O 44: Scanning probe techniques: Method development – Poster

Time: Tuesday 14:00–16:00 Location: P2

O 44.1 Tue 14:00 P2

Determining the electrical transmission to the junction of a scanning tunneling microscope — •Guido Hiller, Gaël Reecht, and Manuel Gruber — University of Duisburg-Essen

Stochastic resonance spectroscopy has recently been implemented in STM to probe dynamics at the atomic scale over a wide range of timescales, down to the picosecond range [1]. A key requirement for this method is a modulation voltage at the STM junction with an amplitude independent of the frequency. This, in turn, demands an accurate characterization and compensation of the frequency-dependent transmission of the cabling.

Several studies have focused on quantifying such transmissions. In particular, Paul et al. [2] quantitatively analyzed the radio-frequency induced broadening of a sharp feature in dI/dV spectra. Building on this method, we carried out such analysis in the Fourier space and discuss the associated advantages.

[1] Betz et al., arXiv:2412.12647 (2024) / Hänze et al., Sci. Adv. 7, no. 33 (2021) [2] Paul et al., Rev. Sci. Instrum. 87, no. 7 (2016)

O 44.2 Tue 14:00 P2

Upgrading an LT-STM with a qPlus-AFM system — •René Knispel, Patrick Härtl, and Matthias Bode — Physikalisches Institut, Experimentelle Physik 2, Julius-Maximilians-Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

The invention of the scanning tunneling microscope (STM) by Binnig and Rohrer in 1981 enabled direct imaging of atomic-scale structures in real space [1]. Shortly thereafter, the recognition of tip–sample interactions enabled the development of the atomic force microscope (AFM) [2]. In 1995, Giessibl achieved true atomic resolution with AFM [3] by measuring the force gradient-induced resonance frequency shifts of a silicon cantilever. Quartz-based cantilevers with enhanced stiffness and sensitivity enabled the development of the so-called qPlus-AFM technique, which surpasses STM in spatial resolution and allows STM measurements to be performed concurrently.

To extend the capabilities of our low-temperature STM, we upgraded it with a qPlus-AFM system. The Pan-type scanner was redesigned to enable cantilever excitation and to integrate both differential oscillation signals and the STM tunneling current. A UHV-LT preamplifier for the oscillation signals was also build and mounted inside the liquid-helium shield of the cryostat. The technical implementation and performance of the upgraded microscope will be demonstrated using suitable test samples.

[1] G. Binnig *et al.*, Phys. Rev. Lett. **49**, 57 (1982).
[2] G. Binnig *et al.*, Phys. Rev. Lett. **56**, 930 (1986).
[3] F. J. Giessibl, Science **267**, 68 (1995).

O 44.3 Tue 14:00 P2

Multifrequency Tunnelling Spectroscopy — •Gleb Neplyakh, Philipp E.J. Maier, Carolina A. Marques, Berk Zengin, Kevin Hauser, Rian Ligthart, Alexander LaFleur, and Fabian D. Natterer — Department of Physics, University of Zurich, Winterthurerstrasse 190, CH-8057, Switzerland

Scanning tunnelling spectroscopy (STS) probes the local density of states by measuring differential conductance as a function of energy. Traditional STS acquires N energy points by sweeping a DC bias with a small modulation superimposed. This requires N sequential measurements, making it impractical for large mapping tasks.

We have developed Parallel Spectroscopy (PS) to overcome this limitation. PS exploits the nonlinearity in the $I(V)$ curve of the materials: a single or multitone AC voltage drive generates a set of higher harmonics that encode the full spectrum. Demodulating N harmonics within one leakage-free integration window enables the energy dependence to be recovered in a single measurement, providing substantial speedups.

We compare conventional STS and single- and multi-frequency PS with respect to signal-to-noise ratio, potential artefacts, and spectral resolution. Using PS in conjunction with compressive sensing could allow us to conduct high-resolution studies of many-body effects in quantum materials.

O 44.4 Tue 14:00 P2

Tip-enhanced Raman Microscopy simulation methods — •Pablo Planelles Prensa, Harshit Sethi, Orlando Silveira Junior, and Adam Foster — Konemiehentie 1, 02150 Espoo / P.O. Box 15600, FI-00076 AALTO

Tip-enhanced Raman Microscopy (TERS) has emerged as a promising technique that overcomes Abbe diffraction limit, which dictates that for green light around 500 nm the spatial resolution is limited to only 250 nm, which is insufficient for studying nanomaterials. In TERS, by using a strongly localized plasmonic field produced at the tip apex, the Raman signal is significantly enhanced, and submolecular resolution can be achieved.

