# O 24: Poster Scanning Probe Techniques: Method Development

Time: Monday 18:00–20:00 Location: P2

O 24.1 Mon 18:00 P2

**Comparative Analysis of Work Function Measurements Using STM/AFM Techniques** — •Daryoush Nosraty Alamdary, Matthias Bode, and Artem Odobesko — Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

The engineering of the work functions at the interface of complex materials is sometimes the key [1] for an energy band tuning that supports proximity-induced effects [2]. While there are handful of established methods that allow a precise measurement and determination of the work function, STM-based methods constitute a class of their own since they are based on a local probe. In this work we present a comparative study of 3 different techniques based on a combined STM/AFM setup. For a few well-characterized sample systems we analyze the benefits and difficulties of each method. Finally, we draw a conclusion as to which method is the more precise and reliable method, whereby the special focus lies on the accuracy and the challenges of the interpretation.

[1] P. Rüßmann em et al., Proximity induced superconductivity in a topological insulator, arXiv:2208.14289 (2022)
[2] L. Fu and C. L. Kane, Superconducting Proximity Effect and Majorana Fermions at the Surface of a Topological Insulator, Phys. Rev. Lett. **100**, 096407 (2008)

O 24.2 Mon 18:00 P2

**Cryogenic, ultrahigh vacuum sample transfer between electrospray ion beam deposition (ESIBD) and scanning probe microscopy (SPM)** — •Alejandro Lynch Gonzalez, Stephan Rauschenbach, Lukas Eriksson, Benjamin Mallada, Tim Esser, and Marko Grabarics — University of Oxford

Electrospray ion beam deposition (ES-IBD) is currently the only viable method for cleanly and selectively depositing large and complex molecules which do not have a vapour pressure while preserving their chemical structure. In our lab, ESIBD[1] and SPM instruments are physically separate and sample transfer between them is performed using a vacuum suitcase system which maintains UHV and cryogenic conditions during transfer, essential for suppressing surface diffusion, conformational changes, and contamination during the transfer. Here, we present the design, implementation, and benchmarking of a cryogenic UHV suitcase and showcase applications.

[1] Fremdling, P. et al. ACS nano 16, 14443-14455 (2022).

O 24.3 Mon 18:00 P2

**Ultra-broadband Terahertz Time-Domain Spectroscopy for Space Exploration** — •Dominic Azih[1,2], Yookyung Ha[2], Jonas Woeste[1,2], Nikola Stojanovic[2], and Michael Gensch[1,2] — [1]Technical University, Berlin, Germany — [2]DLR Ínstitute of Optical Sensor Systems, Berlin, Germany

Femtosecond lasers have in recent years been shown to be space qualified and with the development of compact femtosecond laser systems [1,2], Terahertz Time-Domain Spectroscopy (THz TDS) allows meanwhile to cover an essential part of the molecular fingerprint spectral range and has several technological advantages over the commonly used Fourier-Transform Infrared techniques (FTIR). The advantages are compactness, replacement of components (cryogenic) spectrally broadband infrared detectors with electro-optic/acousto-optic photonic techniques and the potential to be chip-integrable. Here we show our progress enroute to a THz time-domain spectroscopic setup for space applications with a bandwidth of over 30THz and a resolution of better than 100GHz [3].

O 24.4 Mon 18:00 P2

**High-collection efficiency optical scanning probe microscopy with on-axis parabolic mirror** — •Aleksander Bogucki[1], Magdalena Grzeszczyk[1], Yeon-ji Kim[1], Yewon Kim[1], German Orlov[1], Lei Fang[1], Wonjun Jang[1,2], and Andreas Heinrich[1,2] — [1]Center for Quantum Nanoscience, Institute for Basic Science (IBS), Seoul, South Korea — [2]Department of Physics, EWHA Womans University, Seoul, South Korea

Scanning probe microscopy (SPM) techniques are essential for investigating surface physics, from single atoms to complex systems like organic molecules. Combining SPM with optical spectroscopy enhances our ability to explore system dynamics. However, existing setups face photon collection efficiency challenges due to spatial constraints, particularly for systems with long-lived excited states.

We present a homemade optics-integrated scanning probe microscope using a centered on-axis parabolic mirror with a short focal length. The scanning component employs a combined AFM/STM qPlus sensor with a long tip. Free-beam optics maximize photon collection efficiency, reaching an estimated upper limit of 90%. This design eliminates chromatic aberrations, enables polarization measurements, and operates under ultra-high vacuum (UHV) at low temperatures (4K), ensuring high stability and precision.

