MA 25: Surface Magnetism / Magnetic Imaging I

Time: Thursday 10:15–12:45 Location: H23

MA 25.1 Thu 10:15 H23

Measuring the distance dependence of the magnetic exchange interaction across a vacuum gap: First experimental results obtained with magnetic exchange force spectroscopy — Rene Schmidt, Uwe Kaiser, •Alexander Schwarz, and Roland Wiesendanger — Institute of Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

Magnetic exchange force microscopy (MExFM) has been established as an atomic force microscopy (AFM) based imaging technique to map the spin structures of insulating [1] as well as metallic surfaces [2]. Here we employ the spectroscopic mode, i.e., magnetic exchange force spectroscopy (MExFS), to probe the distance dependence of the magnetic exchange interaction between an atomically sharp magnetic tip and the antiferromagnetically ordered Fe monolayer on W(001). The site specific distance dependence of the total tip-sample interaction is recorded above Fe atoms which exhibit parallel as well as antiparallel atomic magnetic moments with respect to the tip. The contribution of the magnetic exchange interaction can be extracted by subtracting the two curves from each other, because all other interactions are identical on both sites. The experimental results are compared with theoretical calculations [3] and thereby allow us to determine the distance dependence of the effective coupling constant J between the tip apex atoms and the surface atoms underneath.

[1] U. Kaiser et al., Nature 446, 522 (2007).
[2] R. Schmidt et al., Nano Lett. 9, 200 (2009).
[3] C. Lazo et al., Phys. Rev. B 78, 214416 (2008).

MA 25.2 Thu 10:30 H23

Ferromagnetic versus antiferromagnetic tips for magnetic exchange force microscopy — •Cesar Lazo and Stefan Heinze — Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, 24098 Kiel, Germany.

Magnetic exchange force microscopy (MExFM) is a promising new technique to perform magnetic imaging with atomic resolution by measuring the magnetic exchange force between a magnetically coated tip and a magnetic sample [1]. Here, we apply density functional theory using the full-potential linearized augmented plane wave (FP-LAPW) method to simulate MExFM on the antiferromagnetic monolayer Fe on W(001) [2]. We use single atom tips of Cr, Mn and Fe, and multi-atom tips of Cr and Fe as models. For single atom tips, we find a magnetic exchange interaction which resembles the Bethe-Slater curve. Using multi-atoms tips, we observe that relaxations of the cluster and the surface are significant and larger for Cr tips than for Fe tips. In conclusion, Cr tips exhibit a higher magnetic exchange force than Fe tips and are well suited for MExFM experiments.

[1] U. Kaiser *et al.*, Nature 446, 522 (2007)
[2] R. Schmidt, C. Lazo. *et al.*, Nano Lett. 9, 200 (2009)

MA 25.3 Thu 10:45 H23

Resolving the interface magnetism of a molecule-based spin filter — Jens Brede[1], •Nicolae Atodiresei[2], Stefan Kuck[1], Predrag Lasic[2], Stefan Blügel[2], Roland Wiesendanger[1], and Germar Hoffmann[1] — [1]Institute of Applied Physics, University of Hamburg, Jungiusstrasse 11, D-20355 Hamburg, Germany — [2]Institut für Festkörperforschung and Institute for Advanced Simulation, Forschungszentrum Jülich, 52425 Jülich, Germany

The use of magnetic molecules opens a gateway to a flexible design of spintronic devices to store, manipulate, and read spin information at nanoscale level. Crucial is the precise knowledge of molecular properties at the interface towards an electrode. Progress in this field relies on resolving and understanding the physics at the relevant interface, the role of individual molecular constituents, and the impact of the atomic environment on molecular properties.

In this work, we apply spin-polarized scanning tunneling microscopy to resolve the physics of such an interface formed of a single magnetic metal-organic molecule adsorbed on a magnetic substrate to observe on an atomic scale the operation of single-molecule spin filter. The experimental data reveal a significant and strongly site dependent localization of spin split states at the interface. To understand the resulting spin-polarization, state of the art first principles calculations are performed. The density functional theory code is extended to describe non-local correlation effects present when a molecule and a metallic substrate are in close proximity. The physical processes at the molecule-electrode interface will be discussed.

