MA 15: Magnetism Poster A

Time: Tuesday 10:00–13:00 Location: Poster E

MA 15.1 Tue 10:00 Poster E

Asymmetric Skyrmion Hall Effect in Systems with Hybrid Dzyaloshinskii-Moriya Interaction — Kyoung-Whan Kim[1,2], Kyoung-Woong Moon[3], Nico Kerber[1,4], •Jonas Nothhelfer[1], and Karin Everschor-Sitte[1] — [1]Institute of Physics, JGU Mainz, Germany — [2]Center for Spintronics Korea Institute of science and Technology, Korea — [3]Spin Convergence Research Team, KRISS Daejeon, Korea — [4]Graduate School MAINZ, Staudinger Weg 9, Mainz, Germany

We demonstrate that magnetic skyrmions can move along the direction of a current without showing a skyrmion Hall effect in ferromagnetic thin films that are subject to both structural and bulk inversion asymmetry.[1] In such systems, a hybrid type of the Dzyaloshinskii-Moriya interaction (DMI) arises as a mixture of interfacial and bulk DMIs. We discuss the current-induced skyrmion dynamics and find that the spin-orbit-torque-induced skyrmion Hall angle is asymmetric for the two different skyrmion polarities, even allowing one of them to be tuned to zero. Our results can be understood within a simple picture by using a global spin rotation which maps the hybrid DMI model to an effective model containing purely interfacial DMI. In this sense, the formalism directly reveals the effective spin torque and effective current acting on systems with a hybrid DMI. We propose several experimental ways to achieve the necessary straight skyrmion motion for racetrack memories, even without any interaction with another magnet or an antiferromagnet. [1] K-W. Kim, K-W. Moon, N. Kerber, J. Nothhelfer, K. Everschor-Sitte, Phys. Rev. B **97**, 224427 (2018)

MA 15.2 Tue 10:00 Poster E

Hall effect and magnetoelectric effect in systems with toroidal order — •Oliver Busch[1], Börge Göbel[2], and Ingrid Mertig[1,2] — [1]Institut für Physik, Martin-Luther-Universität, D-06120 Halle — [2]Max-Planck-Institut für Materialforschung, D-06120 Halle

In systems that exhibit a toroidal moment the magnetoelectric effect arises due to antisymmetric time or space inversion symmetry [1]. The Hall effect and the magnetoelectric effect have already been predicted in metals without local inversion symmetry, described by a effective tight-binding model [2].

We examine a square-octagon lattice with regard to Hall effect and magnetoelectric effect based on a full *sp*-tight-binding model. Our model includes the description of coupling to the magnetic texture that causes toroidal order, spin-orbit coupling and *sp*-hybridization. We confirmed an asymmetric shift of the band structure in the direction of the toroidal moment that changes to a symmetric shift, if there is just *sp*-hybridization and spin-orbit coupling, but no toroidal order.

Breaking the combined TI-symmetry yields the topological Hall effect without spin-orbit coupling resp. the anomalous Hall effect in combination with spin-orbit coupling. Furthermore we show that the system gives rise to a transverse magnetoelectric Hall effect that vanishes for non toroidal order e.g. flux order. Last but not least we analyse the connection of the asymmetric shift and the magnetoelectric effect.

[1] N. Spaldin *et al.*, J. Phys.: Condens. Matter **20**, 434203 (2008).
[2] S. Hayami *et al.*, Phys. Rev. B **90**, 024432 (2014).

MA 15.3 Tue 10:00 Poster E

Electrical writing, deleting, reading, and moving of magnetic skyrmioniums in a racetrack device — Börge Göbel[1], •Alexander F. Schäffer[2], Jamal Berakdar[2], and Ingrid Mertig[1,2] — [1]Max-Planck-Institut für Mikrostrukturphysik, D-06120 Halle (Saale), Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, D-06099 Halle (Saale), Germany

A magnetic skyrmionium (also called 2π-skyrmion) can be understood as a skyrmion — a topologically non-trivial magnetic whirl — which is situated in the center of a second skyrmion with reversed magnetization.

In this contribution, we propose a new optoelectrical writing and deleting mechanism for skyrmioniums in thin films, as well as a reading mechanism based on the topological Hall voltage. Furthermore, we point out advantages for utilizing skyrmioniums as carriers of information in comparison to skyrmions with respect to the current-driven motion.

We simulate all four constituents of an operating skyrmionium-based racetrack storage device: creation, motion, detection and deletion of bits. The existence of a skyrmionium is thereby interpreted as '1' and its absence as '0' bit.

MA 15.4 Tue 10:00 Poster E

Atomistic simulation of electric field assisted writing and deleting of magnetic skyrmions — •Moritz A. Goerzen[1], Stephan v. Malottki[1], Pavel F. Bessarab[2], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel — [2]School of Engineering and Natural Sciences - Science Institute, University of Iceland

Future magnetic skyrmion technologies require a high degree of control of writing and deleting processes. While first experimental results demonstrate, that skyrmions can be nucleated and annihilated at will by varying electric field of a scanning-tunneling microscope tip [1], a theoretical understanding of the underlying effects is still missing. We attempt to clarify the role of the electric field in skyrmion creation and annihilation processes by means of atomistic spin dynamics simulations, minimum energy path calculations, transition state theory and density functional theory [2]. The influence of the electric field is modeled within linear response approximation to the surface magneto-electric effect and Rashba effect. We systematically study how the ground state and skyrmion stabilities are influenced by this parameter change caused by the electric field in Pd/Fe/Ir(111) system.
[1] Hsu *et al.*, Nat. Nano. **12**, 123 (2017)
[2] Haldar *et al.*, Phys. Rev. B **98**, 060413 (2018)

MA 15.5 Tue 10:00 Poster E

Anomalous Hall effect and magneto-optical Kerr effect of SrRuO3 based epitaxial multilayers — •LIN YANG, JÖRG SCHÖPF, LENA WYSOCKI, ROLF VERSTEEG, PAUL VAN LOOSDRECHT, and IONELA LINDFORS-VREJOIU — Universität zu Köln, II. Physikalisches Institut, 50933 Köln, Germany

Ferromagnetic heterostructures with strong interfacial Dzyaloshinskii-Moriya interaction (DMI) have been extensively studied, because they can host topologically non-trivial spin textures, such as skyrmions. The topological magnetic structures stabilized by interfacial DMI can be probed by the occurrence of the topological Hall effect (THE) in an experimental setup in which the anomalous Hall effect (AHE) can be simultaneously measured with the magneto-optic Kerr effect (MOKE). Here, we focus on the study of the AHE and MOKE of epitaxial heterostructures composed of ferromagnetic SrRuO3 and large spin-orbit coupling perovskite oxides, such as SrIrO3. We aim to elucidate the origins of the anomalies of the Hall resistivity exhibited by these heterostructures, as they have been previously assigned to the formation of skyrmions.

MA 15.6 Tue 10:00 Poster E

Floquet dynamics of a chiral magnet — •Nina del Ser and Achim Rosch — University of Cologne

We investigate how the magnon spectrum of a chiral magnet is affected by the application of a time-dependent magnetic field. Our model is a 3D spin lattice Hamiltonian with Heisenberg and Dzyaloshinskii-Moriya interactions driven by a spatially uniform, sinusoidally time-varying magnetic field. We expand analytically around the ground state conical spin arrangement using the Holstein-Primakoff formalism for bosonic excitations. Floquet theory is used to make progress with the time-dependent problem. We investigate the resulting Floquet band structure and study the role of possible instabilities which may occur when the external driving frequency resonantly couples different branches of the magnon spectrum.

MA 15.7 Tue 10:00 Poster E

Production of Inplane Skyrmion — •Venkata Krishna Bharadwaj[1], Kyoung-Whan Kim[2], and Karin Everschor-Sitte[1] — [1]Johannes Gutenberg-University, Mainz — [2]Center for Spintronics, Korea Institute of Science and Technology, South Korea

Magnetic skyrmions are topological magnetic whirls with a trivial magnetization configuration at their boundary. In thin films, most studies consider skyrmions with an out-of-plane easy axis anisotropy, where the magnetization at both the skyrmion centre and boundary is pointing perpendicular to the plane. In this work we analyze skyrmions in inplane magnets, [1] which have recently been observed [2,3]. We do a comparative study of their existence, stability and their properties to those of out-of-plane skyrmions. While in the absence of stray fields a global spin rotation maps an inplane skyrmion to its out-of-plane counterpart exactly, the presence of magnetostatic interactions changes the size and profile of the skyrmion. Furthermore, as the rotational symmetry around the axis perpendicular to the plane is broken, we study the skyrmion dynamics as a function of the relative angle between current and inplane magnetization direction. We also show by means of micromagnetic simulations that the 'blowing bubbles' technique, i.e. the creation of skyrmions due to current flow through constricted geometries, works for inplane skyrmions similar to their out-of-plane analogues [4]. [1] G. Chen et al., Nat. Commun. 8, 15302 (2017), [2] S. A. Meynell, et al., Physical Review B 96, 054402 (2017), [3] T. Yokouchi, et al., Journal of the Physical Society of Japan 84, 104708 (2015) [4] W.Jiang et al., Science 349, 283 (2015)

MA 15.8 Tue 10:00 Poster E

Optimizing spin-orbit torques and DMI in multilayer heterostructures — •Franziska Martin[1], Joel Cramer[1,2], Kyujoon Lee[1], Tom Seifert[3], Alexander Kronenberg[1], Felix Fuhrmann[1], Gerhard Jakob[1,2], Martin Jourdan[1,2], Tobias Kampfrath[3,4], and Mathias Kläui[1,2] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, 55099 Mainz, Germany — [2]Graduate School of Excellence Materials Science in Mainz, 55128 Mainz, Germany — [3]Department of Physical Chemistry, Fritz Haber Institute of the Max Planck Society, 14195 Berlin, Germany — [4]Department of Physics, Freie Universität Berlin, 14195 Berlin, Germany

The use of thin films in magnetic storage devices requires suitable materials that enable for instance ultra-fast and low power domain wall motion. The research of recent years has shown that tri-layers consisting of a heavy metal (HM), a ferromagnetic (FM) and an oxide layer are a promising system for spintronic applications [1]. In these, the combination of large spin-orbit torques [2] and chiral Néel domain walls due to the Dzyaloshinskii-Moriya interaction (DMI) [1] allow for fast domain wall motion. We have recently identified CuIr alloys with strong spin-orbit coupling leading to a large spin hall angle in the HM layer [2][3]. Making use of the large spin-orbit torques in Cu60Ir40, we quantify the DMI in a tri-layer system by current induced domain wall motion [4]. References: [1] A. Brataas et al., Nature Nano 9, 86 (2014), [2] J. Cramer et al., Nano Lett. 18, 1064 (2018), [3] T. Seifert et al., Nature Photon. 10, 483 (2016), [4] F. Martin et al., (in preparation)

MA 15.9 Tue 10:00 Poster E

Dipolar stabilized bubble-like skyrmions in Fe/Gd multilayers — •Michael Heigl[1], Zahra Inanloo Maranloo[1], Henrik Gabold[2], Peter Böni[2], and Manfred Albrecht[2] — [1]Experimental Physics IV, Institute of Physics, University of Augsburg, 86159 Augsburg, Germany — [2]Physics Department E13, Technical University of Munich, 85748 Garching, Germany

Magnetic skyrmions are topologically nontrivial chiral spin textures. Most skyrmionic structures studied in today's research are stabilized by the Dzyaloshinskii-Moriya interaction. In this work, we present a topologically similar spin structure stabilized by the competition of long-range dipolar energy in a thin film and domain wall energy. These chiral bubbles can be also described as dipolar stabilized skyrmions. [1]

We studied highly tunable ferrimagnetic multilayers consisting of Fe, Co and Gd. The layer structures with up to 80 bilayer repetitions are known for forming dipolar stabilized skyrmions [2]. They were magnetron sputtered at room temperature with each layer being thinner than 0.5 nm. We investigated dependent on composition, strain, field and temperature the formation of skyrmions and skyrmion lattices by SQUID magnetometry, magnetic force and lorentz transmission electron microscopy.

References:

[1] N. Nagaosa and Y. Tokura, Nat. Nanotech. 8, 899 (2013).
[2] S. A. Montoya et. al., Phys. Rev. B 95, 024415 (2017).

MA 15.10 Tue 10:00 Poster E

Spin structures in Fe/Rh bilayers on Re(0001) — •Souvik Paul, Stephan von Malottki, and Stefan Heinze — Institute of Theoretical Physics and Astrophysics, Christian-Albrechts-Universität zu Kiel, Germany

Transition-metal-superconductor hybrid systems are promising candidates for realizing Majorana bound states, useful for topological quantum computation [1,2]. The prerequisite is a complex spin structure within the transition-metal layer. Here, we study Fe/Rh and Rh/Fe bilayers on Re(0001), a 5d transition-metal substrate with large spin-orbit coupling (SOC) strength which becomes superconducting at $T = 2.4$ K. Previously, it has been shown that Rh/Fe bilayers on Ir(111) can exhibit intriguing spin structures due to the competition of Dzyaloshinskii-Moriya interaction and higher-order exchange interactions [3]. Using density functional theory (DFT), we explore the magnetic phase space by calculating the energy dispersion of homogeneous flat spin spirals with and without SOC and by computing multi-Q states. From our DFT calculations, we parametrize an atomistic spin model which we study using spin dynamics simulations. This allows us to explore complex magnetic structures beyond those studied explicitly by DFT.

[1] H. Kim *et al.*, Sci Adv. **4**, eaar5251 (2018).
[2] A. Palacio-Morales *et al.*, arXiv:1809.04503.
[3] N. Romming*et al.* , Phys. Rev. Lett. **120**, 207201 (2018).

MA 15.11 Tue 10:00 Poster E

Magnetization hysteresis extraction from MFM images of ultra-thin SrRuO3-films — •Gerald Malsch[1], Dmytro Ivaneiko[1], Peter Milde[1], Lena Wysocki[2], Ionela Lindors-Vrejoiu[2], and Lukas Eng[1] — [1]TU Dresden, Institute for Applied Physics, TU Dresden, 01062 Dresden, Germany — [2]I. Physikalisches Institut, Universität zu Köln, 50937 Köln, Germany

Magnetic force microscopy (MFM) allows the imaging of the domain nucleation and growth during the magnetic switching of a ferromagnetic material. However, as the MFM signal strength cannot be directly translated to a local magnetization and the magnetization of the MFM tip itself is affected by the external field, the extraction of a full hysteresis loop from the analysis of MFM images is difficult. We present an algorithm using Otsu's thresholding method and two fixed thresholds that allows the extraction of a full approximate hysteresis loop from MFM images alone.

