O 50: [MA] Joint Session "Surface Magnetism I" (jointly with O)

Time: Wednesday 16:00–19:00 Location: BH 243

O 50.1 Wed 16:00 BH 243

Observation and quantitative evaluation of superparamagnetic behavior utilizing magnetic exchange force microscopy and spectroscopy — •Schwarz Alexander, Schmidt Rene, and Wiesendanger Roland — Institute of Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

Magnetic exchange force microscopy (MExFM) and spectroscopy (MExFS) can resolve magnetic surfaces and probe the distance dependence of the magnetic exchange interaction with atomic resolution [1,2]. Here we show that the distance dependence of the magnetic exchange interaction can be utilized to modify the barrier height between two magnetization directions in a well-controlled manner. Contrast reversals observed with magnetically coated tips during imaging an antiferromagnetic surface show that tips can switch their magnetization direction by 180°. Since the magnetic exchange interaction is distance dependent, switching rate, lifetimes and the barrier height between the two states are distance dependent as well. Modeling the tip apex as superparamagnetic cluster with uniaxial anisotropy but otherwise independent of the rest of the tip, allows quantifying the energy barrier between both states as well as the zero field anisotropy. Moreover, the influence of a magnetic field via the additional Zeeman energy can be measured. Our study demonstrates the feasibility to observe dynamic magnetic processes utilizing magnetic exchange force microscopy and spectroscopy with atomic resolution.

[1] U. Kaiser et al., Nature 446, 522 (2007).
[2] R. Schmidt et al., Phys. Rev. Lett. 106, 257202 (2011).

O 50.2 Wed 16:15 BH 243

Possible detection of spin contrast on NiO(001) by AFM using a qPlus sensor with a bulk iron tip — •Florian Pielmeier and Franz J. Giessibl — Institute of Experimental and Applied Physics, University of Regensburg, 93040 Regensburg, Germany

Magnetic exchange force microscopy was first demonstrated with atomic resolution on the (001) surface of the antiferromagnetic insulator nickel oxide at low temperatures [1]. In order to detect spin contrast on NiO(001), the tips had to be magnetically polarized by an external field of 5 T [1-3].

Here, we observe spin contrast on NiO(001) at 4.3 K without an external field, using a bulk iron tip mounted on a qPlus sensor. However, magnetic contrast is only observed at a distance of about 10 pm further away than the distance where optimal chemical contrast is observed.

[1] U. Kaiser, A. Schwarz, R. Wiesendanger, Nature 446, 522 (2007)
[2] U. Kaiser, A. Schwarz, R. Wiesendanger, Phys. Rev. B 78, 104418 (2008)
[3] A. Schwarz, U. Kaiser, R. Wiesendanger, Nanotechnology 20, 264017 (2009)

O 50.3 Wed 16:30 BH 243

First-principles study of the magnetic exchange interaction across a vacuum gap — •Cesar Lazo and Stefan Heinze — Institute of Theoretical Physics and Astrophysics, University of Kiel, Germany

The miniaturization of spintronic devices towards the limit of single atoms calls for a quantification and understanding of the magnetic exchange interaction in atomic-scale junctions. Such a situation can be realized experimentally using a magnetic tip in an atomic force or scanning tunneling microscope. Here, we apply density functional theory to study the exchange interaction between tip and sample, i.e. across a vacuum gap. In particular, we choose the antiferromagnetic monolayer of Fe on W(001) as the sample system and consider different tips composed of Cr, Fe, and Cr/Fe alloys. We calculate the magnetic exchange energies and forces as a function of tip-sample distance. Our calculations are in good agreement with experiments [1]. We analyze the electronic structure of the tip and sample system and explain the origin and nature of the magnetic exchange interaction in this system [2].

[1] R. Schmidt, C. Lazo, U. Kaiser, A. Schwarz, S. Heinze, and R. Wiesendanger, Phys. Rev. Lett. **106**, 257202 (2011).

