O 7: Electronic Structure of Surfaces: Magnetism and Spin Phenomena

Time: Monday 10:30–12:45 Location: WIL C107

O 7.1 Mon 10:30 WIL C107

Magnetic properties of rare earth single atoms on metal substrates. — •Aparajita Singha[1], Romana Baltic[1], Fabio Donati[1], Christian Wäckerlin[1], Jan Dreiser[1,2], Luca Persichetti[3], Sebastian Stepanow[3], Pietro Gambardella[3], Stefano Rusponi[1], and Harald Brune[1] — [1]Ecole Polytechnique Fédérale de Lausanne — [2]Paul Scherrer Institute — [3]ETH Zürich

Surface-supported rare earths (RE) single atoms have been recently shown to have unprecedented magnetic stability [Science 318, 352 (2016)]. However to further benefit from their intriguing properties requires an in-depth understanding of the interaction between RE atoms and the surface which defines the energy spectrum of their magnetic quantum levels. Here we show a systematic study of several REs (Dy, Ho, Er,and Tm) on different metal substrates (Pt(111), Cu(111), Ag(100), and Ag(111)). Using x-ray absorption spectroscopy and magnetic circular dichroism we reveal that only $4f^n$ and $4f^{n-1}$ configurations are possible for these RE atoms where n corresponds to the free atom occupation. Moreover, we identify that the ionization potential of the $4f$ elements and the substrate density of states at the Fermi level are the two key factors governing the $4f$ occupation of the REs. All magnetization loops at 2.5 K show no hysteresis indicating that magnetic relaxation is faster than about 10 s. The comparison of our experimental spectra with multiplet calculations provides the identity and energy splitting of the magnetic quantum levels of these RE adatoms.

O 7.2 Mon 10:45 WIL C107

Superlattice of single atom magnets on graphene — •Romana Baltic[1], Marina Pivetta[1], Fabio Donati[1], Christian Wäckerlin[1], Aparajita Singha[1], Jan Dreiser[1,2], Stefano Rusponi[1], and Harald Brune[1] — [1]Institute of Physics, Ecole Polytechnique Fédérale de Lausanne, Switzerland — [2]Swiss Light Source, Paul Scherrer Institute, Switzerland

Regular arrays of single atom magnets represent the model systems for information storage at the ultimate length scales. In this regard, individual rare-earth atoms on decoupling layers have recently received great attention for showing extraordinary magnetic stability [F. Donati et al., Science 352, 318 (2016)]. However, they lack spatial order.

Here we show that the spatial arrangement of Dy atoms on graphene/Ir(111) can be controlled by the substrate temperature during their deposition. Deposition at 40 K leads to the formation of a regular array of Dy atoms with the periodicity defined by the graphene moiré pattern, while deposition at lower temperatures results in disordered systems. In addition, the Dy atoms in both configurations show magnetic hysteresis up to 5.6 T and spin lifetime of 1000 s at 2.5 K. The observed magnetic stability of Dy atoms is a consequence of the low intrinsic electron and phonon densities of graphene, the six-fold adsorption site, and the $J_z = \pm 7$ ground state [R. Baltic et al., Nano Lett. (2016), DOI: 10.1021/acs.nanolett.6b03543].

O 7.3 Mon 11:00 WIL C107

Tailoring the hysteresis of Dy single atom magnets with $4f$ orbital filling — •Fabio Donati[1], Stefano Rusponi[1], Aparajita Singha[1], Romana Baltic[1], Luca Persichetti[3], Christian Wäckerlin[1], Jan Dreiser[2], Pietro Gambardella[3], and Harald Brune[1] — [1]Institute of Physics, École Polytechnique Fédérale de Lausanne (EPFL), Switzerland — [2]Swiss Light Source, Paul Scherrer Institute, Switzerland — [3]Department of Materials, ETH Zürich, Switzerland

Individual rare earth atoms adsorbed on a MgO surface are intensively investigated as they were recently found to preserve magnetic remanence up to 40 K [F. Donati et al., Science **352**, 318 (2016)]. Their magnetic properties are directly related to the occupation of the $4f$ orbitals, which determines the multiplicity of the lowest multiplet and the integer/half-integer character of the total angular momentum J. Therefore, tuning the $4f$ occupation offers a direct way to control the behavior of these single atom magnets. Using x-ray magnetic circular dichroism, we show that the magnetism of Dy atoms on MgO/Ag(100) can be controlled with the thickness of the MgO film. The occupation of the $4f$ orbitals changes from 9 to 10 by increasing the number of MgO layers from 3 to 6. Magnetization loops at 2.5 K exhibit hysteresis with characteristic shape and opening that depend on the electronic configuration of the Dy atoms. Our results highlight the role of the proximity of the metal substrate in determining the magnetism of single atoms on insulating layers.

