# MA 4: Surface Magnetism I

Time: Monday 11:00–13:15 Location: HSZ 403

MA 4.1 Mon 11:00 HSZ 403

**Spin-resolved excitations of single atoms with STM** — •Kirsten von Bergmann[1,2], Sebastian Loth[1], Markus Ternes[1], Alexander F. Otte[1,3], Cyrus F. Hirjibehedin[1,4], Christopher P. Lutz[1], and Andreas J. Heinrich[1] — [1]IBM Almaden Research Center — [2]University of Hamburg — [3]NIST Gaithersburg — [4]London Centre for Nanotechnology

STM with its high lateral resolution can be used to obtain information about magnetic properties in two ways: inelastic tunneling spectroscopy has been shown to enable spin flip excitations in single atoms [1], while spin-polarized STM has been used to study ground state properties of nanoscale structures [2].

We have combined these two approaches to gain further insight by using a spin-polarized STM tip to excite the spin of single Co atoms on a thin insulating layer of $Cu_2N$ on Cu(001). While spin-averaged measurements on this system yield the energy of spin-flip transitions [3], the spin-resolved data enables the determination of the character of the observed excitations. The degree of spin polarization is compared to calculations within the Heisenberg model. Since the Co atom shows the Kondo effect in this environment, this measurement provides additional information about the spin polarization of the Kondo resonance, which is split in an external magnetic field.

[1] A.J. Heinrich *et al.*, Science **306**, 466 (2004).
[2] M. Bode, Rep. Prog. Phys. **66**, 523 (2003).
[3] A.F. Otte *et al.*, Nature Phys. **4**, 847 (2008).

MA 4.2 Mon 11:15 HSZ 403

**Right Rotating Néel Type Domain Walls in the Fe Doublelayer on/W(110)** — •Stefan Meckler, Anett Pressler, Mike Gyamfi, Oswald Pietzsch, and Roland Wiesendanger — Institute of Applied Physics and Microstructure Research Center, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

The system of 1.5 atomic layers Fe on W(110) has been studied intensively in the field of spin polarized scanning tunneling microscopy (SP-STM), and its magnetic properties have been investigated in great detail. It was recognized very early that the out-of-plane domains and the walls separating them form spiral-like structures with a unique sense of rotation. However, it could not be shown experimentally if the domain walls are of Bloch or Néel type since there was no complete control of the direction of the magnetization of the SP-STM tips. For the same reason the handedness could not be determined experimentally. Applying SP-STM in the field of a three axes vector magnet enables us for the first time to align the magnetization of our SP-STM tips in any arbitrary spatial direction. Using this technique we show that the walls in the Fe doublelayer on W(110) are right rotating Néel type walls. This observation is in good agreement with recent calculations that ascribe both the observed wall type and the unique right handedness to the important role of the Dzyaloshinkii-Moriya interaction at crystal surfaces.

MA 4.3 Mon 11:30 HSZ 403

**SPEELS Studies of Oxygen Passivated Fe/W(100) Thin Films** — •Yu Zhang[1], Jacek Prokop[1], Ioan Tudosa[1], Wen-Xin Tang[1], Thiago R. F. Peixoto[1,2], Khalil Zakeri[1], and Jürgen Kirschner[1] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle — [2]Instituto de Física, Universidade de São Paulo, 05508-900, São Paulo, Brazil

We measured the vibrational spectra of oxygen passivated Fe(100) surface by means of spin-polarized electron energy loss spectroscopy (SPEELS). A 30 ML thick Fe film, epitaxially grown on W(100) was exposed to 5 L $O_2$ at room temperature and annealed at 500 K, under ultrahigh vacuum conditions. The surface exhibits a p(1×1)O-Fe(100) reconstruction in the LEED pattern, with the O atoms occupying fourfold hollow sites. SPEELS measurements were performed at different primary energies and a resolution of about 6 meV. These spectra show many peaks in comparison to the spectra obtained for the clean Fe surface. From the analysis of the energy gain and loss features in the asymmetry, one can distinguish between excitations caused by spin-flip and non-flip scattering processes. The O-Fe(100) vibration peaks, which are dominated by the spin independent dipolar scattering [1], surprisingly reveal asymmetries up to 60%. We show results of specular and off-specular geometries and discuss the nature of the observed excitations.

[1] J.-P. Lu, M. R. Albert and S. L. Bernasek, Surf. Sci. 215, 348 (1989).

