

## O 3: Scanning Probe Techniques: Method Development I

Time: Monday 10:30–13:00

Location: TRE Phy

O 3.1 Mon 10:30 TRE Phy

**Characterization and Optimization of High Frequency STM** — ●GREGORY MCMURTIE<sup>1,2</sup>, MAX HÄNZE<sup>1,2</sup>, JACOB BURGESS<sup>1,2</sup>, and SEBASTIAN LOTH<sup>1,2,3</sup> — <sup>1</sup>Max-Planck-Institut für Struktur und Dynamik der Materie, Hamburg — <sup>2</sup>Max-Planck-Institut für Festkörperforschung, Stuttgart — <sup>3</sup>Institut für Funktionelle Materie und Quantentechnologien, Universität Stuttgart

Injecting coherent pulses (pump-probe[1]) or continuous wave signals (spin-resonance[2]) into a tunnel junction has shown promising results for the characterization of fast magnetic surface dynamics using STM. When pushing into the sub-nanosecond time domain, the transmission line characteristics of the instrument strongly modify the signals reaching to the tunnel junction. This is caused by impedance mismatches in the cabling that express as reflections, resonant cavities, or low-pass filtering. We present an in-situ technique for the quantitative measurement of transmission line characteristics. Both amplitude and phase information are detected and generate a more accurate picture of the tunnel junction than conventional high frequency characterization methods. 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 STM, the door is opened to observe a wide range of ultra-fast phenomena at the atomic scale. Additionally, the access to phase information hints at the possibility of observing coherent excitations.

[1] S. Loth, A. J. Heinrich et. al, Science 329 1628 (2010). [2] S. Baumann, W. Paul, A. J. Heinrich et al., Science 350 6259 (2015)

O 3.2 Mon 10:45 TRE Phy

**Tip-induced vs. thermal dehalogenation of 4-bromo-3<sup>i</sup>-iodo-p-terphenyl on Cu(111)** — ●QIGANG ZHONG<sup>1,2</sup>, DANIEL EBELING<sup>1</sup>, TOBIAS SCHLÖDER<sup>3</sup>, SEBASTIAN AHLES<sup>4</sup>, LIFENG CHI<sup>2</sup>, DOREEN MOLLENHAUER<sup>3</sup>, HERMANN A. WEGNER<sup>4</sup>, and ANDRÉ SCHIRMEISEN<sup>1</sup> — <sup>1</sup>Institute of Applied Physics, Justus-Liebig University, Giessen, Germany — <sup>2</sup>Institute of Functional Nano & Soft Materials, Soochow University, Suzhou, P. R. China — <sup>3</sup>Institute of Physical Chemistry, Justus-Liebig University, Giessen, Germany — <sup>4</sup>Institute of Organic Chemistry, Justus-Liebig University, Giessen, Germany

Dehalogenation is an important step in Ullmann reaction, which is widely used in on-surface synthesis of various functional polymers. Controlled stepwise dehalogenation will help to build more refined and customized molecular structures. However, there are few investigations on the sequential dehalogenation process so far, especially at the atomic scale. Here, we evaporated 4-bromo-3<sup>i</sup>-iodo-p-terphenyl (BITP) molecules onto a cold Cu(111) surface (Tsam < 150 K). Subsequently, single-molecule deiodination and debromination reactions were triggered either by applying different voltage pulses above iodine and bromine substituents or by heating the sample substrate. The adsorption structures of the obtained radicals were characterized via low temperature non-contact atomic force microscopy (LT-NC-AFM) with sub-molecular resolution. The distinct pulse voltages needed for deiodination and debromination coincide with the difference in bond cleavage temperatures for iodine and bromine substituents.

