MA 22: Surface Magnetism (Joint Session with O)

Time: Tuesday 9:30–12:30 Location: HSZ 401

Invited Talk MA 22.1 Tue 9:30 HSZ 401

Tuning the zero-point spin-fluctuations of single adatoms — •Julen Ibañez-Azpiroz — Peter Grünberg Institut and Institute of Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Single-adatoms deposited on metallic substrates offer an exceptional playground for studying magnetism at the atomic scale and give rise to several intriguing questions. For instance, although several adatoms exhibit a large magnetic anisotropy energy as measured by X-ray Magnetic Circular Dichroism [1], the very same adatoms behave as paramagnetic objects when probed by Scanning Tunneling Spectroscopy (STS) [2, 3]. Motivated by this apparent contradiction, we analyze the role of quantum fluctuations of the adatom's spin at T=0, the so-called zero-point spin-fluctuations (ZPSF) utilizing time-dependent density functional theory [4]. We investigate several 3d and 4d magnetic adatoms on different substrates, accessing the magnitude of ZPSF and identifying the underlying physical mechanism as well as their implication on the magnetic stability. Remarkably, while spin-fluctuations weaken magnetism, they could be used to detect magnetic signals even in non-magnetic adatoms. We show that the latter can exhibit intense paramagnetic spin-excitations easily tunable with a magnetic field and potentially observable with inelastic STS [5].

[1] P. Gambardella etal., Science 300, 1130 (2003). [2] L. Zhou etal., Nat. Phys. 6, 187 (2010). [3] A. A. Khajetoorians, etal., PRL 106, 037205 (2011). [4] J. Ibañez-Azpiroz etal., Nano Lett. (2016), 10.1021/acs.nanolett.6b01344 [5] J. Ibañez-Azpiroz etal., in prep.

15 min. break

MA 22.2 Tue 10:15 HSZ 401

Measurement of a Nano-Skyrmionic lattice via Magnetic Exchange Force Microscopy — •Josef Grenz, Alexander Schwarz, and Roland Wiesendanger — Institute of Nanostructure and Solid State Physics, University of Hamburg, Jungiusstraße 11A, 20355 Hamburg, Germany

Skyrmions are complex spin textures, which occur in crystals without inversion symmetry due to the Dzyaloshinskii-Moriya interaction. Recently, the monolayer of Fe on a Ir(111) surface attracted a lot of interest, because it exhibits an interface induced Skyrmionic state with a lattice constant of 1 nm [1]. Here, we study the Fe/Ir(111) system utilizing magnetic exchange force microscopy (MExFM). This method has been employed previously to investigate antiferromagnetic structures with atomic resolution [2-4]. We demonstrate that MExFM is able to resolve the arrangement of atoms and the spin texture simultaneously on a non-collinear magnetic structure. Such image data allow to straightforwardly identify the (in-) commensurability between atomic and magnetic structure.

[1] S. Heinze, *et al.*, Nature Phys. **7**, 713 (2011).
[2] U. Kaiser, *et al.*, Nature **446**, 522 (2008).
[3] R. Schmidt, *et al.*, Nano Lett. **9**, 200 (2009).
[4] F. Pielmeier, *et al.*, Phys. Rev. Lett. **110**, 266101 (2013).

MA 22.3 Tue 10:30 HSZ 401

Repulsive Skyrmion Interaction observed in Pd/Fe-Nanoislands on Ir(111) — •Philipp Lindner, Johannes Friedlein, Jonas Harm, Stefan Krause, and Roland Wiesendanger — Department of Physics, University of Hamburg, Jungiusstraße 11A, 20355 Hamburg, Germany

Recently, the realization of a room temperature skyrmionic racetrack-style memory device was reported [1], opening the path to ultradense data storage and high speed processing applications with magnetic skyrmions as information carriers.

