O 2: Scanning probe techniques: Method development I

Time: Monday 10:30–13:00 Location: MA 004

O 2.1 Mon 10:30 MA 004

Near-field driven nonlinear photoemission from the tunnel junction of a Scanning Tunneling Microscope — •Benjamin Schröder, Katharina Kaiser, Thomas Kotzott, Murat Sivis, Claus Ropers, and Martin Wenderoth — IV. Physikalisches Institut, Georg-August-Universität Göttingen, Germany

Scanning Tunnelling Microscopy (STM) is a vital tool for surface chemistry: It gives access to the molecular configuration and the highly site-specific dependencies of chemical reactions. Furthermore, it can drive chemical reactions of individual molecules by applying static fields or injecting electrons by the tunnel current. A desirable extension is the excitation by strongly localized light fields providing intensities that are suitable to trigger nonlinear optical processes.
Here, we present the combination of an ultra-high vacuum low-temperature STM with a femtosecond laser oscillator. The strongly confined optical near-field at the apex is generated by using plasmonic gold nanotips as tunnelling probes. As a demonstration of the field localization, we drive multiphoton photoemission from the tunnel junction under STM operation. The unique capability of the STM to control the tip-sample distance on a sub-Ångström scale allows for the disentanglement of tunnel- vs. photocurrent. We show that the photocurrent gives a topographic contrast of nanometer-scaled surface features.
This project is financially supported by the DFG in the SFB 1073 (project C4).

O 2.2 Mon 10:45 MA 004

A multiprobe scanning tunneling microscope with picosecond time resolution — •Jonas Harm, Johannes Friedlein, Jonas Koch, Maciej Bazarnik, Stefan Krause, and Roland Wiesendanger — Department of Physics, University of Hamburg, Jungiusstraße 11A, 20355 Hamburg, Germany

Here we present a novel design of a 3-tip multiprobe scanning tunneling microscope (MP-STM), which has a picosecond time resolution through the use of RF technology. The microscope consists of two lateral scanners, whose probes are mainly used to contact the sample surface and a central scanner for scanning tunneling microscopy (STM). All three scanners are optimized for their temporal resolution and vibration stability. Using two probes local surface currents can be generated and their effects onto magnetic nanostructures can be investigated on the atomic scale using the central probe tip for spin-polarized STM (SP-STM). Furthermore, the instrument is designed to operate at low temperatures down to 1.5 K and magnetic fields of up to 3 T under UHV conditions. Core concepts of traditional scanning tunneling microscope designs have been combined with novel approaches, such as the use of coaxial RF cabling and connectors. The design concept and first performance tests of the setup under ambient conditions will be presented.

O 2.3 Mon 11:00 MA 004

Influence of microwave radiation on an STM Josephson junction — •Olof Peters[1], Nils Bogdanoff[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

Besides its applications in quantum mechanical circuits the Josephson effect is a powerful tool to study the superconducting ground state. The combination of a Josephson junction with the atomic-scale precision of a scanning tunnelling microscope (STM) would enable the measurement of the superconducting order parameter around single magnetic defects. We present here a current-biased Josephson junction in an STM at $T = 1.3$ K. Both tip and sample consist of Pb.

Extending the setup with coaxial cables suitable for microwaves makes it possible to couple radiation up to $f = 26$ GHz into the junction where the tip acts as an antenna. The Josephson current responds to the incident microwave radiation by showing multiple steps, with the step position and width depending on the amplitude and the frequency of the microwave radiation. Simulations of the step spacing reveal, that the current is dominated by Cooper pair tunnelling. The power dependence of the steps suggests that the Cooper pair tunnelling is a photon-assisted incoherent process similar as seen by [1].

[1] A. Roychowdhury *et al.*, Phys. Rev. Applied **4**, 034011 (2015)

O 2.4 Mon 11:15 MA 004

Setup of a THz-STM for pump-probe experiments using a commercial THz-source — •Philip Kapitza, Hüseyin Azazoglu, Christian Bobisch, and Rolf Möller — Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen, Lotharstr. 1, 47057 Duisburg, Germany

To study the excitations of single atoms or molecules on their intrinsic timescales ultrafast temporal and atomic-scale spatial resolution is essential. This can be achieved by combining the very high spatial resolution of a scanning tunneling microscope (STM) with picosecond duration terahertz (THz) pulses. When coupled to the tip of a STM the THz pulses can modulate the bias voltage in the tunneling junction [1,2,3].