[2] C. Lazo and S. Heinze, Phys. Rev. B **84**, 144428 (2011).

O 50.4 Wed 16:45 BH 243

Micromagnetic simulations of the spin spiral state in bi-atomic Fe chains on Ir(001) — •Matthias Menzel[1], Yuriy Mokrousov[2], Robert Wieser[1], Jessica Bickel[1], Elena Vedmedenko[1], Stefan Blügel[2], Stefan Heinze[3], Kirsten von Bergmann[1], André Kubetzka[1], and Roland Wiesendanger[1] — [1]Institut für Angewandte Physik, Universität Hamburg — [2]Institut für Festkörperforschung, Forschungszentrum Jülich — [3]Institut für Theoretische Physik und Astrophysik, Universität Kiel

Recent spin-polarized scanning tunneling microscopy (SP-STM) measurements in combination with *ab initio* calculations reveal a 120° spin spiral ground state in bi-atomic Fe chains on (5×1)-Ir(001) [1]. Monte-Carlo simulations have shown that thermally induced switching of this magnetic state leads to a time-averaged signal in the SP-STM measurements.

We performed time-resolved and temperature dependent simulations using the Object Oriented MicroMagnetic Framework (OOMMF) [2] to investigate the thermal fluctuations and the stabilization mechanism. Due to their reduced coordination the chain's end atoms are more susceptible to an external magnetic field and the magnetocrystalline anisotropy and play a crucial role for the observability of the spin spiral. The three atom periodicity of the spin spiral leads to three symmetry classes for chains of different lengths, and we show how this affects the stability of the spin spiral.

[1] M. Menzel *et al.*, submitted.
[2] `http://math.nist.gov/oommf/`

15 min. break

O 50.5 Wed 17:15 BH 243

Dzyaloshinskii-Moriya driven spin spiral in Mn chains on Pt(664) — •Benedikt Schweflinghaus[1], Bernd Zimmermann[1], Marcus Heide[2], Gustav Bihlmayer[1], and Stefan Blügel[1] — [1]Peter Grünberg Institut (PGI-1) & Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Precision Science and Technology, Osaka University, Suita, Osaka 565-0871, Japan

Ferromagnetic Co chains decorating the step edges of Pt(997) are historically the prime example of a one-dimensional metallic magnet [1]. We investigate this system in the light of the recently discovered Dzyaloshinskii-Moriya interaction (DMI) for ultrathin films [2], which can induce spiral magnetic structures of unique rotational sense. Besides Co, the research was extended to Fe and Mn chains.

In this contribution we investigate these structures applying density functional theory (DFT) by means of the full-potential linearized augmented plane-wave (FLAPW) method as implemented in the FLEUR code [3]. Using a micromagnetic model that includes the spin stiffness, magnetic anisotropy energy (MAE) and the DMI, we study possible magnetic phases such as homogeneous and inhomogeneous spin spirals. While the DMI induces for Mn chains a large-period spiral magnetic state superimposed on an antiferromagnetic order, the MAE prevents such a noncollinear structure for Co and Fe chains, respectively.

[1] P. Gambardella et al., Nature 416, 301 (2002)
[2] M. Bode et al., Nature 447, 190 (2007)
[3] http://www.flapw.de

O 50.6 Wed 17:30 BH 243

Competing interactions and chiral magnetism in $Mn_1/X(111)$, X = Pd, Pt, Ag and Au — •Manuel dos Santos Dias[1,3], Julie Staunton[1], Andras Deak[2], and Laszlo Szunyogh[2] — [1]Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom — [2]Department of Theoretical Physics, Budapest University of Technology and Economics, H-1111 Budapest, Hungary — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich, D-52425 Jülich, Germany

The magnetism of Mn monolayers on X(111), with X = Pd, Pt, Ag and Au, is analysed, using our Relativistic Disordered Local Moment Theory, based on DFT and the KKR Green function method [1]. The substrates control the antiferromagnetism, favouring either a collinear row–by–row state or a triangular Néel state. The latter is shown to possess a well–defined chirality pattern, originating from the Dzyaloshinksy–Moriya interactions. The anisotropic interactions are

governed not only by the atomic number of the substrate but also by the extent of its hybridisation with the magnetic monolayer. Comparison with the experimental results for $Mn_1/Ag(111)$ [2] is also given.

