O 80: Poster: Scanning Probe Techniques - Method Development

Time: Wednesday 18:15–20:30 Location: Poster A

O 80.1 Wed 18:15 Poster A

Thermally induced sharpening of tungsten STM-tips — •Timm-Florian Pabst, Hendrik Bettermann, and Mathias Getzlaff — Institute of Applied Physics, Heinrich-Heine-Universität Düsseldorf

Scanning Tunneling Microscopy (STM) allows to investigate structures with a lateral resolution down to the atomic scale. Special attention should be paid to the differing quality or sharpness of the used tip.

The goal of this work is to improve the quality of etched tungsten-STM-tips by using electron-bombardment heating. The resulting sharpness is investigated by testing the tips on tungsten oxide ($O-((1\times1)\times12)$) structure, and FeCo- and Co-nanoparticles deposited on a W(110) surface. The nanoparticles have a size of 3 nm to 9 nm and are produced in situ with a Magnetron Aggregation Source (Haberland type) and an Arc Cluster Ion Source. All measurements are carried out under ultra-high vacuum conditions at room temperature.

O 80.2 Wed 18:15 Poster A

Development of a fibre-based interferometer for an aperturless Scanning Near-field Optical Microscope — •Patrick Pietsch, Jonas Albert, and Markus Lippitz — University of Bayreuth, Bayreuth, Germany.

Aperturless scanning near-field optical microscopy (aSNOM) is a technique to measure the electric near-fields of nanoobjects, such as plasmonic structures, with deep subwavelength resolution. For this purpose an interferometer is required to obtain information on amplitude and phase of the near-field.

We will show how stability and signal-to-noise ratio of these experiments could be improved by using a fibre-based Mach-Zehnder interferometer, instead of a setup based on free space optics. Furthermore we will show, how it helps to increase the ease of use of this experiments.

O 80.3 Wed 18:15 Poster A

Design of a cryogenic dip-stick tuning fork-based AFM/STM system — •christian salazar, heiko hädrich, danny baumann, thomas mühl, bernd büchner, and christian hess — Leibniz Institute for Solid State and Materials Research, Dresden, Germany

We present the design of a tuning fork-based AFM/STM system, which consists in a dip-stick device able to operate inside a helium dewar or a magnet bath cryostat. The design allows to use in the AFM mode a frequency modulation feedback loop instead of the typical optical feedback loop. Additionally, this design provides the opportunity to connect a conducting tip to one of the tuning fork electrodes in order to run the STM mode. Measurements can be carried out in the temperature range from approximately 4K to room temperature and under cryogenic vacuum conditions. The system includes a cleaving mechanism for cleaving single crystals and a capacitive automated coarse approach mechanism for bringing the tip close to the sample surface without tip or surface damage.

O 80.4 Wed 18:15 Poster A

Etching tungsten nanotips using nitrogen gas in a field ion microscope — •Alexander Ihle, Sören Zint, Daniel Ebeling, and André Schirmeisen — Institute of Applied Physics, Justus Liebig University Giessen, Germany

Ultra-sharp tungsten nanotips are used in various applications. For low temperature atomic force microscopes, e.g., where quartz tuning forks are used as sensors nanotips are often fabricated from thin tungsten wire. To achieve ultimate lateral resolution or for functionalizing the tips with single CO molecules extremely sharp tips with radii in the nm or even in the sub-nm regime are needed. In 2006 Rezeq et al. [1] introduced a new method for tip fabrication, where electrochemically etched tungsten tips are further sharpened in a subsequent step by field-assisted etching with nitrogen gas. Therewith, tip radii below 1 nm can be reproducibly fabricated. Here, we are analyzing the effect of the nitrogen pressure on the tip etching process. To precisely determine the tip radius we use the so-called *feature size mapping* method [2]. Our measurements reveal that the tip radius decreases linearly in time for various nitrogen gas pressures in a range between 5.6 x 10-8 mbar and 5 x 10-6 mbar. Therefore, the etching rate at a specific pressure is constant. Furthermore, it is demonstrated that the etching rates increase linearly with higher nitrogen pressures, which allows us to precisely estimate the process time.

