# MA 41: Surface magnetism I

Time: Thursday 9:30–12:45 Location: EB 202

MA 41.1 Thu 9:30 EB 202

**Magnetic properties of the $HoAu_2$ surface alloy** — •Maxim Ilyn[1,2], Maria Blanco-Rey[1,3], Enrique Ortega[1,2,4], and Frederik Schiller[1,2] — [1]Donostia International Physics Center (DIPC) — [2]Materials Physics Center CSIC-UPV/EHU — [3]Department of Materials Physics, University of Basque Country UPV/EHU — [4]Department of Applied Physics, University of Basque Country

Magnetic properties of single atoms of Holmium deposited on the surface of different single crystalline substrates were a topic of active investigations in last few years. Hybridization of the Ho orbitals with electronic states of the substrate and symmetry of the crystal field were shown to be crucial in defining Ho ground state.

In this work we present results of the experimental investigation of the magnetic properties of $HoAu_2$ surface alloy. A crystal field in the position of Ho atoms in this alloy has the same $C_{3v}$ symmetry as in the case of the Ho adsorbed on the hollow sites of (111) surface of the fcc crystal. However, the coordination is higher which results in a well-defined stable stoichiometry.

Samples prepared by deposition of Ho on the pre-heated surface of the Au(111) single crystal in the UHV environment were characterized by means of STM, LEED and ARPES. Its magnetic properties were measured in a synchrotron using XMCD spectroscopy and simulated with a help of the multiplet calculations.

MA 41.2 Thu 9:45 EB 202

**Magnetic linear dichroism of ferromagnetic 3d metal thin films** — •Torsten Veltum[1], Tobias Löffler[1], Stefano Ponzoni[2], Mirko Cinchetti[2], and Mathias Getzlaff[1] — [1]Institut für Angewandte Physik, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf — [2]Experimentelle Physik VI, Fakultät Physik, Technische Universität Dortmund, 44221 Dortmund

Magnetic linear dichroism in the angular distribution of photoelectrons (MLDAD) is a technique that allows the study of both the electronic band structure and the magnetic properties of thin films and single crystals. Because we are interested in a deeper understanding of the magnetic linear dichroism of 3d metals, we study epitaxially grown ferromagnetic 3d metal thin films on a W(110) surface.

In this study linearly polarized synchrotron radiation (Beamline 5, DELTA Dortmund) in the VUV regime is used to gain the experimental data. At the beamline we have access to angle-resolved photoemission spectroscopy and low energy electron diffraction.

The electronic structure of the valence band is measured by variation of the photon energy. At excitation energies above 20 eV, dichroism measurements are reconfirmed for iron and cobalt and extended to angle-resolved spectra in off-normal geometry. For iron and cobalt, the resonance between the 3d core-levels and the valence band of these materials shows an influence on the dichroism, whereas for nickel there is no influence.

MA 41.3 Thu 10:00 EB 202

**Layer-specific magnetic excitations in Fe/Co multilayers** — •Sergey Tsurkan, Huajun Qin, and Khalil Zakeri Lori — Heisenberg Spin-dynamics Group, Physikalisches Institut, Karlsruhe Institute of Technology, Wolfgang-Gaede-Str. 1, D-76131 Karlsruhe, Germany

We investigate the terahertz magnetic excitations in multilayers of Fe- and Co epitaxially grown on W(110). The experiments were performed by means of spin-polarized high-resolution electron energy-loss spectroscopy. Different magnon modes were observed and assigned to the excitations localized in different layers. We discuss the origin of the observed magnon modes based on a simple Heisenberg model. The model indicates that the Heisenberg exchange constants are strongly layer dependent. By probing the dispersion relation of these magnon modes over the surface Brillouin zone we quantify the strength of the exchange interaction in different layers [1]. Finally we address the effect of the Dzyaloshinskii–Moriya interaction on the observed magnon modes. [1] Zakeri, J. Phys. Condens. Matter **29**, 013001 (2017). The work has been supported by the Deutsche Forschungsgemeinschaft (DFG) through the Heisenberg Programme ZA 902/3-1 and the DFG grant ZA 902/4-1.

