O 2: Surface Magnetism and Spin Phenomena

Time: Monday 10:30–13:15 Location: MA 004

Invited Talk O 2.1 Mon 10:30 MA 004

Unusual magnetic properties of Fe and Co atoms on MgO — •Andreas Heinrich — IBM Research, San Jose, USA

The ability to control the magnetic properties of nanoscale systems will open novel avenues for spintronics, magnetic memory devices, and quantum computation. Key among those properties is the magnetic anisotropy, which governs the stability and directionality of their magnetization.

I will present scanning tunneling and x-ray absorption spectroscopy measurements of Co and Fe atoms deposited on thin MgO layers. Both species retain most of their free atom orbital moment and interact strongly with the crystal field of their binding site. In the case of Co, the almost cylindrical symmetry of the binding site preserves the full orbital angular momentum around the surface normal and leads to the maximum magnetic anisotropy for 3d transition metal atoms. On the other hand, Fe responds to the four-fold perturbation of the binding site and hence has much smaller magnetic anisotropy.

Spin-polarized tunneling measurements reveal relatively stable magnetic ground states for Fe and Co with long spin relaxation times (ms range) for the excited state with opposite magnetic moment.

These results offer a strategy, based on symmetry arguments and careful tailoring of the interaction with the environment, for the rational design of nanoscopic permanent magnets and single atom magnets.

O 2.2 Mon 11:00 MA 004

Chiral magnetism in nanostructures of adatoms on Au(111) surface — •Juba Bouaziz, Stefan Blügel, and Samir Lounis — Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany

We investigate possible chiral magnetic textures in superstructures made of 3*d* adatoms interacting via the Rashba spin-splitted surface state of Au(111) surface. We utilize multiple-scattering theory based on the Rashba model [1] to describe the related electronic structure and perform a mapping to an extended Heisenberg model and extract the tensor of magnetic exchange interactions among the adatoms. We find different type of interactions that can be of the same order of magnitude: a two-ion anisotropy term besides the usual isotropic exchange interaction and the Dzyaloshinskii-Moriya interaction. The inter-adatom distance controls the strength of these terms, which we exploit to design chiral magnetism for large nanostructures containing up to 169 adatoms deposited on Au(111) surface. Depending on the rim-decoration of the nanostructures, different chiral structures of skyrmionic type are obtained. Also different applied magnetic fields are considered while the evolution of the total energy and the topological charge of the nanoclusters are scrutinized.

[1] S. Lounis *et al.* Phys. Rev. Lett. **108**, 207202 (2012)

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O 2.3 Mon 11:15 MA 004

Conduction-electron mediated Dzyaloshinskii-Moriya interactions between adatoms revealed by ISTS — Alexander A. Khajetoorians[1,2], Manuel Steinbrecher[1], Mohammed Bouhassoune[3], Manuel dos Santos Dias[3], Samir Lounis[3], Markus Ternes[4], •Jens Wiebe[1], and Roland Wiesendanger[1] — [1]Institut für Nanostruktur- und Festkörperphysik, Universität Hamburg, 20355 Hamburg, Germany — [2]Institute for Molecules and Materials, Radboud University, 6525 AJ Nijmegen, The Netherlands — [3]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [4]Max-Planck Institut für Festkörperphysik, 70569 Stuttgart, Germany

It is known since more than three decades that anisotropic exchange between magnetic impurities mediated via strong spin-orbit scattering of conduction electrons by nonmagnetic host atoms leads to a term in the RKKY interaction which is of the Dzyaloshinskii-Moriya (DM) type [1,2]. We report the first direct experimental distance-dependency study of this interaction in pairs of an Fe-H_2 Kondo-complex and an Fe atom adsorbed on Pt(111) by inelastic scanning tunneling spectroscopy (ISTS) showing that the DM exchange is of similar strength as the isotropic exchange. The data is analysed by a model including the coupling to the substrate electrons in third order perturbation theory [3] and is affirmed by our first-principles calculations using the KKR method [4]. [1] A. Fert *et al.*, PRL **44**, 1538 (1980); [2] S. Lounis *et al.*, PRL **108**, 207202 (2012); [3] Y.-H. Zhang *et al.*, Nat. Comm. **4**, 127203 (2013); [4] L. Zhou *et al.*, Nat. Phys. **6**, 187 (2010).

