MA 31: Surface Magnetism / Magnetic Imaging II

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

MA 31.1 Thu 15:15 H23

Theory of chirality selection in magnetic nanostructures: vortex states in magnetic nanodots — •Anna B. Butenko, Ulrich K. Rössler, and Alexei N. Bogdanov — IFW Dresden

Broken inversion symmetry at surfaces or interfaces of magnetic nanostructures induces Dzyaloshinskii-Moriya (DM) couplings. These chiral exchange couplings can essentially change the magnetic properties of nanostructures by stabilizing twisted magnetic states. In particular these DM couplings favour one sense of rotation in non-collinear magnetic configurations. Vortex states in magnetic thin film elements are chiral themselves, but they arise solely due to the demagnetization. In such magnetization structures, the effect of the chiral DM couplings is less obvious, but the degeneracy of the left- and right-handed vortices is lifted. Within a basic micromagnetic approach we analyse this chirality selection for the vortex ground states of circular thin-film elements. We calculate the differences between the core shapes and sizes of vortices with opposite handedness in the presence of DM couplings. These differences of the core structure may be observable in experiments, e.g., as differences in core diameter or net polarity of vortices, when switching their chirality. We suggest that such experiments can be used to determine the magnitude of surface-induced DM couplings in ultrathin magnetic films/film elements.

MA 31.2 Thu 15:30 H23

Non-collinear groundstate in the Fe monolayer on Ir(111) — •Matthias Menzel[1], Stefan Heinze[2], Kirsten von Bergmann[1], Gustav Bihlmayer[3], André Kubetzka[1], Stefan Blügel[3], and Roland Wiesendanger[1] — [1]Institut für Angewandte Physik, Universität Hamburg, 20355 Hamburg — [2]Institut für Theoretische Physik und Astrophysik, Universität Kiel, 24098 Kiel — [3]Institut für Festkörperforschung, Forschungszentrum Jülich, 52425 Jülich

Various complex magnetic groundstates have been observed recently [1,2,3], which depend crucially on the interplay of different magnetic interactions like exchange interaction, magnetocrystalline anisotropy or Dzyaloshinskii-Moriya (DM) interaction. Some uniaxial spin-spirals have been found [1,2] but a two dimensional non-collinear lattice has not been observed yet.

Using spin-polarized scanning tunneling microscopy we revisited the Fe monolayer on Ir(111). With an out-of-plane magnetized tip this system exhibits a quadratic magnetic unit cell on the hexagonal atomic lattice [3]. Recent measurements with an in-plane magnetized tip reveal that this magnetic configuration is indeed a two dimensional non-collinear groundstate. The driving force for the formation of this complex groundstate has been identified by density functional theory calculations as the 4-spin interaction, a higher order magnetic interaction.

[1] M. Bode *et al.*, Nature **447**, 190 (2007)
[2] P. Ferriani *et al.*, Phys. Rev. Lett. **101**, 027201 (2008)
[3] K. von Bergmann *et al.*, Phys. Rev. Lett. **96**, 167203 (2006)

MA 31.3 Thu 15:45 H23

Magnetic order in the ultrathin iron film on the Ir(001) surface — •Frantisek Maca[1], Josef Kudrnovsky[1], Vaclav Drchal[1], Ilja Turek[2], and Josef Redinger[3] — [1]Institute of Physics ASCR, Praha — [2]Institute of Physics of Materials ASCR, Brno — [3]Vienna University of Technology, Vienna

We present detailed ab initio study of structural and magnetic stability of a Fe monolayer on the fcc(001) surface of iridium extending our last investigation [1]. The Fe monolayer has a strong tendency to order antiferromagnetically for the true relaxed geometry. We compare the influence of two adsorbate species on the magnetic ground state - H and O. We found that the adsorption of oxygen (contrary to the H) lowers the stability of antiferromagnetic order and prefers ferromagnetic ground state. The ferromagnetism is stabilized by the increased Fe-Ir layer spacing. The present study centers around the evaluation of pair exchange interactions between Fe atoms in the Fe overlayer as a function of adsorbate coverage which allows for a detailed understanding of the antiferromagnetism of a Fe/Ir(001) overlayer. Our calculations indicate that the nature of the true ground state could be more complex and display a spin spiral like rather than a c(2x2)-antiferromagnetic order. A comparison with recent experimental data [2] will be also given.

[1] J. Kudrnovsky, F. Maca, I. Turek, and J. Redinger, Phys. Rev. B 80, 064405 (2009).
[2] V. Martin at al., Phys. Rev. B 76, 205418 (2007).