MA 4.4 Mon 11:45 HSZ 403

**Magnetic and structural investigations of self-organised iron based nanostructures on GaAs(110)** — •Carsten Godde[1], Sani Noor[1], Athena Rastgoo Lahrood[1], Gregor Nowak[2], Hartmut Zabel[2], and Ulrich Köhler[1] — [1]Institut für Experimentalphysik IV / AG Oberflächen, Ruhr-Universität Bochum, Germany — [2]Institut für Experimentalphysik IV, Ruhr-Universität Bochum, Germany

The structure and the magnetic behaviour of Fe-layers and self-organised iron based nanostructures on GaAs(110) were studied in a UHV system that offers the means for structural analysis by STM and LEED and magnetic characterization by MOKE during deposition. The structure of the Fe-layer when grown at room temperature has a closed granular structure with a magnetic anisotropy depending on the thickness of the Fe-layer. At elevated temperatures a disrupted layer develops. The effect of annealing up to 450°C on the structure and the magnetic behaviour were studied for two different cases - during and after deposition of the iron layer. The increasing temperature leads to a transformation of the Fe-layer to an array of self-organised ferromagnetic nanostructures for both cases. These nanostructures are roof-shaped 3D-islands elongated along the $[1\bar{1}0]$-direction of the GaAs(110) substrate. STM also shows an indication that Ga and As from the substrate diffuse into the Fe-islands. This intermixing by annealing leads to a ternary alloy $Fe_3Ga_{2-x}As_x$ which is proofed by x-ray diffraction. Despite of this alloying magnetic measurements of the nanostructures by MOKE show ferromagnetic characteristics and a correlation between magnetic and structural anisotropy.

MA 4.5 Mon 12:00 HSZ 403

**Visualizing the spin polarizaton of individual molecules** — •Benjamin W. Heinrich[1], Mircea V. Rastei[1], Cristian Iacovita[1], Thomas Brumme[2], Jens Kortus[2], Laurent Limot[1], and Jean-Pierre Bucher[1] — [1]Institut de Physique et Chimie des Matériaux de Strasbourg, UMR 7504, Université Louis Pasteur, F-67034 Strasbourg, France — [2]Institut für Theoretische Physik, TU Bergakademie Freiberg, D-09599 Freiberg, Germany

Low-temperature spin-polarized scanning tunneling microscopy is employed to study spin transport across single cobalt-phthalocyanine molecules adsorbed on well-characterized magnetic nanoleads. A spin-polarized electronic resonance is identified over the center of the molecule and exploited to spatially resolve stationary spin states [1]. These states reflect two molecular spin orientations and, as established by density functional calculations, originate from a ferromagnetic molecule-lead exchange interaction.

[1] C. Iacovita, M.V. Rastei, B.W. Heinrich, T. Brumme, J. Kortus, L. Limot, J.P. Bucher, Phys. Rev. Lett. **101**, 116602 (2008)

MA 4.6 Mon 12:15 HSZ 403

**The role of magnetic anisotropy in the Kondo effect** — •Markus Ternes[1,2], Alexander F. Otte[1,3], Kirsten v. Bergmann[1,4], Sebastian Loth[1], Harald Brune[1,5], Christopher P. Lutz[1], Cyrus P. Hirijbehedin[1,6], and Andreas J. Heinrich[1] — [1]IBM Almaden Research Center — [2]MPI Stuttgart — [3]NIST Gaithersburg — [4]University of Hamburg — [5]EPF Lausanne — [6]London Centre for Nanotechnology

Using a STM to assemble magnetic structures on a thin insulator, we found that the spin of the atom is influenced by the magnetocrystalline anisotropy of the supporting surface which lifts the spin degeneracy of the ground state and enables the identification of individual atoms by using inelastic electron tunneling spectroscopy [1]. Changes in the observed spectra as a magnetic field was applied along different directions yielded the magnetic anisotropy for individual magnetic atoms [2].

Atoms with half-integer spin remain always degenerated at zero field due to Kramers theorem. We found that if these states differ by an orbital momentum of $\Delta m = \pm 1$ the localized spin is screened by the surrounding conducting electrons of the non-magnetic host and form a Kondo resonance close to the Fermi energy at sufficiently low temperature. Applying a magnetic field splits this Kondo resonance at rates that are strongly direction-dependent, which are well-described by the

energies of the underlying unscreened spin states [3].

[1] A. J. Heinrich *et al.*, Science **306**, 466 (2004).
[2] C. F. Hirjibehedin *et al.*, Science **317**, 1199 (2007).
[3] A. F. Otte *et al.*, Nature Physics **4**, 847 (2008).

