MA 28: Surface Magnetism

Time: Thursday 15:15–19:00 Location: H23

MA 28.1 Thu 15:15 H23

Magnetic Exchange Force Microscopy — •Uwe Kaiser, Alexander Schwarz, and Roland Wiesendanger — Institute of Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg

Magnetic Exchange Force Microscopy (MExFM) is a new technique that was proposed to perform magnetic imaging of insulating or conducting surfaces with atomic resolution. It is based on conventional atomic force microscopy, but uses a magnetic tip, which is approached very closely to a magnetic sample in order to detect the magnetic exchange interaction. To prove the magnetic exchange interaction between the magnetic moments of tip and sample, surfaces with an antiferromagnetic arrangement of spins have been proposed as test systems.

Theoretical calculations indicate the feasibility of MExFM and several attempts have been made to perform such an experiment, however, no clear evidence for successful MExFM imaging has been reported so far.

We succeeded performing MExFM on the antiferromagnetic insulator NiO(001), using the dynamic mode with frequency modulation in the non-contact regime. The images show surface atoms with an additional atomic scale modulation originating from the row-wise antiferromagnetic arrangement of the Ni spins. We discuss experimental prerequisites to perform MExFM and present different tests to unambiguously assign the additional modulation to the magnetic exchange force.

MA 28.2 Thu 15:30 H23

Spin-Polarised Scanning Tunneling Spectroscopy as a tool to study magnetic excitations — •Timofey Balashov[1,2], Albert F. Takács[2], Wulf Wulfhekel[1,2], and Jürgen Kirschner[1] — [1]MPI für Mikrostrukturphysik, Weinberg 2, 06108 Halle — [2]Physikalisches Institut, Universität Kalrsuhe (TH), Wolfgang-Gaede Str. 1, 76131 Karlsruhe

Electron scattering processes play an important role in modern spin electronics. In magnetic materials electrons can scatter and create magnons. We used inelastic tunneling spectroscopy (ITS) to laterally resolve magnon excitations.

ITS was performed at 4K in ultra-high vacuum on paramagnetic (Cu) and ferromagnetic (Fe, Co) surfaces. While no inelastic peaks were observed on Cu, ferromagnets exibit inelastic peaks on the d^2I/dU^2 curve in the vicinity of the Fermi energy. We prove that these excitations are of magnetic origin by spin-polarised scanning ITS with ferromagnetic tips. The inelastic peak intensities depend on the relative orientation of tip and sample magnetisations, i.e on the spin of the tunneling electron, indicating that the observed excitations are indeed magnons. We demonstrate that the cross section of magnon creation in these materials is high enough to allow direct observation (≈27% for bulk Fe and ≈2% per monolayer of Co on Cu(111)). Mapping the magnon yield as function of the tip position allows lateral imaging of magnon excitations.

MA 28.3 Thu 15:45 H23

Spin- and angle-resolved inverse photoemission of h-BN/Ni(111) — •Karen Zumbrägel[1], Christian Eibl[1], Kathrin Wulff[1], Matthias Hengsberger[2], and Markus Donath[1] — [1]Physikalisches Institut, Westfälische Wilhelms-Universität, Münster, Germany — [2]Physik-Institut, Universität Zürich, Switzerland

There is great interest in ultrathin insulating films on metal surfaces. One example, which has been already studied in some detail [1, 2], is boron nitride on Ni(111). A monolayer of hexagonal boron nitride (h-BN) is formed in a reaction of borazine $(HBNH)_3$ with the hot Ni(111) surface. The ferromagnetic Ni(111) surface as well as the bulk insulator boron nitride are well-studied systems. We added new information about the unoccupied electronic structure of h-BN/Ni(111) by performing spin- and angle-resolved inverse photoemission experiments. We detected four spectral features: A nickel bulk state at 0.1 eV, two BN-interface-states at 1.7 eV and 2.2 eV and an image-potential surface state at 3.0 eV above the Fermi level. For the interface states, we determined their spin splitting and their energy dispersion $E(k_{||})$ with the corresponding effective mass. Our results are discussed in the context of theoretical and experimental work available in the literature.