We exemplify our method with SrRuO3 (SRO) thin films grown on a stepped (100)-SrTiO3 substrate. SRO shows a strong dependency of the magnetic properties on the layer thickness [1], which we demonstrate by correlating the hysteresis data with atomic force measurements, and separately obtaining a hysteresis for each thickness.

[1] K. Ishigami et al, *Phys. Rev. B* 92, 064402 (2015)

MA 15.12 Tue 10:00 Poster E

Dzyaloshinskii-Moriya Interaction using Spin-Spirals in First Principle Calculations — •Marius Weber[1,2], Ashok Pokhrel[1], Hans Christian Schneider[2], Tim Mewes[1], and Claudia Mewes[1] — [1]The University of Alabama, Tuscaloosa, USA — [2]University of Kaiserslautern, Kaiserslautern, Germany

The Dzyaloshinskii-Moriya Interaction (DMI) is an anti-symmetric exchange interaction and plays a crucial role in the generation of magnetic skyrmions. In order to utilize the DMI one needs a system with broken inversion symmetry, which can be realized in bulk with inherent broken inversion symmetry or in asymmetric multilayer structures, where a ferromagnetic metal is sandwiched between two different nonmagnetic metals with high spin orbit coupling. This work focuses on the analysis of the DMI vector in multilayer structures, such as Platinum/Cobalt/Iridium. The simulations employ first principles calculations based on Density Functional Theory (DFT) using the Vienna Ab initio Package (VASP). To determine the DMI vector we use a constrained simulation method and different spin spiral configurations [1,2]. Due to the anti-symmetric character of the DMI interaction one can extract the DMI contribution by comparing clockwise and anticlockwise spin spiral configurations.

Part of this project was sponsored by NSF CAREER #1452670 and DARPA #D18AP00011. M. Weber would like to thank the MINT center for financial support.

[1] Yang et al., Phys. Rev. Lett. 115, 267210 (2015)
[2] Xiang et al., Phys, Rev. B 84, 224429 (2011)

MA 15.13 Tue 10:00 Poster E

Temperature dependent investigation of stripe morphology and DMI determination from stripe width measurements in multilayer stacks — Nico Kerber[1,2], Kai Litzius[1,2,3], Jakub Zazvorka[1], Niklas Keil[1], Jonas Nothhelfer[1], Pedram Bassirian[1], •Boris Seng[1,2], Marco Asa[4], Ivan Lemesh[5], Markus Weigand[3], Simone Finizio[6], Jörg Raabe[6], Geoffrey D. Beach[5], and Mathias Kläui[1,2] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany. — [2]Graduate School of Excellence Materials Science in Mainz, 55128 Mainz, Germany. — [3]Max Planck Institute for Intelligent Systems, 70569 Stuttgart, Germany. — [4]Department of Physics, Politecnico di Milano, 20133 Milano, Italy. — [5]Department of Materials Science and ENgineering, Massassuchsetts Institute of Technology, Cambridge, Massassuchets 02139, USA. — [6]Swiss Light Source, Paul Scherrer Institut, Villigen PSI CH-5232, Switzerland.

The Dzyaloshinskii-Moriya Interaction (DMI) is recently in the focus of spintronics, due to its fundamental role in the stabilization of chiral magnetic textures in thin films, such as magnetic skyrmions and chiral domain walls. Since for applications good spin structure stability is required across a certain temperature range, the temperature dependence of the DMI is of great interest.

In this work, we investigate the temperature dependence of the DMI, using high-resolution transmission x-ray microscopy to image the evolution of spin textures with temperature and magnetic field in Pt/CoFeB/MgO systems.

MA 15.14 Tue 10:00 Poster E

Semi-analytical approaches for the radius of skyrmions in thin magnetic films — •Fabian R. Lux, Bernd Zimmermann, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, D-52425 Jülich

The skyrmion radius is an important quantity for any skyrmion characterisation, motion and device concept. A closed analytic expression mapping micromagnetic parameters (A, D, K, H, M_s) to the skyrmion radius is unknown. Minimizing the micro-magnetic energy functional for the case of skyrmions in thin magnetic films is equivalent to the solution of the associated Euler-Lagrange equations – a set of highly nonlinear differential equations with no hope for an exact global solution in terms of closed form expressions [1]. However, as we demonstrate, the local analytic properties put strong constraints on possible trial functions which allow us to derive approximate results for the skyrmion radius, valid for a wide range of experimental parameters. Magnetostatic interactions can be included by renormalizing the material parameters for magnetocrystalline anisotropy energy and Dzyaloshinskii-Moriya interaction. Extending previous attempts to this problem [2-4], our approach gives a deep insight into the physical mechanisms by which a competition between local degrees of freedom condenses into an expression for the skyrmion radius.

[1] Leonov, A. O., *et al.* New J. Phys. **18**, 065003 (2016)
[2] Bernand-Mantel, A., *et al.* SciPost Phys. **4**, 027 (2018)
[3] Büttner, F., *et al.*, Sci. Rep. **8**, 4464 (2018)
[4] Wang, X. S., *et al.* Commun. Phys. **1**, 31 (2018)

MA 15.15 Tue 10:00 Poster E

Novel Topological Spin Textures in Helimagnetic FeGe — •Erik Lysne[1,2], Mariia Stepanova[1,2], Peggy Schoenherr[3], Jan Müller[4], Laura Köhler[5], Achim Rosch[4], Naoya Kanazawa[6], Yoshinori Tokura[6,7], Markus Garst[4,5], and Dennis Meier[1,2] — [1]NTNU, Trondheim, Norway — [2]Center for Quantum Spintronics, NTNU, Trondheim, Norway — [3]ETH Zurich, Zürich, Switzerland — [4]Universität zu Köln, Köln, Germany — [5]Technische Universität Dresden, Dresden, Germany — [6]University of Tokyo, Tokyo, Japan. — [7]RIKEN , Wako, Japan

In chiral magnets, the Dzyaloshinskii-Moriya interaction twists the magnetization and leads to a helimagnetic ground state. We use magnetic force microscopy (MFM) to investigate the magnetic long-range order in the near room-temperature helimagnet FeGe with nanoscale spatial resolution. Completely new types of magnetic domain walls are observed, connecting regions with different orientation of the helical structure. Analogous to the much-studied skyrmions, the walls can exhibit a nonzero topological winding number and, hence, possibly give rise to emergent electrodynamics. Our goal is to control the domain wall formation, demonstrating new opportunities for future applications in spintronics.

MA 15.16 Tue 10:00 Poster E

Switching dependence of single skyrmions on in-plane magnetic field — Florian Muckel, •Christian Holl, Marco Pratzer, and Markus Morgenstern — II. Physikalisches Institut B, RWTH Aachen University and JARA-FIT, Germany

We study single skyrmions of about 5 nm in diameter, which are created by applying an out-of-plane magnetic field to the PdFe atomic bilayer on Ir(111) [1]. Using spin-polarized scanning tunneling microscopy at 7 K, we observe a current dependent switching of these skyrmions between different defect positions. The skyrmions are pinned eccentrically at its rim and flip, e.g., in angle around this pinning position exploiting additional defects. The switching rate can be tuned by about 2 orders of magnitude via an in-plane magnetic field of up to 3 T. We also employed high frequency excitation voltages up to 15 GHz to the pinned skyrmions without compelling results yet. The results are compared with micromagnetic simulations based on density functional theory calculations of the interaction potential between different adsorbates and the skyrmions [2].

MA 15.17 Tue 10:00 Poster E

Large magnetocaloric effect in $Ni_2Cr_xMn_{(1.4-x)}In_{0.6}$ Heusler alloys — •C. Salazar-Mejia[1], P. Devi[2], S. Singh[3], C. Felser[2], and J. Wosnitza[1] — [1]High Magnetic Field Laboratory (HLD-EMFL), Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [3]School of Materials Science and Technology, Indian Institute of Technology (BHU), Varanasi, India

In the search for promising magnetocaloric materials for solid-state refrigeration, we have successfully prepared a new family of Heusler alloys, $Ni_2Cr_xMn_{(1.4-x)}In_{0.6}$. Based on the widely studied $Ni_2Mn_{1.4}In_{0.6}$, we have substituted Cr for Mn tuning the structural and the ferromagnetic transition towards lower temperatures. All samples show a structural transition at a temperature located between 200 and 300 K. Here, we present our results on the adiabatic temperature change, ΔT_{ad}, in these compounds under applied magnetic-field pulses of 2 and 6 T. The samples exhibit a large inverse magnetocaloric effect (temperature decrease under field application) due to the martensitic transition and a conventional effect (temperature increase under field application) due the ferromagnetic transition. For instance, the $Ni_2Cr_{0.1}Mn_{1.3}In_{0.6}$ alloy exhibits $\Delta T_{ad} = 5$ K at $T_0 = 315$ K and a large adiabatic temperature change of $\Delta T_{ad} = -7$ K at $T_0 = 270$ K under first field application and −5.7 K after second field application, for a field change of 6 T.

[1]M. Ghorbani Zavareh et al., Appl. Phys. Lett. **106**, 071904 (2015).

MA 15.18 Tue 10:00 Poster E

Effects of decomposition on the magnetocaloric effect in Ni-Co-Mn-In Heusler-based compounds — •Merivan Sasmaz[1], Felix Dreist[2], Michael Farle[2], and Mehmet Acet[2] — [1]Physics Deptartment, Adiyaman University, Adiyaman, Turkey — [2]Experimentalphysik AG Farle Universität Duisburg-Essen, Duisburg

Off-stoichiometric Ni-based Heusler compounds in the form $Ni_{50}Mn_{25+x}Z_{25-x}$ decompose into full Heusler, $Ni_{50}Mn_{25}Z_{25}$, and $Ni_{50}Mn_{50}$ components when annealed in the temperature range $650 \leq T \leq 750$ K. Compounds that are considered in relation to magnetocaloric effects also fall in this composition range, so that any decomposition resulting from heat treatments can influence the magnetocaloric properties. Here we study systematically the effect of decomposition on the magnetocaloric properties of $Ni_{46}Co_7Mn_{35}Z_{12}$, which is known to be a prototype inverse magnetocaloric material. We follow the decomposition process from time-dependent magnetization measurements at 750 K and determine entropy-changes from field-dependent magnetization measurements. Although a broadening of the hysteresis increases in the decomposed state, the entropy-change is found to increase, while the martensitic transition temperatures and the Curie temperature shifts, indicating both a change in the composition and the degree of $L2_1$ ordering.

MA 15.19 Tue 10:00 Poster E

Adiabatic T-change and thermal relaxation of magnetocaloric core-shell wires — •Alexander Funk[1], Tino Gottschall[2], Lukas Beyer[1], Anja Waske[3], and Maria Krautz[1] — [1]IFW Dresden, Germany — [2]HZDR Dresden, Germany — [3]BAM Berlin, Germany

Conventional magnetocaloric materials (MCMs) generate or release heat when magnetized or demagnetized. This effect can be utilized in a cooling device. Although materials and prototypes have been investigated deeply for the last two decades [1], the shaping of the MCMs into complex heat exchanger geometries (HEG) is still challenging.

One possibility to overcome shaping difficulties is to combine MCMs to composites with a 2nd binder phase, e.g. polymers or ductile metals [2]. The composite's shape is commonly limited to plates, however recently magnetocaloric core-shell wires, based on a $La(Fe,Co,Si)_{13}$-core and a steel-shell, were presented [3]. Such wires are versatile semifinished products, which can be assembled to different HEG [4].

In this work, the adiabatic T-change of the core and the shell were assessed by pulse-field measurements in 2T, 5T and 10T. By monitoring the temperature change on both components simultaneously, the thermal transfer between core and shell is investigated. The thermal relaxation of the wire was also investigated via optical infrared microscopy and FEM-simulation.

[1] Franco et al., Progress in Materials Science 93, 2018. [2] Radulov et al., Acta Materialia, 2017. [3] Funk et al., Materials Today Energy 9, 2018. [4] Trevizoli et al., Applied Energy 187, 2017.

MA 15.20 Tue 10:00 Poster E

Magnetic properties of centered spin-rings — •Jonas Heinze and Jürgen Schnack — Fakultät für Physik, Universität Bielefeld, D-33501 Bielefeld

The magnetic properties of centered spin-rings with J_1-J_2-Heisenberg-interaction are determined by exact diagonalization. We characterize the ground state as well as excited states by their respective quantum numbers and investigate the dependence of the latter on the ratio J_1/J_2. General rules are suggested if possible.

MA 15.21 Tue 10:00 Poster E

High-field ESR study of giant single ion magnetic anisotropy in $Li_2(Li_{1-x}Co_x)N$ — •Y. Krupskaya[1], T. Ballé[2], L. Puntigam[2], A. Jesche[2], Z. Zangeneh[1], L. Xu[1], L. Hozoi[1], B. Büchner[1], and V. Kataev[1] — [1]IFW Dresden, Germany — [2]Augsburg University, Germany

Recently an extreme, uniaxial magnetic anisotropy and large magnetic hysteresis were observed in the $Li_2(Li_{1-x}Fe_x)N$ compound [1]. Static magnetization measurements revealed a coercivity field of over 11 T at T = 2 K and allowed to estimate a magnetic anisotropy field of 220 T. Substitution of Fe with other transition metal ions allows to alternate the sign of the magnetic anisotropy, resulting in easy plane - easy axis - easy plane - easy axis configurations when progressing along the Mn - Fe - Co - Ni series [2]. We have studied a $Li_2(Li_{1-x}Co_x)N$ single crystal with x = 0.01 by means of high-field multi-frequency electron spin resonance spectroscopy (HF-ESR), which is known as an efficient tool to directly measure the magnetic anisotropy energy in single-molecule magnets. The measurements have been performed in magnetic fields up to 16 T and excitation frequencies up to 750 GHz. HF-ESR results clearly evidence easy-plane magnetic behavior and enable to determine a Co-ion magnetic anisotropy gap of 972 GHz, in agreement with *ab initio* quantum chemical calculations. Different from the case of the $Li_2(Li_{1-x}Fe_x)N$ compound, where first-order spin-orbit coupling plays the main role, the magnetic anisotropy of Co ions in $Li_2(Li_{1-x}Co_x)N$ is related to second-order effects. [1] A. Jesche et al. Nat. Commun. 5, 3333 (2014); [2] A. Jesche et al. Phys. Rev. B 91, 180403(R) (2015).

