MA 44: Surface Magnetism (jointly with O)

Time: Thursday 15:00–18:45 Location: H3

Invited Talk MA 44.1 Thu 15:00 H3

Spin-polarized scanning field emission microscopy and spectroscopy — •Anika Schlenhoff — Institute of Applied Physics, University of Hamburg

High electric fields can discharge electrons from a solid, thereby generating an emission current, which becomes spin-polarized when using a magnetic emitter. A very local injection of these electrons is achieved when approaching a magnetic tip to a sample in an SP-STM setup, and scanning allows for magnetic imaging by means of spin-polarized emission conductivity measurements. Although field emission is routinely used for microscopy purposes, the question remained open how it affects magnetism on the local scale. A detailed understanding of the interplay of hot-electron spins with magnets is essential for the interpretation of many hot electron spin phenomena and characterization techniques, as well as for applications in spintronic devices.

Here we show that a spin-polarized field-emission current resonantly injected into magnets, consisting of only about 50 iron atoms on a W(110) surface, generates considerable Joule heating and spin-transfer torque, thereby severely affecting the thermally driven magnetization reversal. The switching frequency is increased due to phonon generation, and a lifetime asymmetry develops with increasing emission current, most likely driven by Stoner excitations. Even magnetization reversal of quasistable nanomagnets can be triggered by spin-polarized field-emission. Our experiments demonstrate the capability of spin-polarized scanning field emission microscopy for magnetic observation and controlled manipulation on the atomic scale at nm distances.

MA 44.2 Thu 15:30 H3

Large wave vector surface spin waves of the nanomartensitic phase in ultrathin iron films on Cu(100) and fcc Co(100) — •Rajeswari Jayaraman, Harald Ibach, and Claus M. Schneider — Peter Grünberg Insitut, Forschungszentrum Jülich, 52425 Jülich, Germany

It is generally accepted that thin-film magnetism is strongly affected by even small structural modifications. Much less is known about the influence of structure on magnetic excitations, in particular, spin waves. Using electron energy loss spectroscopy we have studied the dispersion of large wave vector surface spin waves of a system for which details of the structure became known only recently, namely ultrathin iron films grown on Cu(100) surfaces. We find the spin wave dispersion to be nearly identical to the dispersion reported for bcc Fe(110) layers grown on W(110). We therefore conclude that the spin wave signal stems from the "nanomartensitic" phase of Fe/Cu(100) and that this phase is not merely a surface phase but encompasses the deeper layers. The same spin wave dispersion and LEED pattern as for the Fe/Cu(100) system is observed when Fe is deposited on fcc Co(100)/Cu(100). We therefore conclude that these Fe films likewise assume the nanomartensite structure.

MA 44.3 Thu 15:45 H3

Parity effect in ground state localization of antiferromagnetic chains coupled to a ferromagnet — Simon Holzberger[1], Tobias Schuh[1], Samir Lounis[2], Stefan Blügel[2], and •Wulf Wulfhekel[1] — [1]Physikalisches Institut, KIT — [2]Peter Grünberg Institut, Forschungszentrum Jülich

We investigate the ground states of antiferromagnetic Mn nanochains on Ni(110) by spin-polarized scanning tunneling microscopy in combination with theory. While the ferrimagnetic linear trimer experimentally shows the predicted collinear classical ground state, no magnetic contrast was observed for dimers and tetramers where non-collinear structures were expected based on ab-initio theory. This striking observation can be explained by zero-point energy motion for even numbered chains derived within a classical equation of motion leading to non classical ground states. Thus, depending on the parity of the chain length, the system shows a classical or a quantum behavior.

MA 44.4 Thu 16:00 H3

Constant current contrast in spin-polarized STM — •Krisztian Palotas — Budapest University of Technology and Economics, Department of Theoretical Physics, Budapest, Hungary

This work is concerned with the theoretical description of the contrast, i.e., the apparent height difference between two lateral surface positions on constant current spin-polarized scanning tunneling microscopy (SP-STM) images.

We propose a method [1] to predict the bias voltage dependent magnetic contrast from single point tunneling current or differential conductance measurements, without the need of scanning large areas of the surface. Depending on the number of single point measurements, the bias positions of magnetic contrast reversals and of the maximally achievable magnetic contrast can be determined. We validate this proposal by simulating SP-STM images on a complex magnetic surface employing a recently developed approach based on atomic superposition [2]. Furthermore, we show evidence that the tip electronic structure and magnetic orientation have a major effect on the magnetic contrast. Our theoretical prediction should inspire experimentalists to considerably reduce measurement efforts for determining the bias dependent magnetic contrast on magnetic surfaces.