The setup presented in this talk consists of a homebuilt low-temperature STM (LT-STM) and a commercial THz-pulse source for time domain spectroscopy (THz-TDS). The THz-emitter of this THz-TDS system is a photoconducting antenna irradiated by a fs-IR laser.

A laser diode is used for the adjustment and focus of the terahertz beam onto the STM tip. First measurements of the time-dependent tunnel current response as well as possible setup for pump-probe-experiments using two terahertz emitters will be presented.

[1] Cocker, T. L. et al., Nat. Photon. 7, 620-625 (2013).
[2] Cocker, T. L. et al., Nature 539, 263-267 (2016).
[3] Yoshioka, K. et al., Nat. Photon. 10, 762-765 (2016)

O 2.5 Mon 11:30 MA 004

Iso-dI/dV - Imaging isodensity contours of molecular states with STM — •Gaël Reecht[1], Benjamin W. Heinrich[1], Hervé Bulou[2], Fabrice Scheurer[2], Laurent Limot[2], and Guillaume Schull[2] — [1]Freie Universität Berlin , Berlin ,Germany — [2]IPCMS, Strasbourg, France

One of the reason for the success of the Scanning Tunneling Microscopy is the ability to probe the density of states (DOS) of nanostructures adsorbed on surfaces with atomic precision. For mapping the spatial distribution of the DOS, usually constant current or constant height scanning mode is used. Here, we present an alternative method for imaging the DOS of a sample with STM, which consists in mapping the surface topography while keeping the differential conductance (dI/dV) constant [1]. We employ this method, we call iso-dI/dV mapping, to explore archetypical C_{60} molecules on Cu(111). While conventional constant current and constant height mapping methods fail to correctly reproduce the spatial distribution for several orbitals of the C_{60}, the iso-dI/dV maps are in excellent agreement with theoretical simulations of the isodensity contours of the molecular orbitals. Moreover, a direct visualization and unambiguous identification of superatomic C_{60} orbitals and their hybridization is possible.

[1] Reecht et al., New J. Phys., 19, 113033 (2017)

O 2.6 Mon 11:45 MA 004

Resolving Dynamic Processes in Real Space with Variable-Temperature High-Speed Scanning Tunneling Microscopy — •Leonard Gura, Zechao Yang, Patrik Marschalik, Heinz Junkes, Markus Heyde, and Hans-Joachim Freund — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany

Scanning Tunneling Microscopy (STM) atomically resolved 2D-silica in both, the amorphous [1] and the crystalline state, leading to a structural comparison of the two phases [2]. Resolving dynamic changes in 2D network structures can give indications for the fundamental processes at the atomic scale occurring during glass-transformation.

With the scope of monitoring dynamic processes during the temperature induced change of the network structure, we design a variable temperature high-speed STM. A temperature ramp from 4 to 1500 K is enabled by a continuous-flow cryostat and a sample stage heated by electron bombardment. Thermal drift is reduced due to the symmetric setup of the microscope. For higher frame rates, a spiral scan geometry will be applied, which represents a monotonic continuous function of the angle for the radius without points of inflection nor crossing of lines. The scan is realized with a combination of a conventional STM control unit and custom made high-speed electronics. Due to the high data throughput, programs are needed, which automatically

detect atom and ring-center positions in the recorded STM images.

We hope to clarify important structural steps in oxide network structures at so far with STM unrivaled time scales.

[1] DOI: 10.1002/anie.201107097 [2] DOI: 10.1021/jp3062866

O 2.7 Mon 12:00 MA 004

Analysis of the image contrast on Cu(111) using low temperature atomic force microscopy with CO functionalized tips — •Jalmar Tschakert[1], Jannis Jung[2], Tobias Schlöder[2], Olena Lenchuk[2], Doreen Mollenhauer[2], Andre Schirmeisen[1], and Daniel Ebeling[1] — [1]Insitute of Applied Physics, Justus-Liebig-University Giessen, Germany — [2]Insitute of Physical Chemistry, Justus-Liebig-University Giessen, Germany

Low temperature atomic force microscopy with CO-functionalized tips allows to image surfaces and single adsorbed molecules with atomic resolution. Therefore, this so-called bond imaging technique is particularly interesting for studying on-surface catalytic reactions, since it allows to determine molecular adsorption geometries and specific adsorption sites. However, due to the flexibility of the CO tip and different types of short range interactions between the CO tip and the imaged atoms the resulting image contrast is rather complex. When imaging a flat Cu(111) surface this leads to contrast inversions for certain tip-sample distances, which makes it difficult to unambiguously identify atomic sites. To unravel the mechanism behind the contrast formation on Cu(111) we are performing 3D force-field spectroscopy measurements. Therewith, we are able to determine the lateral movement/tilting of the CO molecule and unambiguously identify different atomic sites.

