finite gain. This has been shown to affect STM measurements when the internal resistance of the operational amplifier starts to be on the same order of magnitude as the resistance of the tunneling junction. [1]

We have observed that the presence of the current-to-voltage converter can have a profound effect upon the excitation required to oscillate the cantilever. A phase shift between the non-ideal virtual ground and the cantilever oscillation can account for energy either being pumped into or drained from the cantilever as it oscillates. In this contribution, we discuss our observations and this effect in more detail.

References [1] L. Olesen et al. Phys. Rev. Lett. 76, 1485 (1996)

O 84.6 Thu 16:30 S054

high frequency transmission to a junction of a scanning tunneling microscope — •marie hervé, moritz peter, and wulf wulfhekel — Physikalisches Institut, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

We report on an easy method to calibrate the transmission of radio-frequency (rf) voltages to the tunneling junction of a scanning tunneling microscope. The transmission strongly depends on frequency, as the cabling shows frequency dependent damping and the impedance mismatch between the cable and the tunneling junction induces reflections. To first order, the current-voltage characteristic of the junction induces a rf tunneling current of the same frequency as the rf voltage. Omnipresent non-linearities of the current-voltage characteristic of the junction to second order, however, generates an additional rectified DC current. A direct comparison between this current and the second derivative of the current-voltage curve allows to determine the rf transmission to the tunneling junction. The transmission data up to 2 GHz were used to compensate the rf damping such that at every frequency a constant amplitude at the tunneling junction could be realized expanding the bandwidth of the experiment from less than 100

MHz to 2 GHz [1].

[1] M. Hervé, M. Peter, and W. Wulfhekel, Appl. Phys. Lett. 107, 093101 (2015)

O 84.7 Thu 16:45 S054

Imaging of 2D electronic structures with Intermodulation — •Riccardo Borgani[1], Erik A. Tholén[2], and David B. Haviland[1] — [1]Nanostructure Physics, KTH Royal Institute of Technology, Stockholm, Sweden — [2]Intermodulation Products AB, Segersta, Sweden

We present a Scanning Probe Microscopy (SPM) technique to image the contact potential difference (CPD) between the tip of a conducting cantilever and the sample surface. A multifrequency drive is used to probe the nonlinear electrostatic force and extract the CPD from the intermodulation signals close to the cantilever resonance. This measurement scheme allows for a very high signal to noise ratio and excellent lateral resolution, and it eliminates the DC feedback to null CPD, used on all other types of Kelvin Probe Force Microscopy. The absence of a DC bias is of particular importance with those samples where electrical doping could alter the properties under investigation. We present a theoretical derivation of the technique, as well as it's application for high-resolution imaging of mono- and multi- layer graphene and graphene nano-ribbons, and patterned two-dimensional electron gas devices.

Reference

R. Borgani, D. Forchheimer, J. Bergqvist, P.-A. Thorén, O. Inganäs, and D. B. Haviland, Appl. Phys. Lett. 105, 143113 (2014).

O 84.8 Thu 17:00 S054

A quantitative tool to measure nanoscale electrostatic potentials — •Matthew F. B. Green[1,2], Christian Wagner[1,2], Philipp Leinen[1,2], Thorsten Deilmann[3], Peter Krüger[3], Michael Rohlfing[3], Ruslan Temirov[1,2], and F. Stefan Tautz[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA - Fundamentals of Future Information Technology — [3]Institut für Festkörpertheorie, Westfälische Wilhelms-Universität Münster, 48149 Münster

Interactions between nanoscale objects on surfaces are dominated by the van der Waals and electrostatic contributions. The ability to characterize the electrostatic field on a surface would therefore be a valuable tool for many areas of nanoscience research. Recently we presented a technique called scanning quantum dot microscopy (SQDM), whereby local electrostatic potentials on surfaces can be measured quantitatively and in three dimensions. By registering the charging events of a single molecule weakly hybridized to an nc-AFM tip, acting as a QD, the quadrupole potential of a single molecule and the dipole potential of a single ad-atom were investigated. In addition we demonstrated the remarkable sensitivity of SQDM by probing an ad-atom from 6 nm away [1]. We now present a quantitative model of the charging dynamics based on single electron box theory [2], taking the orbital hybridization and junction geometry into account. By fitting the model to experimental data, we show how the system parameters affect the way that the charging manifests itself in the frequency shift signal.