Similar to Scanning Tunneling and Atomic Force Microscopy techniques, TERS relies on a sharp tip. TERS offers the additional advantage of providing not only topographic information about the sample, but also chemical.

Despite the rapidly increasing interest in TERS, progress remains limited by the difficulty of interpreting the resulting experimental images.

In this context, we aim to contribute by presenting ab-initio simulation methods and demonstrating how they can be used to greatly facilitate the interpretation and prediction of TERS images. Moreover, we will study the influence of the substrate on the images, and how different tip geometries and materials affect resolution and induce image asymmetry. We will also compare several simulation methods with different levels of complexity and computational cost.

O 44.5 Tue 14:00 P2

Automatic tip functionalization with CO on Ag(111) using machine learning — •Johanna Schnorrenberg, Jonas Heggemann, Paul Laubrock, and Philipp Rahe — Universität Osnabrück, Institut für Physik, Barbarastraße 7, 49076 Osnabrück, Germany

Functionalization of scanning probe microscopy tips with CO molecules enables high-resolution imaging, sub-molecular contrast and access to charge distributions of adsorbed molecules. [1, 2]

However, the manual functionalization procedure is time-consuming and limits experimental throughput. To address this, tip functionalization can be automated. [3]

Here, we implement a full pipeline for CO tip functionalization on Ag(111). The process includes localizing a CO molecule during scanning the surface, performing the pick-up of this CO molecule and evaluating the resulting tip condition. Tip quality is assessed by imaging CO molecules on the substrate and classifying the achieved resolution as "good" or "bad" for a CO-tip using a convolutional neural network (CNN). The CNN performance is compared to a conventional image analysis algorithm, in this case a template matching algorithm.

We expect this automated approach to significantly improve the efficiency of AFM experiments and thereby enabling faster and more systematic data acquisition on molecular systems.

[1] B. Schulze Lammers et al., Nanoscale, 13, 13617 (2021)
[2] L. Gross et al., Angew. Chemie Int. Ed., 57, 3888 (2018)
[3] B. Alldritt et al., Comp. Phys. Commun., 273, 108258 (2022)

O 44.6 Tue 14:00 P2

Spectral interferometry scanning near-field optical microscopy; investigating resonant tip-sample near-field interactions — •Tom Jehle, Sam S. Nochowitz, Juanmei Duan, and Christoph Lienau — Institute of Physics, University of Oldenburg, 26129 Germany

Localized phonon polaritons and plasmon polaritons resonantly enhance near-field mediated light matter interactions and are key for strong coupling between single quantum emitters and nanocavities (1). Localized polariton resonances with high oscillator strength show tip-sample distance dependent frequency shifts in scanning probe experiments, requiring spectroscopic analysis at explicit tip-sample distances (2). Here, we introduce a broadband interferometric scattering-type SNOM technique (3) to reconstruct spectral amplitude and phase of visible light scattered from a gold taper. Harmonic sampling with a fast line camera allows reconstruction of spectra with high tip-sample distance resolution. Spectral amplitude, phase and the evaluation of the distance dependence of the near-field interaction allows the retrieval of the temporal near-field dynamics with sub-cycle precision. We demonstrate our technique by measuring the tip-sample distance dependent time dynamics of the near-field at the apex of a resonant gold taper coupled to its image. Our results pave the way towards hyperspectral imaging in the visible with nm spatial resolution and fs temporal resolution of the reconstructed time dynamics. (1) S. Hu et al., Nat. Commun. 15, 6835 (2024); (2) H. Wang et al., Nat Commun. 9, 2005 (2018); (3) J. Zhan et al., Nano Lett. 24 (49),15738 (2024)

O 44.7 Tue 14:00 P2

Cryogenic Band Pass Amplifier for measuring Atomic Shot Noise — •Benjamin Frölich, Kevin Hauser, Lebin Yu, Gleb Neplyakh, Ajla Karić, and Fabian D. Natterer — Department of Physics, University of Zurich, Winterthurerstrasse 190, CH-8057, Switzerland

Scanning tunneling microscopy provides access to the texture and correlation of charge carriers in quantum materials by listening to their characteristic shot noise signatures that reveal 1e and 2e charge quantization effects at the atomic scale. Previous studies introduced a band pass amplifier with center frequency of 3 MHz based on their in house made high electron mobility transistor (HEMT) and LC tank circuit to measure such shot noise. Here we build a similar band pass amplifier with a center frequency of 17 MHz based on a comercially available InP HEMT. Another goal is the evaluation of resonating circuits like the LC tank at cryogenic temperatures. We achieve 26 dB single stage amplification at liquid nitrogen temperatures. Simulations suggest a noise figure of < 0.12 dB. Experiments at even lower temperatures present challenges impacting implementation into the cryostat.