O 2.8 Mon 12:15 MA 004

COFI characterization and imaging of graphene with O-terminated Cu tips — •Alexander Liebig, Daniel Meuer, Angelo Peronio, and Franz J. Giessibl — Institute of Experimental and Applied Physics, University of Regensburg, Germany

The use of chemically inert tips allows to directly probe the repulsive interaction regime and thus to obtain high spatial resolution. Gross et al. found in 2009 [1] that CO terminated metal tips enable intramolecular resolution imaging of organic molecules. Later, it was found that terminating the tip apex with noble gas atoms [2] achieves a similar spatial resolution. Recently, Mönig et al. [3] proposed to use oxygen terminated Cu tips that apparently are also quite inert, but are stiffer in lateral directions than CO tips. To further characterize such O-terminated tips, we apply the COFI method [4], where a CO molecule adsorbed on the Cu surface is used to probe the tip apex. With COFI we are able to resolve the atomic structure of the tip apex. We then use a CuO tip that was characterized with COFI to measure on a graphene monolayer grown on SiC. AFM images of graphene recorded with CO-terminated tips show a deformation of the graphene honeycomb lattice due to the flexibility of the tip apex [5]. We find that for close distances we also see a deformation of the graphene lattice when measuring with an O-terminated Cu tip.

[1] L. Gross et al., Science, 325 (2009) 1110. [2] F. Mohn et al., Appl. Phys. Lett., 102 (2013) 073109. [3] H. Mönig et al., ACS Nano, 10 (2016) 1201. [4] J. Welker, F.J. Giessibl, Science, 336 (2012) 6080. [5] M.P. Boneschanscher et al., ACS Nano, 6 (2012) 10216.

O 2.9 Mon 12:30 MA 004

Compensation method using electrostatic cantilever excitation in electrochemical strain microscopy — •Sebastian Badur, Valon Lushta, Thomas Göddenhenrich, and André Schirmeisen — Institut für Angewandte Physik, Justus-Liebig-Universität Gießen, D-35392

In contact resonance atomic force microscopy such as electrochemical strain microscopy or piezoresponse, the local tip to sample interaction is superimposed by global electrostatic cantilever excitation due to the cantilever capacitance. Especially when using soft cantilevers, topography and mechanical coupling between tip and sample leads to a significant contribution to the electromechanical imaging signal. On the other hand, one can excite the cantilever in a low and high frequency electric field regime to investigate the latter influence. The cantilever resonance response was measured and analyzed by using the band excitation method on the first contact eigenmode. Measurements are performed under UHV condition using cantilevers with electrical conductive diamond tips.

First results on a $LiNi_{0.5}Mn_{1.5}O_4$ substrate show that with this method we can compensate electrostatic and mechanical crosstalk. This paves the way to obtain true quantitative information about the Vegard strain, which is important for the analysis of ionic movement in battery electrode materials.

O 2.10 Mon 12:45 MA 004

Probing the quantum nature of protons in water with STM/S — •Jing Guo[1], Jinbo Peng[1], Xinzheng Li[2,3], En-Ge Wang[1,3], and Ying Jiang[1,3] — [1]International Center for Quantum Materials, School of Physics, Peking University, Beijing 100871, P. R. China — [2]School of Physics, Peking University, Beijing 100871, P. R. China — [3]Collaborative Innovation Center of Quantum Matter, Beijing 100871, P. R. China

Quantum behaviors of protons in terms of tunneling and zero-point motion have significant effects on the macroscopic properties, structure, and dynamics of water even at room temperature or higher. In spite of tremendous theoretical and experimental efforts, accurate and quantitative description of the nuclear quantum effects (NQEs) is still challenging. The main difficulty lies in that the NQEs are extremely susceptible to the structural inhomogeneity and local environments, especially when interfacial systems are concerned. In this talk, I will highlight the recent advances of scanning tunneling microscopy and spectroscopy (STM/S), which allows the access to the quantum degree of freedom of protons both in real and energy space. Then I will discuss how the STM/S are used to directly visualize the concerted quantum tunneling of protons within the water clusters and quantify the impact of zero-point motion on the strength of a single hydrogen bond (H bond) at a water/solid interface. Those results may open up the new possibility of exploring the exotic quantum states of light nuclei at surfaces, as well as the quantum coupling between the electrons and nuclei.