Using spin-polarized scanning tunneling microscopy, controlled writing and deleting of single atomic-scale magnetic skyrmions was demonstrated via local injection of spin-polarized tunnel electrons in the Pd/Fe/Ir(111) system [2]. To design and construct novel spintronic devices, one has to understand and tailor the interaction of skyrmions in close vicinity to each other.

For our study we epitaxially grew Pd nanoislands on the Fe-monolayer on top of Ir(111). For a perpendicular magnetic field above 2 T, an isolated skyrmion phase is observed. We report experimental evidence of a repulsive short range interaction between individual skyrmions, supported by complementary time-resolved and static scanning tunneling microscopy studies. The experimental findings are discussed in terms of displacement, structural changes and lowered stability of the affected skyrmions.

[1] S. Woo et al., Nature Materials 15, 501 (2016).
[2] N. Romming et al., Science 341, 713 (2013).

MA 22.4 Tue 10:45 HSZ 401

Tuning DMI in antiferromagnetic Fe/Ir interfaces — •Sebastian Meyer, Bertrand Dupé, Paolo Ferriani, and Stefan Heinze — Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel, Leibnizstr. 15, 24098 Kiel

Recently, magnetic skyrmions could be stabilized in ultrathin films at surfaces due to the interfacial Dzyaloshinskii-Moriya interaction (DMI) [1,2]. Their intriguing topological and dynamical properties make them interesting for future spintronic applications [3]. It has been predicted that skyrmions in antiferromagnets posses favorable transport properties compared to those in ferromagnets [4]. Here, we present a way to tune the DMI in antiferromagnetic Fe/Ir interfaces. We study Fe/Ir bilayers on Rh(001) using density functional theory as implemented in the FLEUR code (www.flapw.de). For both stackings of the bilayer, i.e. Fe/Ir/Rh(001) and Ir/Fe/Rh(001), the nearest-neighbor (NN) exchange is antiferromagnetic. Fe/Ir/Rh(001) has magnetic properties similar to Fe/Ir(001) [5] and for Ir/Fe/Rh(001), we find very large values of the DMI. Due to exchange frustration, the DMI even exceeds the NN exchange in absolute value. By adding a second Ir overlayer, the DMI is reduced by 60% emphasizing the impact of the Fe/Ir interface on the DMI.

[1] S. Heinze *et al.*, Nature Phys. **7**, 713 (2011).
[2] N. Romming *et al.*, Science **341**, 636 (2013).
[3] A. Fert *et al.*, Nature Nano, **8**, 3 (2013).
[4] J. Barker *et al.*, Phys. Rev. Lett. **116**, 147203 (2016).
[5] M. Hoffmann *et al.*, Phys. Rev. B **92**, 020401 (2015).

MA 22.5 Tue 11:00 HSZ 401

Probing short and long range magnetic interactions on the nanoskyrmion system Fe/Ir(111) with force spectroscopy — •Alexander Schwarz, Josef Grenz, and Roland Wiesendanger — Universität Hamburg, Institut für Nanostruktur- und Festkörperphysik, Jungiusstr. 11, 20355 Hamburg

With a lattice constant of just 1 nm the Fe monolayer on Ir(111) exhibits the smallest skyrmion lattice observed so far [1]. Utilizing magnetic exchange force microscopy (MExFM) [2] we are able to simultaneously resolve the atomic and magnetic structure. Unlike on antiferromagnetic surfaces studied previously with MExFM [2,3], the long range dipolar magnetic force does not cancel out completely above the surface.

To investigate the interplay between chemical, magnetic exchange and magnetic dipolar interactions, we recorded site specific force spectroscopy data. We find that the magnetic lattice can be detected before atomic resolution is achieved, indicating that long-range magnetic dipolar forces contribute significantly to the magnetic signal. This finding suggests that magnetic force microscopy (MFM) imaging of such a nanoskyrmion lattice is feasible. Since MFM is performed at larger tip sample separations than required for MExFM the magnetic structure is less perturbed by the presence of a magnetic tip.