O 3.3 Mon 11:00 TRE Phy

**Design and Realization of a Variable-Temperature Scanning-Tunneling-Microscope for the Liquid-Solid Interface** — ●OLIVER OCHS<sup>1,2,3</sup> and MARKUS LACKINGER<sup>1,2,3</sup> — <sup>1</sup>Physik-Department - Technische Universität München, Munich, Germany — <sup>2</sup>Deutsches Museum, Munich, Germany — <sup>3</sup>Center for Nanoscience, Munich, Germany

Scanning-Tunneling-Microscopy (STM) at the liquid-solid interface is a widespread experimental technique in the field of nanoscience to investigate self-assembly of supramolecular monolayers. Most liquid-solid STMs work under ambient conditions at room temperature. However, to clarify relevant and fundamental scientific questions concerning the kinetics and thermodynamics of self-assembly, it is desirable to carry out experiments at variable temperatures. Yet, the common approach of just heating the sample inside an STM normally causes temperature gradients that result in thermal drift. Furthermore, increased solvent evaporation at higher temperatures leads to unwanted concentration changes of the solution. As a new strategy for instrument design, we propose an STM that operates fully immersed into solution. Therefore

the STM is integrated in a heatable, hermetically closed container with precise temperature control and stability. This minimizes temperature gradients, facilitates rapid thermalization upon temperature changes, and completely avoids solvent evaporation. First tests and measurements proved the functionality and suitability of the instrument for variable temperature experiments in liquids up to 100°C without any limitation of experimental duration due to solvent evaporation.

O 3.4 Mon 11:15 TRE Phy

**Electrochemistry at the Nanoscale: Theoretical and Practical Aspects of Electrochemical Strain Microscopy** — ●VALON LUSHTA<sup>1</sup>, STEPHAN BRADLER<sup>2</sup>, BERNHARD ROLING<sup>2</sup>, and ANDRÉ SCHIRMEISEN<sup>1</sup> — <sup>1</sup>Institute of Applied Physics, Justus-Liebig-University Gießen, D-35392 Gießen, Germany — <sup>2</sup>Department of Chemistry, Philipps-University Marburg, D-35032 Marburg, Germany

The implementation of renewable energy as the main energy source is only possible with reliable energy storage techniques. Current batteries lose a significant amount of storing capacity after a few hundreds of charge-discharge cycles.

Mechanical strain is one of the main causes for degradation processes in solid-state batteries. Electrochemical Strain Microscopy (ESM) is a powerful tool to measure strain at the nanoscale [1].

Recent studies have shown that quantitative measurements of the local strain require a deeper understanding of the ESM signal formation [2]. Here, we present a theoretical model for the cantilever motion, and we use this model to evaluate experimental results. We show that quantitative ESM requires corrections of the signals with respect to the local contact stiffness and to frequency tracking errors [3].

[1] S. Kalinin et al., Materials Today 14 (2011) 548

[2] S. Jesse et al., J. Phys. D: Appl. Phys. 44 (2011) 464006

[3] S. Bradler, A. Schirmeisen, B. Roling, MJ. Appl. Phys. (2016)

O 3.5 Mon 11:30 TRE Phy

**Utilizing STM and AFM simultaneously to study atomic-scale magnetism** — ●NADINE HAUPTMANN, JAN GERRITSEN, DANIEL WEGNER, and ALEXANDER AKO KHAJETOORIANS — Institute for Molecules and Materials, Radboud University, 6500 GL Nijmegen, The Netherlands

Recent developments in surface and interfacial magnetism have raised the question if it is possible to realize a memory derived from single atoms or nanometer sized skyrmions. Therefore, it is important to understand how the local magnetic anisotropy driven by the crystal field symmetry, magnetic exchange, and hybridization influences the magnetization at the atomic length scale. Nevertheless, a vast majority of atomic-scale studies have utilized spin-polarized scanning tunneling microscopy (SP-STM), limiting the scope of materials which can be probed. In order to gain new insight into magnetism at the atomic scale, we combine SP-STM with magnetic exchange force microscopy (MExFM), based on a qPlus tuning fork design. We discuss our recent developments and demonstrate that our approach enables simultaneous measurement of the spin polarized current and the exchange force at the single atom level.