We acknowledge funding from Portugal (SFRH/BD/35738/2007) and Hungary (contract OTKA K77771 and project TAMOP-4.2.1/B-09/1/KMR-2010-0002).

[1] M. dos Santos Dias, J. B. Staunton, A. Deak and L. Szunyogh, Phys. Rev. B **83**, 054435 (2011)
[2] C. L. Gao, W. Wulfhekel and J. Kirschner, Phys. Rev. Lett. **101**, 267205 (2008)

O 50.7 Wed 17:45 BH 243

Tunneling anisotropic magnetoresistance on the atomic scale — •Kirsten von Bergmann[1], Matthias Menzel[1], David Serrate[1], Yasuo Yoshida[1], André Kubetzka[1], Roland Wiesendanger[1], and Stefan Heinze[2] — [1]Institute of Applied Physics, University of Hamburg, Germany — [2]Institute of Theoretical Physics and Astrophysics, University of Kiel, Germany

In non-collinear magnetic structures such as spin spirals, which have recently been found to occur at surfaces due to the Dzyaloshinskii-Moriya interaction [1,2], the spin quantization axis changes from atom to atom. In such a magnetic state the electronic structure of adjacent atoms is not equivalent due to spin-orbit coupling. We demonstrate that this effect leads to a tunneling anisotropic magnetoresistance on the atomic scale which can be detected using scanning tunneling microscopy (STM). This allows to image non-collinear magnetic structures at surfaces by STM with non-magnetic tips. We apply a simple model to relate the changes of the local density of states at the atoms with the tunnel current [3]. Thereby, we can explain the experimentally observed STM and spin-polarized STM images for spin-spirals observed for Mn/W [1,2] and for the atomic-scale magnetic skyrmion lattice found for Fe/Ir(111) [4].

[1] M. Bode et al., Nature 447, 190 (2007).
[2] P. Ferriani et al., Phys. Rev. Lett. 101, 27201 (2008).
[3] S. Heinze, Appl. Phys. A 85, 407 (2006).
[4] S. Heinze et al., Nature Phys. 7, 713 (2011).

O 50.8 Wed 18:00 BH 243

The spin structure of Mn on Co/Cu(001) studied by spin-polarized STM with bulk Cr tips and bulk Fe ring probes — •Chii-Bin Wu, Jiaming Song, and Wolfgang Kuch — Arnimallee 14, 14195 Berlin

Spin-polarized scanning tunneling microscopy with bulk Cr tips and bulk Fe ring probes was used to study the antiferromagnetic (AFM) domains of Mn on Co/Cu(001) at room temperature. Layerwise spin contrast was observed, as well as spin frustration along the overgrown steps of the underlying Co film. Besides, comparison of shape and size of additional small scattered areas with opposite spin contrast on flat terraces to islands at the surface of the Co layer indicates the importance of interface roughness on the spin structure of AFM layers in exchange bias systems.

O 50.9 Wed 18:15 BH 243

Exchange interactions in Fe clusters on Rh(111) and Ru(0001) from first principles — •Fabian Otte, Paolo Ferriani, and Stefan Heinze — Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstr. 15, 24098 Kiel, Germany

In the last few years it has been found that a non magnetic substrate can dramatically affect the magnetic properties of an adsorbed magnetic monolayer. For example, the nearest neighbor exchange of a Fe monolayer, which is the prototypical ferromagnetic material, becomes antiferromagnetic on W(001) [1] and Ru(0001) [2], while complex non-collinear magnetic order has been observed on Fe/Ir(111) [3].