[1] Rezeq et al. *The Journal of Chemical Physics* **124**, 204716 (2006)
[2] Zint et al. *Phys. Rev. B* **90**, 241413 (2014)

O 80.5 Wed 18:15 Poster A

Design and performance of a UHV spin-polarized STM operating at 30 mK in vector magnetic fields — •Henning von Allwörden[1], Elze J. Knol[1], Andreas Eich[1], Jan Hermenau[2], Andreas Sonntag[2], Jan W. Gerritsen[1], Daniel Wegner[1], and Alexander A. Khajetoorians[1] — [1]Institute for Molecules and Materials, Radboud University, Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands — [2]Fachbereich Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany

Scanning tunneling microscopy (STM) has developed into a leading technique to explore atomic-scale magnetism. However, to enhance the energy resolution in order to probe spin-dependent phenomena, our instrument design is based on a wet dilution refrigerator. Its base temperature is around 30 mK and it is capable of vector magnetic fields in two dimensions. The connection to an ultra-high vacuum (UHV) system allows in-situ sample preparation and transfer. The setup is situated in an ultra-quiet and ultra-low noise laboratory (SPiN laboratory at the IMM in Nijmegen), and also special care was taken to do signal filtering in-situ. We demonstrate the instrumentational performance by showing the noise characteristics at the tunnel junction, atomic resolution of a surface and measured quasi-particle interference (QPI), showing the ability to perform QPI mapping. Furthermore, we illustrate spectra of low temperature BCS superconductors and discuss the electron temperature.

O 80.6 Wed 18:15 Poster A

Four-point probe measurements using current probes with voltage feedback to measure electric potentials — •David Cuma[1,2], Felix Lüpke[1,2], Stefan Korte[1,2], Vasily Cherepanov[1,2], and Bert Voigtländer[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, 52425 Jülich, Germany — [2]JARA-FIT, 52425 Jülich, Germany

Four-point probe sensing is a widespread measurement technique to determine electrical impedances. The underlying idea is to separate current injection and voltage sensing probes to eliminate the influence of distorting contact resistances. Among others, the technique is commonly utilized in multi-tip scanning tunneling microscopy setups (see e.g. [1]). The necessity to perform both voltage and current measurements, however, requires either impracticable rewiring in between measurements or complex electronics, which can perform both measurements but are prone to induce additional electrical noise. By using current sensing probes to measure the voltage via a feedback loop [2] we introduce a new approach that allows to conduct low noise and in principle truly non-invasive four-point probe measurement at the nanometer scale.

[1] S. Just, M. Blab, S. Korte, V. Cherepanov, H. Soltner, and B. Voigtländer, Phys. Rev. Lett. 115, 066801 (2015)
[2] F. Lüpke, S. Korte, V. Cherepanov, and B. Voigtländer, Rev. Sci. Instr. 86, 123701 (2015)

O 80.7 Wed 18:15 Poster A

Detection of spin-polarized transport in topological insulators using a 4-tip STM — •Arthur Leis, Sven Just, Vasily Cherepanov, and Bert Voigtländer — Peter Grünberg Institut (PGI-3) and JARA-FIT, Forschungszentrum Jülich, Germany

Spin-momentum locked surface states as a hallmark of topological insulators are of particular interest in solid-state physics. However, the detection of these states in transport measurements is a challenge, as a spin-sensitive measurement technique is needed. While most measurement efforts are based on optical methods, reports on the electrical detection of spin-polarized charge transport are still scarce and include lithographic sample preparation. Our approach to this challenge is an in-situ distance-dependent four-point probe measurement technique using a multi-tip STM with magnetic tips. While distance-dependent measurements are used for the distinction between 2D- and 3D-transport, using magnetic tips allows for the detection of spin-polarization.