MA 31.4 Thu 16:00 H23

Non-collinear magnetism in the Mn double layer on W(110) — •Silke Schröder, Paolo Ferriani, and Stefan Heinze — Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstr. 15, 24098 Kiel, Germany

The discovery of a homochiral spin-spiral state for a monolayer (ML) Mn on W(110) [1] has dramatically demonstrated that magnetism in ultrathin films can be extremely complex. Heisenberg exchange, magnetic anisotropy and Dzyaloshinskii-Moriya interaction compete and span a vast magnetic phase space that is still largely unexplored. Recently the double layer (DL) of Mn on W(110) has been studied by spin-polarized scanning tunneling microscopy [2] and a spin-spiral propagating along the [001] direction has been found. Surprisingly, the finding of a short period hints at a ferromagnetic exchange interaction in the Mn DL, on the contrary to what was found in the Mn ML.

To shed light onto this issue, we studied the magnetic properties of the Mn DL on W(110) by means of density functional theory calculation, using the full-potential linearized augmented plane wave (FLAPW) method. We considered several possible magnetic configurations that revealed an antiferromagnetic nearest neighbour exchange and performed spin-spiral calculations to explore the magnetic phase space. We found a non-collinear magnetic ground state. By including spin-orbit coupling we investigated the influence of the magnetic anisotropy and the Dzyaloshinskii-Moriya interaction.

[1] M. Bode *et al.*, Nature **447**, 190 (2007)
[2] Y. Yoshida *et al.*, in preparation

MA 31.5 Thu 16:15 H23

Unoccupied quantum-well states in Co/Cu(001): Spin-orbit coupling and magnetic linear dichroism — Cheng-Tien Chiang, Aimo Winkelmann, Ping Yu, Jürgen Kirschner, and •Jürgen Henk — Max Planck Institute of Microstructure Physics, Halle, Germany

A prerequisite for magnetic linear dichroism (MLD) is the hybridization of electronic states due to spin-orbit coupling (SOC). The sp_z quantum well states in thin Co films on Cu(001) are marginally affected by SOC but nevertheless exhibit a sizable MLD in two-photon photoemission (2PPE) [1], thereby questioning the established origin of MLD.

To resolve this conflict, we performed extensive 2PPE experiments which are completed by electronic-structure, photoemission, and analytical calculations. Having obtained this way a detailed characterization of the quantum well states, the MLD is fully explained; it turns out that a key issue is the proper choice of light polarization. Other sources of the MLD, e. g., the occupied Co states, are ruled out.

Our joint investigation establishes that MLD in 2PPE is a valuable tool for probing SOC in unoccupied electronic states.

[1] C.-T. Chiang, A. Winkelmann, P. Yu, and J. Kirschner, Phys. Rev. Lett. **103**, 077601 (2009).

MA 31.6 Thu 16:30 H23

Spin-polarized two-photon photoemission from Co/Cu(001) via unoccupied quantum well states — •Cheng-Tien Chiang, Aimo Winkelmann, and Jürgen Kirschner — Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, Halle(Saale), Germany

We measured spin-resolved two-photon photoemission (2PPE) from ultrathin cobalt films grown on Cu(001). By using p-polarized light with 3.1 eV photon energy, we observed a dominant majority spin-polarization in 2PPE, extending from the initial states at 1.4 eV below the Fermi level up to the Fermi level. Moreover, we resolved an enhancement of spin-polarization by about 10% in 2PPE through the majority quantum well state in a 6 ML cobalt film. This is confirmed by a cobalt thickness dependent measurement. Comparison between spin-resolved one- and two-photon photoemission conveys the important role of the intermediate states in spin-dependent nonlinear photoemission.

MA 31.7 Thu 16:45 H23

Influence of Co-Cu alloying on spin-dependent surface states — •Tobias Allmers[1], Markus Donath[1], Jürgen Braun[2], Jan Minár[2], and Hubert Ebert[2] — [1]Physikalisches Institut, University of Münster, Germany — [2]Dep. Chemie und Biochemie, LMU Universität München, Germany