[1] W. Auwärter, T.J. Kreutz, T. Greber, J. Osterwalder, Surf. Sci. **429**, 229 (1999) [2] G.B. Grad, P. Blaha, K. Schwarz, W. Auwärter and T. Greber, Phys. Rev. B **68**, 085404 (2003)

MA 28.4 Thu 16:00 H23

YCo_2: Intrinsic magnetic surface of a paramagnetic bulk material — •Yury Dedkov[1], Clemens Laubschat[1], Sergii Khmelevskyi[2], Josef Redinger[2], Peter Mohn[2], and Michael Weinert[3] — [1]Institut für Festkörperphysik, Technische Universität Dresden, 01062 Dresden, Germany — [2]Center for Computational Materials Science, Vienna University of Technology, Vienna, Austria — [3]Departament of Physics, University of Wisconsin-Milwaukee, P. O. Box 413, Milwaukee, Wisconsin 53201, USA

Here we report on results of a spin-resolved photoelectron spectroscopic (SRPES) study of YCo_2 thin films (150Å-thick) grown on a W(110) substrate. The films were prepared by co-deposition of stoichiometric amounts of Y and Co on to a clean W surface followed by thermal annealing leading to (2×2) overstructure with respect to W(110) in the low-energy electron diffraction pattern indicated formation of a structurally ordered $YCo_2(111)$ surface. While no clear spin-asymmetry was observed for bulk sensitive SRPES data taken at $h\nu = 1253.6$eV, the surface sensitive SRPES data obtained at $h\nu = 21.2$eV photon energy revealed a clear spin-asymmetry probing the validity of the recent theoretical prediction [1].

[1] S. Khmelevskyi, P. Mohn, J. Redinger, and M. Weinert, Phys. Rev. Lett. 94, 146403 (2005).

MA 28.5 Thu 16:15 H23

Spin-dependence of Ce $4f$ hybridization in magnetically ordered systems: A spin-resolved photoemission study of Ce/Fe(110) — •Yury Dedkov[1], Mikhail Fonin[2], Yury Kucherenko[3], Serguei Molodtsov[1], Ulrich Rüdiger[2], and Clemens Laubschat[1] — [1]Institut für Festkörperphysik, Technische Universität Dresden, 01062 Dresden, Germany — [2]Fachbereich Physik, Universität Konstanz, 78457 Konstanz, Germany — [3]Institute for Metal Physics, National Academy of Sciences of Ukraine, 03142 Kiev, Ukraine

Spin- and angle-resolved resonant (Ce $4d \rightarrow 4f$) photoemission spectra of a monolayer Ce on Fe(110) reveal spin-dependent changes of the Fermi-level peak intensities. That indicate a spin-dependence of $4f$ hybridization and, thus, of $4f$ occupancy and local moment. The phenomenon is described in the framework of the periodic Anderson model by $4f$ electron hopping into the exchange split Fe $3d$ derived bands that form a spin-gap at the Fermi energy around the G point of the surface Brillouin zone.

MA 28.6 Thu 16:30 H23

Strong Even-Odd Effects in Non-collinear Magnetism of Nanochains — •Samir Lounis, Peter Dederichs, and Stefan Blügel — IFF, Forschungszentrum Jülich, D-52425 Jülich, Germany

Parity of number of adatoms in finite antiferromagnetic nanowires is shown to be crucial in predicting whether the magnetic ground state is non-collinear or collinear. Using the full-potential Korringa-Kohn-Rostoker method for non-collinear magnetism [1, 2, 3] and a Heisenberg model we show that nanochains with an even number of adatoms are always magnetically non-collinear while an odd number of adatoms leads under given conditions to a collinear ferrimagnetic ground state. Very large chains are predicted to be always non-collinear independently from the parity.

[1] S. Lounis, Ph. Mavropoulos, P. H. Dederichs, S. Blügel, Phys. Rev. B **72**, 224437 (2005).
[2] S. Lounis, M. Reif, Ph. Mavropoulos, L. Glaser, P. H. Dederichs, M. Martins, S. Blügel and W. Wurth, submitted to Phys. Rev. Lett., cond-mat/0608048.
[3] S. Lounis, Ph. Mavropoulos, R. Zeller, P. H. Dederichs and S. Blügel, submitted to Phys. Rev. B, cond-mat/0608481.