O 44.8 Tue 14:00 P2

all-in-one preparation stage of STM/AFM QPlus sensors for ultrahigh vacuum — •reza habibipour, jakob pelster, marco pratzer, michiel reul, and markus morgenstern — II. Institute of Physics B, RWTH Aachen University and JARA-FIT, Germany

QPlus sensors enable the combination of atomic force microscopy (AFM) and scanning tunneling microscopy (STM) with high resolution. We developed a compact preparation stage for positioning, glueing, annealing and tip etching of wires with diameters down to 7.5 um and length down to 200 um. The QPlus sensors are based on a piezoelectric quartz tuning fork with nominal frequency of 32.6 kHz. A tip wire is attached to one prong with the other prong is fixed to a ceramic block on the ultrahigh-vacuum (UHV) sample holder. Two tuning-fork contacts connect to the sample plate for AFM oscillatory function and for STM current. Sensor preparation utilizes a long-working-distance optical microscope (~6 cm) and micrometer manipulators for precise glue and wire positioning. A heater is used to cure the glue. A tungsten-carbide flush cutter trims the wire to within 0.2 mm of the prong edge. Alternatively, an etching ring is employed for tip shaping. Afterwards contacts can be checked in-situ by a Keithley instrument. Q-factors at room temperature and UHV amount to 16.000. The resulting QPlus sensors will be employed in a 300 mK STM/AFM cryostat mostly for maneuvering towards stacks of 2D materials by AFM prior to STM measurements.

O 44.9 Tue 14:00 P2

Iron Implantation from a Ferrocene Ion Source — •Urs Boison, Ajla Karić, Berk Zengin, Lebin Yu, and Fabian D. Natterer — Department of Physics, University of Zurich, Winterthurerstrasse 190, CH-8057, Switzerland

The scattering of electrons on defects in low dimensional materials provides insight into the electronic structure using quasiparticle interference or tunneling spectroscopy. Since natural defects are mostly spin averaging and obscure magnetic textures, using magnetic impurities would allow a richer inspection of the underlying magnetic properties. At present, magnetic impurities are difficult to produce because chemically active defects are required to chemisorb magnetic atoms, such as hydrogen. We use metal ions in a volatile molecule that can easily and directly be delivered to ion sources commonly used for sample cleaning. Using a conventional sputtering source and heated ferrocene (vapor pressure of 1773 Pa at 400 K), we implant ferrocene molecules between 100 and 3000 eV and use different vapor pressures to investigate the ion implantation efficiency and possible defect generation. We test the optimal dose as a function of these parameters using ion current measurements and mass deposition on a quartz crystal microbalance. To verify successful implantation, we use scanning tunneling microscopy on graphene and superconducting layers. Magnetic defects should exhibit signatures related to Yu-Shiba-Rusinov states, confirming the conservation of their spin upon implantation.

O 44.10 Tue 14:00 P2

Development of a Low-Temperature Scanning Probe Microscope — •Tingwen Miao — Tsung-Dao Lee Institute, Shanghai, China

We independently designed and constructed a low-temperature ultrahigh-vacuum scanning probe microscope (SPM) system which is equipped with a single-axis 9T magnetic field and can be cooled down to 400mK. The system integrates the functionalities of atomic force microscopy (AFM) and scanning tunneling microscopy (STM) into the scanning head, enabling in-situ measurements of both electrical signals and force signals. The cooling curve, current noise, non-contact AFM and STM imaging and I(V) spectroscopy are characterized to verify that the system achieve the fundamental SPM capabilities. Subsequent magnetic field test and low-temperature test will be performed to confirm that the system can achieve all designed performance.