This research was supported by the OTKA PD83353, K77771, TAMOP-4.2.2.B-10/1-2010-0009 projects, and a Bolyai Grant.

[1] K. Palotas, arXiv:1207.3995 (2012).

[2] K. Palotas et al., Phys. Rev. B 83, 214410 (2011); Phys. Rev. B 84, 174428 (2011); Phys. Rev. B 85, 205427 (2012).

MA 44.5 Thu 16:15 H3

Mapping the energy landscape of the magnetoelectric phase transition in Fe nanoislands — •Lukas Gerhard[1], Rien Wesselink[1,2], Arthur Ernst[3], and Wulf Wulfhekel[1] — [1]Physikalisches Institut, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Faculty of Science and Technology and MESA+ Institute for Nanotechnology, University of Twente, 7500AE Enschede, The Netherlands — [3]Max-Planck-Institut fuer Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany

Magnetoelectric coupling (MEC) offers the possibility to control the magnetic state of a material by applying an electric field raising the prospect of new applications in magnetic storage devices. Using the electric field of a scanning tunneling microscope (STM) tip we recently demonstrated strong MEC in metallic nano islands [1]. High electric fields of the order of 1 GV/m trigger a crystallographic and magnetic phase transition from antiferromagnetic fcc to ferromagnetic bcc in bilayer Fe islands on a Cu(111) surface. An extensive statistical analysis of the thermally activated switching at subcritical electric fields unveils the characteristic energies of the balance between the two states. We map this energy landscape as function of strain and electric field which gives us a thorough understanding of the critical parameters necessary to fine-tune the dynamics of MEC induced phase transitions. [1] L. Gerhard et al. Magnetoelectric coupling at metal surfaces. Nat. Nano 5, 792-797 (2010)

MA 44.6 Thu 16:30 H3

Role of magnetism in Catalysis: RuO2 (110) surface — •Engin Torun[1], Changming Fang[1,3], Gilles A de Wijs[1], and Robert de Groot[1,2] — [1]Electronic Structure of Materials, Radboud University Nijmegen, Institute for Molecules and Materials, Heyendaalseweg 135, 6525 AJ Nijmegen, The Netherlands — [2]Laboratory of Chemical Physics, Zernike Institute of Advanced Materials, Nijenborgh 4, NL-9747 AG Groningen, The Netherlands — [3]University of Vienna, Faculty of Physics, Computational Materials Physics, Sensengasse 8/12, 1090 Wien, Austria

The three conservation laws (energy, momentum and angular momentum) are well known, but the consequences of the last one are too often neglected. A clear example in electrochemistry is the electrolysis of water. Hydrogen production by electrolysis of water seemingly violates conservation of angular momentum because only one magnetic species is involved (oxygen). The losses in electrolysis are overwhelmingly dominated by the production of oxygen. While the ground state of oxygen is magnetic its first and second excited states are non-magnetic singlet states. This explains the losses at the anode. The oxygen is initially produced in a non-magnetic excited state. A fundamental solution of this problem is only possible by the introduction of a second magnetic species. We report calculations on the surface electronic structure of one of the best anodes, the RuO2 (110) surface. This surface itself is magnetic and a mechanism will be proposed how this second magnetic species allows the production of oxygen in its magnetic ground state. A similar situation in biology will be discussed.

MA 44.7 Thu 16:45 H3

Scanning tunneling spectroscopy of quantum well states in thin Pd(001) films — •Sujit Manna[1], Marek Przybylski[1,2], and Jürgen Kirschner[1,3] — [1]Max-Planck-Institut für Mikrostrukturphysik, Halle, Germany — [2]Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Kraków, Poland — [3]Naturwissenschaftliche Fakultät II, Martin-Luther-Universität Halle-Wittenberg, Halle, Germany

Scanning Tunneling Spectroscopy (STS) on transition metals with filled d-bands below Fermi level is hardly expected to yield features due to the d-states because their contribution to the tunneling current is much smaller than that of the sp-band states. We have investigated the electronic structure of thin Pd films grown on Cu(001) by STS at T=4.7K with single layer thickness resolution. We have identified the occupied d-band quantum well states (QWS), which arise from the electron confinement along the growth axis of Pd films and give rise to sharp peaks in the tunneling spectra. A quantitative analysis of the spectra yields the band dispersion, which is similar to the calculated free electron dispersion in bulk Pd along the Γ-L direction. Also the correlation between the QWS formed in the Pd films with magnetic anisotropy (MA) of adjacent Co films in the Co/Pd bilayer system will be shown and discussed. The step induced uniaxial MA is found to oscillate as a function of Pd film thickness with a period of 6 ML, in agreement with theoretical calculations [1]. [1] M. Cinal, J. Phys.: Condens. Matter 13, 901 (2001).