O 80.8 Wed 18:15 Poster A

STM with fibre tips : A new approach to probe the local optical response of surfaces — •René Jakob and Niklas Nilius — Institute of Physics, Carl von Ossietzky University, 26111 Oldenburg, Germany

STM is an ideal tool to measure topographic and electronic properties of surfaces at atomic length scales. STM luminesce spectroscopy, which uses the inelastic tunnelling current to stimulate photon emission, enables a local optical characterization in addition. Main drawback is the low coupling strength of electrons and photons in the tip-sample gap, yielding reasonable signal-to-noise ratios only if using plasmonic materials for tip and sample. We have attempted to overcome this difficulty by coupling laser light directly into the STM junction via an optical fibre tip. To activate also the tunnelling channel, the fibre tip is coated with layers of Cr/Ag or Cr/Au. The interaction of incident photons with the surface is measured via a CCD detector in the far-field. The approach allows us to probe the optical response of surfaces covered with molecules, metal particles or oxide colour centres with high spatial resolution.

O 80.9 Wed 18:15 Poster A

Analysis of CO-terminated tips used by combined STM/AFM at low temperatures — •Julian Berwanger, Ferdinand Huber, and Franz J. Giessibl — University of Regensburg, 93040 Regensburg, Germany

The functionalization of scanning probe microscope tips with a carbon monoxide molecule - introduced by Bartels et al. [1] for STM and by Gross et al. [2] for AFM - is widely used today due to their atomic resolution capability on molecules, metallic clusters and other sample systems [2-4]. The exact imaging mechanism and the influence of bending effects of the CO tip on experimental data was studied extensively [5-8]. Nonetheless a study which explains that various CO-terminated tips can lead to different qualitative and quantitative results, especially in the short range interaction regime, is - to our knowledge - missing. We analyze AFM data of single metal adatoms on Cu(111) imaged by CO-terminated metal tips with various opening angles and present a hypothesis about the observed difference in the experimental contrast of single adatoms.

[1] L. Bartels et al. Appl. Phy. Lett. 71, 2 (1997)
[2] L. Gross et al. Science 325, 110 (2009)
[3] M. Emmrich et al. Science 348, 6232 (2015)
[4] M. Ellner et al. Nano Lett. 16, 3 (2016)
[5] M. Neu et al. PRB 89, 205407 (2014)
[6] N. Moll et al. New J. Phys. 12, 125020 (2010)
[7] P. Hapala et al. PRB 90, 085421 (2014)
[8] P. Hapala et al. Nat. Com. 7, 11560 (2016)

O 80.10 Wed 18:15 Poster A

Practical considerations in 3D magnetic resonance force microscopy — •Marc-Dominik Krass, Urs Grob, Alexander Eichler, Martin Héritier, Hiroki Takahashi, and Christian Degen — Department of Physics, ETH Zurich, Otto-Stern-Weg 1, 8093 Zurich, Switzerland

Magnetic resonance force microscopy (MRFM) is a technique that reconstructs the 3D density distribution of nuclear spin species in nanoscale samples, such as individual macromolecules. While the feasibility of the method has been demonstrated [Degen et al. PNAS 106, 1313 (2009)], state-of-the-art experiments have not yet reached the subnanometer regime required to reveal detailed molecular structures.

MRFM experiments operate at the physical boundaries of technology where every improvement in resolution must be earned by overcoming a manifold of physical and technical problems. Of crucial importance are, for instance, a stable feedback control of the mechanical resonator, a superb displacement detection sensitivity, suppression of standing waves in the rf-circuit and clever NMR pulse shaping for evading unwanted electrostatic interaction, and robust spin inversion protocols. Our poster summarizes our progress in MRFM technology and demonstrates first signal scans of single isotope-labeled influenza virus particles.

O 80.11 Wed 18:15 Poster A

Measuring Single Iron Magnetic State Lifetimes Using Distortion Compensated Signals — •Gregory McMurtrie[1,2,3], Max Hänze[2,3], Steffen Rolf-Pissarczyk[2,3], Luigi Malavolti[2,3], Mohammad Abdo[2,3], Björn Schlie[1,2,3], and Sebastian Loth[1,2,3] — [1]Institute for Functional Matter and Quantum Technologies, Stuttgart, Germany — [2]Max Planck Institute for Structure and Dynamics of Matter, Hamburg, Germany — [3]Max Planck Institute for Solid State Research, Stuttgart, Germany