O 84.9 Thu 17:15 S054

Quantitative mapping of magnetic stray fields by dynamic mode magnetic force microscopy — Christopher F. Reiche[1], •Clemens Gütter[1], Silvia Vock[1], Volker Neu[1], Bernd Büchner[1,2], and Thomas Mühl[1] — [1]Leibniz-Institut für Festkörper- und Werkstoffforschung IFW Dresden — [2]Institut für Festkörperphysik, Technische Universität Dresden

Dynamic mode magnetic force microscopy (MFM) is a successful method to study magnetic stray fields of samples with high spatial resolution. Quantitative approaches based on frequency modulation measurements and a point probe approximation for the magnetic tip can supply information about the first or the second order spatial derivative of the magnetic stray field of a sample. However, often it would be favorable to know the more fundamental stray field itself. Here, we demonstrate a technique that enables the measurement of one component of the magnetic stray field of a sample in real space. This technique is based on the integration of frequency shift signal maps gathered at different measurement heights. It employs calibrated iron filled carbon nanotube magnetic tips with monopole-like characteristic [1]. While this technique has some requirements on the sample it does not need any special kind of MFM equipment. The viability of this approach was validated by measurements on a well-characterized Pt/Co magnetic multilayer sample. For such a sample it is possible to calculate its magnetic stray field based on an effective magnetic surface charge pattern approach and compare it to the measured results.

[1] F. Wolny et al., Nanotechnology 21 (2010) 435501

O 84.10 Thu 17:30 S054

Tip-enhanced Raman spectroscopy: comparison between AFM and STM feedback mechanism performance — •Jana Kalbacova, Raul D. Rodriguez, Axel Fechner, and Dietrich R.T. Zahn — Semiconductor Physics, Technische Universität Chemnitz, 09126 Chemnitz, Germany

Tip-enhanced Raman spectroscopy (TERS) is a relatively young technique, with the first experimental reports around the year 2000. This technique combines features of two distinct methods - Raman spectroscopy that can e.g. provide details on the chemical composition of a sample, while the metallic tip acts as a nano-antenna enhancing the sample signal only beneath the tip apex. In this way, the chemical information can be resolved at the nanoscale. The way to control the position of the tip apex is the feedback mechanism of the scanning probe microscope. In this contribution, we first review the pros and cons of the atomic force microscopy (AFM) and scanning tunnelling microscopy (STM) feedback loop in TERS. For experimental part of this comparative study, we prepared a sample comprised of single-walled carbon nanotubes and graphene oxide deposited on a gold substrate. An etched gold tip was employed for TERS imaging in both modes. We demonstrate TERS in ambient conditions with sub-10 nm spatial resolution for both approaches (AFM and STM) showing the availability of various working conditions that can be chosen to accommodate different samples with STM, as a feedback loop, displaying better spatial resolution.

O 84.11 Thu 17:45 S054

Quantitative description of light-excited scanning tunneling spectroscopy — •Michael Schnedler, Verena Portz, Phillip Weidlich, Rafal Dunin-Borkowski, and Philipp Ebert — Peter Grünberg Institut, Forschungszentrum Jülich GmbH, 52425 Jülich, Germany

The efficiency of solar cell and optoelectronic devices is closely connected to the nanoscale distribution of charge carriers. In order to understand the physical processes involved at the atomic scale, the materials need to be investigated simultaneously under illumination and with atomic resolution. Photo-excited scanning tunneling spectroscopy (STS) is ideally suited to probe the illumination-induced local surface photo-voltage, band bending, carrier concentration, and the electrostatic potential distribution with atomic resolution. For a quantitative analysis, particularly of the local charge carrier concentration, a fundamental physical understanding of the photo-excited tunneling spectra is needed. We will present a new theoretical model of photo-excited STS that incorporates a fully three dimensional solver for both, the electric field and the (intrinsic and photo-excited) carrier concentrations near the semiconductor's surface. In order to take into account both, the tip induced band-bending and the photo-excited carrier concentration, we present a modification of the tunnel current model of Feenstra and Stroscio by introducing Quasi-Fermi levels.

O 84.12 Thu 18:00 S054

Application of Photothermal Expansion for Optical Absorption Mapping at the Nanoscale — •Teresa Isabel Madeira[1], Raul David Rodriguez[2,3], Yuvaprasad Ravikumar[2], Harsha Shah[2], Eugene Bortchagovsky[4], and Dietrich RT Zahn[2,3] — [1]BioISI-Department of Physics-Faculdade de Ciencias-Universidade de Lisboa, Campo Grande, 1749-016 Lisboa, Portugal — [2]Semiconductor Physics-Technische Universität Chemnitz, D-09107 Chemnitz, Germany — [3]cfaed-TU Dresden — [4]V. Lashkarev Institute of Semiconductor Physics of NASU, pr.Nauki 41, Kiev 03028, Ukraine

We demonstrate photothermal expansion can be used to obtain images of nanostructured semiconductor materials such as GaSe flakes on graphite and carbon nanotubes on SiO_2 in ambient conditions with high sensitivity and spatial resolution. The principle behind is the detection of the mechanical force exerted on an atomic force microscopy (AFM) tip by the thermal expansion of the materials excited with pulses of optical radiation, taking advantage of the different absorption properties between substrate and sample. Characterization of semiconductor nanostructures, with a bandgap in the optical range enables the use of cw lasers chopped and synchronized with the resonance frequency of custom-made fully metallic cantilever AFM Au tips. The spatial resolution achieved by the synchronization procedure described is indeed in the nanometer range below 60 nm, and by taking advantage of the difference between optical absorption and thermal

coefficients material contrast can be achieved. The optimal conditions | to make the most of this technique are also discussed.