15 min. break

MA 44.8 Thu 17:15 H3

Spin-dependent Smoluchowski effect — •Marco Corbetta[1], Oleg Polyakov[1,2], Oleg Stepanyuk[1,2], Hirofumi Oka[1], Aleksander Saletsky[2], Dirk Sander[1], Valeriy Stepanyuk[1], and Jürgen Kirschner[1] — [1]Max-Planck-Institut für Mikrostrukturphysik, Halle (Saale), Germany — [2]Faculty of Physics, Moscow State University, Moscow, Russia

The Smoluchowski effect [1] focuses on the total electron charge density and it neglects that electrons carry a spin. In spin-polarized materials, it is not clear how majority and minority states contribute to the spin-dependence of this effect. To elucidate this point we perform spin-polarized scanning tunneling microscopy at the step edge of a bilayer high Co island on Cu(111) at 8 K. We measure maps of the differential conductance (dI/dV) for states of parallel (P) and anti-parallel (AP) orientation between tip and sample magnetization. From these maps we extract the asymmetry A of the differential conductance A=(dI/dVAP-dI/dVP)/(dI/dVAP+dI/dVP). This quantity is proportional to the spin polarization of the sample. We reveal striking spatial variations of the spin-polarization at the transition between the Co step and the Cu substrate with sub-nm spatial resolution and investigate its energy dependence. We find a variation of the tunnel magneto resistance ratio of more than 20% on a length scale of few Angstroms. We discuss our results on the basis of ab-initio calculations, spin-dependent electron charge flow supports our findings [2]. [1] R. Smoluchowski, Phys. Rev. 60, 661 (1941). [2] O. P. Polyakov et al., Phys. Rev. B, accepted (2012).

MA 44.9 Thu 17:30 H3

Temperature-dependent magnetic hysteresis of the differential conductance in spin-polarized scanning tunneling spectroscopy with Fe-coated W tips — •Soo-hyon Phark[1], Jeison Fischer[1,2], Marco Corbetta[1], Dirk Sander[1], and Jürgen Kirschner[1] — [1]Max-Planck-Institut für Mikrostrukturphysik, Weinberg 2, 06120 Halle, Germany — [2]Laboratório de Filmes Finos e Superfícies, Departamento de Física, Universidade Federal de Santa Catarina , Florianópolis, SC, Brazil

We performed spin-polarized scanning tunneling spectroscopy on bilayer high Co islands of the nm size range [1] on Cu(111) for temperatures between 10 and 30 K in magnetic fields oriented normal to the sample surface. We use a W tip, heated to 2200 K in UHV, coated with 40-monolayer Fe. Increasing the temperature from 10 to 30 K, we observe a decline of the switching field of an individual Co island, and a reduced slope of the differential conductance around zero field [2]. The Néel-Brown model for the magnetic reversal process of the Co islands and a superparamagnetic response of the tip magnetization as described by the Langevin function gives a favorable description of the data. We estimate that the tip apex is composed of roughly 200 Fe atoms. This suggests that a Fe cluster, rather than a Fe film, determines that magnetic response of the tip. The role of the magnetic stray field of the Co island for the magnetic response of the tip is discussed.

[1] Ouazi, Wedekind, Rodary, Oka, Sander, Kirschner, Phys. Rev. Lett. 108, 107206 (2012). [2] Rodary, Wedekind, Sander, Kirschner, Jap. J. Appl. Phys. 47, 9013 (2008).

MA 44.10 Thu 17:45 H3

Magnetic coupling of single Co adatoms through Pd spacer layers — •Liudmila Dzemiantsova, Mahboubeh Hortamani, Christian Hanneken, André Kubetzka, Kirsten von Bergmann, and Roland Wiesendanger — Institut für Angewandte Physik, Universität Hamburg, Germany

The knowledge about the magnetic coupling on the atomic scale is crucial for the tailoring magnetic devices in reduced dimensions and the tuning their properties [1]. In particular, the dependence of the exchange coupling of magnetic adatoms on the thickness of the spacer layer is important for the fundamental understanding of magnetism and practical applications in spin-based technology [2].

We performed a combined experimental and theoretical investigation of Co atoms on top of a Pd spacer on Co/Ir(111). Using spin-polarized STM, spin contrast is achieved on Pd mono (ML)- and double-layer (DL) and on Co adatoms, which means that the electron density above the surfaces and adatoms is spin-polarized. In accordance with our experimental observations of Co atoms on the Pd spacer, our *ab initio* calculations show that Co layers adsorbed on top of a Pd mono- and double-layer are ferromagnetically coupled to the Co/Ir(111) underneath. The size of the magnetic coupling is reduced by a factor of three from a ML to a DL Pd spacer between the Co layers [3].