O 24.5 Mon 18:00 P2

**Electron wavefront shaping with light** — •martino zanetti[1,2], Tilman Kraeft[1,2], Luis Alfredo Ixquiac Mendez[1,2], Alexandra Pernishova[1,2], and Thomas Juffmann[1,2] — [1]University of Vienna, Faculty of Physics — [2]University of Vienna, Max Perutz Laboratories

Electron Microscopes (EM) are common and fundamental tools in many research fields, as they can image samples with resolutions down to the nanometric scale. The ability to arbitrarily shape the electron beam of an EM with light can help overcome intrinsic limits like electron lens aberrations and pave the way to new EM techniques [1].

For shaping the electron beam, a modified Scanning-EM is coupled to a high-power pulsed laser. The electron-light interaction takes place in the SEM chamber. The electrons are then detected after free propagation to measure their spatial distribution. Here, we present our advancements in applying the electron beam shaping technique to demonstrate single electron wavefront modulation. The intensity profile of a TEM01 laser mode is imprinted on the wavefront of the electron, which thus resembles that of an electron going through a double slit. Adding up the detection of multiple electrons, we expect to see an interference pattern that proves the effective modulation of the electron wavefront. The need for micrometric resolution measurements required us to develop a single-electron detector which outperforms many commercially available ones in the 20-30 keV range, being at the same time more flexible and cheaper.

[1] Mihaila et al., Phys. Rev. X 12, 031043 (2022)

O 24.6 Mon 18:00 P2

**Optimizing ESR-STM for mK Temperatures in a Closed-Cycle Dilution Refrigerator** — •Luise Renz, Máté Stark, Jonas Arnold, Johannes Schwenk, Christoph Sürgers, Wolfgang Wernsdorfer, and Philip Willke — Physikalisches Institut (PHI), Karlsruhe Institute of Technology, Karlsruhe, Germany

Using Electron Spin Resonance (ESR) combined with Scanning Tunneling Microscopy (STM), electronic and magnetic properties of single atoms and molecules can be studied. However, the possibility of applying RF voltages to the tip often limits the achievable minimum temperature of the STM. We here describe an ESR-STM setup mounted in ultra-high vacuum (UHV) in a closed-cycle Dilution Refrigerator (DR). The focus here is on the wiring of the STM, the material choice and the filtering of the RF and DC cables with the goal of having a good transmission of the RF lines but nevertheless also mK-temperatures in the STM junction. The resulting bandwidth and transmission of these cables, the noise level of the STM as well as the electronic temperature of the STM junction, is presented. The electronic temperature is estimated on a Pb(111) crystal by evaluating the superconducting gap and the Josephson peak (using a superconducting tip).

O 24.7 Mon 18:00 P2

**Detection and Localization of Atoms and Molecules on Different Surfaces Using Computer Vision** — •Lovis Hardeweg, Johannes Schwenk, Wantong Huang, Kwan-Ho Au-Yeung, Máté Stark, Paul Greule, Christoph Sügers, Wolfgang Wernsdorfer, and Philip Willke — Physikalisches Institut (PHI), Karlsruhe Institute of Technology, Karlsruhe, Germany

Scanning Probe Microscopy (SPM) methods are unparalleled in their ability to image and manipulate structures on the atomic scale. In combination with machine learning techniques, this allowed to automate processes such as removing a molecule from a thin layer [1] or moving an adsorbed molecule to a specific position [2]. However, this often relies on prior human interaction to identify and localize objects of interest, like a thin film or a single adsorbate. Here, we discuss methods that automate several steps in SPM experiments, with the goal of advancing single atomic and molecular spin detection experiments. For that, we employ computer vision techniques to STM topography data and are able to extract information, such as the location of single atoms and molecules or the presence of different sample surfaces, for instance ultra-thin MgO films grown on Ag(001). We believe that these abilities, once sufficiently developed, can lead to a significant reduction in the need for human intervention in the automated use of high-resolution low temperature SPM. [1] P. Leinen et al. Sci. Adv., vol. 6, no. 36, p. eabb6987, Sep. 2020, doi: 10.1126/sciadv.abb6987. [2] B. Ramsauer et al. J. Phys. Chem. A, vol. 127, no. 8, pp. 2041-2050, Mar. 2023, doi: 10.1021/acs.jpca.2c08696.