O 7.4 Mon 11:15 WIL C107

Inelastic Electron Tunneling: Selection Rules and Orbital Exchange — •Jindrich Kolorenc — Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic

We investigate tunneling of electrons from an STM tip to a substrate through a magnetic adatom by means of the Anderson impurity model. We employ an approximation analogous to the cotunneling theory [1] and concentrate on f-electron adatoms with large spin-orbital coupling. We compare the obtained inelastic electron tunneling spectra (IETS) with predictions of the spin model that has been very successful in the case of transition-metal adatoms [2]. When the spin model is applied to f electrons, the adatom spin **S** is replaced with its angular momentum **J** [3,4]. The spectra calculated in the two models differ, and we trace this difference to the exchange interaction between the adatom and the tunneling electrons. The bilinear (Heisenberg) exchange $\mathbf{J} \cdot \mathbf{s}$, assumed in the spin model [3,4], implies a selection rule $\Delta m_J = 0, \pm 1$ for single-electron scatterings, whereas the Anderson model indicates a larger number of allowed scattering channels. The less restrictive selection rule originates in the orbital exchange that is active for the orbital contribution to the magnetic moment of the adatom. This more general exchange influences also the lifetime of the magnetic states since they are destabilized, among other mechanisms, by the exchange with substrate electrons [4]. [1] F. Delgado and J. Fernández-Rossier, Phys. Rev. B **84**, 045439 (2011), [2] M. Ternes, New. J. Phys. **17**, 063016 (2015), [3] T. Schuh *et al.*, Phys. Rev. B **84**, 104401 (2011), [4] T. Miyamachi *et al.*, Nature **503**, 242 (2013).

O 7.5 Mon 11:30 WIL C107

Orbital Picture of Yu-Shiba-Rusinov Multiplets — •Benjamin W. Heinrich[1], Michael Ruby[1], Yang Peng[2], Felix von Oppen[2], and Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin

Magnetic impurities on an *s*-wave superconductor induce Yu-Shiba-Rusinov (YSR) bound states within the excitation gap of the superconductor. Here, we investigate single manganese (Mn) atoms adsorbed on different surface orientations of superconducting lead (Pb) and the nature of their YSR states. Depending on the adsorption site and surface, we detect a distinct number and characteristic patterns of YSR states around the Mn atoms. We show that the YSR states inherit their properties from the Mn d levels, which are split by the surrounding crystal field [1]. The periodicity of the long-range YSR oscillations allows us to identify a dominant coupling of the d states to the outer Fermi sheet of the two-band superconductor Pb. The long-range and directional nature of the states are promising for the design of coupled adatom structures, which could bear topological phases.
[1] M. Ruby *et al.*, Phys. Rev. Lett. **117**, 186801 (2016).

O 7.6 Mon 11:45 WIL C107

Proximity coupled Co chains on Pb(110) — Michael Ruby, Benjamin W. Heinrich, Yang Peng, Felix von Oppen, and •Katharina J. Franke — Fachbereich Physik, Freie Universität Berlin

Proximity-coupled ferromagnetic chains on a superconductor with strong spin-orbit coupling have been predicted as a nearly universal system for topological superconductivity and for hosting Majorana zero modes [1]. Experiments on Fe chains on Pb(110) indeed exhibit signatures of Majorana end states [2]. Here, we test the universality prediction by growing Co chains on a Pb(110) surface. Using Co-coated STM tips, we detect spin-polarized d-bands reflecting ferromagnetic coupling along the chain. The Yu-Shiba-Rusinov bands inside the superconducting energy gap also exhibit spin contrast. However, the rich subgap structure does not provide evidence of Majorana end states. In a simple model of tight-binding calculations, we ascribe the absence of Majorana end states to an even number of d-band crossings of the Fermi level. This is the crucial difference to the case of Fe chains.

[1] J. Li, et al., Phys. Rev. B 90, 235433 (2014).
[2] S. Nadj-Perge, et al., Science 346, 602 (2014).