MA 41.4 Thu 10:15 EB 202

**Theoretical studies of 2D-materials adsorbed onto magnetic surfaces** — •Nicolae Atodiresei, Vasile Caciuc, and Stefan Blügel — Peter Grünberg Institut (PGI-1) and Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich, Germany

Using density functional theory calculations we explored how the interaction between magnetic surfaces with 2D materials as graphene (Gr) and transition metal dichalcogenites (TMDs) monolayers reciprocally modifies their electronic and magnetic properties. On one hand, the 2D material–substrate chemisorption induces a spin–unbalanced electronic structure of the 2D material with specific system dependent features. On the other hand, the strong hybridization at the hybrid interface leads to an increase of the magnetic exchange interactions between the surface magnetic atoms as compared to those of the clean substrate. Similarly to the case of organic molecules adsorbed on magnetic surfaces, the presence of the magnetic hardening effect at the 2D material–substrate interface emphases the generality of this adsorbate induced–effect on magnetic surfaces.

This work is supported by DFG through SFB 1238 (Project C01).

[1] M. Callsen *et al.*, Phys. Rev. Lett. **111**, 106805 (2013).
[2] R. Decker *et al.*, J. of Phys.: Cond. Matter. **26**, 394004 (2014).
[3] R. Brede *et al.*, Nature Nanotech. **9**, 1018 (2014).
[4] F. Huttmann *et al.*, Phys. Rev. Lett. **115**, 236101 (2015).
[5] F. Huttmann *et al.*, Phys. Rev. B **95**, 075427 (2017).

MA 41.5 Thu 10:30 EB 202

**Excited spin-state trapping in spin crossover complexes on ferroelectric substrates** — Christian Wäckerlin[1,2], Fabio Donati[3,4], Aparajita Singha[1], Romana Baltic[1], Silvio Decurtins[5], Shi-Xia Liu[5], Stefano Rusponi[1], and •Jan Dreiser[1,6] — [1]Ecole Polytechnique Federale de Lausanne, 1015 Lausanne, Switzerland — [2]Swiss Federal Laboratories for Materials Science and Technology, 8600 Dübendorf, Switzerland — [3]Institute for Basic Science, Seoul 03760, Republic of Korea — [4]Ewha Womans University, Seoul, Republic of Korea — [5]University of Bern, 3012 Bern, Switzerland — [6]Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

Spin crossover molecules exhibit a switchable spin state. Combining them with inorganic ferroelectrics represents a promising path toward magnetoelectric devices. Here we report on a study of films of Fe(II) spin crossover molecules deposited on differently poled ferroelectric PMN-PT ($[Pb(Mg_{1/3}Nb_{2/3})O_3]_{1-x}$ $[PbTiO_3]_x$, $x = 0.32$). X-ray absorption spectroscopy shows complete temperature driven conversion between high-spin and low-spin states independent of the substrate ferroelectric polarization down to 100 K. However, at $T = 3$ K, in the regime of soft X-ray induced excited spin-state trapping (SOXIESST), the cross section for the SOXIESST process varies by more than one order of magnitude between the two ferroelectric polarizations. We explain our findings by the internal electric fields of the substrates modulating the scattering of X-ray generated secondary electrons at the molecules.

MA 41.6 Thu 10:45 EB 202

**Step Edge Induced Anisotropic Chiral Spin Coupling Observed in Ultrathin Magnetic Films** — •Stefan Krause, Anika Schlenhoff, and Roland Wiesendanger — Department of Physics, University of Hamburg, Germany

Breaking the symmetry at planar interfaces and surfaces results in a chiral spin coupling due to Dzyaloshinskii-Moriya interactions (DMI), driven by spin-orbit coupling. DMI stabilize an inhomogeneous right-rotating cycloidal spin spiral ground state in the Fe double layer (DL) on W(110), as has been demonstrated by means of spin-polarized scanning tunneling microscopy (SP-STM) [1]. In contrast, the Fe monolayer (ML) on W(110) is found to be ferromagnetic [2].

An atomic step edge separating DL and ML areas of coverage results in a breaking of the lateral symmetry of the film, potentially giving rise to localized additional DMI. In our SP-STM experiments we investigate the spin configurations around Fe/W(110) ML/DL step edges. The data give clear indications for a chiral spin coupling of the DL to the ML. Depending on the step edge orientation, the DL spin texture is locally affected by a deformation of the spin spiral and selection rules for the formation of 90° domain walls. Interestingly, an inversion of the spin coupling chirality is found for step edges oriented along the [001] and close-packed crystallographic directions, respectively. The

SP-STM data will be presented and discussed in terms of anisotropic chiral spin coupling of the DL to the ML.
[1] S. Meckler *et al.*, Phys. Rev. Lett. **103**, 157201 (2001).
[2] M. Pratzer *et al.*, Phys. Rev. Lett. **87**, 127201 (2001).