Injecting pulses [1] or continuous wave signals [2] into a tunnel junction has shown promising results for the characterization of fast magnetic surface dynamics using scanning tunneling microscopy. When pushing into the sub-nanosecond time domain, the transmission line characteristics of the instrument strongly modify the signals reaching the tunnel junction [3], limiting the effective time resolution. We present an in-situ technique for the quantitative measurement of the transmission line characteristics, both in phase and amplitude. This information is used to compensate for imperfections in the transmission lines, resulting in a greatly increased effective bandwidth. By improving the time resolution of the instrument, it becomes possible to measure spin relaxation times of individual atoms which are often well under a nanosecond. The door is now opened to further implement the pulse correction technique and observe a wide range of ultra-fast phenomena at the atomic scale. [1] S. Loth, et. al. Science 329 1628 (2010). [2] S. Baumann et. al. Science 350 6259 (2015) [3] C. Grosse, et. al. Appl. Phys. Lett. (2013)

O 80.12 Wed 18:15 Poster A

Design of a 30 mK scanning tunneling microscope for spin-polarized measurements — •Sebastian Schimmel, Danny Baumann, Alexander Horst, Ralf Voigtländer, Dirk Lindackers, Bernd Büchner, and Christian Hess — IFW Dresden, Helmholtzstrasse 20, 01069, Dresden, Germany

In order to obtain experimental access and to disentangle the intertwined phases found in unconventional superconductors, which are namely the electronic ordering, superconductivity and static magnetism, we designed the presented milli-Kelvin scanning tunneling microscope (STM) system for spin-polarized investigation with very high resolution in energy as well as in real space. Using a 3He/4He Dilution Refrigerator allows to cool the tip and sample to a measurement temperature of 30 mK that improves the energy resolution to the corresponding value of only about 15 micro-eV and enables to study all classes of unconventional superconductors, also including heavy fermion compounds. Long term measurements at base temperature can be performed for up to 7 days. A 9-4 T vector magnet allows the systematic in-situ manipulation of the spin-polarization axis. For the preparation of tips and samples for spin-polarized STM measurements, a UHV chamber has been designed with a suitable system for tip/sample transfer. The suppression of disruptive vibrations is done by a two stage passive/active damping system.

O 80.13 Wed 18:15 Poster A

Tests and first results of an RF-compatible UHV-based multiprobe-STM system — •Jonas Koch, Jonas Harm, Johannes Friedlein, Maciej Barzanik, Stefan Krause, and Roland Wiesendanger — Dept. of Physics, University of Hamburg, Hamburg, Germany

We present the concept of a 3-tip multiprobe scanning tunneling microscope (MP-STM), which achieves picosecond time resolution by the use of RF technology. The evaluation of the microscope's performance is carried out in ultra-high vacuum (UHV) and at variable temperatures from 30 K up to room temperature. For this purpose we have designed a vibration-damped UHV setup equipped with electrical RF feedthroughs (for up to 40 GHz). The tests focus on the thermal coupling of individual components, in particular the RF cabling, and on the vibration decoupling from external noise sources. Furthermore, we analyzed the behavior of the coarse drive in x-, y- and z-direction for each of the three scanners at low temperatures. First results of the 3-tip multiprobe-STM will be presented.

O 80.14 Wed 18:15 Poster A

GXSM3: an open source scanning probe system — Percy Zahl[1], •Thorsten Wagner[2], and GXSM community[3] — [1]Center for Functional Nanomaterials, Brookhaven National Laboratory, USA — [2]Experimental Physics, Johannes Kepler University, Linz, Austria — [3]gxsm.sf.net and sranger.sf.net

Pushing the limits of scanning probe microscopy (SPM) does not only require a dedicated hardware (microscope) but also a sophisticated control system. In particular, the open source and community driven project GXSM [1-3] provides a high level of flexibility so that different kinds of SPMs can be operated via a digital signal processor (DSP) based hardware. Recently, the third version of the graphical user interface was released. Besides the completely overhauled user interface based on the Gtk+3/Gnome3-standard, there are also significant changes under the hood: The possibilities to remotely control GXSM3 via Python scripts were widely extended. Complex data acquisition tasks like automatic mosaic/survey scans are easily programmed in a simple script. Even auto-approach schemes with 'watch dog'-option for the frequency (AFM mode) can be put into action by Python scripting. Tip position can now be controlled via mouse/objects and is fully programmable via python. A new open GL based 3D view was implemented, which allows also the rendering of volumetric data. Now, several wave forms can be used for the coarse motion.