MA 28.7 Thu 16:45 H23

Low-spin phase in bi-atomic chains grown on vicinal Pt(997) surfaces — •Jan Honolka[1], Klaus Kuhnke[1], Tae-Yon Lee[1], Violetta Sessi[1], Pietro Gambardella[3], Sandra Gardonio[2], Diego

Repetto[1], Axel Enders[1], and Klaus Kern[1] — [1]Max-Planck Institute for Solid State Research, Stuttgart, Germany — [2]Catalan Institute for Research and Advanced Studies, Barcelona, Spain — [3]Instituto di Struttura della Materia, Trieste, Italy

For 3d metal nanostructures on surfaces, magnetic properties such as the magnetic anisotropy and the magnetic exchange interaction are strongly dependent on the symmetry of coordination as well as the hybridization with the substrate atoms. In particular Fe nanostructures on Pt surfaces are of interest due to the strong hybridization of Fe-3d and Pt-5d states leading to large magneto-crystalline anisotropy energies observed for example in FePt L10 bulk structures. In this paper we show the results of extensive X-ray magnetic circular dichroism (XMCD) measurements of in-situ grown Fe stripes, which self-assemble along the steps of Pt(997) surfaces as described elsewhere[1]. We observe a dramatic decrease of the average spin-moment between monoatomic chains and bi-chains by about a factor 4. At the same time the magnetic easy axis rotates from the in-plane to the out-of plane direction. When the stripes become even larger in width the spin-moment recovers gradually and reaches Fe bulk values at coverages of ˜ 0.8ML. The results are discussed in terms of a possible antiferromagnetic coupling of the adjacent chains within the bi-chain structure depending on the interchain distance.

MA 28.8 Thu 17:00 H23

Two-dimensional antiferromagnetism of the Co monolayer on W(001) — •Paolo Ferriani[1], Andre Kubetzka[1], Stefan Heinze[1], Matthias Bode[1], Gustav Bihlmayer[2], Stefan Blügel[2], Kirsten von Bergmann[1], Oswald Pietzsch[1], and Roland Wiesendanger[1] — [1]Institut für Angewandte Physik, Universität Hamburg, Jungiusstr. 11, 20355 Hamburg — [2]Institut für Festkörperforschung, Forschungszentrum Jülich, 52425 Jülich

The technological call for smaller devices boosted nanomagnetism. In surface magnetism, this led to the study of magnetic materials at mono- and submonolayer coverages. In this regime, the effect of the adjacent substrate on the magnetic properties can become crucial. E.g., it has been lately found that one monolayer (ML) Fe, the prototypical ferromagnet (FM), surprisingly exhibits antiferromagnetic (AFM) order on W(001) [1]. An even more complex nanoscale magnetic structure was discovered for the Fe ML on Ir(111) [2]. The question arises whether the magnetic order of other ferromagnetic metals can be changed as well if their ML is grown on strongly hybridizing substrates.

Here we give strong evidence of unexpected AFM order for 1 ML Co/W(001) by a combination of *ab-initio* calculations and scanning tunneling microscopy. The electronic structure close to the Fermi level of 1 ML Co/W(001) prevents a direct imaging of the AFM state, at variance with 1 ML Fe/W(001) [1]. However, the dI/dU spectrum and the dispersion of a surface state extracted by dI/dU maps of standing wave patterns fit the theoretical results for the AFM state, but not for the FM one. [1] A. Kubetzka *et al.*, Phys. Rev. Lett. **94**, 087204 (2005) [2] K. von Bergmann *et al.*, Phys. Rev. Lett. **96**, 167203 (2006).

MA 28.9 Thu 17:15 H23

Non-collinear magnetic order in one monolayer Fe on Ru(0001) — •Björn Hardrat[1], Paolo Ferriani[1], Marjana Ležaić[2], and Stefan Heinze[1] — [1]Institute of Applied Physics and Microstructure Research Centere, University of Hamburg, 20355 Hamburg, Germany — [2]Institut für Festkörperforschung, Forschungszentrum Jülich, 52425 Jülich, Germany

Two-dimensional (2D) antiferromagnetic systems on hexagonal lattices are expected to exhibit non-collinear order due to the inherent topological frustration of exchange interaction. We propose one ML Fe on Ru(0001) as a good candidate for the observation of a non-collinear magnetic structure in a 2D system. Experimentally, no long range ferromagnetic order was observed down to a temperature of 100K [1]. Surprisingly, density functional theory (DFT) calculations based on the local density approximation found a row-wise antiferromagnetic ground state [2]. We have performed calculations of the Fe ML on Ru(0001) in the generalized gradient approximation of the DFT, using the full-potential linearized augmented plane wave method, as implemented in the FLEUR code (www.flapw.de). We have explicitly taken non-collinear states such as spin-spirals into account. Among all solutions of the Heisenberg model, we obtain the Néel state with an angle of 120° between magnetic moments of adjacent atoms as the magnetic ground state. We have further determined the Heisenberg exchange constants and considered the effect of higer order spin interactions such as the biquadratic and four-spin interaction.