[1] S. Heinze et al., Nature Physics **7**, 713 (2011).
[2] U. Kaiser et al., Nature **446**, 522 (2007).
[3] R. Schmidt et al., Nano Lett. **9**, 200 (2009).

MA 22.6 Tue 11:15 HSZ 401

Energy barriers of skyrmion annihilation in Pd/Fe/Ir(111) — •Stephan von Malottki[1], Bertrand Dupé[1], Pavel Bessarab[2], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel, Germany — [2]School of Engineering and Natural Sciences - Science Institute, University of Iceland, Iceland

Magnetic skyrmions are currently discussed as promising candidates for spintronic devices [1]. The understanding of skyrmion stability in realistic systems is a key issue. The calculation of minimum energy paths (MEPs) using the geodesic nudged elastic band (GNEB)

method provides detailed information about energy barriers protecting skyrmions from other available states as well as reveals microscopic mechanisms of their formation and annihilation [2,3]. Up to now, such calculations have been performed with nearest-neighbour exchange [2,3]. Here, we investigate an ultrathin film of Pd/Fe/Ir(111) – a model system for skyrmion formation [4,5] – with atomistic spin dynamics, based on parameters obtained by density functional theory [5]. The energy barriers of skyrmion annihilation are calculated with the GNEB method, including the effects of frustrated exchange.

[1] A. Fert *et al.*, Nature Nanotech **8**, 152-156 (2013)
[2] P. Bessarab *et al.*, Computer. Phys. Comm. **196**, 335-347 (2015)
[3] I. Lobanov *et al.*, Phys. Rev. B **94**, 174418 (2016)
[4] N. Romming *et al.*, Phys. Rev. Lett. **114**, 177203 (2015)
[5] B. Dupé *et al.*, Nature Comm. **5**, 4030 (2014)

MA 22.7 Tue 11:30 HSZ 401

B-T phase diagram of Pd/Fe/Ir(111) — •Marie Böttcher[1,2], Bertrand Dupé[1,2], Jairo Sinova[2], and Stefan Heinze[1] — [1]University of Kiel, Germany — [2]University of Mainz, Germany

Skyrmions are localized and chiral non-collinear magnetic structures, which could be used as bits in data storage devices [1]. Such a device would require the stabilization and manipulation of skyrmions at room temperature. Recently, skyrmions have been stabilized and manipulated at 4.2 K in Pd/Fe/Ir(111) ultra-thin film [2]. Density functional theory calculations showed that skyrmions are stabilized by the competition between the Dzyaloshinskii-Moriya and the exchange interaction beyond the first nearest neighbor as well as the anisotropy [3, 4]. This competition can result in a spin glass behavior that has to be treated accordingly in Monte Carlo simulations. We performed parallel tempering Monte Carlo (PTMC) simulations [5] in order to calculate the B-T phase diagram of Pd/Fe/Ir(111). We identified order parameters that characterize the spin spiral, the skyrmion lattice and the isolated skyrmion phases. The calculated critical temperatures are in good agreement with previous calculations [4]. PTMC offers also the possibility to create and delete metastable skyrmions. Moreover, we used PTMC to calculate the chemical potentials of skyrmions and antiskyrmions at different magnetic fields, which indicates the possible creation of net topological charge. [1] A. Fert *et al.*, Nat. Nanotech. **8** (2013). [2] N. Romming *et al.*, Science **341** (2013). [3] B. Dupé *et al.*, Nat. comm. **5** (2014). [4] L. Rózsa *et al.*, Phys. Rev. B **93** (2016). [5] K. Hukushima *et al.*, Phys. Soc. Jap. **65** (1996).

