MA 5: Surface magnetism and magnetic coupling phenomena (joint session MA/O/TT)

Time: Monday 9:30–13:15 Location: H53

MA 5.1 Mon 9:30 H53

Magneto-Seebeck Tunneling on the Atomic Scale — Cody Friesen, •Hermann Osterhage, Johannes Friedlein, Anika Schlenhoff, Roland Wiesendanger, and Stefan Krause — Department of Physics, University of Hamburg, Germany

The tunneling of spin-polarized electrons in a magnetic tunnel junction driven by a temperature gradient is a fundamental process for the thermal control of electron spin transport. As we have shown recently, scanning Seebeck tunneling microscopy is a technique that enables spin-averaged thermopower measurements in a metal-vacuum-metal tunnel junction with atomic-scale lateral resolution [1]. Using a magnetic tip and sample allows for the experimental investigation of the details of the magneto-Seebeck tunneling, with vacuum serving as the tunneling barrier. Heating the tip with a laser and measuring the thermopower of the junction while scanning across the spin texture of the sample leads to spin-resolved Seebeck coefficients that can be determined and mapped with atomic-scale lateral resolution [2].

The experiments on Fe/W(110) and Fe/Ir(111) will be presented and discussed in terms of spin-averaged, magneto-Seebeck and anisotropic magneto-Seebeck thermopower in an ideal single atom tunnel junction. Based on the experimental findings we propose a spin detector for spintronics applications that is solely driven by waste heat, utilizing magneto-Seebeck tunneling to convert spin information into a voltage that can be used for further data processing.

[1] C. Friesen *et al.*, J. Phys. D: Appl. Phys. **51**, 324001 (2018).
[2] C. Friesen *et al.*, Science (accepted).

MA 5.2 Mon 9:45 H53

Tunable spin-superconductor coupling of spin 1/2 molecules — •Luigi Malavolti[1,2,3], Matteo Briganti[4], Max Hänze[1,2,3], Giulia Serrano[4], Irene Cimatti[4], Gregory McMurtie[1,2,3], Edwige Otero[5], Philippe Ohresser[5], Federico Totti[4], Matteo Mannini[4], Roberta Sessoli[4], and Sebastian Loth[1,2,3] — [1]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Stuttgart, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [3]Max Planck Institute for Solid State Research, Stuttgart, Germany — [4]Università degli Studi di Firenze, Sesto Fiorentino (Firenze), Italy — [5]Synchrotron SOLEIL, Gif-sur-Yvette, France

Assemblies of magnetic molecules with long coherence time are being investigated as quantum bits that may be embedded in superconducting resonators [1]. Bringing the spin center into contact with the superconducting surface maximizes coupling to the resonator but may also reduce the spin's coherence time by increased scattering of quasiparticles. Here we report the capability to tune the exchange coupling of spin 1/2 vanadyl phthalocyanine molecules (VOPc) with a Pb superconducting surface. This system offers a fully tunable spin superconductor coupling from uncoupled spin to strongly coupled, screened spin [2]. These findings highlight the possibility to scale superconducting resonator experiments down to single molecule sensitivity.

[1] M. D. Jenkins, et al., Dalt. Trans. 2016, 45, 16682.
[2] L. Malavolti, et al., Nano Letters DOI: 10.1021/acs.nanolett.8b03921

MA 5.3 Mon 10:00 H53

Reduced magnetic moment in polycrystalline Co thin films — •Sabine Pütter[1], Amir Syed Mohd[1], Artur Glavic[2], Stefan Mattauch[1], and Thomas Brückel[3] — [1]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science at MLZ, Garching, Germany — [2]Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut, Villigen PSI, Switzerland — [3]Forschungszentrum Jülich GmbH, Jülich Centre for Neutron Science (JCNS) and Peter Grünberg Institute (PGI): JCNS-2, PGI-4: Quantum Materials and Collective Phenomena, Jülich, Germany

The variation of the magnetic moment with dimensionality of magnetic materials, i. e. from atoms to bulk, is a longtime studied issue. For thin films, a constant magnetic moment is often assumed in modelling, however, intermixing and surface roughness may also have an impact.

With the help of polarised neutron reflectometry (PNR) we study the magnetic moment of polycrystalline Co/20 nm Pt/MgO(001). The samples were grown by molecular beam epitaxy and subsequently measured with PNR at room temperature and in saturation in UHV.