In literature it is reported that Co films grown on Cu(001) held at 300 K can be annealed to ≈ 500 K without Co diffusion towards the surface [1]. As will be shown in this contribution, Cu diffusion takes place even at 295 K. This can be avoided when the film is grown at 115 K. In this case the surface can be annealed to 555 K without Cu diffusion. For annealing temperatures above 555 K an alloying between Co and Cu takes place. Due to the low miscibility of Co and Cu the alloy consists of different phases, mainly Co- and Cu-rich areas. The alloying has a significant influence on the surface states. It results in a suppression of the occupied minority surface state around $\bar{\Gamma}$ [2]. This indicates that the symmetry cap closes for the Co-Cu alloy due to the non-magnetic Cu. In contrast, the projected bulk band structures for Co(001) and Cu(001) are very similar to each other including the gap position. Consequently, the unoccupied surface state $\bar{\mathrm{X}}$ persists for the Co-Cu alloy. The spin splitting is reduced with increasing Cu content. The same is true for the exchange splitting of the image potential state. Our results show impressively how important a careful thin film preparation is for the study of pure Co films. [1] Schneider *et al.*, in Magnetism and Structure in Systems of Reduced Dimension, p. 453 (Plenum Press, 1993). [2] Schmidt *et al.*, J. Phys. D **41** (2008) 164003.

MA 31.8 Thu 17:00 H23

On the magnetic anisotropy of free-standing and deposited Fe_xCo_{1-x} monolayers — •Sven Bornemann[1], Ondřej Šipr[2], Jan Minár[1], Sergey Mankovsky[1], Julie B. Staunton[3], and Hubert Ebert[1] — [1]Department Chemie und Biochemie, LMU München, Germany — [2]Institute of Physics of the ASCR v. v. i., Prague, Czech Republic — [3]Department of Physics, University of Warwick, United Kingdom

An accurate theoretical determination of the magnetic anisotropy energy (MAE) is still today a very challenging task for current ab-initio theories. The results can be highly dependend on the applied computational scheme as well as on various approximations and calculational parameters. As the magnetic anisotropies are so sensitive to these factors special care has to be taken when comparing new numerical results with values from the literature. Here, we present MAE results for free-standing and deposited Fe_xCo_{1-x} monolayers and analyse in detail the occuring trends with corresponding changes in the electronic band structure. Our findings are compared with results of Moulas et al. and the various conjectures of Wang et al., Daalderop et al. as well as Kondorskii and Straube. Furthermore, a decomposition of the spin-orbit coupling (SOC) operator into spin-diagonal and spin-off-diagonal contributions allows for a distinct comparison with the models of Bruno and van der Laan. In line with all these considerations we discuss the most important features that are necessary for obtaining a very large MAE.

MA 31.9 Thu 17:15 H23

Magnetic properties of Fe films on flat and vicinal Au(111): Consequences of the different growth behavior — •Tobias Allmers and Markus Donath — Physikalisches Institut, University of Münster, Germany

The epitaxial growth of Fe on flat Au(111) differs from Fe on vicinal Au(111). One consequence is a higher critical Fe overlayer thickness at which a phase transition from fcc(111) to bcc(110) takes place for Fe on vicinal Au(111) in comparison to flat Au(111) [1]. Accompanied with the structural phase transition is a spin-reorientation transition (SRT) of the easy magnetization direction from out-of-plane to in-plane. In agreement with the impeded phase transition an impeded SRT on vicinal Au(111) was observed. The SRT, however, proceeds in a narrow coverage range while the structural phase transition occurs gradually over a larger thickness range. A further consequence of the different growth behavior is a different topography for thicknesses beyond the phase transition. Fe on flat Au(111) exhibits a six-fold symmetry, Fe on vicinal Au(111) only a two-fold symmetry. The different symmetries influence the magnetic properties: While for bcc Fe(110) on flat Au(111) no easy magnetization direction could be determined, a preferred direction for Fe on vicinal Au(111) was identified which is perpendicular to the step edges. The two-fold symmetry causes an uniaxial magnetic behavior. This knowledge of the magnetization behavior is essential for correctly analyzing spin-resolved measurements of the electronic structure as demonstrated by photoemission measurements. [1] T. Allmers and M. Donath, New J. of Physics **11** (2009) 103049.