MA 25.4 Thu 11:00 H23

SP-STM of Co nano-islands on Cu(111) with bulk Cr tips — •Marco Corbetta[2], Fabio Donati[1,2], Andrea Li Bassi[1], Matteo Passoni[1], Carlo Casari[1], Safia Ouazi[2], Yasmine Nahas[2], Dirk Sander[2], and Jürgen Kirschner[2] — [1]CNISM, NEMAS and Dipartimento di Energia - Politecnico di Milano, Milano, Italy — [2]Max Planck Institut für Mikrostrukturphysik, Halle, Germany

From its first application, SP-STM has been performed using tunneling tips fabricated with a great variety of ferromagnetic (Fe, Ni, Co or Fe-coated W tips) or antiferromagnetic materials (MnNi, MnPt, Cr-coated or Mn-coated W tips). In order to avoid perturbing stray fields induced by strong magnetic polarization of the tip, antiferromagnetic materials are usually preferred [1]. The main drawback of coated tips is that an in-situ preparation is required. Recently an easy, reliable and reproducible procedure for the production of bulk Cr tips has been developed using only a standard electrochemical etching [2]. We produced and used such tips for in-field spin-polarized STM measurements at 7 K on Co nano-islands on Cu(111). The obtained images show a spin resolved high spatial resolution on the Co islands. Changing the magnetic field we measured the variation of the dI/dV signal. We obtained butterfly hysteresis loops which show that the magnetization direction of the tip apex is not pinned but follows the external magnetic field direction, similar to our previous results obtained with Cr-coated W tips [3]. [1] A. Kubetzka et al., Phys. Rev. Lett. 88, 057201 (2002). [2] A. Li Bassi et al., Appl. Phys. Lett. 91, 173120 (2007). [3] G. Rodary et al., Jpn. J. Appl. Phys. 47, 9013 (2008).

MA 25.5 Thu 11:15 H23

Cr Bulk Tips for Spin Polarized Scanning Tunneling Microscopy with both In-plane and Out-of-plane Sensitivity — •Anika Emmenegger, Gabriela Herzog, Stefan Krause, and Roland Wiesendanger — Institute of Applied Physics, University of Hamburg

Spin-polarized scanning tunneling microscopy (SP-STM) is a powerful technique to investigate magnetic surface properties on the local scale. The advantage of antiferromagnetic probe tips, e.g. Cr- or Mn-coated W-tips, is their negligible stray field, that otherwise may interact with the sample magnetization. Chromium has a bulk Néel temperature of 311 K which makes it a promising bulk tip material for SP-STM measurements over a wide temperature range.

While first indications exist that Cr bulk tips are sensitive to the in-plane-component of sample magnetization [1], we show that these tips are also sensitive to the out-of-plane component. After introducing our *ex situ* and *in situ* tip preparation method we present SP-STM measurements on 1.8 monolayers of Fe/W(110) which is known to have the easy magnetization direction in the surface plane for the monolayer [2] and perpendicular to the surface in the second layer [3]. Imaging with a Chromium bulk tip reveals a magnetic contrast in the monolayer as well as in the double layer, thereby proving not only the in-plane but also the out-of-plane sensitivity of the tip.

[1] A. L. Bassi *et al.*, APL **91**, 173120 (2007).
[2] M. Pratzer *et al.*, PRL **87**, 127201 (2001).
[3] O. Pietzsch *et al.*, PRL **84**, 5212 (2000).

MA 25.6 Thu 11:30 H23

Non-collinear magnetism in monatomic transition-metal chains — •Franziska Schubert[1], Paolo Ferriani[1,2], Yuriy Mokrousov[3], and Stefan Heinze[1,2] — [1]Institute of Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg — [2]Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstr. 15, 24098 Kiel, Germany — [3]Institut für Festkörperforschung, Forschungszentrum Jülich, 52425 Jülich, Germany

Recent advances in experimental techniques allow the creation of one-dimensional transition-metal nanostructures on surfaces by self-assembly [1] or by atom manipulation with an STM tip [2]. Here, we used density functional theory calculations based on the full-potential linearized augmented plane wave (FLAPW) method to study the possibility of non-collinear magnetism in monatomic 3*d* transition-metal chains. We first focus on freestanding Mn and Fe chains as a function

of the interatomic spacing. While Fe chains remain ferromagnetic independent of interatomic distance, Mn chains possess spin-spiral ground states in a broad regime of lattice constants. Therefore, we investigated Mn chains on the (110)-surfaces of Cu, Pd, Ag, and NiAl. We demonstrate that the chain-surface hybridization is sufficient to dramatically change the magnetic coupling in the chain. Nevertheless, a non-collinear magnetic ground state is found for Mn chains on Cu(110) and Ag(110).