O 3.6 Mon 11:45 TRE Phy

**Sensing complex tip-surface interactions with multifrequency AFM** — ●DANIEL PLATZ<sup>1,2</sup>, DANIEL FORCHHEIMER<sup>2</sup>, and DAVID B. HAVILAND<sup>2</sup> — <sup>1</sup>Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — <sup>2</sup>KTH Royal Institute of Technology, Albanova University Center, 10691 Stockholm, Sweden

In recent years multifrequency atomic force microscopy (AFM) revealed its potential to overcome limitations in the spatial and compositional resolution of conventional force microscopy methods. Conventionally tip-surface interactions are considered as functions of the tip position only, so-called force curves. However, especially for soft materials tip-surface interactions often depend on the tip velocity and the past tip trajectory. Here, we introduce a compact and general description of these interactions appropriate to dynamic AFM where the measurement of force is restricted to a narrow frequency band. We represent the tip-surface interaction in terms of a force disk in the phase space of position and velocity. Determination of the amplitude dependence of tip-surface forces at a fixed static probe height allows

for a comprehensive treatment of conservative and dissipative interactions. We illuminate the fundamental limitations of force reconstruction with narrow band dynamic AFM and we show how the amplitude dependence of the Fourier component of the force at the tip oscillation frequency, gives insight into the detailed nature of the tip-surface interaction and allows for a quantitative force reconstruction.

**O 3.7 Mon 12:00 TRE Phy**  
**Observation of non-linear dynamics in ultra high vacuum Atomic Force Microscopy** — •DANIEL FORCHHEIMER<sup>1,2</sup>, CHRISTIAN WAGNER<sup>3</sup>, DANIEL PLATZ<sup>1</sup>, and DAVID HAVILAND<sup>1</sup> — <sup>1</sup>Kungliga Tekniska Högskolan, Stockholm, Sweden — <sup>2</sup>Intermodulation Products AB, Sweden — <sup>3</sup>Peter Grünberg Institute, Jülich, Germany

The tip-surface force in atomic force microscopy goes from being attractive to repulsive as the tip-surface separation change by only a few nano meters. Despite this highly nonlinear force the motion of cantilevers and tuning forks in ultra high vacuum AFMs lack many of the typical signatures of a nonlinear system, such as the the generation of higher harmonics. This is due to the extremely high quality factors of the force probes in vacuum which effectively dampen any off-resonance motion, masking the nonlinear interaction.

We have previously developed Intermodulation AFM for ambient condition, in which the AFM cantilever is excited with two frequencies near a single resonance. We applied such an excitation to a tuning fork AFM in vacuum and could observe the generation of several mixing tones, or intermodulation products, near resonance. These are clear signatures of a nonlinear interaction and by measuring the amplitude and phase at multiple such frequencies we could characterize conservative and dissipative properties of the interaction.

**O 3.8 Mon 12:15 TRE Phy**  
**Characterization and variation of a single molecule-metal bond via AFM-based manipulation** — •PHILIPP LEINEN<sup>1,2</sup>, MATTHEW F. B. GREEN<sup>1,2</sup>, CHRISTIAN WAGNER<sup>1,2</sup>, RUSLAN TEMIROV<sup>1,2</sup>, and F. STEFAN TAUTZ<sup>1,2</sup> — <sup>1</sup>Peter Grünberg Institut (PGI-3), Forschungszentrum Jülich, Germany — <sup>2</sup>JARA-Fundamentals of Future Information Technology

Mechanical manipulation of molecules with the scanning probe microscope (SPM) is a versatile technique to study single-molecule properties and create new devices. A single bond established between the SPM tip and a reactive atom within the molecule is a very precise way to apply forces in such a manipulation and its understanding is therefore crucial. We studied the prototypical bond between carboxylic oxygen atoms of perylene-tetracarboxylic dianhydride (PTCDA) and the Ag terminated tip of a non-contact AFM/STM regarding its mechanical properties as well as the deformation the molecule undergoes during contacting and slight tip retraction. We focus on molecules within a layer which are retained by their neighbors, thus facilitating controlled tip-molecule bond breaking by mechanical stress alone. The bond forming and breaking also provides a sensitive probe to study the balance between intra- and intermolecular interactions. For the two inequivalent molecules in the unit cell of PTCDA/Ag(111) we observe that the tip height at which the bond to chemically identical oxygen atoms is established varies by 0.4 Å depending on the local environment of each oxygen in the monolayer. The data thus provides a sensitive

benchmark for theory beyond just adsorption energy and height.