O 2.4 Mon 11:30 MA 004

Magnetotransport at surfaces of epitaxially grown Bi and BiSb thin films — •Philipp Kröger[1], Julian Koch[1], Sergii Sologub[2], Herbert Pfnür[1], and Christoph Tegenkamp[1] — [1]Leibniz Universität Hannover, Festkörperphysik, 30167 Hannover — [2]Inst. of Physics, Nat. Acad. of Sc., Nauky Av. 46, 03028 Kyiv, Ukraine

Bi has unique electronic properties such as low carrier concentrations, large mobilities and pronounced Rashba splitting of the surface states. We investigated the manipulation of spin-polarized transport properties in Bi(111) films by controlled adsorption of magnetic adatoms (Fe,Co,Tb,Cr). Besides pronounced effects of charge carrier doping and surface diffusion the spin-orbit scattering rate ($1/\tau_{SO}$) can be tuned by the amount and type of the adsorbate giving rise to weak anti- / weak- localization transitions. To enhance the spin polarization, $Bi_{1-x}Sb_x$ alloys were grown which exhibit a topological non-trivial phase for certain concentrations x. Magnetotransport measurements of a 30 BL $Bi_{0.82}Sb_{0.18}$ film on Si(111) reveals weak anti localization behavior. Compared to Bi(111) films the τ_{SO} is increased by one order of magnitude reflecting the strong spin-orbit coupling in this system with carrier concentrations of $n = 1 \cdot 10^{13} cm^{-2}$ and $p = 2 \cdot 10^{13} cm^{-2}$. The corresponding mobilities amounts to $\mu_n = 260\ cm^2(Vs)^{-1}$ and $\mu_p = 190\ cm^2(Vs)^{-1}$. By adsorption of Cr (4,8 μ_B) we got a first insight into the spin dependent scattering processes in this class of material.

O 2.5 Mon 11:45 MA 004

Ballistic Anisotropic Magnetoresistance of Single-Atom Contacts — •Johannes Schöneberg[1], Fabian Otte[2], Nicolas Néel[3], Alexander Weismann[1], Yuriy Mokrousov[4], Jörg Kröger[3], Richard Berndt[1], and Stefan Heinze[2] — [1]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, D-24098 Kiel, Germany — [2]Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, D-24098 Kiel, Germany — [3]Institut für Physik, Technische Universität Ilmenau, D-98693 Ilmenau, Germany — [4]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich, Germany

Junctions involving a non-magnetic and a single ferromagnetic layer may exhibit anisotropic magnetoresistance (AMR), i. e., their resistances depend on the magnetization direction relative to the crystallographic axes via spin-orbit coupling. Large AMR effects were predicted for the ballistic transport range but their experimental verification is challenging. We deposited single Co and Ir atoms on domains and domain walls of ferromagnetic Fe layers on W(110) to control their magnetization directions. At a temperature of 5 K they are contacted with nonmagnetic tips in a scanning tunneling microscope to measure the junction conductances. AMR is observed and changes drastically between tunneling and the ballistic regime. First-principles calculations demonstrate that this change is due to a competition of delocalized and localized d states of different orbital symmetry.

O 2.6 Mon 12:00 MA 004

ISTS of Ho atoms and Ho-Fe atom pairs on Pt(111) in the RKKY-coupling regime — •Manuel Steinbrecher[1], Andreas Sonntag[1], Manuel dos Santos Dias[2], Mohammed Bouhassoune[2], Samir Lounis[2], Jens Wiebe[1], Roland Wiesendanger[1], and Alexander Ako Khajetoorians[1,3] — [1]INF, Hamburg University, 20355 Hamburg, Germany — [2]PGI-1 and IAS-1, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [3]IMM, Radboud University, 6525 AJ Nijmegen, The Netherlands

Rare-earth atoms which are adsorbed on surfaces [1] or introduced as metal centers into molecules [2] are regarded as promising quantum-bit candidates due to the strong localization of their 4*f*-electrons. For the same reason, an electrical read-out of the rare-earth bit's magnetic state and the coupling of two bits is more challenging than for 3*d* atoms, where a read-out via inelastic scanning tunneling spectroscopy

(ISTS) and coupling via RKKY-interaction has been unambiguously demonstrated [3, 4]. Here, we show magnetic field dependent ISTS at 300 mK on individual Ho adatoms and Ho-Fe pairs on Pt(111) with distances in the RKKY regime. In conflict with [1] there are no signatures of spin-excitations on Ho in the tunneling regime, and the RKKY-coupling strength is below our thermal energy resolution. These results are supported by our *ab-initio* calculations which show that RKKY interaction of Ho via the Pt(111) conduction electrons is very weak. [1] Miyamachi *et al.*, Nature **503**, 242 (2013); [2] Fahrendorf *et al.*, Nat. Comm. **4**, 2425 (2014); [3] Khajetoorians *et al.*, PRL **106**, 037205 (2012); [4] Khajetoorians *et al.*, Nat. Phys. **8**, 497 (2012).