**15 minutes break**

MA 41.7 Thu 11:15 EB 202

**Hot electrons interacting with non-collinear surface spins** — •Anika Schlenhoff, Stefan Krause, and Roland Wiesendanger — Department of Physics, University of Hamburg (Germany)

Understanding the interactions of hot electrons with localized spins is an important prerequisite for the development of spintronic applications. An ideal model system to investigate these interactions are image-potential states (IPS) forming a Rydberg-like series of unoccupied exchange-split states in front of a magnetic surface. While IPS on ferromagnetic systems have been investigated [1,2], their electronic structure on non-collinear magnets is yet not explored.

In our experiments, we use a spin-polarized scannning tunneling microscope (SP-STM) in the field emission mode to locally investigate IPS above non-collinear spin textures. Our studies on the double layer (DL) Fe/W(110) spin spiral, the DL Fe/Ir(111) spin spiral and the monolayer Fe/Ir(111) nano-skyrmion lattice reveal the IPS exhibiting the local spin quantization axis of the underlying surface, rotating on the lateral atomic-scale. High-order IPS located 10 nm away from the surface still reflect the non-collinear spin texture, allowing for atomic-scale magnetic imaging at unprecedented large tip-sample distances. Our experiments indicate that the exchange-correlations between hot electrons with about 20 eV and bulk electrons in non-collinear thin-film magnets are governed by the interplay of Heisenberg exchange, Dzyaloshinskii-Moriya, spin-orbit and four-spin interaction.
[1] M. Donath *et al.*, Surf. Sci. **601**, 5701 (2007).
[2] A. Schlenhoff *et al.*, Phys. Rev. Lett. **109**, 097602 (2012).

MA 41.8 Thu 11:30 EB 202

**Slowing down magnetization relaxation of lanthanide phthalocyanine double and triple deckers using a thin oxide film** — •Michał Studniarek[1], Aparajita Singha[2], Romana Baltic[2], Christian Wäckerlin[2], Katharina Diller[2], Fabio Donati[2,3,4], Yanhua Lan[5], Svetlana Klyatskaya[5], Mario Ruben[5], Stefano Rusponi[2], Harald Brune[2], and Jan Dreiser[1] — [1]PSI, Villigen, Switzerland — [2]EPFL, Lausanne, Switzerland — [3]Inst. f. Basic Science, Seoul, Republic of Korea — [4]Ewha Womans Univ., Seoul, Republic of Korea — [5]KIT, Eggenstein-Leopoldshafen, Germany

Recently, Wäckerlin *et al.* demonstrated a three-Tesla magnetic hysteresis opening on a submonolayer of $TbPc_2$ single-ion magnets (SIMs) on a thin MgO film [1] opening a new pathway for applications of surface adsorbed SIMs. To check for the generality of this approach and to grasp the role of the insulating film we performed similar experiments on $DyPc_2$ and $Tb_2Pc_3$. X-ray circular dichroism measurements at 3 K of $DyPc_2$ and $Tb_2Pc_3$ on MgO/Ag(100) revealed unprecedentedly large openings of magnetic hysteresis loops. However, the enhancement of the coercivity of these molecules on MgO is less pronounced compared to the one observed for $TbPc_2$. Besides, we demonstrate an increased blocking temperature of $DyPc_2$/MgO compared to, *e.g.*, $DyPc_2$/HOPG, what is not observed for $TbPc_2$. Finally, in this talk I will discuss the effect of the substrate phonon density of states and of the molecular symmetry on the magnetization dynamics in the light of this new study.
[1] Wäckerlin *et al.*, *Adv. Mater.* **28**, 5142 (2016)

MA 41.9 Thu 11:45 EB 202

**X-ray spectroscopy of simple transition-metal–oxygen model systems** — •Vicente Zamudio-Bayer[1,2], Rebecka Lindblad[1,3], Christine Bülow[2], Martin Timm[2], Konstantin Hirsch[2], Arkadiusz Ławicki[2], Akira Terasaki[4], Bernd von Issendorff[1], and Tobias Lau[2] — [1]Physikalisches Institut, Universität Freiburg, 79104 Freiburg, Germany — [2]Institut für Methoden und Instrumentierung der Forschung mit Synchrotronstrahlung, Helmholtz-Zentrum Berlin für Materialien und Energie, 12489 Berlin, Germany — [3]Department of Physics, Lund University, 22100 Lund, Sweden — [4]Department of Chemistry, Kyushu University, Fukuoka 812-8581, Japan