O 44.11 Tue 14:00 P2

Correlative AFM-SEM-EDS microscopy on nanoparticles and -wires — Chris Schwalb[1], •Lukas Stühn[1], Hajo Frerichs[1], Sebastian Seibert[1], Darshit Jangid[1], Marion Wolff[1], Kerim Arat[2], Hamed Alemansur[2], Afshin Alipour[2], Andreas Amann[2], Luis Montes[2], Jost Diederichs[2], Jeff Gardiner[2], Will Neils[2], and Stefano Spagna[2] — [1]Quantum Design Microscopy GmbH, Pfungstadt, Germany — [2]Quantum Design Int., San Diego, USA

Correlative AFM-SEM-EDS microscopy enables multimodal nanoscale analysis but is often hindered by complex sample transfers and the lack of a joined coordinate system. Our approach integrates these techniques to allow simultaneous acquisition of topographical, mechanical, electrical, SEM and EDS data from the same region of interest[1]. We illustrate the advantages of such in-situ correlative measurements through several case studies, including hard-to-access structures such as bone lacunae, individual nanowires on 5 nm TEM grids, and nanoparticles relevant for multimodal characterization workflows[2]. In addition, we present first results on individual ZnO nanowires for energy-harvesting concepts, where SEM enables rapid localization and AFM provides mechanical and electrical characterization[3,4]. Overall, the presented in-situ correlative strategy, the FusionScope, expands the analytical capabilities for nanoscale inspection and process control across a wide range of materials and devices. [1] https://doi.org/10.1093/mictod/qaad083 [2] https://doi.org/10.1093/mam/ozae044.233 [3] https://doi.org/10.3390/mi1608 [4] https://doi.org/10.1002/adfm.202310110

O 44.12 Tue 14:00 P2

Distance dependent of local work function on Pb/Si(111) islands — •Ajay Kumar[2], Thomas Späth[1], Ben Lottenburger[2], Zeineb Ben Tanfous[3], Daniel Rothhardt[2,4], Paul P. Schmidt[2], Manuel Schulze[2], Ralf Metzler[2], Kurt Busch[3], Gino Wegner[3,5], and Regina Hoffmann-Vogel[2] — [1]Institute of Physics and Astronomy, University of Potsdam, Karl-Liebknecht-Str. 24-25, 14476, Potsdam, Germany — [2]Physikalisches Institute, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [3]Humboldt University of Berlin, 12489 Berlin, Germany — [4]Swiss Federal Laboratories for Materials Science and Technology, CH-8600 Dübendorf, Switzerland — [5]Max-Born-Institute, 12489 Berlin, Germany

A quantitative description of the measured local contact potential difference (LCPD) as a function of tip-sample separation is essential for a deeper understanding of Kelvin probe force microscopy (KPFM), since it permits a more complete characterization of the sample's electronic properties and of the forces acting on the probe. We employ Pb islands on the Si(111)-7*7 reconstruction as a model system of metallic islands on a semiconducting substrate. Using a frequency-modulation scanning force microscope, we have performed frequency-shift bias-approach measurements at 115 K on these Pb islands and have studied the variation of the LCPD with tip-sample distance.

O 44.13 Tue 14:00 P2

Nonlinearity mapping using adaptive control schemes in scanning force microscopy — •Lukas Böttcher[1], Hannes Wallner[2], Niklas Kruse[2], Franziska Dorn[1], Wolfram Just[2], Ingo Barke[1], Jens Starke[2], and Sylvia Speller[1] — [1]Institute of Physics, Universität Rostock, Germany — [2]Institute of Mathematics, Universität Rostock, Germany

When probing surfaces by scanning force microscopy methods using oscillating cantilevers, bistabilities may occur [1,2]. This is a result of nonlinearities arising due to tip-sample interactions. In this work we focus on the attractive regime. Using an adaptive control scheme we track branches of unstable periodic orbits of the oscillating cantilever, arising between the two stable states [3]. Combining this with a topography scan of a polymer blend surface we explore spatial changes of the unstable branch. Parameters, such as the frequency width of the bistable region or the slope at the unstable branch can serve as nonlinearity parameters and respective maps can be acquired. The aim is to connect such nonlinearity maps to material-related properties such as density and elasticity.

[1] Gleyzes, P. et al.: Bistable behavior of a vibrating tip near a solid surface. Appl. Phys. Lett. 58, 2989 (1991) [2] Misra, S. al.: Event-driven feedback tracking and control483 of tapping-mode atomic force microscopy. Royal Society of London Proceedings484 Series A 464, 2113*2133 (2008) [3] Böttcher, L. et al.: Exposing hidden periodic orbits in scanning force microscopy. Commun Phys 8, 57 (2025)

O 44.14 Tue 14:00 P2

Realizing Spin-Polarized Scanning Tunneling Microscopy for an Atomic-Scale Study — •Leon Bojunga, Felix Otto, Jonas Brandhoff, Maximilian Schaal, Christian Haberland, Lorenz Brill, and Torsten Fritz — Institute of Solid State Physics, Friedrich Schiller University Jena, Helmholtzweg 5, 07743 Jena, Germany