O 24.8 Mon 18:00 P2

**A Closed-Cycle Atomic Force Microscopy Setup for Electron Spin Resonance Measurements at mK Temperatures** — •Adrian Seiler, Lovis Hardeweg, Luise Renz, Arian Vosoghi Marand, Kwan Ho Au-Yeung, Wantong Huang, Paul Greule, Máté Stark, Christoph Sürgers, Wolfgang Wernsdorfer, Johannes Schwenk, and Philip Willke — Physikalisches Institut (PHI), Karlsruhe Institute of Technology, Karlsruhe, Germany

Combining scanning probe techniques with electron spin resonance (ESR) provides a unique tool for the investigation as well as the manipulation of individual surface-adsorbed spins. Most experiments up to date are relying on Scanning Tunneling microscopy (STM) and thus conductive samples [1]. As a result, scattering of electrons with the spin system is a major source of decoherence and relaxation. In contrast, atomic force microscopy (AFM) provides the possibility to reduce the scattering intensity with the conducting electrodes. Here, we present the first implementation steps of a commercial AFM head and ultra-high vacuum setup in a compact dilution refrigerator. The final setup is designed to reach milli-Kelvin temperatures ($\approx$ 50 mK) with short cool-down times on the order of several hours. In addition to the dilution unit, the system utilizes a closed-cycle cryocooler allowing longtime stable operation. We further improve the time-consuming sample preparation by automation of the sputter and annealing process to allow for a rapid turnaround of samples in the future.

[1] Y. Chen et al. Adv. Mater. 35, 2107534 (2023).

O 24.9 Mon 18:00 P2

**Lightwave driven magnetic field scanning tunneling microscopy** — •Leo Ringer, Andreas Rank, Peter Menden, Christian Meineke, Rupert Huber, and Jascha Repp — University of Regensburg, Regensburg, Germany

Lightwave driven scanning tunneling microscopy (LW-STM) is based on the key idea to directly steer electron tunneling in STM by ultrashort light pulses. Combining the development of LW-STM with a tunable magnetic field would allow following spin dynamics - e.g. spin precession - in molecules and other atomistic structures with single-electron sensitivity. To this end, we develop a novel lightwave driven scanning tunneling microscope including an external magnetic field to resolve single-spin dynamics with atomic spatial and ultrafast temporal resolution. Instrumental challenges of this development will be discussed, and we present the resulting instrument design including the head of the scanning tunneling microscope, the laser source as well as the solution to introduce the laser transient from outside the vacuum system to the tip-sample junction.

O 24.10 Mon 18:00 P2

**Implementation of radio-frequency magnetic fields for electron spin resonance atomic force microscopy** — •Raffael Spachtholz, Lisanne Sellies, Franziska Bruckmann, Sonja Bleher, Philipp Scheuerer, and Jascha Repp — Department of Physics, Universität Regensburg

Implementing electron spin resonance in scanning tunneling microscopy represents a milestone in controlling spin systems at atomic scales [1]. In this emerging research field the required radio-frequency (RF) signal is provided as an electric field, translating to an effective magnetic field.

Here we report the integration of a radio-frequency (RF) magnetic field, in the frequency range of 0.1 to 3 GHz, into a scanning-probe microscope. We utilized a flexible polyimide printed-circuit-board coil to generate the RF magnetic fields. Additionally, an insulating sample, coated with a gold microstructure, was designed to locally enhance the RF magnetic field while mitigating the screening effects caused by a metallic substrate. Up to 3 GHz the transmission only moderately depends on frequency and exhibits no sharp resonances. This development enabled the implementation of electron spin resonance in atomic force microscopy, as demonstrated for individual pentacene molecules [2].

[1] S. Baumann, et al., Science 350, 417-420 (2015)
[2] L. Sellies, et al., Nature 624, 64-68 (2023)

O 24.11 Mon 18:00 P2

**Implementation and characterization of all-electronic pump-probe spectroscopy on a low-temperature scanning tunneling microscope** — •Guido Hiller, Gaël Reecht, and Manuel Gruber — Universität Duisburg Essen, Duisburg

Pump-probe spectroscopy is a powerful technique for investigating non-equilibrium dynamics, where the time resolution is determined by the duration of the pump and probe pulses rather than the detectors bandwidth. When combined with a scanning tunneling microscope (STM), this method enables dynamic measurements at the level of individual atoms and molecules, achieving both high temporal and spatial resolutions [1].

In this work, we implement an all-electric pump-probe scheme on a low-temperature STM. Cross-correlation measurements on an Au(111) surface reveal a time resolution of 100 ns. This resolution is constrained by the broadening of voltage pulses during transmission to the STM junction [2]. To address this, we conducted a detailed analysis of the frequency-dependent transmission function of the instrument. Funding support from the CRC 1242 is gratefully acknowledged.

[1] Loth et al., Science 329, 1628 (2010)
[2] Herve et al., Applied Physics Letter 107, 093101 (2015)