[1] P. Gambardella *et al.*, Nature **416**, 301 (2002)
[2] C. Hirjibehedin *et al.*, Science **312**, 1021 (2006)

MA 25.7 Thu 11:45 H23

Nonequilibrium effects in spin inelastic tunneling spectroscopy — •Björn Sothmann and Jürgen König — Universität Duisburg-Essen and CeNIDE, 47048 Duisburg, Germany

In a recent experiment, Hirjibehedin et al. [1] measured the differential conductance of a single iron atom absorbed on a substrate using an STM tip. While the observed steps could be explained [2] in terms of inelastic tunneling processes exciting the atom out of its ground state, an explanation for the nonmonotonic conductance behaviour as a function of bias voltage is missing.

Here we develop a generalized theory which takes into account nonequilibrium spin occupations using a master equation approach. We find that the conductance overshoots at the inelastic steps and drops to its equilibrium values afterwards. This behaviour can be explained by bias-dependent spin occupations. Furthermore, we show that the experimentally observed absence of these overshoots at certain spin excitations can be ascribed to a spin-dependent relaxation mechanism. Finally, we discuss that the nonequilibrium effects also give rise to a super-Poissonian current noise.

[1] C. Hirjibehedin et al., Science **317**, 1199 (2007).
[2] J. Fernández-Rossier, Phys. Rev. Lett. **102**, 256802 (2009).

MA 25.8 Thu 12:00 H23

Determining the Magnetism of Single Atoms on a Semiconductor Surface — •Bruno Chilian, Alexander Khajetoorians, Jens Wiebe, and Roland Wiesendanger — Institute of Applied Physics, University of Hamburg, Hamburg, Germany

We demonstrate a method in which we combine spin-resolved Landau level spectroscopy and inelastic tunneling spectroscopy (IETS) to determine the magnetization and anisotropy of single Fe atoms coupled to a 2D electron gas on a III-V (110) semiconductor surface. We show here, using ultra-low temperature (300mK) scanning tunneling spectroscopy in high magnetic fields (12T) that the states of the Fe atom couple to the spin-split Landau levels thereby producing an overall asymmetry in the local density of states (LDOS) for a given Landau level. By probing the LDOS with changing magnetic field, we determine the magnetization of the atom. Furthermore, we observe spin excitations of the Fe atom by IETS. From these excitations, we observe a zero-field splitting of the Fe spin which we attribute to magnetic anisotropy. We relate these two measurements using a simple quantum magnetic Hamiltonian which suitably describes both experimental observations.

MA 25.9 Thu 12:15 H23

Lifetime information of excited states in magnetic single atoms and clusters studied by STM — •Toshio Miyamachi[1,2], Tobias Schuh[1], Timofey Balashov[1], Albert. F. Takács[1], Shigemasa Suga[2], and Wulf Wulfhekel[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Graduate School of Engineering Science, Osaka University, Toyonaka, Japan

The magnetic stability of bits in a hard disk relies on the energetic barrier to reverse the magnetization, which is governed by magnetic anisotropy energy (MAE). Recent x-ray magnetic circular dichroism study has revealed a giant MAE of Co atoms on Pt(111) of 9.3 meV [1], raising hope for realizing ultimate miniaturization of bits. This technique, however, cannot extract information about the magnetization dynamics, which also plays an important role for the stability of bits. Here we demonstrate that inelastic tunneling spectroscopy using scanning tunneling microscopy (STM) can investigate the lifetimes of magnetically excited states in addition to MAE [2]. By virtue of atomic manipulation capabilities of the STM, these properties are determined with the highest precision for single atoms, dimers and trimers of Fe and Co on Pt(111). The estimated short lifetimes of the order of femtoseconds are explained from efficient electron-electron scattering processes induced by the strong hybridization of the impurity state and the substrate.

[1] P. Gambardella et al., Science 300, 1130 (2003)
[2] T. Balashov et al., PRL 102, 257203 (2009)

MA 25.10 Thu 12:30 H23

Inversion of Spin Polarization above Magnetic Adatoms — •Lihui Zhou, Focko Meier, Jens Wiebe, and Roland Wiesendanger — Hamburg University, Germany

The spin-resolved electronic structure of magnetic adatoms on surfaces is essential to the understanding of magnetism and the realization of magnetic devices at the atomic level. Here we present an investigation of the electronic density of states of Co adatoms on platinum(111) using spin-polarized scanning tunneling spectroscopy at cryogenic temperature. It revealed a pronounced spin-polarized resonance of majority character just below the Fermi energy in the vacuum above the adatoms, giving rise to a positive spin polarization at the Fermi energy. This is in contrast to atomically flat surfaces where minority states are dominating. The comparison to other Co nanostructures suggests that the inversion of the spin polarization is a unique property for single adatoms on surfaces.