Our results reveal the vertical depth profile of the magnetic moment of the Co films. In fact, the magnetisation is not constant but smeared out at the edges, due to roughness. Measurements at different film thicknesses reveal the evolution of the magnetic moment which is separated in a bulk and a surface contribution and discussed with respect to published results.

This project has received funding from the EU's H2020 research and innovation programme under grant agreement n. 654360.

MA 5.4 Mon 10:15 H53

Investigation of the structural and magnetic properties of self-organized MnO_2 chains on Pt(001) — •Chong-Heeon Park, Martin Schmitt, Matthias Vogt, and Matthias Bode — Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, Am Hubland, Würzburg, Germany

Recently, the self organized growth of 3d transition metal oxide (TMO) chains on Ir(001) and Pt(001) was investigated by STM, LEED, and DFT calculations [1,2]. Along with the structural (3×1) phase of the MnO_2 chains, antiferromagnetic (AFM) coupling on Ir(001) was predicted along and between adjacent chains. In this study, we investigate the structural and magnetic properties of self-organized MnO_2 chains, grown on Pt(001), with low temperature spin-polarized scanning tunneling microscopy (SP-STM). Similar to Ir(001), we observe a perfectly ordered (3×1) structural phase with an inter-chain periodicity of $3a_{\mathrm{Pt}}$. When these chains are scanned with either an in-plane or out-of-plane polarized tip (Cr-coated W tip), we observe a spin structure that can be modeled by a (15×2) magnetic unit cell. It is formed by AFM coupling along the MnO_2 chains and 72° spin spiraling across the chains.

[1] P. Ferstl, *et. al.*, Phys. Rev. B. **96**, 085407 (2017)
[2] P. Ferstl, *et. al.*, Phys. Rev. Lett. **120**, 089901 (2018)

MA 5.5 Mon 10:30 H53

Coexistence of RW-AFM and 3Q state in the Mn/Re(0001) monolayer investigated with SP-STM — •Jonas Spethmann, Jonas Sassmannshausen, André Kubetzka, Roland Wiesendanger, and Kirsten von Bergmann — Institut für Nanostruktur- und Festkörperphysik, Hamburg

Exciting new physics is predicted to arise at the interface of non-collinear magnetic and superconducting materials. In order to study this subject, promising model systems need to be found. Therefore, we investigated the growth and the magnetism of a monolayer of Mn on Re(0001) using spin-polarized scanning tunneling microscopy.

Re becomes superconducting below a critical temperature of 1.69 K, which is a temperature well accessible with modern cryogenics. Mn typically prefers an antiferromagnetic order. If it is forced into a hexagonal atomic lattice, like the (0001) surface of Re, complex magnetic structures might arise due to geometric frustration. Furthermore, it is known that differently stacked monolayers of the same material can show different magnetic ground states. By adding Co to the Re surface prior to the Mn deposition, we managed to grow the Mn in two different stackings. We show that the fcc stacking exhibits a row-wise antiferromagnetic state with three symmetry-equivalent rotational domains. The hcp-stacked area shows a magnetic texture that is compatible with a so-called 3Q state [1], which is a non-collinear state with four spins in the unit cell that have an angle of 109.4° between each other.

[1] Ph. Kurz, G. Bihlmayer, K. Hirai, and S. Blügel. Phys. Rev. Lett., 86:1106-1109, Feb 2001.

MA 5.6 Mon 10:45 H53

Zero field sub-10 nm skyrmions and antiskyrmions in ultrathin Co films — •Sebastian Meyer[1], Stephan von Malottki[1], Marco Perini[2], André Kubetzka[2], Roland Wiesendanger[2], Kirsten von Bergmann[2], and Stefan Heinze[1] — [1]Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität zu Kiel — [2]Department of Physics, University of Hamburg

Non-collinear spin structures such as skyrmions are being intensively studied due to their promise for spintronic devices [1]. For applications it is envisioned to use isolated skyrmions with diameters below 10 nm that are stable at zero magnetic field [2]. Here, we use density functional theory and atomistic spin dynamics simulations [3] to show how we can stabilize magnetic skyrmions and antiskyrmions in ultra-

thin Co films in zero external magnetic field. In contrast to Co being a ferromagnetic material with a strong exchange stiffness we obtain very large frustration effects in the magnetic interactions of ultrathin Co films which imperatively requires an atomistic spin model. We find that the frustration enhances the energy barriers for skyrmions and antiskyrmions against collapse into the ferromagnetic ground state.