MA 15.22 Tue 10:00 Poster E

Giant magnetic hyperfine field, spin dynamics and colossal transverse field sensitivity in the single-atomic magnet $Li_2(Li_{1-x}Fe_x)N$ with $x \ll 1$ — •Sascha Albert Bräuninger[1], Sirko Kamusella[1], Felix Seewald[1], Rajib Sarkar[1], Manuel Fix[2], Stephan Jantz[2], Anton Jesche[2], Andre Zvyagin[3], and Hans-Henning Klauss[1] — [1]Institute of Solid State and Materials Physics, TU Dresden, D-01069 Dresden, Germany — [2]Institute of Physics, University Augsburg, D-86135 Augsburg, Germany — [3]Max-Planck-Institute for the Physics of Complex Systems, Nöthnitzer Str., 38, D-01187 Dresden, Germany

We present ^{57}Fe Mössbauer studies on large single crystals of diluted Fe centers in $Li_2(Li_{1-x}Fe_x)N$ which forms a hexagonal symmetric α-Li_3N crystal matrix. The homogeneity of the nanoscale distributed isolated Fe centers is shown. The isolated Fe centers, e.g. for $x = 2.5(1)\%$, exhibit a giant magnetic hyperfine field of $B = 70.22(1)$ T parallel to the largest principle axis $V_{zz} = -154.10(19)\,\mathrm{V/Å^2}$ of the electric field gradient at 2 K, same for other $x \ll 1$. The magnetic hyperfine field fluctuates between 50 K and 300 K probed by Mössbauer spectroscopy described by a two-level relaxation model. The spin dynamics is similar to a behavior known from single-molecule magnets. An Arrhenius frequency plot $\nu = \nu_0 e^{-E_A/k_B T}$ yields a thermal activation barrier of $E_A = 542(8)$ K and $\nu_0 = 216(22)$ GHz which is consistent with magnetization investigations. An applied transverse magnetic field study up to 5 T at 70 K shows a sensitivity two orders of magnitude higher than expected from the conventional theory of nanomagnets.

MA 15.23 Tue 10:00 Poster E

Surface- and ligand-dependent quenching of the spin magnetic moment of Co porphyrins — Lucas M. Arruda[1], Matthias Bernien[1], Fabian Nickel[1], Nino Hatter[1], Lalminthang Kipgen[1], C. Felix Hermanns[1], Dennis Krüger[1], Timo Bisswanger[1], Enrico Schierle[2], Eugen Weschke[2], Katharina J. Franke[1], and •Wolfgang Kuch[1] — [1]Freie Universität Berlin, Institut für Experimentalphysik, Arnimallee 14, 14195 Berlin, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Albert-Einstein-Straße 15, 12489 Berlin, Germany

The bonding flexibility of metalloporphyrin molecules makes them versatile candidates for spintronic applications. The magnetic properties of these molecules can be readily influenced by changes to their ligands. We investigate the electronic and magnetic properties of cobalt octaethylporphyrin (CoOEP), deposited on two similar surfaces, Cu(100) and Cu(111), with x-ray absorption spectroscopy and x-ray magnetic circular dichroism. A significant magnetic moment is observed from the cobalt ions of the molecules deposited on Cu(100), but it is completely quenched on Cu(111). Subjecting the molecules to an annealing process causes an intramolecular reaction, resulting in cobalt tetrabenzoporphyrin. The new molecules on both substrates have a quenched magnetic moment and similar electronic properties as the CoOEP molecules deposited on Cu(111). We propose that the CoOEP molecules on Cu(100) display an unusual mixed-valence configuration caused by the hybridization of the cobalt ion with the copper substrate, leading to the quench of the cobalt ions' magnetic spin moment.

MA 15.24 Tue 10:00 Poster E

Ligand-induced spin-state locking of a spin-crossover molecule on a graphite surface — Lalminthang Kipgen[1], Matthias Bernien[1], Andrew J. Britton[1], Holger Naggert[2], Sascha Ossinger[2], Fabian Nickel[1], Lucas M. Arruda[1], Evangelos Golias[1], •Ivar Kumberg[1], Chen Luo[3], Hanyo Ryll[4], Florin Radu[4], Felix Tuczek[2], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Institut für Anorganische Chemie, Christian-Albrechts-Universität zu Kiel, Max-Eyth-Straße 2, 24118 Kiel, Germany — [3]Institut für Experimentelle und Angewandte Physik, Universität Regensburg, Universitätsstrasse 31, 93053 Regensburg, Germany — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, Albert-Einstein-Straße 15, 12489 Berlin, Germany

Spin-crossover molecules (SCMs) have potential applications in optical memory and display elements as they can exist in two different magnetic states – high-spin (HS, S = 2) and low-spin (LS, S = 0) – which can be reversibly switched by temperature or light. The property of SCMs can be largely altered by suitably modifying the ligands; this is interesting especially for SCMs deposited on a surface — a prerequisite for device fabrication. Herein, four methyl groups are added to the SCM $[Fe(H_2B(pz)_2bipy]$ (pz = pyrazole; bipy = bipyridine) at the bipy ligand. While the original molecule is reported to undergo both optical- and thermal-induced spin switching on a graphite surface, the modified molecule is locked in the HS state on the same surface; only molecules lying at the second-monolayer onward retain their spin-crossover.

MA 15.25 Tue 10:00 Poster E

Suppression and revival of long-range ferromagnetic order in the multiorbital Fermi-Hubbard model — •Agnieszka Cichy[1,2] and Andrii Sotnikov[3] — [1]Faculty of Physics, Adam Mickiewicz University, Umultowska 85, 61-614 Poznan, Poland — [2]Institut fuer Physik, Johannes Gutenberg-Universitaet Mainz, Staudingerweg 7, D-55099 Mainz, Germany — [3]Institute of Solid State Physics, TU Wien, Wiedner Hauptstrasse 8, 1020 Vienna, Austria

By means of dynamical mean-field theory allowing for complete account of SU(2) rotational symmetry of interactions between spin-1/2 particles, we observe a strong effect of suppression of ferromagnetic order in the multiorbital Fermi-Hubbard model in comparison with a widely used restriction to density-density interactions. In the case of orbital degeneracy, we show that the suppression effect is the strongest in the two-orbital model (with effective spin S=1) and significantly decreases when considering three orbitals (S=3/2), thus magnetic ordering can effectively revive for the same range of parameters, in agreement with arguments based on vanishing of quantum fluctuations in the limit of classical spins. We analyze a connection to the double-exchange model and observe high importance of spin-flip processes there as well.

MA 15.26 Tue 10:00 Poster E

The Cyclotron resonance as a smoking gun for U(1) spin liquids with gapless fermions — •Peng Rao — Max Planck Institute

for the Physics of Complex Systems, Dresden, Germany

Certain U(1) spin liquids with gapless neutral fermions are expected to have the mind-boggling property that their optical conductivity vanishes as a power law of frequency. Thus, they are insulators to DC electric fields but without a "hard" optical gap, allowing them to absorb light at low frequencies. Additionally, they can also develop Landau levels in a magnetic field. In this work, we show that they can also have cyclotron resonance peaks in their optical spectrum analogous to metals, even though they are charge insulators. Interestingly, we have found that in contrast to metals, the principal Kohn harmonic of the cyclotron resonance is missing. The cyclotron resonance could therefore serve as a beautiful smoking gun test for the existence of these states which have been proposed in 2D organic materials and SmB_6.

MA 15.27 Tue 10:00 Poster E

Self-energy contribution of electron-magnon coupling in the homogeneous electron gas — •Maximilian Kulke and Arno Schindlmayr — Department Physik, Universität Paderborn, 33095 Paderborn, Germany

Electronic band structures of ferromagnetic materials are not only affected by electronic correlation but also by the coupling to magnons. This coupling can be treated as part of the electronic self-energy, where the magnon propagator is either described by many-body perturbation theory or by time-dependent density-functional theory. The latter is computationally simpler, because the self-energy can be evaluated analogous to the *GW* approximation for electronic correlation, but the quality of the results depends on the accuracy of the exchange-correlation kernel. In practice, the adiabatic local-density approximation (ALDA) is used almost universally until now. To study the influence of the kernel, we focus on the spin-polarized homogeneous electron gas and evaluate the electron-magnon coupling with different wave-vector-dependent exchange-correlation kernels that go beyond the ALDA. As further numerical approximations that are typically required for real materials can be avoided in this case, we are thus able to assess the essential features of the exchange-correlation kernel that are relevant for the electron-magnon coupling.

MA 15.28 Tue 10:00 Poster E

Transport in graphene and possible Cooper pair formation — •Klaus Morawetz — Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil

Based on the quantum kinetic equations for systems with SU(2) structure, regularization-free density and pseudospin currents are calculated in graphene realized as the infinite mass-limit of electrons with quadratic dispersion and a proper spin-orbit coupling. The currents possess no quasiparticle part but only anomalous parts. The intraband and interband conductivities are discussed with respect to magnetic fields and magnetic domain puddles. For large Zeeman fields the dynamical conductivities become independent of the density and are universal. The optical conductivity agrees well with the experimental values using screened impurity scattering and an effective Zeeman field. The universal value of Hall conductivity is shown to be modified due to the Zeeman field. The pseudospin current reveals an anomaly since a quasiparticle part appears though it vanishes for particle currents. The density and pseudospin response functions to an external electric field are calculated. A frequency and wave-vector range is identified where the dielectric function changes sign and the repulsive Coulomb potential becomes effectively attractive allowing Cooper pairing. Phys. Rev. B 94 (2016) 165415, Phys. Rev. B 92 (2015) 245425 errata: Phys. Rev. B93 (2016) 239904(E), Phys. Rev. B 92 (2015) 245426

MA 15.29 Tue 10:00 Poster E

Towards nanoscale magnetic resonance imaging using single spins in diamond — •Tetyana Shalomayeva[1], Dominik Schmid-Lorch[1], Thomas Oeckinghaus[1], Qi-Chao Sun[1], Rainer Stöhr[1], and Jörg Wrachtrup[1,2] — [1]3rd Institute of Physics, University of Stuttgart — [2]Max Planck Institute for Solid State Research

Due to amazing advances in the development of 2D magnetic materials [1], Heusler compounds [2], multiferroic materials [3], etc., the need for quantitative real-space imaging techniques of magnetic textures is greater than ever before. We use the nitrogen vacancy (NV) centre in diamond as an atom-sized magnetic field sensor by monitoring the Zeeman-shift of its spin sublevels. By integrating the NV centre into an AFM tip consisting of a diamond cantilever with a monolithic nanopillar, magnetic field maps with a spatial resolution of tens of nanometers are obtained at ambient conditions.

In this contribution, we will demonstrate the general principle of this technique by emphasizing its strengths and limitations. We will show examples where we measure quantities such as noise and excitation spectra, which are inaccessible to other techniques.

[1] M. Bonilla et al. Nature Nanotechnology 13, 289*293 (2018) [2] A.K. Nayak et al. Nature 548, 561*566 (2017) [3] J.A. Mundy et al. Nature 537, 523*527 (2016)

MA 15.30 Tue 10:00 Poster E

Levitating antennas to excite magnetization dynamics for optical and non-optical spectroscopy — •Toni Hache[1,2], Marek Vanatka[3], Lukas Flajsman[3], Michal Urbanek[3], and Helmut Schultheiss[1,4] — [1]HZDR — [2]TU Chemnitz — [3]CEITEC — [4]TU Dresden

Modern spectroscopic techniques for the investigation of magnetization dynamics in microstructures use usually microwave antennas which are directly patterned on the sample using electron-beam-lithography (EBL). Following this approach every magnetic structure on the sample needs its own antenna and insulation layer requiring additional EBL and layer deposition. We demonstrate a new device for magnetization excitation compatible with optical methods based on antennas on a flexible glass cantilever. Since we use flexible transparent glass as substrate, optical spectroscopic techniques like Brillouin-light-scattering microscopy (BLS) and time resolved magneto-optical Kerr effect measurements (TRMOKE) can be performed. This cantilever is connected to adapters with standard SMA connectors and is positionable in all three dimensions to get access to all magnetic structures on the sample under investigation. We show the functionality of these antennas using BLS. We excite the magnetization in a 5 nm thick Permalloy film and compare the intensity with the intensity of only thermally excited magnons. A increase by a factor of 400 could be achieved, showing the high impact of the magnetization excitation by the antenna. The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within programme SCHU 2922/1-1

MA 15.31 Tue 10:00 Poster E

Towards machine-learning-based far-field phase-retrieval for dichroic imaging — •Michael Lohmann, Ofer Kfir, Sergey Zayko, and Claus Ropers — Georg August Universität Göttingen

Machine learning (ML) is a highly powerful tool for data analysis and classification, across many fields and platforms. First demonstrations of ML for lensless imaging by phase-retrieval of diffraction patterns show great potential [1], however, they do not necessarily provide for a consistent solution, and require a vast amount of training data.

Here, we propose the use of a known forward operator, linking the sample and its diffraction, that is, the Fourier transform, to improve the image retrieval. The resulting reduction of complexity could relieve the need for a large training set, and could reduce the algorithm convergence time. In the case of dichroic imaging, such as in magnetic circular dichroism, advanced algorithms can jointly solve the two dichroic diffraction patterns, and directly access the magnetic information separately from the non-magnetic background. Furthermore, combining magnetic imaging with standard ML applications, as de-noising, would enhance the image quality and sensitivity.