[1] P. Zahl *et al.*, Imaging & Microscopy (GIT), Jan. 26, 2015.
[2] P. Zahl, *et al.*, J. Vac. Sci. Technol. B 28 (2010) C4E39.
[3] P. Zahl, *et al.*, Rev. Sci. Instr. 74 (2003) 1222.

O 80.15 Wed 18:15 Poster A

An STM in a Pulse-Tube Refrigerator — •Marcel Rost, Gert Koning, Ko Koning, and Tjerk Oosterkamp — Huygens-Kamerlingh Onnes Laboratory, Leiden University, P.O. Box 9504, 2300 RA Leiden, The Netherlands

The advantage of Pulse-Tube Refrigerators over conventional (wet) ones becomes obvious, if one considers the (future) increase in helium costs as well as the complexity, maintenance, and time investment that is required to run a wet-type refrigerator. However, the clear downside of a pulse-tube-system is the acoustical and mechanical noise introduced by the pulsing pump.

Although we have successfully shown earlier that it is possible to obtain atomic resolution on HOPG with an STM in our system, the real demonstration, however, is obtaining at least full atomic resolution on a closed packed fcc(111) surface! Here we show our current approach, the modifications of the STM, and present the latest results.

O 80.16 Wed 18:15 Poster A

Modelling force sensor oscillations for non-contact atomic force microscopy — •Daniel Heile, Philipp Rahe, and Michael Reichling — Universität Osnabrück, Barbarastraße 7, 49076 Osnabrück

The force sensors utilized in non-contact atomic force microscopy are prevalently described by the Euler-Bernoulli beam equation which is commonly analytically solved in the load free, homogeneous case. Furthermore we consider cases, where this analytical approach is not viable any more and introduce the finite differences method (FDM) to describe the force sensor oscillation and dynamics. FDM allows the description of the cantilever oscillations as an eigenvalue problem based on the Euler-Bernoulli beam equation. The results of both approaches are compared for several fundamental cases verifying the reliability of the FDM for force sensor modelling. Based on these results more advanced models, for example coated force sensors, can be considered.

O 80.17 Wed 18:15 Poster A

Coupling microwave radiation into an STM Josephson junction — •Nils Bogdanoff[1], Olof Peters[1], Gaël Reecht[1], Clemens B. Winkelmann[2], and Katharina J. Franke[1] — [1]Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Univ. Grenoble Alpes, Institut Neél, 25 Avenue des Martyrs, 38042 Grenoble, France

Josephson junctions (JJ) have been extensively studied as promising elements in quantum mechanical circuits. Combining them with the high spatial resolution of a scanning tunneling microscope (STM) would allow for the local investigation of the superconducting groundstate close to magnetic defects. We present a current-biased JJ formed between Pb tip and Pb sample in a $T = 1.3\,\mathrm{K}$ STM.

Microwave frequencies of up to $f = 26\,\mathrm{GHz}$ can be introduced into the junction using coaxial cables. The Josephson current responds to the irradiation by showing multiple frequency- and power-dependent steps. Simulations allow to distinguish their origin between coherent and incoherent as well as Cooper pair- and quasiparticle-based processes.