[1] Liu *et al.* PRB **41** 553 (1990) [2] Wu *et al.* PRB **44** 4449 (1991)

MA 28.10 Thu 17:30 H23

Growth and Magnetism of Fe on vicinal Au(111) — •Tobias Allmers and Markus Donath — Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster

We investigated the growth and the magnetism of Fe on the Au(11 12 12) surface, which is vicinal to Au(111), by scanning tunnelling microscopy, spin- and angle-resolved photoemission and magneto-optical Kerr effect (MOKE). We observe the same growth behavior as on Au(788) in the range between 0.02 and 0.3 monolayers (ML) which has been investigated by Shiraki *et al.* [1]. The terraces are wider on Au(11 12 12) then on Au(788) but the reconstruction pattern is the same [2]. For higher coverage, the film topography shows similarities to Fe films grown on a vicinal Cu(111) surface [3]. In our MOKE investigations performed at 160 K we found that the paramagnetic limit of Fe on vicinal Au(111) is reached for a film thickness below 2 ML. We deduced the inelastic mean free path (IMFP) for Fe by photoemission. Our result is in agreement with other measurements for Fe on different substrates but disagrees with measurements on Au(788) [4]. In addition, we studied the magnetic $3d$ bands of Fe.

[1] S. Shiraki *et al.*, Appl. Surf. Science **237**, 284 (2004)
[2] S. Rousset *et al.*, J. Phys. Condens. Matter **15**, S3363 (2003).
[3] J. Shen *et al.*, Phys. Rev. **B 56**, 11134 (1997)
[4] H. Fujisawa *et al.*, Surf. Interface Anal. **37**, 124 (2005)

MA 28.11 Thu 17:45 H23

Large wave vector spin wave and dispersion in 2 monolayers Fe on W(110) by spin polarized electron energy loss spectroscopy — •Wen Xin Tang, Yu Zhang, Ioan Tudosa, Jacek Prokop, and Jürgen Kirschner — Max-Planck-Institut für Mikrostrukturphysik

Spin polarized electron energy loss spectroscopy (SPEELS) is a unique technique to probe the surface large wave vector spin waves [1]. Recently the spin wave dispersion of 8 monolayer (ML) fcc Co/Cu(001) and 8 ML hcp Co/W(110) were observed[2,3]. In this report, We present SPEEL-spectra of surface spin wave in 2 monolayers Fe deposited on W(110) at room temperature. The pronounced features of large wave vector spin wave peaks are detected. For the first time the full spin wave dispersion of an Fe film is obtained up to the surface Brillioun Zone boundary along the Fe[001] direction. The measurements are compared and discussed with the theoretical results known from the literature. The broadening of the widths of the spin waves peak is attributed to the Stoner damping.

[1] M. Plihal,D. L. Mills, and J. Kirschner, Phys. Rev. Lett. 82, 2579 (1999).
[2] R. Vollmer, M. Etzkorn,P.S. Kumar, H. Ibach, and J. Kirschner, Phys. Rev. Lett. 91, 147201 (2003).
[3] M. Etzkorn, P.S. Kumar, W. X. Tang, Y. Zhang and J. Kirschner, Phys. Rev. B 72, 184420 (2005).

MA 28.12 Thu 18:00 H23

First-principles calculations of domain-wall orientations: Double-layer Fe on W(110) — •Marcus Heide, Gustav Bihlmayer, and Stefan Blügel — IFF, Forschungszentrum Jülich, Germany

A double layer of Fe atoms deposited on the W(110) surface exhibits ferromagnetic domains. These domains form long stripes that are predominantly aligned along a certain crystallographic direction. The mesoscopic shape (step edges, etc.) of the sample hardly influences the domain pattern [e.g. 1,2]. In order to understand this anisotropic behavior in more detail, we compare the energies of differently oriented domain walls with the aid of ab initio calculations. These calculations show, that the preferred wall orientation cannot be ascribed to the anisotropy of the spin stiffness. Instead, we identify the Dzyaloshinskii-Moriya interaction as the reason for the observed wall orientation. This interaction appears in structures without inversion symmetry, e.g. on surfaces. Thus, it is of particular importance in ultrathin surface films like in the studied system. This work is supported by DFG, grant BI 823/1-1.