[1] Mathew J. Cherukara, Youssef S. G. Nashed & Ross J. Harder; Scientific Reports **8** 16520 (2018), Real-time coherent diffraction inversion using deep generative networks

MA 15.32 Tue 10:00 Poster E

Ab initio calculations on the Intrinsic Spin Hall effect — •Alexander Fabian, Michael Czerner, and Christian Heiliger — Institut für theoretische Physik, Justus-Liebig-Universität Gießen, Heinrich-Buff-Ring 16, 35392 Gießen

Spintronic devices gain much attention for applications, since the additional spin degree of freedom can be used to manufacture even more efficient and faster devices. For such applications, a spin polarized current is neccessary. To generate such currents it is most suitable to use physical effects such as the Spin Hall effect. We show here the application of ab initio calculations in the framework of a full relativistic Korringa-Kohn-Rostoker density functional theory to describe the intrinsic Spin Hall effect in materials with strong spin orbit coupling. Whereas typical methods rely on the implementation of a semi-classical Boltzmann formalism in conjunction with an additional term resulting from the Berry curvature, we describe the intrinsic Spin Hall effect by only relying on the full relativistic Kohn-Sham-Dirac Hamiltonian, which evokes a spin orbit coupling in the material, and the non-equilibrium Greens function formalism. Within this framework it is possible to give a prediction of Spin Hall angles in different materials for use in applications. By expanding the method with scattering times and spin flip scattering it should be possible to also give a prediction of extrinsic Spin Hall effects as well. To prove the applicability of this method, the magnetization distribution of a thin film of a material with strong spin orbit coupling like Platinum is calculated under an applied bias voltage.

MA 15.33 Tue 10:00 Poster E

Local projection of the intrinsic spin Hall conductivity in heterostructures — •Franziska Töpler[1], Tomáš Rauch[2], and Ingrid Mertig[1,3] — [1]Martin Luther University Halle-Wittenberg, Halle, Germany — [2]Friedrich-Schiller University Jena, Jena, Germany — [3]Max Planck Institute of Microstructure Physics, Halle, Germany

We study the intrinsic contribution to the spin Hall conductivity (SHC) in a system with a magnetic/nonmagnetic interface. On that account we use an extended unit cell composed of n and m atomic layers of Cu and Co, respectively. The electronic structure is calculated within the tight-binding approach. We use the Kubo formula to describe the transverse spin current in linear response to an external electric field [1]. To obtain a better understanding of the role of the Cu/Co interface in the spin Hall effect, we derive and test different formulations of the local SHC. The local projection methods are introduced in analogy to Ref. [2] and Ref. [3] wherein a local marker is used to probe the anomalous Hall effect in inhomogeneous systems. We compare the results of the different approaches and discuss there significance with respect to the chosen model system.

[1] Gradhand *et al.*, J. Phys.: Condens. Matter **24**, 213202 (2012)
[2] Rauch *et al.*, Phys. Rev. B **98**, 115108 (2018)
[3] Marrazzo *et al.*, Phys. Rev. B **95**, 121114(R) (2017)

MA 15.34 Tue 10:00 Poster E

Photoinduced modulation of resistivity in metallic wires under DC Bias — Lea Apel, Şaban Tirpanci, •Palvan Seyidov, and Georg Woltersdorf — Institutte of Physics, Martin-Luther-Universität Halle-Wittenberg

Charge to spin current conversion due to the spin Hall effect (SHE) was intensely studied in the last decade. Even in metallic wires direct magneto-optic detection of the current-induced spin accumulation has been reported [1]. Recently, Yang et al. demonstrated the direct visualization of current-induced spin accumulation at wire edges using a novel light helicity-dependent scanning photovoltage measurement technique at room temperature [2]. Unfortunately a reasonable physical explanation of observed signals was not presented.

In our experiments we reproduce the results by Yang et al. qualitatively for Pt wires with a spatial resolution of 300 nm. Using a very similar setup as discussed in [2] we compare the spatial dependence of the photovoltages in Pt, Ta and Cu wire structures under DC bias. In Pt we find signals at the wire edges, which have a similiar magnitude and the same symmetry as in [2] upon switching the current direction. However, we also observe very similar helicity dependent photo voltage signals also for Cu and Ta wires under DC bias. Therefore, we conclude that most of the signals we observed at the wire edges are not caused by the SHE induced spin accumulation. We perform a careful analysis of the possible origins of these signals.

[1]C.Stamm et al. Phyy. Rev. Lett. 119,087207(2017)
[2]L. Yang et al., Nat. Commun. 9,2492(2018)

MA 15.35 Tue 10:00 Poster E

Characterization of individual YIG/Pt nano-structures via Spin Transfer Torque-FMR — •Steffen Steinert[1], Björn Heinz[1,2], Thomas Brächer[1], Michael Schneider[1], Philipp Pirro[1], Bert Lägel[1], Anna M. Friedel[1], David Breitbach[1], Carsten Dubs[3], Burkard Hillebrands[1], and Andrii V. Chumak[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany — [3]INNOVENT e.V., Technologieentwicklung Jena, 07745 Jena, Germany

Yttrium iron garnet (YIG) is a unique material with outstanding magnetic properties such as the lowest known spin-wave damping. It is therefore well suited for the investigation of fundamental spin-wave dynamics and a promising candidate for the application in spin-wave based circuits and logic devices. In this work, we investigate spin-wave conduits fabricated from a thin YIG(27nm)/Pt(10nm) bi-layer system with varying width ranging from microns down to about 100nm. The investigation of the magnetic properties, e.g. the ferromagnetic resonance linewidth (FMR), in dependency of the width of the structure is carried out by means of spin transfer torque ferromagnetic resonance spectroscopy (ST-FMR). In addition, the impact of an applied dc-current on the linewidth is examined. This research has been supported by ERC Starting Grant 678309 MagnonCircuits and DFG Grant DU 1427/2-1.

MA 15.36 Tue 10:00 Poster E

Electronic and magnetic structure of ultrathin SrRuO3 film grown on SrTiO3 (001) substrate — •Kartik Samanta, Marjana Ležaić, Yuriy Mokrousov, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Oxides interfaces offer a new perspective to stabilize the skyrmion due to their response to electric fields, low Ohmic losses, variety of interface symmetry as well as the prospective anisotropic Dzyaloshinskii-Moriya interaction (DMI). We investigate by virtue of spin density functional theory (DFT) as realized in the FLEUR code [1], magnetic structure of the ultrathin film of SrRuO3 grown on the SrTiO3 (001) substrate in c(2 x 2) unit cell to search the interface stabilized skyrmion in oxide structure. At the ultrathin limit of three monolayers the SrRuO3, the film is found to show a metal to insulating (MIT) ground state with antiferromagnetic magnetic order. The t2g level difference, lattice distortion, as well as the layer thickness, play together a crucial role in determining this magnetic ground state. At the ultrathin limit of three monolayers of the SrRuO3 film, a reasonable amount of orbital magnetic moment is found at the Ru sites compared the bulk SrRuO3. We have also calculated the anomalous Hall conductivity for bulk as well as the thin film. We hope that strong spin-orbit coupling ant Ru site together with broken inversion symmetry in the ultrathin film will give rise DMI which can stabilize the Skyrmion in this system.

[1] www.flapw.de

MA 15.37 Tue 10:00 Poster E

Magnon Chemical Potential Evolution in the BEC Formation by Rapid Cooling — •Michael Schneider[1], Thomas Brächer[1], Viktor Lauer[1], Phillip Pirro[1], Dmytro A. Bozhko[1], Alexander A. Serga[1], Halyna Yu. Musiienko-Shmarova[1], Björn Heinz[1,2], Qi Wang[1], Thomas Meyer[3], Frank Heussner[1], Sascha Keller[1], Evangelos Th. Papaioannou[1], Bert Lägel[1], Thomas Löber[1], Vasyl S. Tiberkevich[4], Andrei N. Slavin[4], Carsten Dubs[5], Burkard Hillebrands[1], and Andrii V. Chumak[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, D-55128 Mainz — [3]THATec Innovation GmbH, Bautzner Landstraße 400, D-01328 Dresden — [4]Department of Physics, Oakland University, Rochester — [5]INNOVENT e.V. Technologieentwicklung, Prüssingstraße 27B, D-07745 Jena

Recently we presented a fundamentally new approach for the formation of a magnon Bose-Einstein Condensate (BEC) due to the rapid cooling of a preheated magnetic nano-structure. Using time-resolved Brillouin light scattering spectroscopy (BLS), a strong increase of the magnon population at the bottom of the spectrum is observed. Here we show the direct measurement of the chemical potential by means of BLS. The potential is found to reach the minimum magnon energy confirming the BEC formation. This research has been supported by ERC StG 678309 MagnonCircuits, ERC AdG 694709 SuperMagnonics and DFG Grant DU 1427/2-1.

MA 15.38 Tue 10:00 Poster E

Realization of a micro-scaled spin-wave majority gate — •Martin Kewenig[1], Thomas Brächer[1], Carsten Dubs[2], Philipp Pirro[1], Andrii Chumak[1], and Burkard Hillebrands[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany — [2]INNOVENT e.V. Technologieentwicklung Jena, 07745 Jena, Germany

Spin-wave logic devices offer large advantages compared to modern CMOS-based elements. An example for such a logic element is the majority gate, in which the logical output is given by the majority of the logical inputs. The operation of a macroscopic spin-wave majority gate made from a 5.4 μm-thick yttrium iron garnet (YIG) film is already proven, the output phase of the signal was defined by the majority of the input phases. The miniaturization of the device is naturally the next step and the functionality of a micro-scaled spin-wave majority gate has already been investigated by numerical methods. We will show spin-wave dynamics in microstructured YIG waveguides and microstructured combiner areas. In addition, we will present the fabrication and investigation of a micro-scaled spin-wave majority gate device made from a 70 nm and a 85 nm thick YIG film. This research has been supported by: DFG SFB/TRR 173 Spin+X, Project B01, ERC Starting Grant 678309 MagnonCircuit, DFG (DU 1427/2-1)and the EU Horizon 2020 research and innovation programme within the CHIRON project (contract number 801055).

MA 15.39 Tue 10:00 Poster E

Two-dimensional magnon supercurrents — •Alexander J. E. Kreil, Dmytro A. Bozhko, Alexander A. Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

Earlier, we reported on supercurrent transport of a room-temperature magnon Bose-Einstein condensate (BEC) observed in yttrium iron garnet films by means of time- and space-resolved Brillouin light scattering spectroscopy (BLS) [1-3]. By locally heating the sample, a spatially variation of the saturation magnetization was induced, which lead to a magnon supercurrent flowing out of the heated spot. The condensed magnons being propelled out of the heated area formed compact humps of BEC density, which propagated many hundreds of micrometers in the form of second sound Bogoliubov waves. Our theoretical estimations predict a strong anisotropy in the propagation characteristics of the magnon supercurrents. In the current work, we show the results of a two-dimensional spatially resolved BLS probing the magnon BEC formed in a magnetically non-uniform sample and compare the experimental data with theoretical estimations.

[1] D.A. Bozhko *et al.*, *Supercurrent in a room temperature Bose-Einstein magnon condensate*, Nat. Phys. **12**, 1057 (2016).
[2] A.J.E. Kreil *et al.*, *From kinetic instability to Bose-Einstein condensation and magnon supercurrents*, PRL **121**, 077203 (2018).
[3] D.A. Bozhko *et al.*, *Long-distance supercurrent transport in a room-temperature Bose-Einstein magnon condensate*, arXiv:1808.07407.

MA 15.40 Tue 10:00 Poster E

Surface acoustic wave mediated magneto elastic investigation of magnetic thin films — •Matthias Küss[1], Michael Heigl[2], Andreas Hörner[1], Manfred Albrecht[2], and Achim Wixforth[1] — [1]Lehrstuhl für Experimentalphysik I, Universität Augsburg — [2]Lehrstuhl für Experimentalphysik IV, Universität Augsburg

Magnetostriction describes the geometrical deformation of a magnet, caused by an applied magnetic field. The effect vice versa is named inverse magnetostriction. This mechanism in combination with surface acoustic strain waves (SAW) enables the manipulation of the magnetization on short time scales ($\sim$ ns) and on micrometer distances. Since the SAW and magnonic modes are typically excited in the same radio frequency regime, both degrees of freedom have the potential to become strongly or even resonantly coupled [1]. Therefore, not only the magnetization, but also the properties of the SAW itself are mutually and characteristically changed. This can be easily measured in a delay line setup, made up of two interdigital transducers (IDT).

We use a vector network analyzer to study the interaction between GHz Rayleigh type SAWs and a ferromagnetic cobalt film as a function of magnetic field and sample orientation. On the one hand these experiments show the typical fourfold symmetry of elastically driven ferromagnetic resonance, which is caused by the longitudinal strain, accompanying the Rayleigh wave [1]. On the other hand, clear signature of vertical shear strain is observed, which gives rise to phenomena like nonreciprocal SAW propagation.

[1] M. Weiler et al., Phys. Rev. Lett. **106**, 117601 (2011).

MA 15.41 Tue 10:00 Poster E

Investigation of non-linear spin-wave excitation at low magnetic bias field — •Lea Apel, Rouven Dreyer, and Georg Woltersdorf — Institutte of Physics, Martin-Luther-Universität Halle-Wittenberg

Recently, it was demonstrated that the Suhl instability processes describing parametric spin wave excitations are not an adequate model at low magnetic bias fields [1]. In the low field regime a novel instability process dominates the response at high excitation amplitudes. This process leads to critical spin-wave modes which can be parametrically driven at half integer multiplies of excitation frequency.

Here we use micro-focus Brillouin light scattering (μBLS) to study the formation of $3/2\ \omega$ and $5/2\ \omega$ non-linear spin-wave excitations and the corresponding threshold rf-amplitudes for this parametric process in Permalloy microstructures. Simultaneously we detect the spatial dependence of the uniform mode as well as the parametrically excited spin waves. Overall we find agreement with the critical behavior prediction in [1] at small magnetic bias fields. Our results are supported by magneto-optical microscopy expriments which map the spin waves in a phase resolved fashion.