[1] F. Meier *et al.*, Science, 320, 82 (2008).
[2] A. A. Khajetoorians *et al.*, Science, 332, 1062 (2011).
[3] L. V. Dzemiantsova *et al.*, Phys. Rev. B, 86, 094427 (2012).

MA 44.11 Thu 18:00 H3

Complex Magnetism in Fe nanoclusters on Ir(111) — •David Bauer, Phivos Mavropoulos, Rudolf Zeller, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich

Recently, a square lattice of skyrmions of nanoscale dimension has been experimentally identified by spin-polarized scanning tunneling microscopy combined with first-principles calculations [1] as the magnetic ground state of an hexagonal Fe monolayer on the Ir(111) substrate. The magnetic structure is a result of a fine balance between the Heisenberg and biquadratic exchange, the four-spin interaction, magnetic anisotropy and the Dzyaloshinskii-Moriya interaction. This raises the question whether a single skyrmion is already encoded in a minimal hexagonal cluster of 7 atoms or *e.g.* in the next larger one of 19 atoms. To shed light onto this problem we apply our recently developed all-electron full-potential relativistic Korringa-Kohn-Rostoker Green-function method jointly with a model spin-dynamics code to study the non-collinear magnetism in finite nano-structures and clusters perfectly embedded in bulk materials or on surfaces.We find that the finite size of these clusters changes the balance between the magnetic interactions significa ntly. For example, also for the 19 atom cluster a strong non-collinear formation of spins was found, but qualitatively different to the skyrmion in the sense that most spins relax to an almost rectangular alignment with respect to their neighbors indicating that the Dzyaloshinskii-Moriya interaction determines the magnetic structure.

[1] S. Heinze et al. Nature Phys. **7**, 713 (2011).

MA 44.12 Thu 18:15 H3

Nano-skyrmions lattices and magnetic phase diagram of Fe/Ir(111) — •Nikolai Kiselev, David Bauer, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Recently, a square lattice of skyrmions of nanoscale dimension has been experimentally identified by spin-polarized scanning tunneling microscopy combined with first-principle calculations [1] as the ground state of an hexagonal Fe monolayer on the Ir(111) substrate. Here, we present a detailed theoretical description of the magnetic phase diagram of Fe/Ir(111) obtained from Monte Carlo simulations in extended Heisenberg model employing parameters obtained from first-principles calculations. We give a comprehensive analysis of the ground state and field/temperature induced transitions and compare our results with experiment. We predict the existence of a new modulated state: an hexagonal lattice of skyrmions stabilized at high field and tempera-

ture. The transition between hexagonal and square skyrmion lattices is characterized by an extremely strong hysteretic effect and the abrupt change of the topological number. We discuss in details general aspects of the nano-skyrmions, in particular leading terms in the Hamiltonian, which are responsible for the stability of skyrmions in low dimensional magnetic systems.

[1] S. Heinze et al. Nature Phys. 7, 713 (2011).

MA 44.13 Thu 18:30 H3

Ab initio study of ferromagnetic Co-chains on the (5x1) Iridium(001) surface — •Bertrand Dupe[1], Yuriy Mokrousov[2], and Stefan Heinze[1] — [1]Institut für Theoretische Physik und Astrophysik, CAU Kiel, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation Forchungszentrum Jülich,Jülich, Germany

Nanostructures of 3d transition metals on 4d or 5d substrates have been shown to exhibit complex spin structures [1-4]. A recent study demonstrated the intriguing magnetism of Fe biatomic chains on the (5x1) reconstructed Ir(001) surface due to the interplay of magnetocrystalline anisotropy, Dzyaloshinskii-Moriya interaction and exchange interaction [4]. Here, we use first-principles calculations based on density functional theory to explore Co biatomic chains on the (5x1) Ir(001) surface. Due to the key role of 3d-5d hybridization for the magnetic properties of such systems [5], we study Co chains in different structural arrangements and the impact of structural relaxations. We report the magnetic properties of the Co chains such as the magnetocrystalline anisotropy energy and the spatial distribution of spin-polarization. We compare our results with recent spin-polarized STM experiments [6].

[1] B. Hardrat et al. PRB 79, 094411 (2009) [2] S. Heinze et al. Nature Phys. 7, 713 (2011) [3] Y. Yoshida et al., PRL 108, 087205 (2012) [4] M. Menzel et al PRL, 108, 197204 (2012) [5] S. Baud et al Phys. Rev. B 73, 104427 (2006) [6] J. Bickel, K. et al to be published