**O 3.9 Mon 12:30 TRE Phy**  
**simultaneous high-resolution AFM/STM/IETS imaging of FePc on Au(111)** . — •BRUNO DE LA TORRE<sup>1,2</sup>, MARTIN SVEC<sup>1</sup>, RADEK ZBORIL<sup>2</sup>, and PAVEL JELINEK<sup>1</sup> — <sup>1</sup>Institute of Physics of the CAS, Prague, Czech Republic. — <sup>2</sup>Regional Centre of Advanced Technologies and Materials, Palacký University, Olomouc, Czech Republic.

The recent progress in scanning probe microscopy provided unprecedented atomic resolution of single organic molecules on surfaces. Namely, the submolecular resolution was achieved in AFM [1], STM [2] and also IETS [3] mode employing functionalized tips. The origin of the submolecular contrast can be rationalized by a simple mechanical model introducing a lateral bending of a flexible tip apex [4,5]. However direct experimental evidence correlating the AFM/STM/IETS imaging mechanisms has been missing so far.

Here we present simultaneous high resolution AFM/STM/IETS imaging of iron(II) phthalocyanine (FePc) on Au(111) surface acquired with CO-functionalized probe. The acquired data demonstrate unambiguously the common imaging mechanism of the modes. We will show that not only renormalization of the frustrated translational mode [5], but also renormalization of the amplitude of IETS signal affect the IETS imaging.

[1] L. Gross et al., Science 325,1110 (2009). [2] C. Weiss et al., Phys. Rev. Lett. 105, 086103 (2010). [3] C.I. Chiang et al Science 344, 885 (2014). [4] P. Hapala et al., Phys. Rev. B 90, 085421 (2014). [5] P. Hapala et al., Phys. Rev. Lett. 113, 226101 (2014).

**O 3.10 Mon 12:45 TRE Phy**  
**Characterization of polycyclic conjugated hydrocarbons by means of NCAFM** — •ZSOLT MAJZIK<sup>1</sup>, NIKO PAVLIČEK<sup>1</sup>, MANUEL VILAS-VARELA<sup>2</sup>, NIKOLAJ MOLL<sup>1</sup>, DOLORES PÉREZ<sup>2</sup>, ENRIQUE GUITIÁN<sup>2</sup>, GERHARD MEYER<sup>1</sup>, DIEGO PEÑA<sup>2</sup>, and LEO GROSS<sup>1</sup> — <sup>1</sup>IBM Research-Zurich, 8803 Rüschlikon, Switzerland — <sup>2</sup>CIQUS and Departamento de Química Orgánica, Universidade de Santiago de Compostela. Santiago de Compostela 15782, Spain.

The development of organic field effect transistors (OFETs) and organic photovoltaics (OPVs) triggered a strong interest for synthesizing and characterizing conjugated polycyclic hydrocarbons. Anti-aromatic and open-shell systems received recently a special attention because of their distinct electronic and magnetic behavior. The strong reactivity of pristine molecules creates a challenge for probing their structural and electrical properties. Until now, the fundamental analyses of these reactive compounds have been limited to theoretical works or the lifetime of a molecule was increased by careful attachment of protecting ligands for experimental investigations. Advances in atomic force microscopy, particularly resolving and modifying the structure of molecules at the atomic scale opened new routes for studying highly reactive compounds. Here we present an alternative route for the synthesis and characterization of conjugated systems. We deposited custom synthesized precursor molecules and carried out the final synthesis step in UHV environment via atomic manipulation. We used combined AFM/STM analyses supported by DFT calculations to determine the aromatic configuration of a molecule.