[1]H.G. Bauer et al., Nat. Commun. 6, 8274(2015)

MA 15.42 Tue 10:00 Poster E

Reflectionless magnonic crystal — •Pascal Frey[1], Aleksei Nikitin[2], Qi Wang[1], Florin Ciubotaru[3], Sergey A. Bunyaev[4], Gleb N. Kakazei[4], Boris A. Kalinikos[2], Andrii V. Chumak[1], Aleksandr A. Serha[1], and Burkard Hillebrands[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany — [2]Department of Physical Electronics and Technology, St. Petersburg Electrotechnical University St. Petersburg, Russia — [3]Imec, Leuven, Belgium — [4]IFIMUP and IN-Institute of Nanoscience and Nanotechnology, Departamento de Física e Astronomia, Universidade do Porto, Porto, Portugal

The interest in artificial magnetic media like magnonic crystals visibly increased during the recent years in view of their application for information processing at microwave frequencies. The main features of these crystals are the presence of bandgaps in the spin wave spectra. The bandgaps are formed due to the Bragg reflections from the artificially created periodic structures. We studied spin wave propagation in longitudinally magnetized width-modulated yttrium iron garnet waveguides by means of both Brillouin light scattering and microwave techniques in the cw and pulsed regime. 30 ns pulses of backward volume magnetostatic spin waves were excited close to the ferromagnetic resonance frequency and their propagation was visualized and measured, both in pass and rejection frequency bands. No pronounced Bragg reflection was observed. The effect is discussed in comparison with results of micromagnetic simulations. Financial support by the DFG (B01 and DE 639) as well as by DAAD grant 57213643 is gratefully acknowledged.

MA 15.43 Tue 10:00 Poster E

Controlling spin transmission in collinear ferroic magnetic multilayer systems — Joel Cramer[1], •Felix Fuhrmann[1], Ulrike Ritzmann[1], Ulrich Nowak[2], Eiji Saitoh[3], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, 55128 Mainz, Germany — [2]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [3]WPI Advanced Institute for Materials Research, Tohoku University, Sendai 980-8577, Japan

In the research field of spintronics, devices can use spin currents rather than charge currents [1]. In particular in insulators, pure spin currents can be employed and we report on spin pumping [2] measurements in collinear magnetic yttrium iron garnet (YIG)/CoO/Co multilayers. By means of microwaves and external magnetic fields, YIG is brought into ferromagnetic resonance, resulting in a pure spin current that propagates through the sample stack and is finally detected in the Co layer via the inverse spin Hall effect [3]. The CoO layer enables the spin current transmission and de-coupling of the ferromagnets and furthermore increases the coercive field of the Co layer by exchange bias. This allows for the switching between a parallel or antiparallel alignment of the YIG and Co magnetization. Depending on the alignment of the YIG and Co magnetization, we observe a strongly different spin transport signal amplitude and thus a magnon spin-valve-like behavior is observed [4]. [1] S.A. Wolf et al., Science 294, 1488 (2001). [2] Y. Tserkovnyak et al., Phys. Rev. Lett. 88,117601 (2002). [3] J. Sinova et al., Rev. Mod. Phys. 87, 1213 (2015). [4] J. Cramer et al., Nature Commun. 9, 1089 (2018).

MA 15.44 Tue 10:00 Poster E

Theoretical description of spin waves in disordered materials — Pawel Buczek[1], •Martin Hoffmann[2], Stefan Thomas[3], and Arthur Ernst[2,3] — [1]Fakultät Technik und Informatik, Hochschule für Angewandte Wissenschaften Hamburg, Germany — [2]Institute for Theoretical Physics, Johannes Kepler University Linz, Austria — [3]Max Planck Institute of Microstructure Physics, Halle, Germany

In order to study spin waves in disordered materials, we present two theoretical approaches based on a Heisenberg model. Both complement each other in the description of magnon properties in spin systems with disorder of arbitrary kind and concentration of impurities. Firstly, magnons in systems with substitutional (uncorrelated) disorder can be efficiently calculated within a single-site coherent potential approximation for the Heisenberg model. From the computational point of view, this method has several advantages, is inexpensive, and directly applicable to systems like alloys and doped materials. We show that it performs exceedingly well across all concentrations and wave vectors. However, we need another approach for more complex systems like layers forming island or short-range order. Therefore, we will present a second possibility using a configurational average over possible realizations of large supercells in direct numerical simulations. The effective interaction between magnetic moments entering the Heisenberg model in both methods can be obtained from first-principles using a self-consistent Green function method within the density functional theory. Thus, our method can be viewed as an *ab initio* approach and can be used for calculations of magnons in real materials.

MA 15.45 Tue 10:00 Poster E

An analog magnon adder for all-magnonic neurons — Thomas Brächer and •Philipp Pirro — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern

Neuromorphic computing is one of the most promising more-than-Moore technologies that can greatly outperform conventional CMOS computing architecture for an important set of tasks like pattern recognition, machine learning and cognitive tasks. Spintronics constitutes a highly interesting platform for neuromorphic networks since its non-volatility allows for a straight-forward integration of the data processing and memory functionality on the same level, one of the key features of brain-inspired computation. Spin-waves are a highly promising data carrier to convey information in a neural network, as they are ultra-low in energy and as they can travel over large distances without the need for spin-to-charge or charge-to-spin interconversion. In this work, we demonstrate that a leaky resonator together with a parametric amplifier can perform the action of an analogue addition over incoming spin-wave pulses. For this operation, the losses in the resonator are just compensated by the parametric amplification process. The signal integration in the spin-wave domain is similar to the signal integration in neurons in spiking neural networks and the biological original, where a nonlinearity triggers the neuron to '*fire*' and release its energy. By adjusting the gain of the amplifier, various applications for such an adder can be envisioned. Together with the intrinsic nonlinearity of the spin-wave dynamics, magnonic neurons can, thus, be envisioned.

MA 15.46 Tue 10:00 Poster E

Spin-wave propagation in individual sub-micron YIG magnonic conduits — •Björn Heinz[1,2], Thomas Brächer[1], Michael Schneider[1], Philipp Pirro[1], Bert Lägel[1], David Breitbach[1], Anna M. Friedel[1], Carsten Dubs[3], and Andrii V. Chumak[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany — [3]INNOVENT e.V., Technologieentwicklung Jena, 07745 Jena, Germany

Yttrium iron garnet (YIG) is a unique material with outstanding magnetic properties such as the lowest known spin-wave damping. It is therefore well suited for the investigation of fundamental spin-wave dynamics and a promising candidate for the application in spin-wave based circuits and logic devices. In this work, we study the impact of nanostructuring by means of electron beam lithography and successive ion milling on individual spin-wave waveguides. These structures are fabricated from a 44 nm thin film grown by liquid phase epitaxy (LPE). Their width varies from a few microns down to the sub-100 nm regime. By exciting the magnetization dynamics with a coplanar waveguide antenna and performing spacial resolved Brillouin light scattering (BLS) microscopy measurements, we investigate the spin-wave decay length in these conduits in dependency on the conduit width. Additionally the spin-wave mode spectra are extracted by means of thermal BLS measurements. This research has been supported by ERC Starting Grant 678309 MagnonCircuits and DFG Grant DU 1427/2-1.

MA 15.47 Tue 10:00 Poster E

Influence of chiral interactions on domain wall creation by electric current — •Nils Sommer, Davi Rohe Rodrigues, and Karin Everschor-Sitte — Institute of Physics, Johannes Gutenberg-University, Mainz, Germany

We show how the presence of Dzyaloshinskii-Moriya interaction modifies the critical current density necessary to inject domain walls into a nanowire at a pinned domain wall: The creation of domain walls by electric means is of critical importance to the proposal of future magnetic domain wall based racetrack memories. In a recent work, [1] it was shown that domain walls can be periodically injected into nanowires in the presence of inohomogeneities without the aid of any twisting contribution, such as dipole-dipole and chiral interactions. In this work, we demonstrate that it is possible to reduce the critical current density by introducing Dzyaloshinskii-Moriya interaction. Moreover, we find a split in the critical current density depending on the chirality of the generated domain walls. We investigate the motion of the periodically created domain walls in the chiral nanowire due to the current and their interaction between each other. The reduced critical current density might allow the domain wall shedding in experimentally observable real chiral ferromagnetic nanowires.

[1] Sitte, M. et al., Physical Review B **94** (2016) 064422.

MA 15.48 Tue 10:00 Poster E

Dynamic imaging of the delay- and tilt-free motion of Néel domain walls with 200 ps time resolution — Simone Finizio[1], Sebastian Wintz[1,2], Katharina Zeissler[3], Alexandr Sadovnikov[4,5], Sina Mayr[1,6], Sergej Nikitov[4,5], Christopher Marrows[3], and •Jörg Raabe[1] — [1]Paul Scherrer Institut, 5232 Villigen PSI, Switzerland — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [3]University of Leeds, Leeds LS2 9JT, UK — [4]Saratov State University, 410012 Saratov, Russia — [5]Russian Academy of Sciences, 125009 Moskow, Russia — [6]ETH Zürich, 8093 Zürich, Switzerland

In this contribution, we present a time-resolved scanning-transmission x-ray microscopy investigation of the current- and magnetic field-induced domain wall motion of Néel-type domain walls in perpendicularly magnetized microwires fabricated out of Pt/CoB/Ir multilayer superlattice stacks exhibiting anti-symmetric exchange interaction. A time step of 200 ps, combined with a spatial resolution of 25 nm, was employed for the time-resolved imaging experiments, providing a first direct imaging of the dynamics of the domain wall motion with sub-ns temporal resolution. For both the current- and magnetic field-induced processes, the domain wall motion occurs synchronously with the excitation, indicating that an inertia-free motion of the domain wall. Furthermore, it was observed that, in the case of short current and magnetic field excitations, the domain wall remains perpendicular to the wire axis, providing a potential mechanism for a fast, tilt-free motion of magnetic domain walls in perpendicularly magnetized systems.

MA 15.49 Tue 10:00 Poster E

Simulations of magnetic domain wall propagation in width-modulated wires — •Olga Lozhkina, Pascal Kraunscheid, Robert Reeve, Gerhard Jacob, and Mathias Kläui — Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany

Magnetic domain walls (DWs) are of interest to the sensor industry due to their stability at room temperature and their ability to be nucleated and propagated by fields in wires, attributes which can be exploited for multi-turn sensors [1]. DW propagation and pinning depend on many factors that must be carefully controlled for reliable devices. DW propagation below the Walker field is the most robust, but in most cases the Walker field is close to the field required to propagate the DWs, resulting in a small operating window. Periodic modulations of the wire width have been proposed to suppress the Walker breakdown [2], which would be advantageous for such sensors. We performed simulations of DW propagation through Py wires with modulated width using mumax3 . Our simulations show that the longitudinal distance before DW transformation (Walker period) gradually drops with increasing field and tends to a certain limit depending on the wire cross-section. For thinner wires with energetically stable transverse DWs, width modulation with a period smaller than this limit leads to a significant increase of the Walker field. Thereby magnetic wire modulation may enhance the robustness of sensor operation and enlarge in particular the field operation window. [1] B. Borie et al., Appl. Phys. Lett. 111, 242402 (2017) [2] J. Ieda et al. J. Magn. Magn. Mater. 322, 1363 (2010)

MA 15.50 Tue 10:00 Poster E

Imaging domain wall motion using time-resolved SEMPA — •Daniel Schönke[1], Andreas Oelsner[2], Pascal Krautscheid[1,3], Robert Reeve[1,3], and Mathias Kläui[1,3] — [1]Institut für Physik, Johannes Gutenberg-University, 55128 Mainz, Germany — [2]Surface Concept GmbH, 55099 Mainz, Germany — [3]Graduate School of Excellence Materials Science in Mainz (MAINZ), 55128 Mainz, Germany

Scanning electron microscopy with polarization analysis (SEMPA) is a magnetic imaging technique with a high spatial resolution. While conventional setups only provide quasi-static imaging modes, which have limited the adoption of the technique, recent developments have enabled dynamic measurements and allow SEMPA to favorably compete with a range of synchrotron based techniques [1]. Here we show that with our upgraded SEMPA system we can perform new time-resolved imaging schemes including phase-sensitive detection of periodically changing magnetic states with up to 5x demonstrated enhanced signal-to-noise ratio and full dynamic imaging with a temporal resolution of 2 ns [2]. This novel SEMPA system can be used for a variety of measurement applications and fulfills the desire for high spatial and temporal resolution in a laboratory setting. We take advantage of the new system to study geometry-induced automotive domain wall dynamics in asymmetric permalloy rings [3] at different temperatures. [1] Frömter et al., Appl. Phys. Lett. 108, 142401 (2016) [2] Schönke et al., Rev. Sci. Instrum. 89, 083703 (2018) [3] Mawass et al., Phys. Rev. Applied 7, 044009 (2017)

MA 15.51 Tue 10:00 Poster E

Phase transition dynamics of CMR manganites — •Tommaso Pincelli[1,2], Gian Marco Pierantozzi[2], Chiara Bigi[2,3], Riccardo Cucini[2], Francesco Borgatti[4], Aleksandr Yu. Petrov[2], Christian H. Back[5], Masaki Oura[6], Giorgio Rossi[2,3], and Giancarlo Panaccione[2] — [1]Fritz-Haber-Institut of MPG, Faradayweg 4-6, 14195 Berlin, Germany — [2]Istituto Officina dei Materiali of CNR, c/o Area Science Park, S.S.14 km 163,5 - I-34149 Trieste, Italy — [3]Dipartimento di Fisica, Università di Milano, Via Celoria 16, I-20133 Milano - Italy — [4]Istituto per lo Studio dei Materiali Nanostrutturati of CNR, via P. Gobetti 101, I-40129 Bologna, Italy — [5]Department of Physics, Technical University Munich, D-85748 Garching b. München, Germany — [6]RIKEN SPring-8 Center, Kouto 1-1-1, Sayo-cho, Sayogun, Hyogo 679-5148, Japan

In CMR manganites, delocalization of electronic states results from competing double-exchange-driven delocalization and polaronic trapping. We explore the dynamics of the ferromagnetic metal-paramagnetic bad-metal phase transition. In the wide-band half-metallic La(1-x)Sr(x)MnO3 we isolate the evolution of delocalized electronic states with time-resolved hard x-ray photoemission, showing that the slow collapse of magnetization keeps the double-exchange interaction active for several hundreds of picoseconds, suggesting a slow timescale evolution of electronic correlation. When competing polaron trapping is brought into play in the narrow-band La(1-x)Ca(x)MnO3, new metastable phases emerge, optically accessible on ultrafast timescales.