MA 4.7 Mon 12:30 HSZ 403

**Magnetic anisotropy of single 3*d* atoms on CuN surface** — •Alexander B. Shick[1], Frantisek Maca[1], and Alexander I. Lichtenstein[2] — [1]Institute of Physics ASCR, Prague, Czech Rep. — [2]University of Hamburg, Germany

The magnetic anisotropy energy for Mn, Fe and Co atoms on CuN/Cu(001) surface is investigated making use of the first-principles FP-LAPW calculations and the torque method. For Mn and Fe atoms, the easy magnetization direction is found to be in accord with the experiment [1]. The magnetic anisotropy has a single-ion character and mainly originates from the local magnetic moment of Mn and Fe atoms. The uniaxial magnetic anisotropy constants are calculated in reasonable agreement with the experiment [2].

For Co atom case, the conventional band theory fails to reproduce even qualitatively the experimentally observed magnetic anisotropy [3]. The orbital polarization beyond that given by LSDA has to be included. The effect of the orbital polarization is studied making use of the LDA+U method. The LDA+U induced orbital polarization yields strong enhancement of the orbital component of the magnetic moment for different directions of the Co-atom magnetization and can modify substantially the magnetic anisotropy energy. It is shown that LDA+U induced orbital polarization improves substantially agreement with the experimental magnetic anisotropy energies.

[1] S. Hirjibehedin *et al.*, Science 317, 1199 (2007). [2] A. B. Shick, F. Máca, and A.I. Lichtenstein, arxiv:0810.3389. [3] A. F. Otte *et al.*, Nature Physics 4, 847 (2008).

MA 4.8 Mon 12:45 HSZ 403

**Comparing magnetic properties of Co adatoms measured with X-ray magnetic dichroism and spin excitation spectroscopy** — •M. Etzkorn[1], C. Hirjibehedin[2], A. Lehnert[1], S. Stepanow[3], S. Ouazi[1], C. Tieg[4], P. Thakur[4], S. Rusponi[1], P. Gambardella[3], A. Heinrich[5], and H. Brune[1] — [1]Institut de Physique des Nanostructures, EPF-Lausanne, Switzerland — [2]London Centre for Nanotechnology, UCL, United Kingdom — [3]ICREA and Catalan Institut of Nanotechnology, Barcelona, Spain — [4]ESRF, Grenoble, France — [5]IBM Research Center, San Jose, USA

Spin excitation spectroscopy offers a new approach to determine the magnetic moment and anisotropy of single adatoms and atomic chains with a scanning tunneling microscope [1]. In order to compare these results with established methods we have started a series of X-ray circular magnetic dichroism (XMCD) measurements on one of the systems investigated with STM, namely Co-monomers on $Cu_2N$/Cu(100). The XMCD spectra show that the Co is electronically largely decoupled from the Cu-substrate by the $Cu_2N$-layer in agreement with the STS data. The X-ray adsorption spectra reveal that the electronic state of the Co on this surface has a predominant $d8$-character while the STS studies indicate a $d7$-state. On one hand the XMCD spectra clearly show a large orbital moment of the Co while the STS analysis has been performed in terms of an effective spin moment only. On the other hand the anisotropy determined by STS is in very good agreement with the angular dependance of the magnetic moment measured by XMCD. [1] A. Otte et al., Nature Physics 4 (2008) 847.

MA 4.9 Mon 13:00 HSZ 403

**Magnetic Anisotropy of small metal clusters on Pt(111)** — •Stefan Gerstl[1], Tobias Schuh[1], Timofey Balashov[1], Albert F. Takács[1], Sergey Ostanin[2], Arthur Ernst[2], Jürgen Henk[2], Toshio Miyamachi[1], Shigemasa Suga[3], Ingrid Mertig[2,4], Patrick Bruno[2], and Wulf Wulfhekel[1] — [1]Physikalisches Institut, Universität Karlsruhe (TH), Germany — [2]Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany — [3]Graduate School of Engineering Science, Osaka University, Japan — [4]Institut für Physik, Martin-Luther-Universität Halle, Germany

The key for higher storage density is the magnetic anisotropy energy (MAE), as it is related to the stability of bits in magnetic storage devices. Giant MAE was found for Co clusters on Pt(111) using X-ray magnetic circular dichroism (XMCD) [1]. We show a new approach to obtain the MAE of individual clusters using inelastic scanning tunneling spectroscopy. Single Fe or Co atoms were deposited on Pt(111) at 4 K and assembled by atomic manipulation to form clusters of up to three atoms. The magnetic excitation energy that we determined corresponds to a spin-flip process and is proportional to the MAE. The excitation energies were recorded on a large number of atoms and clusters and averaged. The obtained values of the MAE are 6.5, 5.2 and 5.5 meV/atom for Fe atoms, dimers and trimers respectively, and 10.2, 5.5 and 5.0 meV/atom for Co atoms and clusters. For Co this corresponds well to the MAE values obtained with XMCD [1]. Relativistic *ab-initio* calculations of fully relaxed structures confirm our results.

[1] P. Gambardella *et al.*, Science 300, 1130 (2003).