In the recent literature (Rau et al., Science 344, 988) it was demonstrated that a cobalt adatom on an MgO layer shows a record high magnetic anisotropy energy with an out-of-plane easy axis. The symmetry of the system is dominated by the uniaxial configuration of the cobalt atom on top of the oxygen site. With the dominating uniaxial configuration in mind, we have performed x-ray absorption and x-ray magnetic circular dichroism spectroscopy on free, diatomic ions consisting of a 3*d* metal and an oxygen atom (TM-$O^+$ with TM = Mn, Fe, Co, Ni, Cu). We are thus able to study, at a fixed symmetry, trends and correlations between electronic configuration, orbital magnetic moment, and spin polarization in this model oxide systems. Moreover, we gain an improved understanding of how the interplay between symmetry, orbital occupation, and charge-transfer excitations influence the shape of the x-ray absorption spectra. Possible consequences of large MAE for the magnetization of free particles will also be discussed.

MA 41.10 Thu 12:00 EB 202

**Large tunneling anisotropic magnetoresistance mediated by surface states** — •Marie Hervé[1], Timofey Balashov[1], Arthur Ernst[2], and Wulf Wulfhekel[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology, Wolfgang-Gaede-Strasse 1, 76131 Karlsruhe, Germany — [2]Institute for Theoretical Physics, Johannes Keppler University Linz, Altenberger Strasse 69, 4040 Linz, Austria

Tunneling anisotropic magnetoresistance (TAMR) is an effect originating from the spin-orbit coupling (SOC). It is related to changes in the density of state of a magnetic layer upon changes of the magnetization axis. It has been observed in a large variety of magnetic thin films. In this communication we report on a large TAMR effect (up to 30 %) observed in hcp Co using scanning tunneling microscopy. With the help of ab initio calculations the TAMR can be traced back to the spin-polarized occupied surface state of Co which experiences a strong spin-orbit interaction.

MA 41.11 Thu 12:15 EB 202

**Tunneling anisotropic magnetoresistance via molecular $\pi$ orbitals of Pb dimers** — Johannes Schöneberg[1], Paolo Ferriani[2], •Stefan Heinze[2], Alexander Weismann[1], and Richard Berndt[1] — [1]Institute of Experimental Physics, Christian-Albrechts-Universität zu Kiel, Germany — [2]Institute of Theoretical Physics and Astrophysics, Christian-Albrechts-Universität zu Kiel, Germany

Tunneling anisotropic magnetoresistance (TAMR) [1,2] has been observed down to the single atom limit [3]. However, so far mostly 3*d* transition-metals with a considerable magnetic moment have been studied. Here, we demonstrate a large TAMR for individual Pb dimers on a ferromagnetic surface due to molecular $\pi$ orbitals. Dimers oriented differently with respect to the magnetization directions of a ferromagnetic Fe double layer on W(110) were made with a scanning tunneling microscope. Depending on the dimer orientations, TAMR is absent or as large as 20% at the Fermi level. General arguments and first-principles calculations show that mixing of molecular orbitals due to spin-orbit coupling, which leads to TAMR, is maximal when the magnetization is oriented parallel to the dimer axis.

[1] M. Bode *et al.*, Phys. Rev. Lett. **89**, 237205 (2002).
[2] C. Gould *et al.*, Phys. Rev. Lett. **93**, 117203 (2004).
[3] N. Néel *et al.*, Phys. Rev. Lett. **110**, 037202 (2013).

MA 41.12 Thu 12:30 EB 202

**Elliptical spin excitations by engineering the magnetic interactions of Fe adatoms and dimers on Cu(111)** — •Filipe Souza Mendes Guimarães, Manuel dos Santos Dias, Benedikt Schweflinghaus, and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

We investigate the role of spin-orbit coupling on the spin dynamics of Fe adatoms and dimers deposited on the Cu(111) [1]. The spin excitations of an Fe adatom can be surprisingly anisotropic and may be controlled either via a large in-plane external magnetic field, or by forming a dimer with a neighboring Cu adatom, as previously shown on a semi-insulating surface [2]. We also consider spin excitations of two kinds of Fe dimers. While the dimer with nearest-neighbor separation is strongly ferromagnetic, and its lowest spin excitation can be described as the elliptical precession of a giant spin with biaxial magnetic anisotropy, the one with twice the separation has an antiferromagnetic ground state but also present a ferromagnetic metastable state thanks to the magnetic anisotropy. For the latter, we explore the spin excitations from both kinds of magnetic states, and propose that the metastable state can be accessed with a pump-probe STM experiment [2]. This work is supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (ERC-consolidator grant 681405 – DYNASORE).
[1] F. S. M. Guimarães *et al.*, Phys. Rev. B **96**, 144401 (2017)
[2] S. Loth *et al.*, Science **329**, 1628 (2010)