MA 15.52 Tue 10:00 Poster E

Monitoring picosecond strain pulse echos in magnetostrictive heterostructures — •Steffen Peer Zeuschner[1,2], Tymur Parpiiev[3], Thomas Pezeril[3], Jan-Etienne Pudell[2], Marc Herzog[2], Alexander von Reppert[2], and Matias Bargheer[1,2] — [1]Helmholtz-Zentrum Berlin, BESSY II, Berlin, Germany — [2]Institut für Physik und Astronomie, University of Potsdam, Potsdam, Germany — [3]Institut des Molécules et Matériaux du Mans (UMR CNRS 6283), Université du Maine, Le Mans cedex, France

We investigate picosecond strain pulses in laser-excited highly magnetostrictive $TbFe_2$/Nb heterostructures with time-resolved magneto-optical Kerr-effect (MOKE) probing and ultrafast X-ray diffraction (UXRD). Burying the Nb layer underneath the laser excitation region in $TbFe_2$ allows for a heat-background free characterization of the laser-generated strain pulses. We clearly observe a decomposition of the strain transient into an asymmetric bipolar and a unipolar pulse, when an amorphous SiO_2 capping layer covers the excited $TbFe_2$. The inverse magnetostriction of the temporally separated unipolar strain pulses leads to a MOKE signal from the $TbFe_2$ surface that linearly depends on the strain pulse amplitude, giving an estimate of the magneto-acoustic coupling strength. Linear chain model simulations accurately predict the timing and shape of UXRD and MOKE signals that are caused by the strain reflections from multiple interfaces in the heterostructure. A second excitation pulse allows the construction of an inverted bipolar strain pulse which is expected to exhibit drastically different nonlinear acoustic propagation.

MA 15.53 Tue 10:00 Poster E

Non-equilbrium spin-orbit physics at high frequencies — •Hanan Hamamera, Filipe Souza Mendes Guimarães, Manuel dos Santos Dias, and Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany

The field of spintronics is driven by the desire to develop new spin-based devices with performances surpassing the ones used in present-day technologies. It is then important to understand the ultrafast dynamical properties of such devices. This is challenging, as the electronic and spin dynamics have very different intrinsic time scales and simultaneously being intricately coupled — and so, they are best described by a unified theory. We build such a theory by parametrizing a realistic tight-binding hamiltonian based on first-principles electronic structure calculations, and then solving it for the real-time evolution of the system. We benchmark this approach with a simple model, meant to abstract the main features of the spin-polarized electronic structure. We then perform calculations for Co/Pt(001) and Fe/W(110) bilayers, and compare and contrast the results of the time-dependent approach with existing linear response ones [1]. This work was supported by the Palestinian-German Science Bridge BMBF program and the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (ERC-consolidator Grant No. 681405-DYNASORE).

[1] F.S.M. Guimarães *et al.*, Sci. Rep. **7**, 3686 (2017)

MA 15.54 Tue 10:00 Poster E

Picosecond Strain Dynamics driven by Ultrafast Demagnetization in Dysprosium — •Alexander von Reppert[1], Jan-Etienne Pudell[1], Steffen Zeuschner[1,2], Karine Dumesnil[3], and Matias Bargheer[1,2] — [1]Institut für Physik und Astronomie, Universität Potsdam, Potsdam, Germany — [2]Helmholtz-Zentrum Berlin, Berlin, Germany — [3]Institut Jean Lamour (UMR CNRS 7198), Université Lorraine, Nancy, France

We investigate the effects of the ultrafast demagnetization on the picosecond strain pulses launched in the highly magnetostrictive material Dysprosium (Dy). The laser-induced spin-disorder in heavy rare earth materials triggers a large negative stress, which dominates the c-axis lattice dynamics over the expansive stress that originates from (in)-coherent phonon excitations. The application of an in-plane B-field shifts the FM-AFM phase transition to higher temperatures and enhances the laser-induced contraction. By observing the coherent strain pulses spatially separated from the laser excited region, we eliminate the thermal background. We find strong changes to the characteristic bipolar strain pulse that is observed in the high temperature paramagnetic region, which we attributed to the depth dependent magnetostrictive stress in the inhomogeneously heated Dy layer. Our systematic exploration of the different magnetic phases characterizes to which extend the magnetostrictive stress in this material class can be used as a transducer for novel picosecond strain experiments with unipolar, or even inverted bipolar strain pulses.

MA 15.55 Tue 10:00 Poster E

Ultrafast Demagnetization: Role of Transport and Substrates — •S. Ashok, S. T. Weber, C. Seibel, J. Briones, and B. Rethfeld — Department of Physics and Optimas Research Center, University of Kaiserslautern, Germany

Ultrafast demagnetization [1], its mechanism and the spin-resolved currents generated during it, have attracted immense attention and posses great technological applicability. The non-equillibrium in the spin-resolved chemical potentials can be described as a driving force behind ultrafast demagnetization [2]. Using this observation, the thermodynamic μT-model traces the spin-resolved non-equillibrium electron temperatures, chemical potentials and demagnetization dynamics [3]. The demagnetization in thin Nickel ferromagnetic films was studied, when the material is uniformly heated and all transport effects can be neglected.

We extend the model to the case of thicker ferromagnetic films where the role of transport becomes prominent. Here, we present the role of particle and energy transport in the ultrafast demagnetization by observing the temporal and spatial evolution of temperatures, chemical potentials and magnetization. We also present preliminary results on the role of substrates.

[1] Beaurepaire E. et al., PRL 76, 4250 (1996)
[2] Mueller B. et al., PRL 111, 167204 (2013)
[3] Mueller B. and B. Rethfeld, PRB 90, 144420 (2014).

MA 15.56 Tue 10:00 Poster E

Ultrafast negative thermal expansion driven by spin-disorder in antiferromagnetic Holmium — •Jan-Etienne Pudell[1], Alexander von Reppert[1], Daniel Schick[2], Flavio Zamponi[1], Matthias Rössle[3], Marc Herzog[1], Hartmut Zabel[4], and Matias Bargheer[1,3] — [1]Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht- Str. 24-25, 14476 Potsdam, Germany — [2]Max-Born-Institut, Max-Born-Strasse 2A, 12489 Berlin, Germany — [3]Helmholtz Zentrum Berlin, Albert-Einstein-Str. 15, 12489 Berlin, Germany — [4]Fakultät für Physik und Astronomie, Ruhr-Universität Bochum, 44780 Bochum, Germany

We measure the transient strain profile in a nanoscale multilayer system composed of Yttrium, Holmium and Niobium after femtosecond laser excitation using ultrafast X-ray diffraction (UXRD) at a laser-driven Plasma X-ray Source (PXS) setup. The strain propagation through each layer is determined by transient changes of the material-specific Bragg angles. We experimentally derive the exponentially decreasing stress profile driving the strain wave and show that it closely matches the optical penetration depth. Below the Neel temperature of Ho, the optical excitation triggers negative thermal expansion caused by a decrease of the strong magnetostriction in Holmium, which is induced by a quasi-instantaneous contractive stress, and a second contractive stress contribution rising on a 12 ps timescale. These two timescales have recently been measured for the spin-disordering in Ho [Rettig et al, PRL 116, 257202 (2016)]. As a consequence, we observe an unconventional bipolar strain pulse with an inverted sign.

MA 15.57 Tue 10:00 Poster E

Investigation of the interaction between magnetic nanoparticles in different geometries by using FMR — •Nils Neugebauer[1], Matthias Elm[1,2,3], Peter Klar[1,2], Detlev Hofmann[1,2], Alexander Fabian[2,4], Michael Czerner[2,4], and Christian Heiliger[2,4] — [1]Institute of Experimental Physics I, Heinrich-Buff-Ring 16, 35392 Gießen, Germany — [2]Center for Materials Research (LaMa), Heinrich-Buff-Ring 16, 35392 Gießen, Germany — [3]Institute of Physical Chemistry, Heinrich-Buff-Ring 17, 35392 Gießen, Germany — [4]4Institute for Theoretical Physics, Justus Liebig University Gießen, Heinrich-Buff-Ring 16, 35392 Giessen, Germany

Assemblies with well defined sizes and spacings consisting of magnetite nanoparticles (Fe3O4) with an average diameter of 20 nm were created by using meniscus force deposition method on substrates pre-patterned by electron beam lithography. To study the magnetic properties of the nanoparticle arrangements, angle-dependent ferromagnetic resonance experiments (FMR) were carried out for different measurement geometries. The analysis of the FMR spectra reveals that there are two resonances present. In in-plane geometry one resonance exhibits a clear angular dependence, while the second one remains constant. In order to get a deeper understanding of the results, micromagnetic simulations were carried out. By studying the dynamic properties in terms of solving the Landau-Lifschitz-Gilbert equation numerically it has been possible to assign these signals to different areas within the magnetic structures.

MA 15.58 Tue 10:00 Poster E

Magnetization dynamics in LSMO-heavy-metal bilayers — •Christopher Heins, Cinja Seick, Vitaly Bruchmann-Bamberg, Daniel Steil, Vasily Moshnyaga, and Henning Ulrichs — I. Physikalisches Institut, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, 37077 Goettingen, Germany

On this poster, we report on magnetization dynamics in a bilayer of $La_{1-X}Sr_XMnO_3$ (LSMO) and a heavy metal (Pt, beta-W). As a necessary prerequisite for further experimental investigations of this sample system, we in particular report on the implementation and application of stripline Ferromagnetic Resonance. With this technique we characterize the spin conductance of the interface between the two materials in the bilayer. When depositing Pt on LSMO, we find a significant increase of the Gilbert damping, whereas the magnetization is not affected. These results serve as guidelines for material selection and sample growth procedures regarding the prospect of time-resolved MOKE experiments including spin current generation in the heavy metal.

We acknowledge financial support by the Deutsche Forschungsgemeinschaft within SFB 1073.

MA 15.59 Tue 10:00 Poster E

Spin Pumping and Low Gilbert Damping in $Co_{25}Fe_{75}$ Heterostructures — •Luis Flacke[1,2], Lukas Liensberger[1,2], David Rogerson[1,2], Matthias Althammer[1,2], Hans Huebl[1,2,3], Stephan Gerprägs[2], Katrin Schultheiss[4], Aleksandr Buzdakov[4], Tobias Hula[4], Helmut Schultheiss[4], Eric Edwards[5], Hans Nembach[5], Justin Shaw[5], Rudolf Gross[1,2,3], and Mathias Weiler[1,2] — [1]Physics-Department, Technical University of Munich, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [3]Nanosystems Initiative Munich, Munich, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [5]National Institue of Standards and Technology, Boulder, CO, USA

Itinerant ferromagnets offer advantages for magnonic and spintronic devices, but typically suffer from drastically higher Gilbert damping than insulating ferrimagnets. We fabricated and investigated low-damping $Co_{25}Fe_{75}$-heterostructures and separated Gilbert damping and spin pumping contributions to the total damping using broadband ferromagnetic resonance spectroscopy. From our measurements, we extrapolate that the intrinsic damping of the magnetic alloy reaches the low 10^{-3} regime. The extracted damping is in agreement with micro-focused Brillouin-Light-Scattering experiments, which spatially resolve the spin wave propagation in patterned devices.

Financial support by Deutsche Forschungsgemeinschaft via projects WE5386/4 and WE5386/5 is gratefully acknowledged.

MA 15.60 Tue 10:00 Poster E

3D check board pattern formation of martensite/austenite domains in NiCoMnAl shape memory alloys — •Andreas Becker, Daniela Ramermann, Martin Gottschalk, Inga Ennen, Björn Büker, Tristan Matalla-Wagner, Andreas Hütten, and Günter Reiss — Center for Spinelectronic Materials and Devices, Physics Department, Bielefeld University, 33615 Bielefeld, Germany

NiMnX (X=Al,Ga,Sn,In) magnetic shape memory Heusler alloys are considered as promising materials for magnetocaloric cooling applications due to their magnetoelastic coupling near room temperature. However most of them show a very large thermal hysteresis, which limits their potential in future applications.

Thin martensite interclations in thin films could be benificial for transforming films, because the formation energy during martensite nucleation is reduced. Our aim is to decrease the thermal hysteresis in off-stoichiometric NiCoMnAl thin films by preparing multilayer systems, which consist of alternatively grown martensite intercalations and active transforming austenitic layers. The stoichiometry of these two layers is chosen in such a way that their thermal hysteresis do not overlap.

Temperature dependent magnetization measurements show a significant decrease in hysteresis width as a function of the number of martensite intercalations. If the austenite active layers have a similar thickness compared to the martensite intercalations a 3D check board pattern becomes visible in HRTEM cross section images. The contrast is due to alternating martensite/austenite domains.

MA 15.61 Tue 10:00 Poster E

Heusler compound layer systems analysed with different HRTEM techniques — •Daniela Ramermann, Andreas Becker, Inga Ennen, Martin Gottschalk, Björn Büker, and Andreas Hütten — Center for Spinelectronic Materials and Devices, Physics Department, Bielefeld University, 33615 Bielefeld, Germany

Heusler compounds are with their strong magnetic properties promising candidates for thin film devices as also for magnetocaloric applications. Needed are custom-tailored magnetic properties, where the electron microscope helps with evaluation of the properties on a nanoscopic scale. Especially **NiCoMnAl** in intercalating layers of martensite/austenite crystal structure show unexpected behavior: a reproducable checkerboard pattern when certain layer thickness requirements are met. This pattern is investigated with HR-TEM methods also including energy-loss magnetic dichroism and differential phase contrast imaging, revealing slightly twisted against each other alternating stacked structures of martensite and austenite and magnetism centering on the **Mn** atoms.

MA 15.62 Tue 10:00 Poster E

Temperature-dependent red-shift of the absorption edge of thin ferromagnetic EuO-layers — Marcel Ney[1], Paul Rosenberger[2], Patrick Lömker[2], •Günther Prinz[1], Martina Müller[2,3], and Axel Lorke[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, D-47057 Duisburg — [2]Peter Grünberg Institut, Forschungszentrum Jülich GmbH, D-52428 Jülich — [3]Faculty of Physics, TU Dortmund, D-44227 Dortmund

EuO-layers are interesting candidates for spin-filter applications in spintronic research. Below the Curie temperature of T_C=69K, EuO becomes ferromagnetic, which has a strong influence on its optical band-gap.