[1] A. Fert, V. Cros, and J. Sampaio, Nat. Nanotech. **8**, 152 (2013)
[2] A. Fert, N. Reyren, and V. Cros, Nat. Rev. Mater. **2**, 17031 (2017)
[3] S. Haldar, *et al.*, Phys. Rev. B **98**, 060413 (2018)

MA 5.7 Mon 11:00 H53

Scanning Seebeck Tunneling Microscopy — Cody Friesen, Hermann Osterhage, Johannes Friedlein, Anika Schlenhoff, Roland Wiesendanger, and •Stefan Krause — Department of Physics, University of Hamburg, Germany

The field of spin caloritronics is specifically concerned with effects that arise in the presence of a temperature gradient, and their effect on spin-dependent electronic transport. The advent of increasingly detailed techniques for nano-scale fabrication, measurement, and manipulation have led to an improved understanding of spin caloritronic effects, and their potential uses in engineering sensors and devices at all size scales, e.g. waste-heat recycling and efficient computing.

Within this field, the thermally induced Seebeck tunneling of electrons is a fundamental effect. In our experiments, it is studied in a metal-vacuum-metal junction using scanning tunneling microscopy (STM). Selective heating of the tip with a laser generates a well-defined temperature difference at the tunnel junction. The thermovoltage between the tip and the sample is measured with atomic-scale lateral resolution and related to the band structure of the junction, as revealed by local tunneling spectroscopy. Tunnel current rectification experiments in compensated conditions allow for a direct measurement of the Seebeck coefficient without the need for tip heating, thereby realizing Seebeck mapping on the atomic scale. The STM studies will be presented and discussed in terms of thermally induced tunneling across a single-atom ideal vacuum barrier.

C. Friesen *et al.*, J. Phys. D: Appl. Phys. **51**, 324001 (2018).

15 min. break

MA 5.8 Mon 11:30 H53

***Ab initio* simulations of 2D-materials interacting with magnetic clusters and 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 elucidate how the subtle interplay between the electrostatic, the weak van der Waals and the strong chemical interactions determines the geometric, electronic and magnetic structure of hybrid systems formed by magnetic substrates and atomic clusters with 2D materials as transition metal dichalcogenites (TMDs) monolayers and graphene (Gr). More precisely, the interaction between 2D and magnetic materials (i.e. surfaces, atomic clusters) shapes the (i) spin-polarization, (ii) magnetic exchange couplings, (iii) magnetic moments and (iv) their orientation of the hybrid systems. This work has been supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project number 277146847 - CRC 1238 (C01).

[1] R. Brede *et al.*, Nature Nanotech. **9**, 1018 (2014).
[2] F. Huttmann *et al.*, Phys. Rev. Lett. **115**, 236101 (2015).
[3] F. Huttmann *et al.*, Phys. Rev. B **95**, 075427 (2017).
[4] V. Caciuc *et al.*, Phys. Rev. Mat. **2**, 084001 (2018).

MA 5.9 Mon 11:45 H53

Electronic and magnetic structure of monolayer and double layer GdFe/W(100) surface alloy — •Vikas Kashid, Gustav Bihlmayer, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The rare earth-transition metal alloy films are attractive materials for high density mageto-optic storage due to their magnetic recording and magneto-optical anisotropy. We investigate by virtue of spin density functional theory (DFT) as realized in the FLEUR code [1], the structural and magnetic properties of the monolayer and double layer film of GdFe on the W(100) substrate in c(2×2) unit cell, where highly localized Gd-4f orbitals are treated within GGA+U method. Gd buckles outward by 0.96 Å and 0.88 Å with respect to Fe atoms in the monolayer and double layer surfaces, respectively. The calculated monolayer and double layer GdFe/W(100) exhibits a checkerboard antiferromagnetic ground state configurations between Fe and Gd atoms. The Fe atoms in the double layer GdFe/W(100) exhibit large magnetic moment of 2.30 μ_B, larger than that of 1.45 μ_B in the monolayer film. The easy axes for the spin quantization arising from spin-orbit coupling in both the surfaces lie in the surface plane and along the diagonal of c(2×2) cell with the magneto-crystalline anisotropy energy larger for the double layer than for the monolayer.