O 80.18 Wed 18:15 Poster A

Development of an ultrafast THz-gated Scanning tunneling microscope combined with optical photoexcitation — •Natalia Martín Sabanés, Mellanie Müller, and Martin Wolf — Fritz Haber Institute, Berlin, Germany

Unravelling the complex spatio-temporal dynamics of nanostructures and molecules is essential to optimize a variety of applications in nanoelectronics or energy conversion devices. Focusing THz-pulses into the junction of a scanning tunneling microscope (STM) modulates the bias on ps to fs time scales, providing ultrafast control of the tunneling current. THz-gated STM has been successfully used to monitor ultrafast processes on atomic length scales employing a THz pump-THz probe excitation scheme.[1] Despite the outstanding capabilities that this scheme holds for the study of ultrafast phenomena on the atomic level, different experimental configurations allowing the use of optical photoexcitation remain unexplored. We introduce the technical development of an ambient THz-gated STM combined with near-field optical photoexcitation. We discuss the suitability of different THz emitters as well as the use of plasmonic nanofocusing on nanostructured gold tips to increase photoexcitation efficiency and to reduce the thermal load of the tunneling junction.[2] Combining the atomic spatial and fs temporal resolution of a THz-gated STM with optical photoexcitation will provide access to a broader range of spatio-temporal phenomena.

[1] Nature Photonics, 2013, 7(8), 620-625. Nature,2016 539(7628), 263-267. Nature Physics, 2017, 13(6), 591-598. [2] ACS Photonics, 2016, 3(4), 611-619.

O 80.19 Wed 18:15 Poster A

Reinforcement learning for automatic SPM-based single molecule manipulation — •Philipp Leinen[1,2], Kristof Schütt[3], Klaus-Robert Müller[3], Ruslan Temirov[1,2], F. Stefan Tautz[1,2], and Christian Wagner[1,2] — [1]Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — [2]JARA-Fundamentals of Future Information Technology, Jülich, Germany — [3]Institut für Softwaretechnik und Theoretische Informatik, Technische Universität Berlin, Germany

To realize the vision of molecular electronics, the precise control of molecular conformations is critical. The scanning probe microscope (SPM) is the tool of choice for the controlled manipulation of single molecules on surfaces. Finding the right manipulation protocol for a given task can be complicated due to the large number of degrees of freedom of such systems. The computationally demanding search for correct manipulation trajectories via simulation can be avoided if a clear manipulation goal can be formulated. In this case the experimenter can *learn* to achieve this goal in a trial and error approach [1,2]. Here we go one step further and delegate the learning process to a computer. We use reinforcement learning to train a neural network for the task of removing individual PTCDA (3,4,9,10-perylene-tetracarboxylicdianhydride) molecules from a monolayer on Ag(111). The feasibility of our approach is proven using simulated manipulation and first steps are shown of how to employ the method in an experimental SPM setup. [1] M. F. B. Green et al. Beilstein J. Nanotechnol. 5, 1926 (2014) [2] P. Leinen et al. J. Vis. Exp. (116), e54506 (2016)

O 80.20 Wed 18:15 Poster A

Towards a radio frequency four tip scanning tunneling microscope — •Jonas Duffhauss[1], Marco Pratzer[1], Vasily Cherepanov[2], Bert Voigtländer[2], and Markus Morgenstern[1] — [1]RWTH Aachen University/JARA-Fit — [2]Jülich Research Center

A four tip STM [1] has been modified with different cablings that allow for STM measurements in the GHz regime. The time resolution has been determined by a pump-probe experiment using a sample with a non-linear $\mathrm{d}I/\mathrm{d}V$ characteristic (Gold, HOPG) [2].

A time resolution of $< 180\,\mathrm{ps}$ was demonstrated if a RF-cable is used as tip, which is likely limited by the voltage pulse generator. Using the four tip STM with the already implemented tip exchange mechanism, the time resolution gets worse ($\approx 350\,\mathrm{ps}$) due to the additional impedance missmatch. Ringing effects caused by standing waves inside the cable and a low transmission at high frequencies (10 GHz) are identified as main cause for the reduced time resolution.

Options for further improvements of the RF parts, e.g., a low noise bias-tee, are discussed.

[1] V. Cherepanov, E. Zubkov, H. Junker, S. Korte, M. Blab, P. Coenen, and B. Voigtländer, Rev. Sci. Instr., 83, 033707 (2012).
[2] C. Saunus, J. R. Bindel, M. Pratzer, and M. Morgenstern, Appl. Phys. Lett. 102, 051601 (2013).