We investigate the optical transmission of EuO-layers with thicknesses below 50nm from room temperature down to ≈25K. The EuO-layers are grown by a molecular-beam-epitaxy process on YSZ-substrates. Below the T_C we observe a step-like shift of the absorption edge towards lower energies. This behavior can be explained by the magnetic exchange interaction, which leads to a splitting of the conduction band. Thinner layers not only show a blue-shift towards higher band-gap energies due to quantum confinement effects, but also exhibit a larger red-shift of the absorption edge during cooling below T_C. This stronger red-shift of the absorption edge starts at lower temperatures compared with thicker samples, which is attributed to a reduced magnetic exchange interaction for very thin EuO-layers. In contrast to reports in the literature, we observe a monotonic red-shift of the absorption edge for different layer thicknesses.

MA 15.63 Tue 10:00 Poster E

Influence of granularity on the magnetotransport-properties of manganese-monosilicide — •Sebastian Kölsch and Michael Huth — Goethe Universität, Max-von-Laue-Str. 1, 60438 Frankfurt am Main, Germany

Silicon-based alloys with 3d magnetic metals offer the potential for applications in spintronics and magnetic storage devices. Recently the manganese-monosilicide (MnSi) of B20-type attracted high interest due to a topological non-trivial magnetic phase in bulk MnSi at low temperatures (<30K), which could be identified as magnetic whirls known as skyrmions [1].

Considering potential applications, a reduction of dimensionality in terms of thin magnetic/semiconducting films is mandatory. In this case change of the magnetic phase diagram due to surface anisotropy and strain effects have to be taken into account. So far research has focused on optimizing the thin film growth conditions to obtain ideally monocrystalline epitaxial thin films. However, polycrystalline thin films grown by pulsed laser deposition (PLD) with increased degree of disorder, e.g. caused by non stoichiometric proportions of Mn and Si show a high-temperature (>300K) ferromagnetic phase near an insulator-metal-transition [2].

Here we present recent results on the successful growth of epitaxial but nano-granular MnSi thin films showing an unexpectedly high magnetoresistance effect.

[1] Mühlbauer, S. et al. Science 323, 915-919 (2009)
[2] Nikolaev, S. N. et al. AIP Advances 6, 015020 (2016)

MA 15.64 Tue 10:00 Poster E

Quantum entanglement of charge and spin in frustrated κ-(BEDT-TTF)2Hg(SCN)2Br — •Mamoun Hemmida[1,2], Hans-Albrecht Krug von Nidda[2], Björn Miksch[1], Leonid Samoilenko[1], Andrej Pustogow[1], Sebastian Widmann[2], Alois Loidl[2], and Martin Dressel[1] — [1]1. Phys. Inst., Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany — [2]EP V, EKM, Universität Augsburg, 86135 Augsburg, Germany

Detailed static and dynamic spin susceptibilities as well as transport investigations [1] of the two-dimensional frustrated organic metal κ-(BEDT-TTF)2Hg(SCN)2Br exhibit unusual properties below the metal-insulator transition temperature of 90 K of both charge and spin degrees of freedom. Such properties like weak ferromagnetism and glassy state seem to result from the dominant role of quantum fluctuations associated with frustration and disorder at low temperatures. Based on the experimental observations, a strong entanglement between spin and charge degrees of freedom has been suggested in Ref. 2. We gratefully acknowledge sample preparation and structural characterization by A. Henderson, T. Siegrist and J. A. Schlueter.

[1] T. Ivek et al., Phys. Rev. B 96, 085116 (2017).
[2] M. Hemmida et al., arXiv:1710.04028 (2017).

MA 15.65 Tue 10:00 Poster E

Spin reduction in covalent chain antiferromagnet $RbFeSe_2$ — •Hans-Albrecht Krug von Nidda[1], Airat Kiiamov[2], Lenar Tagirov[2,3], Yury Lysogorsky[2,5], Dmitrii Tayurskii[2], Zakir Seidov[1], Vladimir Tsurkan[1,4], Dorina Croitori[4], Axel Günther[1], Farit Vagizov[2], Franz Mayr[1], and Alois Loidl[1] — [1]EP V, EKM, University of Augsburg, D-86135 Augsburg — [2]Institute of Physics, Kazan Federal University, RUS-420008 Kazan — [3]Zavoisky Physical-Technical Institute, Kazan FRC of RAS, 420029 Kazan — [4]Institute of Applied Physics, MD-20208 Chisinau — [5]ICAMS, Ruhr-University Bochum, D-44801 Bochum

SQUID susceptibility, Mössbauer and specific-heat measurements show that $RbFeSe_2$ exhibits antiferromagnetic order below T_N=248 K. The magnetic specific heat of $RbFeSe_2$ and the spin state of Fe^{3+} ions in the compound have been analyzed. Phonon dispersion and PDOS, were evaluated from first-principles calculations. It is shown that iron atoms in quasi-one-dimensional chains have dramatically different vibrational properties against Rb and Se atoms. Analysis of our Mössbauer data, utilizing the calculated Fe PDOS, as well as our optical absorption measurements have shown full agreement with the location of the high-frequency optical-type lattice vibrations within the $FeSe_4$ tetrahedra. The phonon heat capacity has been used to evaluate the magnetic specific heat of the quasi 1D antiferromagnetically correlated Fe^{3+} ion chains. The magnetic entropy suggests an intermediate spin state S=3/2 for Fe^{3+} ions in agreement with the reduced hyperfine field of 216 kOe at 4.2 K detected by Mössbauer spectroscopy.

MA 15.66 Tue 10:00 Poster E

MBE growth of Sr(Mn,As)2 — •Martin Brajer[1,2] and Vít Novák[1] — [1]Institute of Physics ASCR, v.v.i., Cukrovarnicka 10, 162 53 Praha, Czech Republic — [2]Faculty of Mathematics and Physics, Charles University in Prague, Ke Karlovu 3, 121 16 Prague, Czech Republic

We report on growth of antiferromacnetic (AF) semiconductor by means of molecular beam epitaxy: trigonal Sr(Mn,As)2, extending the I-Mn-V family of room-temperature AFs. It has broken inversion symmetry, allowing for current-induced switching of AF moments. It can be successfully grown on lattice-matched zinc-blende semiconductor substrate, (111)InAs, which allows for a stable 2D growth, but hinders its basic transport characterization because of the high substrate conductivity. We study growth, crystal quality and surface morphology of the material depending on the growth parameters.

MA 15.67 Tue 10:00 Poster E

Reversible tuning of structural, magnetic and transport properties via oxygen desorption/absorption in epitaxial La(0.7)Sr(0.3)MnO(3-δ) thin films — Lei Cao[1], •Oleg Petracic[1], Paul Zakalek[1], Alexander Weber[2], Ulrich Rücker[1], Jürgen Schubert[3], Alexandros Koutsioubas[2], Stefan Mattauch[2], and Thomas Brückel[1] — [1]Jülich Centre for Neutron Science (JCNS-2) and Peter Grünberg Institut (PGI-4), JARA-FIT Forschungszentrum Jülich GmbH, Jülich, Germany — [2]Jülich Centre for Neutron Science (JCNS) at Heinz Maier-Leibnitz Zentrum (MLZ) Forschungszentrum Jülich GmbH, Garching, Germany — [3]Peter Grünberg Institute (PGI9-IT), JARA-Fundamentals of Future Information Technology Forschungszentrum Jülich GmbH, Jülich, Germany

An oxygen vacancy induced topotactic transition from perovskite to brownmillerite and vice versa in epitaxial La(0.7)Sr(0.3)MnO(3-δ) thin films is identified by real-time x-ray diffraction. A novel intermediate phase with a non-centered crystal structure is observed for the first time during the topotactic phase conversion which indicates a distinctive transition route. Polarized neutron reflectometry confirms an oxygen deficient interfacial layer with drastically reduced nuclear scattering length density, further enabling a quantitative determination of the oxygen stoichiometry (La(0.7)Sr(0.3)MnO(2.65)) for the intermediate state. Associated physical properties of distinct topotactic phases (i.e. ferromagnetic metal and anti-ferromagnetic insulator) can be switched reversibly by an oxygen desorption/absorption cycling process.

MA 15.68 Tue 10:00 Poster E

Thickness dependence of the anomalous Hall effect in thin films of the magnetic Weyl Co_2MnGa — •Anastasios Markou, Liguo Zhang, Dominik Kriegner, Yi-Chen Cheng, Jacob Gayles, Yan Sun, and Claudia Felser — Max Planck Institute for Chemical Physics of Solids, Dresden, Germany

Magnetic Weyl semimetals with broken time-reversal symmetry show exotic transport properties, due to the Weyl points and the associated large Berry curvature in their electronic structure [1]. Therefore, the anomalous Hall effect is expected to be large, and due to the intrinsic contribution that derives from the net Berry curvature. Here, we present the thickness dependence of the structural, magnetic, and transport properties of thin films in the magnetic Weyl semimetal Co_2MnGa. We find a large anomalous Hall conductivity and anomalous Hall angle up to 1187 $\Omega^{-1}cm^{-1}$ and 13%, respectively, which is an order of magnitude larger than typical magnetic systems.

[1]K. Manna *et al.*, Nature Reviews Materials **3**, 244 (2018)

MA 15.69 Tue 10:00 Poster E

Spin-resolved ACAR measurements of Co_2MnGa — •Josef Ketels[1], Michael Leitner[2], Kaustuv Manna[3], Rolf Stinshoff[3], Claudia Felser[3], and Christoph Hugenschmidt[1,2] — [1]Physik Department E21, Technische Universität München, Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Garching, Germany — [3]Max-Planck-Institut für Chemische Physik fester Stoffe, Dresden, Germany

The ferromagnetic compound Co_2MnGa crystallizes in the full Heusler $L2_1$ structure. This material is expected to be a half-semimetal due to a small Fermi surface in the minority spin channel. The spin polarization was experimentally determined to be close to $4.0\mu_B$/formula unit [1]. Furthermore this Heusler compound was one of the first materials to show the anomalous Nernst effect beyond the magnetization scaling relation due to the large net Berry curvature close to the Fermi energy originating from Weyl points and nodal lines [2]. The measurement of the angular correlation of positron annihilation radiation (ACAR) is a very powerful tool to investigate the bulk electronic structure. Based on the spin polarization of the positrons from a Na^{22} source, the minority and majority spin-channels can be determined separately. Here we present the first spin-resolved ACAR experiments showing the anisotropy of the Fermi surface of Co_2MnGa.

[1] Kolbe, M. *et al.*, Phys. Rev. B 86, 024422 (2012)
[2] Guin, S.N. *et al.*, arXiv:1806.06753 [cond-mat.mtrl-sci], (2018)

MA 15.70 Tue 10:00 Poster E

Structural characterization and magneto-transport properties of magnetron co-sputtered Weyl semimetal candidate Co2TiGe — •Denis Dyck[1], Andreas Becker[1], Jan Krieft[1], Anish Rai[2], Robin-Pierré Klett[1], Jungwoo Koo[1], Karsten Rott[1], Jan-Michael Schmalhorst[1], Tim Mewes[2], and Günter Reiss[1] — [1]Center for Spinelectronic Materials and Devices, Bielefeld University, Germany, Bielefeld — [2]Center for Materials for Information Technology, The University of Alabama, United States of America, Tuscaloosa

Weyl semimetals theoretically promise exotic transport properties and are also interesting for spintronic devices. Thus, the research is pursued with high effort in the recent years. Implementation in real life applications requires a scalable and energy efficient approach. As a highly tunable material class, Heusler compounds are particularly interesting in this respect. Here, we investigate the Weyl semimetal candidate and transition metal based Full Heusler compound Co2TiGe. X-ray diffraction (XRD) analysis and phi scans of the magnetron co-sputtered thin films show a highly textured L21 structure of the 225 (Fm-3m) space group with a lattice constant close to the literature value. Transmission electron microscopy (TEM) confirms the crystallographic quality. The magnetic properties have been examined by magneto-optical Kerr effect (MOKE), vibrating sample magnetometry (VSM) and ferromagnetic resonance (FMR). In addition, anomalous and planar Hall effect, and tunnel magneto resistance (TMR) measurements have been carried out.

MA 15.71 Tue 10:00 Poster E

Ferromagnetic ordering and heavy fermion behavior in $Ce_2Ru_3Ge_5$ — Ramesh Kumar Kamadurai[1,2], Djoumessi Fobasso Redrisse[2], and •Andre M Strydom[2] — [1]Institute of Physics, Chinese Academy of Sciences, Beijing, China — [2]Department of Physics, University of Johannesburg, South Africa

The series of intermetallic compounds $Ce_2T_3Si_5$ (T- Transition metal X - Si, Ge) exhibit wide range of magnetic behaviour such as magnetic ordering, heavy fermion behaviour and Kondo effect. We present the magnetic susceptibility (χ), specific heat (C_P), resistivity (ρ) thermopower (S) and magnetoresistivity (MR) properties of $Ce_2Ru_3Ge_5$. The refined lattice parameter was observed to be *a = 9.9497 (4) , b = 12.416 (4), c = 5.8978 (2) . By means of $\chi(T)$, $C_P(T)$ $\rho(T)$, $S(T)$ and MR measurements we show that the system exhibits ferromagnetic-like long-range ordering below 7.9 K with localized Ce^{3+} ions and Sommerfeld coefficient γ = 85 mJ/mol.K. A strong influence of field dependent $\chi(T)$, $\rho(T)$ and reduced saturation moment (0.32 μ_B) suggest that the crystalline electric field (CEF) plays a role in the ground state properties. The CEF splitting energies are estimated to be Δ_1 = 567 K and Δ_2 = 1491 K for the first and second excited states respectively. Absence of logarithmic variation of ρ_{mag} at low temperatures, negative MR at 2 K indicate that the Kondo energy scales are small ($\approx$ 10 K) the system exhibit incoherent Kondo scattering.