We acknowledge discussions with Prof. Alexander Ako Khajetoorians.

[1] www.flapw.de

MA 5.10 Mon 12:00 H53

Nonlocal electron correlations in an itinerant ferromagnet — •Christian Tusche[1,2], Martin Ellguth[3], Vitaliy Feyer[1], Alexander Krasyuk[3], Carsten Wiemann[1], Jürgen Henk[4], Claus M. Schneider[1,2], and Jürgen Kirschner[3,4] — [1]Forschungszentrum Jülich GmbH, Peter Grünberg Institut (PGI-6), Jülich — [2]Fakultät für Physik, Universität Duisburg-Essen, Duisburg — [3]Max-Planck-Institut für Mikrostrukturphysik, Halle — [4]Martin-Luther-Universität Halle-Wittenberg, Halle

A fundamental concept in solid state physics describes the electrons in a solid by the relation of the energy E vs. the crystal momentum $\boldsymbol{k}$ in a band structure of independent quasi particles. However, even for the most simple elemental ferromagnets, electron correlations are prevalent, requiring descriptions of their electronic structure beyond this simple single-electron picture. Our comprehensive measurements of the spectral-function by spin-resolved momentum microscopy show that in itinerant ferromagnets like cobalt these electron correlations are of nonlocal origin. This manifests in a complex self-energy $\Sigma_\sigma(E,\boldsymbol{k})$ that disperses as function of spin σ, energy E, and momentum $\boldsymbol{k}$. Combining the experiments with one-step photoemission calculations, we quantify the dispersion of the self-energy over the whole Brillouin zone [1]. The observation of nonlocal electron correlations in cobalt substantially affects our understanding of electron interactions, and makes itinerant ferromagnets a paradigmatic test case for the interplay between band structure, magnetism, and correlations.

[1] C. Tusche et al., Nat. Commun. 9, 3727 (2018)

MA 5.11 Mon 12:15 H53

Magnetic coupling of ferromagnetic $SrRuO_3$ epitaxial layers separated by ultrathin spacers with large spin-orbit coupling — •Lena Wysocki[1], Michael Ziese[2], Lin Yang[1], Jörg Schöpf[1], Rolf Versteeg[1], András Kovács[3], Lei Jin[3], Felix Gunkel[4], Regina Dittmann[4], Paul H.M. van Loosdrecht[1], and Ionela Lindfors-Vrejoiu[1] — [1]University of Cologne, Institute of Physics II, Germany — [2]Felix Bloch Institute for Solid State Physics, University of Leipzig, Germany — [3]Forschungszentrum Jülich, PGI-5, Germany — [4]Forschungszentrum Jülich, PGI-7, Germany

$SrRuO_3$, a 4d ferromagnet exhibiting several Weyl nodes in proximity of the Fermi level, offers a rich playground to tailor its physical properties in epitaxial heterostructures and superlattices. Interfacing $SrRuO_3$ with large spin-orbit coupling perovskite oxides, as $SrIrO_3$, results in intriguing physical phenomena like pronounced anomalies in the Hall resistivity, attributed either to the existence of Néel type skyrmions or to modifications of the Berry curvature of electronic bands with non-trivial topology. The nature of the coupling between the magnetic layers in such superlattices is an important component influencing the global multilayer properties. We present the investigation of the magnetic coupling between ferromagnetic $SrRuO_3$ layers separated by ultrathin spacers of perovskite oxides exhibiting strong spin-orbit coupling[1]. The type and strength of the magnetic interlayer coupling was determined by major and minor magnetization measurements for various spacer geometries.