O 7.7 Mon 12:00 WIL C107

Magnetic character of holmium atom adsorbed on platinum surface — Alexander Shick[1], Dmitry Shapiro[2], Jindrich Kolorenc[1], and •Alexander Lichtenstein[3] — [1]Institute of Physics ASCR, Prague, Czech Republic — [2]Institute of Radio Engineering and Electronics RAS, Moscow, Russia — [3]University of Hamburg, Hamburg, Germany

We address recent controversy concerning the magnetic state of holmium adatom on platinum surface. Within a combination of the density functional theory (DFT) with the exact diagonalization (ED) of Anderson impurity model, the $\langle J_z \rangle = 0$ paramagnetic ground state is found. In an external magnetic field, this state is transformed to a spin-polarized state with $\langle J_z \rangle = 6.6 - 6.8$. We emphasize the role of $5d$-$4f$ interorbital exchange polarization in modification of the $4f$ shell energy spectrum. It is further suggested that when an external magnetic field is removed, the spin-polarized state relaxes back to the paramagnetic state through an intermediate quasi-degenerate and magnetically unstable state overruling the existence of long living magnetic moment, and the magnetic remanence for Ho adatom on Pt surface.

O 7.8 Mon 12:15 WIL C107

Spin-spirals in bottom-up fabricated Fe chains induced by Dzyaloshinskii-Moriya interaction — •Manuel Steinbrecher[1], Khai Ton That[1], Jan Hermenau[1], Alexander Ako Khajetoorians[2], Jens Wiebe[1], and Roland Wiesendanger[1] — [1]Department of Physics, Hamburg University, 20355 Hamburg, Germany — [2]IMM, Radboud University, 6525 AJ Nijmegen, The Netherlands

Magnetic atoms adsorbed on the surface of strong spin-orbit coupling materials experience indirect Dzyaloshinskii-Moriya interaction (DMI) [1]. DMI is an exchange interaction responsible for the stabilization of spin-spirals or Skyrmions by favoring perpendicular orientation of neighboring spins. By depositing single magnetic atoms on a surface and using the tip of a scanning tunneling microscope as a tool, those atoms can be moved to build bottom-up fabricated nanostructures [2]. Spin-sensitive measurements of such bottom-up fabricated chains enable the observation of the spin-state of each atom within the chain. So far, only collinear ferromagnetic [3] or antiferromagnetic [4] ground states have been observed. Here, we were able to measure DMI induced non-collinear ground states on chains of Fe atoms on Pt(111) of different lengths. By fixing the magnetization of the outermost atom in a 16 atoms long chain, we were able to stabilize a spin-spiral and investigate its properties by spin-polarized tunneling spectroscopy. [1] Khajetoorians *et al.*, Nat. Commun. **7**, 10620 (2016), [2] Khajetoorians *et al.*, Nat. Phys. **8**, 497 (2012); [3] A. Spinelli *et al.*, Nat. Mat. **13**, 782 (2014); [4] Khajetoorians *et al.* Science 332, 1062 (2011).

O 7.9 Mon 12:30 WIL C107

Electronic and magnetic properties of the $GdAu_2$ surface alloy probed by SP-STM — •Maciej Bazarnik[1], Emil Sierda[1], Mikel Abadia[2], Micha Elsebach[1], Jens Brede[2], and Ronald Wisendanger[1] — [1]Department of Physics, University of Hamburg, Jungiusstrasse 11, D-20355 Hamburg, Germany — [2]Centro de Física de Materiale, P Manuel de Lardizabal 5, Donostia - San Sebastián, Gipuzkoa E-20018, Spain

In light of recent developments in spintronics it is essential to develop interfaces between magnetic materials and superconductors, topological insulators or organic structures. Tailoring magnetic properties of structurally robust and chemically inert systems is therefore of high importance. In this respect, there has recently been a lot of interest in novel kinds of systems such as intercalated graphene, h-BN, or thin oxide films. Lately a new class of 2D systems has been discovered that is very promising to fulfill all requirements, namely $GdAu_2$ and $GdAg_2$ surface alloys. Those systems are confined to one bilayer of the material grown on Au(111) or Ag(111) surface respectively. The 2D structure exhibits magnetic properties very different from its bulk counterpart, ie. while $GdAu_2$ alloy is antiferromagnet in bulk it is in fact a ferromegnet as a 2D film. In this presentation we will focus on the $GdAu_2$ surface alloy on Au(111) as examined by SP-STM. We will first address the local electronic and magnetic properties and compare our results to investigations by complementary surface science techniques. Then we will prove that the $GdAu_2$ surface alloy acts as a catalyst for the on-surface Ullmann reaction.