15 min. break

MA 31.10 Thu 17:45 H23

Spin-dependent quantum interference within a single Co nanoisland — •Hirofumi Oka, Sebastian Wedekind, Guillemin Rodary, Dirk Sander, Pavel Ignatiev, Larissa Niebergall, Valeri Stepanyuk, and Jürgen Kirschner — Max-Planck-Institute of Microstructure Physics, Weinberg 2, D-06120, Halle, Germany

We present a combined experimental and theoretical study of spin-polarized electron confinement on individual Co nanoislands on Cu(111). Low-temperature SP-STM in magnetic fields is used to identify parallel (P) and anti-parallel (AP) states of the magnetization orientation between a Co island and a magnetic tip.[1,2] We find a pronounced spatial modulation of the differential conductance (dI/dV) within one island, which is ascribed to electron confinement, in both states. Maps of the asymmetry of the dI/dV, $(dI/dV_{AP} - dI/dV_P)/(dI/dV_{AP} + dI/dV_P)$, which is related to the spin-polarization within the Co islands, show strong spatial variations and bias-voltage dependence of the contrast. Comparing the results with theory, we conclude that the modulated spin-polarization and its variation with energy can be described by the relative magnitudes between majority and minority spin states, where the spatial modulation is mainly due to electron confinement of the majority state.

[1] G. Rodary *et al.*, JJAP 47, 9013 (2008). [2] G. Rodary *et al.*, APL 95, 152513 (2009).

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MA 31.11 Thu 18:00 H23

Imaging the in-plane magnetisation of Co microstructures by soft x-ray holography — •Carsten Tieg[1], Robert Frömter[2], Daniel Stickler[2], Sebastian Hankemeier[2], André Kobs[2], Hans Peter Oepen[2], Simone Streit-Nierobisch[3], Christian Gutt[3], and Gerhard Grübel[3] — [1]Helmholtz-Zentrum für Materialien und Energie GmbH, Berlin, Germany — [2]Institut für Angewandte Physik, Universität Hamburg, Hamburg, Germany — [3]Deutsches Elektronen-Synchrotron, Hamburg, Germany

We report how Fourier transform holography (FTH) experiments can be used to image the magnetic state of isolated Co microstructures. Up to now, FTH imaging has been applied solely to magnetic systems with out-of-plane magnetisation, owing to the large magnetic sensitivity in transmission geometry at normal incidence. The angular dependence of the x-ray magnetic circular dichroism (XMCD) does not allow to sense the in-plane magnetization with the standard holography sample design, containing reference holes fabricated perpendicularly to the membrane surface by focussed ion beam milling. Samples with an in-plane magnetisation have to be imaged at off-normal incidence to obtain XMCD, so the transmission of the high-aspect-ratio reference holes is lost. The solution is to mill the reference holes at the same tilt angle that is used for imaging. We have used this scheme to image a $2 \times 2\,\mu m^2$ Co element with 20 nm thickness. We found a multi domain state that differs from the expected Landau state for this element size. We attribute the observed higher-energy domain state to the presence of pinning centers and to imperfections of the shape of the Co element.

MA 31.12 Thu 18:15 H23

Magnetism of Rh nano-structures on inert Xe buffer layers and in contact with Ag(100) surfaces — •J. Honolka[1], V. Sessi[1,2], K. Kuhnke[1], C. Tieg[2], O. Sipr[3], J. Minar[4], H. Ebert[4], and K. Kern[1] — [1]MPI für Festkörperforschung, Stuttgart, Germany — [2]ESRF, Grenoble, France — [3]Academy of Sciences of the Czech Republik, Prague, Czech Republik — [4]LMU München, Germany

Previous x-ray magnetic circular dichroism measurements have shown that submonolayer coverages of Rh directly deposited on Ag(100) at T=5K are not magnetic [1], in contrast to theoretical predictions (see [2] and references therein). We further investigated this discrepancy and studied the magnetism of nano-structures of Rh prepared on inert Xe buffer layers on Ag(100). For Rh nano-structures (monomers, dimers, trimers etc.) situated on the Xe buffer layer we find a cluster size dependet magnetic moment similar to the one measured on free clusters in the Stern-Gerlach experiment [3]. During desorption of the Xe layer the Rh nano-structures grow in size and make contact with the substrate, which leads to a full quenching of the magnetic moment.

The results are discussed modelling the Rh cluster size distribution on Xe and Ag(100) and comparing the spectroscopy results with ab initio theory.