[1] L. Wysocki et al., Appl. Phys. Lett. **113**, 192402 (2018)

MA 5.12 Mon 12:30 H53

Charge-transfer driven ferromagnetism in a disordered three-dimensional 3d-5d spin system — •Philipp Komissinskiy[1], Supratik Dasgupta[1], Ilya Radulov[1], Andrei Rogalev[2], Fabrice Wilhelm[2], Marton Major[1], and Lambert Alff[1] — [1]Institute of Materials Science, Technische Universität Darmstadt, Alarich-Weiss-Straße 2, 64287 Darmstadt, Germany — [2]European Synchrotron Radiation Facility, 71 Avenue des Martyrs, 38000 Grenoble, France

A three-dimensional disordered spin system consisting of the 3d tran-

sitional metal ion Mn^{4+} with strong electronic correlations and the heavy 5*d* transition metal ion Ir^{4+} with large spin-orbit coupling has been investigated in form of a perovskite thin film. The studied compound of the composition $SrMn_{0.5}Ir_{0.5}O_3$ does not exist as bulk or single crystal, but can be stabilized by epitaxy as fully disordered double perovskite thin film onto $SrTiO_3$ single-crystal substrate using pulsed laser deposition. As measured by X-ray circular dichroism, the ground state of this material is ferromagnetic with both, Mn and Ir, spins aligned in parallel. This unusual ground state can be qualitatively explained by charge-transfer driven magnetic exchange involving the effective $J = 1/2$ state of Ir. Due to the coexistence of competing magnetic interactions and randomness in the system, spin-glass features are observed at low temperatures.

MA 5.13 Mon 12:45 H53

Thickness independent magnetism of the magnetic MAX phase films $(Cr_{0.5}Mn_{0.5})_2GaC$ — •Iuliia P. Novoselova[1], Andrejs Petruhins[2], Ulf Wiedwald[1], Johanna Rosen[2], Michael Farle[1], and Ruslan Salikhov[1] — [1]Faculty of Physics and Center for Nanointegration (CENIDE), University of Duisburg-Essen, Duisburg, Germany — [2]Department of Physics, Linköping University, Linköping, Sweden

Atomically laminated magnetic MAX phases $M_{n+1}AX_n$ (n = 1, 2, 3) have attracted interest as novel materials exhibiting both ceramic and metallic properties. Here 12.5 to 156 nm thick films $(Cr_{0.5}Mn_{0.5})_2GaC$ were investigated by ferromagnetic resonance, electron scanning microscopy and magnetometry. The X-ray diffraction reveals a high crystalline quality and phase purity. Magnetocrystalline anisotropy energy density of 140 mT as well as magnetization of 240 kA/m are found to not depend on thickness. All films are environmentally stable without a change of magnetic properties for more than one year at ambient conditions and without any protection layer. Such independence on thickness combined with the chemical stability makes the $(Cr_{0.5}Mn_{0.5})_2GaC$ films attractive for various applications such as spintronic devices or corrosion resistant magnetic sensors. This work is supported by DFG, Grant SA 3095/2-1 and DAAD Doctoral Programmes in Germany,57214224. [1] M. W. Barsoum, Prog. Solid State Chem. 28, 201 (2000).[2] A. Petruhins, et al. Journal of Mat. Sci. 50-13, 4495 (2015).[3] R. Salikhov, et al. Mat. Res, Lett. 3-3, 156-160 (2015).[4] I. P. Novoselova, Sci. Reports 8, 2637 (2018).

MA 5.14 Mon 13:00 H53

The polar distortion and its relation to magnetic order in multiferroic HoMnO3 — •Nazaret Ortiz[1], Yoav William Windsor[2], Jose Renato Linares Mardegan[1], Christof Schneider[1], Gareth Nisbet[3], and Urs Staub[1] — [1]Paul Scherrer Institute, Swiss Light Source, Switzerland — [2]Fritz Haber Institut der Max Planck Gesellschaft, Germany, — [3]Diamond Light Source, United Kingdom

The orthorhombic (Pbnm) HoMnO3 is of particular interest due to its high magnetically-induced polarization values (P) and magnetoelectric coupling strength. The mechanism behind this involves high magnetic frustration, which results in a magnetic order that creates a distortion in the crystal lattice. This distortion breaks inversion symmetry and creates a macroscopic electric polarization P along the a-axis.

We investigated the atomic distortion to identify the broken symmetry of Pbnm in thin films of HoMnO3 at low temperature and the relation between the magnetic order of Ho and the structural distortion. Forbidden reflections for Pbnm has been observed, showing that the distortion does not exclusively affect to the atomic position along the polar axis, it also moves atoms along other directions. Moreover, studying reflections with component along the polar axis we observe the polar distortion directly, visualized by the difference diffraction intensity from opposite domains.