Motivated by XMCD experiments [4] that found a surprisingly small dichroism in Fe clusters on Rh(111) and Ru(0001), we studied the magnetic properties of these systems by means of density functional theory calculations, using the projector augmented planewave method as implemented in the VASP-code. We considered collinear magnetic states and cluster sizes up to five atoms with different geometries and mapped total energy calculations onto an effective Heisenberg model. We found a complex trend of the magnetic exchange interaction which alternate between ferro- and antiferromagnetic depending on cluster size, geometry and interatomic distance.

[1] P. Ferriani *et al.*, Phys. Rev. Lett. **94**, 087204 (2005). [2] B. Hardrat *et al.*, Phys. Rev. B, **79**, 094411 (2009). [3] S. Heinze *et al.*, Nature Physics **7**, 524-526 (2011). [4] V. Sessi, S. Krotzky, M. Wasnioska, C. Tieg, J. Honolka and K. Kern, private communication

O 50.10 Wed 18:30 BH 243

SP-STM study of individual Co atoms on Pd/Co/Ir(111) — •Liudmila Dzemiantsova, André Kubetzka, Kirsten von Bergmann, and Roland Wiesendanger — Institut für Angewandte Physik, Universität Hamburg, Germany

Magnetic atoms adsorbed on nonmagnetic surfaces have become an active research topic in the last few years due to their importance in the fundamental understanding of magnetism and practical applications for spin-based computing schemes. In particular, the knowledge about the magnetic interactions on the atomic scale is crucial for the tailoring of magnetic devices in reduced dimensions and the tuning of their properties [1].

In this study we designed a system consisting of two atomic-scale magnets decoupled by a metallic layer. Magnetic monolayer Co islands on Ir(111) covered with a single atomic Pd layer were used as a substrate and a decoupling spacer, respectively. Individual Co atoms were deposited on the Pd surface and studied by spin-polarized STM (SP-STM). We observe that Pd grows in two stackings on Co/Ir(111) and gets spin-polarized by the underlying magnetic Co layer. We show that the spin polarization of the Co adatoms at the Fermi level is reversed with respect to Pd. This suggests that the spin moments of Co adatom and Co film are antiferromagnetically coupled [2] or the inversion is unique for single adsorbates on atomically flat surfaces [3].

[1] A. A. Khajetoorians et al., Science, 332, 1062 (2011).
[2] Y. Yayon et al., Phys. Rev. Lett., 99, 067202 (2007).
[3] L. Zhou et al., Phys. Rev. B, 82, 012409 (2010).

O 50.11 Wed 18:45 BH 243

How the local environment affects the magnetic anisotropy and Kondo Screening of a high-spin atom — •Jenny C. Oberg[1,2], Reyes M. Calvo[1], and Cyrus F. Hirjibehedin[1,2,3] — [1]London Centre for Nanotechnology, UCL, UK — [2]Department of Physics and Astronomy, UCL, UK — [3]Department of Chemistry, UCL, UK

We study the magnetic anisotropy and the Kondo screening of the spin of Co atoms on Cu2N using STM-based tunneling spectroscopy. We find that variations of the surface close to the edges of both small (ca 25nm^2) and large (ca 400 nm^2) Cu_2N islands result in changes in both anisotropy and Kondo screening. For small Cu_2N islands, we find that when the Co atoms are placed very close to the edges the Kondo screening weakens while the anisotropy increases in magnitude and changes its symmetry. Surprisingly, on larger Cu_2N islands formed on supersaturated Cu_2N surfaces, we find that a similar behavior occurs as the Co atoms move away from the edge of the islands: at the center of these large islands, Kondo screening is completely suppressed while the anisotropy energy is twice as large as at the edge of the islands. We examine possible causes for these dramatic changes in the Kondo screening and magnetic anisotropy, including a possible interaction with a quantum-confined surface state below the Cu_2N.