[1] Bode et al., Phys. Rev. Lett. 89, 237205 (2002)
[2] Vedmedenko et al., Phys. Rev. Lett. 92, 077207 (2004)

MA 28.13 Thu 18:15 H23

Magnetic ordering and switching of iron porphyrin molecules mediated by ferromagnetic films — •H. Wende[1,2], M. Bernien[2],

J. Luo[2], C. Sorg[2], N. Ponpandian[2], J. Kurde[2], J. Miguel[2], M. Piantek[2], X. Xu[2], Ph. Eckhold[2], W. Kuch[2], K. Baberschke[2], P.M. Panchmatia[3], B. Sanyal[3], P.M. Oppeneer[3], and O. Eriksson[3] — [1]Angewandte Physik, Fachbereich Physik, Universität Duisburg-Essen, Lotharstr. 1, D-47048 Duisburg, Germany — [2]Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany — [3]Department of Physics, Uppsala University, Box 530, S-751 21 Uppsala, Sweden

We studied the structural and magnetic ordering of paramagnetic Fe-based porphyrin molecules on Ni and Co films on Cu(100) by means of X-ray absorption spectroscopy. Angle-dependent NEXAFS spectra at the C and N K-edges reveal that for a coverage of 1 ML the porphyrin molecules lie flat on the surface. With XMCD measurements at the Fe, Co and Ni $L_{2,3}$ edges we show that the Fe magnetic moment is always aligned parallel to the magnetization of the ferromagnetic layers. This allows to switch the Fe magnetic moment in all four cartesian directions relative to the molecular plane. The experimental results are combined with density functional theory to analyze the nature of the magnetic coupling. Thereby we show that the coupling is not due to a trivial direct exchange between the Fe atom and the Ni or Co films. The dominant mechanism is a 90 degree indirect exchange via the N-ligands yielding a magnetic polarization of the Fe. Supported by BMBF (05 KS4 KEB 5) and DFG (Sfb 658, Heisenberg-Programm).

MA 28.14 Thu 18:30 H23

Exchange-split surface state on Gd(0001) revisited — •Michael Budke, Juliet Correa, and Markus Donath — Physikalisches Institut, Wilhelm-Klemm-Str. 10, 48149 Münster

The behavior of the spin-split surface state on Gd(0001) close to the Curie temperature T_C has been controversially discussed: spin-resolved inverse photoemission (SR-IPE) has identified an empty minority state and a partially empty majority state [1]. While the majority state shifts to higher energies upon approaching T_C the minority state shifts to lower energies and seems to become partially occupied. This Stoner-like behavior is in contradiction to early results from spin-resolved photoemission (SR-PE), where the surface state shows up at 0.2 eV binding energy, exhibiting spin-mixing behavior upon approaching T_C [2]. In the last years a mixture of these two behaviors is becoming more and more accepted [3]. However, SR-PE does not see a peak crossing the Fermi energy E_F as seen before in IPE. To solve this discrepancy we performed SR-PE and -IPE measurements on a 30 ML Gd film grown on Y(0001). To exclude preparation-dependent effects, the measurements were performed in the same chamber on the same sample preparation. While the spectral features in PE do not strongly depend on the film preparation, the IPE spectral features show a significant dependence on the film quality. We present temperature-dependent measurements of a well-defined film to contribute to the understanding of the magnetism of the Gd(0001) surface. [1] Donath *et al.* Phys. Rev Lett. **77**, 5138 (1996) [2] Li *et al.* Phys. Rev. B **51**, 13895 (1995) [3] Fedorov *et al.* Phys. Rev. B **65**, 212409

MA 28.15 Thu 18:45 H23

Intrinsically nonmagnetic surface on a magnetic bulk: Sm(0001) vs. Eu/Gd(0001) — •Daniel Wegner and Günter Kaindl — Freie Universität Berlin, Institut für Experimentalphysik, Arnimallee 14, 14195 Berlin

Samarium is a lanthanide metal with unusual electronic structure: While the bulk is trivalent with five electrons in the 4f shell, the (0001) surface is known to be divalent (six 4f-electrons). According to Hund's rule, spin and orbital moment cancel each other. This opens the possibility of a nonmagnetic surface layer, whereas the trivalent bulk is antiferromagnetic. We performed cryogenic scanning tunneling microscopy and spectroscopy on a thin Sm(0001) film grown on a W(110) single crystal. STM reproduces the well known hexagonal surface reconstruction. STS reveals a so far unknown unoccupied surface state that is not exchange-split. We interpret this as evidence that the surface layer is nonmagnetic. We compare the results with the electronically similar monolayer Eu/Gd(0001) that is known to couple ferromagnetically to the Gd substrate. Also the divalent Eu monolayer exhibits an unoccupied surface state. However, this state is clearly exchange-split due to the ferromagnetic ordering of the surface layer with non-vanishing magnetic moment.