[1] J. Honolka et al., Phys. Rev. B 76, 144412 (2007) [2] V. Bellini, N. Papanikolaou, R. Zeller, and P. H. Dederichs, Phys. Rev. B 64, 094403 (2001) [3] A.J. Cox, J. G. Louderback, and L.A. Bloomfield, Phys. Rev. Lett. 71, 923 (1993)

MA 31.13 Thu 18:30 H23

Wurtzite-type CoO nanocrystals in ultrathin ZnCoO films observed by surface x-ray diffraction — •Meyerheim H. L.[1], Tusche C.[1], Ernst A.[1], Ostanin S.[1], Maznichenko I.[2], Mohseni K.[1], Jedrecy N.[3], Zegenhagen J.[4], Roy J.[4], Mertig I.[2], and Kirschner J.[1] — [1]MPI f. Mikrostrukturphysik, Halle, Germany — [2]Institut f. Physik, Martin-Luther-Univ. Halle-Wittenberg, Halle, Germany — [3]INSP, Université P. et M. Curie-Paris 6 and CNRS-UMR7588, Paris, France — [4]ESRF, B.P. 220, Grenoble, France

We present a surface x-ray diffraction study on 2-5 monolayer thick Co-doped (25 at. %) ZnO-films deposited on Ag(111) by pulsed laser deposition to study the arrangement of the Co-atoms within the ZnO host in the ultrathin film limit [1]. The film structure is dramatically different from a random alloy commonly assumed: Wurtzite (WZ) type CoO nanocrystals are coherently embedded within the ZnO host. In contrast to the WZ-CoO nanoislands, ZnO adopts the hexagonal Boron-Nitride (h-BN) type structure within the first layers next to the Ag(111) surface. In the h-BN structure the metal atoms are surrounded by O-atoms in a planar trigonal coordination, whereas in the WZ-structure the metal atoms are tetrahedrally coordinated. Our study supports the proposed phase separation model to explain the weak ferromagnetic signatures of doped ZnO films and other systems [2]. [1] H. L. Meyerheim, C. Tusche, A. Ernst, S. Ostanin, I.V. Maznichenko, K. Mohseni, N. Jedrecy, J. Zegenhagen, J. Roy, I. Mertig, and J. Kirschner, Phys. Rev. Lett. 102, 156102 (2009); [2] T. Dietl, T. Andrearczyk, A. Lipinska, M. Kiecana, M. Tay, and Y. Wu, Phys. Rev. B 76, 155312 (2007);

MA 31.14 Thu 18:45 H23

Iron filled carbon nanotubes - Novel high resolution high stability probes for quantitative magnetic force microscopy — •Wolny Franziska, Weissker Uhland, Mühl Thomas, Lipert Kamil, Vock Sylvia, Schumann Joachim, Leonhardt Albrecht, and Büchner Bernd — IFW Dresden, Helmholtzstraße 20, 01069 Dresden

Iron filled carbon nanotubes (FeCNT) exhibit various outstanding properties that make them ideal candidates for the application as magnetic force microscopy (MFM) probes [1]. An Fe-CNT contains a single domain single crystalline iron nanowire of 20-30 nm diameter and several microns length. The carbon shell around the ferromagnetic core inhibits its oxidation and makes the Fe-CNT mechanically very stable. This ensures a much longer probe lifetime compared to coated MFM probes. The high aspect ratio leads to MFM images with a high resolution. Furthermore, due to the large shape anisotropy the magnetization direction of the nanowire remains aligned with the nanotube axis and thus perpendicular to the sample surface even in parallel external magnetic fields exceeding 250 mT. For the calibration of these MFM probes, the point probe model can be applied with very good agreement [2]. The long iron nanowire can be regarded as an extended dipole of which only the monopole closest to the sample surface interacts with the sample stray field. Thus, the determination of the probe's monopole moment enables quantitative MFM.

[1] Wolny et al., JAP 104, 064908 (2008)
[2] Lohau et al., JAP 86(6), 3410 (1999)

MA 31.15 Thu 19:00 H23

Measuring GMR of single phthalocyanine molecules — •Detlef Kramczynski[1], Stefan Schmaus[1,2], Annika Bork[1], Yasmine Nahas[1], Toyokazu Yamada[1], and Wulf Wulfhekel[1,2] — [1]Physikalisches Institut, Karlsruher Institut für Technologie, Germany — [2]Center for Functional Nanostructures, Karlsruher Institut für Technologie, Germany

The ongoing downsizing process in electronics and data storage has set the focus of the last years on studying the properties of nanoscale objects, like single molecules and single atoms.
We present the results of our measurements of the spin-dependent conductance of single hydrogen phthalocyanine molecules, obtained with low temperature scanning tunneling microscopy. The molecules were evaporated on different magnetic metal surfaces, that serve as one of the spin-polarized electrodes. The second electrode was a W-tip coated with magnetic material (Co, Fe). Direct contact was established by a controlled approach of the tip towards the surface, until a sidegroup of the molecule flipped up, touching the tip and bridging the tunneling gap. By changing the relative magnetization of tip or substrate, we were able to measure the GMR of a single molecule.