O 2.7 Mon 12:15 MA 004

Room-temperature magnetic ordering of an Eu monolayer under graphene on Ni and Co thin films — •Felix Huttmann[1], David Klar[2], Carolin Schmitz-Antoniak[2], Antonio J. Martínez-Galera[1], Alevtina Smekhova[2], Nicolae Atodiresei[3], Vasile Caciuc[3], Stefan Blügel[3], Heiko Wende[2], and Thomas Michely[1] — [1]II. Physikalisches Institut, Universität zu Köln, Zülpicher Straße 77, 50937 Köln, Germany — [2]Fakultät für Physik and Center for Nanointegration (CENIDE), Universität Duisburg-Essen, Lotharstr. 1, 47048 Duisburg, Germany — [3]Peter Grünberg Institut (PGI) and Institute for Advanced Simulation (IAS), Forschungszentrum Jülich, 52425 Jülich, Germany

We expose epitaxial graphene on ferromagnetic thin films of Co and Ni to vapor of the rare earth metal Eu at elevated temperatures, resulting in the intercalation of an Eu monolayer in between graphene and its substrate. The Eu monolayer forms a $(\sqrt{3} \times \sqrt{3})$R30° superstructure with respect to the graphene lattice irrespective of any epitaxial rotation of graphene with respect to its Co or Ni substrate. We use X-ray magnetic circular dichroism at the Co and Ni $L_{2,3}$, Eu $M_{4,5}$, and C K edges as an element-specific technique to investigate magnetism in these systems. We find an antiferromagnetic alignment between Eu and Co/Ni moments, while for C, a dichroic signal is not unambiguously identified. Density functional theory calculations confirm the antiferromagnetic coupling and provide an insight into the coupling mechanism.

O 2.8 Mon 12:30 MA 004

ISTS of Fe adatoms in contact to superconducting Ta — •Anand Kamlapure[1], Lasse Cornils[1], Lihui Zhou[1,2], Alexander A. Khajetoorians[1,3], Jens Wiebe[1], and Roland Wiesendanger[1] — [1]Department of Physics, Hamburg University, Hamburg, Germany — [2]Max-Planck Institute for Solid State-Research, Stuttgart, Germany — [3]Institute for Molecules and Materials, Radboud University, Nijmegen, The Netherlands

Recent local scale investigations of the competition of superconductivity and magnetism in molecular systems revealed rich physics associated with a quantum phase transition [1]. Here, we experimentally study individual Fe atoms adsorbed on a reconstructed surface of superconducting Ta by inelastic scanning tunneling spectroscopy (ISTS) at a temperature of 1 K and as a function of magnetic field of strength up to 3 T perpendicular to the surface. We observe strong inelastic excitations at three different adsorption sites of the Fe adatoms. The majority site shows a sharp step around 2 meV which is almost independent of the magnetic field. The other two sites exhibit excitations around 1 meV and 4 meV which have a weak magnetic field dependence indicating the magnetic origin of this excitation. In all three cases the superconducting energy gap and coherence peaks are preserved at zero magnetic field indicating very weak coupling between the magnetic moment and the cooper pairs. [1] K. J. Franke *et al.*, Science **332**, 940 (2011).

Invited Talk O 2.9 Mon 12:45 MA 004

Interface-induced magnetic skyrmions studied with spin-polarized STM — •Kirsten von Bergmann — Department of Physics, University of Hamburg, Germany

The spin textures of ultra-thin magnetic layers exhibit surprising variety. The loss of inversion symmetry at the interface of magnetic layer and substrate gives rise to the so-called Dzyaloshinsky-Moriya interaction which favors non-collinear spin arrangements with unique rotational sense [1]. An ideal tool to investigate such systems down to the atomic scale is spin-polarized scanning tunneling microscopy, which has enabled the discovery of spin spirals with unique rotational sense at surfaces [2]. Recently, different interface-driven skyrmion lattices have been found [3,4], which can be viewed as a two-dimensional analogon to spin spirals. Depending on the involved magnetic interactions single particle-like skyrmions can be realized and their writing as well as the deletion based on local spin-polarized current injection has been demonstrated [4]. Such interface-induced non-collinear magnetic states enable the study of fundamental magnetic interactions and are promising candidates for future spintronic applications.

[1] K. von Bergmann et al., J. Phys.: Cond. Mat. 26, 394002 (2014).
[2] M. Bode et al., Nature 447, 190 (2007).
[3] S. Heinze et al., Nature Phys. 7, 713 (2011).
[4] N. Romming et al., Science 341, 636 (2013).