MA 22.8 Tue 11:45 HSZ 401

Tailoring non-collinear magnetism by misfit dislocation lines — •Aurore Finco, Pin-Jui Hsu, André Kubetzka, Kirsten von Bergmann, and Roland Wiesendanger — University of Hamburg, Germany

Epitaxial ultrathin films can often exhibit reconstructed surfaces because of lattice mismatch with the substrate. Unlike in pseudomorphic films, the film structure thus induces symmetry breakings and has dramatic consequences on the magnetism. In the case of a three-layer-thick Fe ultrathin film on Ir(111), the large epitaxial strain is relieved by the formation of a dense dislocation lines network. Spin-polarized scanning tunneling microscopy investigations [1] reveal that the strain is locally varying within the Fe film and that this variation affects its non-collinear magnetic state. Two types of dislocation line regions are distinguished and show spin spirals with strain-dependent periods (between 3 nm and 10 nm). Using a simple micromagnetic model, we attribute the changes of the period of the spirals to variations of the effective exchange coupling in the magnetic film. This assumption is supported by the observed dependence of the saturation magnetic field on the period of the zero field spin spiral. Moreover, magnetic skyrmions appear in an external magnetic field [2] only in one type of dislocation line areas, which we impute to their different pinning properties. Exploiting the strain relief in epitaxial ultrathin films hence appears to be an effective way to precisely and locally control magnetic states.

[1] A. Finco et al, Phys. Rev. B, in press.
[2] P.-J. Hsu et al, Nat. Nano., advance online, 2016.

MA 22.9 Tue 12:00 HSZ 401

Hosting of spin polarized surface states in spin-orbit induced bulk band gaps of W — •Hans-Joachim Elmers[1], Dmitro Kutnyakhov[1,3], Sergej V. Chernov[1], Katerina Medjanik[1], Olena Fedchenko[1], Anna Zaporozhchenko-Zymaková[1], Martin Ellguth[1], Christian Tusche[2], Jens Viefhaus[3], and Gerd Schönhense[1] — [1]Universität Mainz — [2]FZ Jülich — [3]DESY Hamburg

Spin momentum locking of surface states has attracted great interest due to potential applications in spintronics. Normal metal surfaces like W(110) and Ir(111) show surface states with energy dispersions and spin-polarization structures, which are reminiscent of topological surface states. In order to understand this phenomenon the connection of bulk and surfaces states has to be explored. Using time-of-flight momentum microscopy [1], we measured bulk bands with soft X-ray excitation within the first 3D Brillouin zone. Surface states are determined by the same method at low photon energy. The comparison of the results reveals the hosting of surface states within the gap topology of bulk bands projected on the surface Brillouin zone. [1] D. Kutnyakhov et al., Sci. Rep. 6, 29394 (2016).

MA 22.10 Tue 12:15 HSZ 401

Adsorption of pyrene molecules on Fe/W(110) — •S. Schleicher[1], J. Rawson[2], F. Matthes[1], D. E. Bürgler[1], P. Kögerler[2], and C. M. Schneider[1] — [1]Peter Grünberg Institut (PGI-6), Forschungszentrum Jülich — [2]Institute of Inorganic Chemistry, RWTH Aachen University

The chemisorption of aromatic molecules on transition metal surfaces is governed by strong hybridization of molecular π-orbitals with spin-split d-orbitals of the substrate. The resulting spin-imbalanced molecular density of states yields an induced molecular magnetic moment for strong and spin-filter properties for weak coupling [1], respectively. We study conventional pyrene molecules as a precursor for pyrene-based double-decker molecules by spin-polarized scanning tunneling microscopy/spectroscopy (SP-STM/STS) at 4 K to investigate the adsorption and hybridization properties. Molecules are deposited in UHV at room temperature, and two atomic layers of Fe on W(110) serve as ferromagnetic substrate with perpendicular magnetization. STM images reveal that the molecules remain intact upon deposition and adsorb in a flat and unique geometry. At higher coverages they self-assemble in ordered arrays. STS data reveal broad, band-like features indicating strong molecule-surface hybridization. The well-defined adsorption geometry and the strong hybridization are key requirements for the observation of spin-filtering in double-decker molecules.

[1] K.V. Raman et al., Nature 493, 509 (2013).