Spin-polarized scanning tunneling microscopy and spectroscopy (SP-STM/STS) is a powerful tool for investigating spin structures with real-space resolution down to the atomic scale. By combining a spin-sensitive tip with controlled magnetic fields at cryogenic temperatures, SP-STM/STS enables the study of phenomena such as Kondo resonances, spin excitations, organic radicals, and magnetism. Realizing SP-STM/STS requires, beyond standard low-temperature STM stability, a magnetically sensitive tip and a precisely tunable external magnetic field. In this work, we fabricate Ni tips by electrochemical etching and verify their apex geometry via SEM to ensure high quality. This is achieved using a home-built etching setup that enables a reproducible process with consistent results. Testing of the fabricated tips is carried out using an STM at cryogenic temperatures, which, together with a perpendicular magnetic field of up to 3 T, allows controlled magnetization of the tip. To assess the magnetic sensitivity and spatial resolution of the Ni tips, we employ Co bilayer islands on Cu(111), whose well-defined magnetic structure provides an ideal benchmark for validating tip polarization and imaging performance.

O 44.15 Tue 14:00 P2

Low latency, galvanically isolated data transfer architecture for distributed low-level precision measurements — Toni Marković, Shane O'Neill, Aitziber Herrero, David Zurbriggen, Daniel Uehli, and •Alessandro Pioda — SPECS Zurich GmbH, Technoparkstrasse 1, 8005 Zurich

Many recent achievements in the field of quantum devices, spintronics, novel materials and surface science, have been possible thanks to the ability to cool samples to temperatures significantly below 1 Kelvin and to the use of state of the art measurement electronics. Requirements for signal resolution, precision and quality increase significantly at low temperatures, while the growing complexity of experiments and higher measurement throughput require a growing number of signals, larger bandwidths, and push the cost of measurement electronics upwards.

Here we present a data transfer architecture that enables a low-latency, synchronous transfer of raw DAC and ADC data from multiple signal generation and acquisition interfaces to a central processing core. The architecture allows transfer of very high-resolution data with microsecond resolution, high resolution data with nanosecond resolution or a combination thereof. The use of off-the-shelf optical fiber cables for data transfer allows for decentralized measurements, simultaneous experiments on different experimental set-ups, as well as galvanic isolation between the processing core and the signal interfaces. The architecture can handle hundreds of signals, all synchronous and with no multiplexing. We also discuss state of the art signal interfaces and typical applications for this novel architecture.

O 44.16 Tue 14:00 P2

Development of low noise cryogenic circuitry for shot noise measurements in STM — •Anne-Catherine Oeter, Soumyaranjan Jhankar, Christian Ast, and Klaus Kern — Max Planck Institut for Solid State Research

Tunneling currents of electrons are subject to shot noise. Measuring shot noise in a scanning tunneling microscope (STM) can give more insight into the tunneling dynamics and the properties of the tunneling charges. Our goal is to measure shot noise at low tunneling currents simultaneously with the dc tunneling current. To this end, we are developing a low-noise cryogenic pre-amplification circuit. It is made up of a tank oscillator circuit, to filter and amplify the white noise signal at a frequency beyond flicker noise, as well as a HEMT based cryogenic amplification circuit. We will discuss how we want to improve the shot noise circuitry already used in the literature, for example, how to enhance the quality factor of the inductances used to filter the ac signal.

O 44.17 Tue 14:00 P2

Realization of laser-assisted UHV sample surface preparation for STM — •Clara Marie Nieder, Soumyaranjan Jhankar, David Sousa, and Christian Ast — Max Planck Institute for Solid State Research

Scanning tunneling microscopy (STM) enables the study of the electronic properties of superconductors such as vanadium. To achieve reliable STM measurements, the preparation of clean and well-defined metal surfaces under ultra-high vacuum (UHV) conditions is essential. This requirement becomes particularly demanding for reactive transition metals, where surface oxides can form even under high-quality UHV conditions. In this work, we present a laser-assisted UHV sample preparation approach to obtain clean vanadium surfaces. For this method, we utilize a diode laser directed at the front surface of the sample to achieve high temperatures. To prevent mechanical or electrical complications inside the UHV chamber, we place all optical and diagnostic components, including pyrometric temperature monitoring, outside the chamber. This enables a controlled and localized high-temperature annealing for oxide removal. Therefore the method represents a promising way to reproducibly prepare reactive and superconducting surfaces for subsequent STM measurements.