MA 15.72 Tue 10:00 Poster E

Correlating structural and magnetic properties of polycrystalline exchange bias systems — •Maximilian Merkel[1], Jonas Zehner[2], Karin Leistner[2], Dennis Holzinger[1], and Arno Ehresmann[1] — [1]Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel — [2]Leibniz Institute for Solid State and Materials Research Dresden, IFW Dresden, Helmholtzstr. 20, D-01069 Dresden

Magnetic properties of sputter-deposited polycrystalline exchange bias thin films evolve from a complex interplay of different individual magnetic anisotropies which are directly connected to the grain size distribution, crystallite texture and interface structure of the layer system. These structural characteristics can be controlled via deposition parameters or manipulated during a thermal activation procedure in an external magnetic field. Angular-resolved hysteresis measurements using Kerr magnetometry in comparison to an extended Stoner-Wohlfarth model [1], X-ray diffraction experiments and interface roughness characterization allowed for the quantification of material properties in dependence of the layer thickness, deposition parameters and the field cooling temperature, supporting common structure zone models.

[1] Müglich, N. D., Gaul, A., Meyl M., Ehresmann, A. , Götz, G., Reiss, G., Kuschel T., Time-dependent rotatable magnetic anisotropy in polycrystalline exchange-bias systems: Dependence on grain-size distribution, Physical Review B **94**, 184407 (2016)

MA 15.73 Tue 10:00 Poster E

Influence of layer thickness on exchange-spring behavior of $SrRuO_3$-$La_{0.7}Sr_{0.3}MnO_3$ bilayers — •Martin Michael Koch, Lukas Bergmann, Aurora Diana Rata, and Kathrin Dörr — Martin-Luther-Universität Halle-Wittenberg, Deutschland

Thin epitaxial bilayers of $SrRuO_3/La_{0.7}Sr_{0.3}MnO_3$ on $SrTiO_3(001)$ substrates have been suggested to form an exchange spring in $SrRuO_3$ at the interface where strong antiferromagnetic exchange coupling with the adjacent manganite layer is present. We analyze temperature- and field-dependent magnetization data in sample series of systematically varied layer thicknesses of both components grown by pulsed laser deposition on TiO_2-terminated substrates. Magnetic switching of such bilayers is strongly different from that of a conventional exchange-bias-coupled bilayer. A model of the interfacial spin structure is suggested as a vertical Bloch wall with gradually increasing out-of-plane spin canting, with in-plane magnetic easy axes at the interface and strained-bulk-like $SrRuO_3$ characteristics in sufficient distance from the interface. Results indicate a maximum extension of the exchange spring of about 10 unit cells (4 nm) into the $SrRuO_3$ layer. We discuss the impact of such interfacial spin textures on magnetic switching as well as on further properties which are important for spintronics applications.

MA 15.74 Tue 10:00 Poster E

Interlayer Exchange Coupling Dependent Variation of the Saturation Magnetization of Multilayered Systems — •Frank Schulz[1], Erol Girt[2], Zachary Nunn[2], and Eberhard Goering[1] — [1]Max-Planck-Institut für Intelligente Systeme, Stuttgart, Germany — [2]Simon Fraser University, Burnaby, Canada

The effect of interlayer exchange coupling in magnetic thin films has proven to be of great technological use, enabling the development of hard drives with very high storage densities. And yet, there are aspects of this effect that are still not fully understood. Recent studies have found that the interlayer thickness of Co/RuFe/Co sandwiches does not only affect the type of interlayer coupling and its strength, but also causes a non-monotonous variation of the saturation magnetization of these systems. In order to investigate this effect, X-ray absorption spectra have been measured in total electron yield. Making use of the X-ray magnetic circular dichroism (XMCD) effect, this gives an element specific method of measuring the magnetic properties of the samples. Additionally, magnetometric measurements have been performed using a superconducting quantum interference device (SQUID), which were combined with simulations using an enhanced Stoner-Wohlfarth model. With these methods, it could be shown that the change in saturation magnetization does not stem from the magnetic contribution of the Fe in the interlayer, but instead can be attributed to a non-magnetic *dead layer* of Co near the interface of Co and RuFe. The thickness of this dead layer was estimated, under consideration of self absorption effects, to be approximately 0.1 nm.

MA 15.75 Tue 10:00 Poster E

Ferromagnetism in $LaMnO_3/SrMnO_3$ superlattices: role of structural layout — •Robert Gruhl[1], Vitaly Bruchmann-Bamberg[1], Jan Philipp Bange[1], Vladimir Roddatis[2], and Vasily Moshnyaga[1] — [1]I. Physikalisches Institut, Georg-August-Universität Göttingen, Germany — [2]Institut für Materialphysik, Georg-August-Universität Göttingen, Germany

Interfaces in the heterostructures of transition metal oxides show unique properties which cannot be observed in the constituent bulk materials. The prominent example is a 2D electron gas in $LaAlO_3/SrTiO_3$. These emergent interfacial phenomena are believed to arise due to the complex charge, spin and orbital reconstructions at the interfaces. Superlattices (SLs) of $LaMnO_3$ (LMO) and $SrMnO_3$ (SMO) were prepared on $SrTiO_3$(100) substrates using the metalorganic aerosol deposition. The growth, controlled in-situ by optical ellipsometry, results in superlattices with flat and chemically sharp interfaces as well as in an atomically smooth surface morphology. The prepared SLs, composed from two antiferromagnets, show complex magnetic behavior with high- and low-temperature ferromagnetic phases. Samples with a constant bilayer and total thickness but with varying thicknesses of LMO and SMO were studied to determine the mutual influence of the LMO/SMO thicknesses on the interfacial magnetic properties as well as on the magnetism of the whole superlattice. Financial support of the Deutsche Forschungsgemeinschaft via SFB 1073 TP A02 is acknowledged.

MA 15.76 Tue 10:00 Poster E

Influence of defects inside the (Ni_xMn_{1-x}) antiferromagnetic layer on exchange bias in Ni_xMn_{1-x}/Co bilayers — •Tauqir Tauqir[1], M. Yaqoob Khan[2], Ismet Gelen[1], Ivar Kumberg[1], Yasser A. Shokr[1], Evangelos Golias[1], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Kohat University of Science and Technology, Kohat 26000, Khyber Pakhtunkhwa, Pakistan

A series of experiments are carried out to identify the fundamental mechanism leading to the exchange bias effect in ultrathin epitaxial ferromagnetic/antiferromagnetic (FM/AFM) Co/Ni_xMn_{1-x} (x=0; 0.25; 0.35; 0.5) bilayer samples on a Cu_3Au(001) substrate. Structural or chemical defects are deliberately introduced by Ar^+ ion bombardment for short times at a certain depth of the AFM layer. The approach is to influence the pinning sites inside the AFM material by the controlled insertion of disorder. Comparison of the magnetic properties measured by magneto-optical Kerr effect then allows a precise determination of the influence of the Ar^+ ion bombardment of the AFM layer. We find that for each sample, defects result in an increase of coercivity and exchange bias field (H_{eb}). We interpret this by the formation of domains within the AFM layer by the defects, which in turn give rise to uncompensated pinned moments that are responsible for the increased H_{eb} as predicted in the domain-state model.

MA 15.77 Tue 10:00 Poster E

Investigation of Granular Magnetic Exchange Coupled Nano-Composites — •Runbang Shao, Siming Zou, Balati Kuerbanjiang, and Ulrich Herr — Institut für Mikro- und Nanomaterialien, Universität Ulm, Ulm, Deutschland

Exchange coupling of ferromagnetic (FM) nanoparticles to antiferromagnets (AF) can increase the coercivity and the stability against superparamagnetic fluctuations. It has potential applications in further increasing the storage density of hard disk drive and manufacturing permanent magnets with high energy products. We have studied nano-composites with FM Co or Ni nanoparticles embedded in AF FeMn or IrMn thin films. To determine the average size of nanoparticles, the superparamagnetic room-temperature m-H curves of reference samples with FM nanoparticles embedded in non-magnetic Cu films are fitted using a superposition of Langevin functions calculated for varying particle size. The fitted size distribution agrees well with the result obtained by T-SEM analysis of free standing nanoparticles. After application of a field cooling procedure, exchange bias is observed for both Ni/IrMn and Co/FeMn samples at 10K. We observe a pronounced dependence of the exchange bias on FM volume filling factor. Blocking temperatures are determined via zero field cooled (ZFC) and field cooled (FC) measurements. Comparison of the blocking temperatures of nanoparticles embedded in AF films and nanoparticles embedded in non-magnetic films reveals the influence of the exchange coupling on the magnetic energy landscape.

MA 15.78 Tue 10:00 Poster E

Magnetic and structural properties of MBE grown Fe/Gd films on W(110) investigated with XRR and XMCD-R — •Dominic Lawrenz[1], Wibke Bronsch[1], Markus Gleich[1], Xinwei Zheng[1], Abdallah Elkalash[1], Christian Schüssler-Langeheine[2], Emmanuelle Jal[3], Nele Thielemann-Kühn[1], and Martin Weinelt[1] — [1]Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin — [2]Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, Albert-Einstein-Strasse 15, 12489 Berlin — [3]Laboratoire de Chimie Physique-Matiere et Rayonnement, 4 place Jussieu, 75252 Paris Cedex 05

We studied bilayers of Fe/Gd on W(110) grown via molecular beam epitaxy (MBE). Thickness as well as roughness of the overall film and its constituent layers can be determined from an analysis of X-ray reflectrometry (XRR) measurements. Employing the dichroic response of the Fe L_3 and the Gd M_5 edges measured with XMCD in reflection, we examined the temperature-dependent magnetization of the bilayer element specifically. Our results show a ferrimagnetic coupling between the Fe and Gd layers in agreement with previous investigations [1]. Close to room temperature we observe that both layers first demagnetize and at slightly higher temperatures remagnetize in the opposite direction. This is very promising as it hints at the possibility of single shot all-optical switching of such layers with short laser pulses, shown for FeGd alloys before [2].

[1] Haskel *et al.*, *Phys. Rev. Lett.* **87**, 207201 (2001)
[2] Stanciu *et al.*, *Phys. Rev. Lett.* **99**, 047601 (2007)

MA 15.79 Tue 10:00 Poster E

Fabrication of tunnel junctions using a combination of sputtering and atomic layer deposition — •L. P. Potapov[1,2], K. Geishendorf[3], R. Schlitz[1,2], K. Nielsch[3,4], S. Fabretti[1,2], S. T. B. Goennenwein[1,2], and A. Thomas[3] — [1]Institute for Solid State and Materials Physics, Technical University of Dresden — [2]Center for Transport and Devices of Emergent Materials, Technical University of Dresden — [3]Leibniz Institute for Solid State and Materials Research Dresden (IFW Dresden), Institute for Metallic Materials — [4]Institute of Materials Science, Technical University of Dresden

Since more than 20 years, magnetic tunnel junctions are attracting great attention in spin electronics research. One of the key challenges for the fabrication of high-quality tunnel elements is the deposition of ultrathin, homogeneous and pinhole free tunnel barriers.

Atomic layer deposition (ALD) seems to be very promising for that, since it allows for conformal and robust coating of arbitrarily shaped surfaces. Following up on a recent publication [1], this work investigates the fabrication and properties of magnetic tunnel junctions fabricated by a combination of magnetron sputtering and ALD. Specifically, we look into the combination of shadow masks and ALD deposition in view of high-quality (magnetic) tunnel junctions. The characterization of the tunnel junctions is performed using complementary structural and electrical methods.

[1] S. Fabretti *et. al.*, Appl. Phys. Lett. **105**, 132405 (2014)

MA 15.80 Tue 10:00 Poster E

Strain-induced perpendicular magnetic anisotropy and Gilbert damping in Tm3Fe5O12 thin films — •Oana Ciubotariu[1], Anna Semisalova[2], Killian Lenz[2], and Manfred Albrecht[1] — [1]Institute of Physics, University of Augsburg, Universitätsstraße 1, 86135 Augsburg, Germany — [2]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, BautznerLandstr. 400, 01328 Dresden, Germany

In the attempt of implementing iron garnets with perpendicular magnetic anisotropy (PMA) in spintronics, the attention turned towards strain-grown iron garnets. One candidate is Tm3Fe5O12 (TmIG) which shows strain-induced PMA when grown under tensile strain [1]. Possible substrate choices are GGG(111) and substituted-GGG(111) substrates, where the latter generated a higher in-plane tensile strain for the growth of TmIG. TmIG films with thicknesses between 20 and 300 nm were grown by PLD on sGGG(111) substrates. XRD measurements showed that films thinner than 200 nm exhibit in-plane tensile strain, thus, they meet the requirement for PMA. As expected, these films show PMA due to strain-induced magneto-elastic anisotropy. However, with increasing film thickness a relaxation of the unit cell towards its bulk structure is observed resulting in a rotation of the magnetic easy axis from out of the sample plane towards the sample plane. The Gilbert damping parameter extracted from FMR measurements is in the range of 0.03 independent of the film thickness.

[1] Kubota, M. et al. App. Phys. Exp. 5, 103002 (2012)

MA 15.81 Tue 10:00 Poster E

Interface coupling between 3*d*-$La_{0.67}Sr_{0.33}MnO_3$ and 5*d*-$SrIrO_3$ — •Lukas Bergmann, Diana Rata, Pia Düring, and Kathrin Dörr — Martin Luther University Halle-Wittenberg, Institute of Physics, Halle (Saale), Germany

Iridate compounds are of high scientific interest, since they show emergent phenomena due to competition between the relevant energy scales of electron correlation, bandwidth and, most importantly, strong spin-orbit coupling. We investigate how the interface coupling between 3*d*-$La_{0.67}Sr_{0.33}MnO_3$ (LSMO) and 5*d*-$SrIrO_3$ (SIO) alters the magnetic properties such as magnetic order and anisotropy of LSMO which is a bulk collinear ferromagnet with high spin polarization.

High-quality superlattices and bilayers of LSMO and SIO were coherently grown with systematically varied layer thicknesses by pulsed laser deposition on TiO_2 terminated (100) $SrTiO_3$ substrate. The structure characterization was done by XRD. The magnetic and electrical properties were investigated by SQUID and transport measurements. Bilayers of reversed growth sequence show strongly different magnetic properties. Depending on layer thickness and sample type, the saturated magnetic moment and the Curie temperature of LSMO is strongly suppressed. Our results suggest the occurrence of non-collinear Mn spin textures at the LSMO/SIO interfaces.

MA 15.82 Tue 10:00 Poster E

Investigation of tunneling anisotropic magnetoresistance (TAMR) in fully epitaxial oxide stacks — •Kevin Lancaster[1], Camillo Ballani[1], Christoph Hauser[1], Philip Trempler[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg 06120 Halle (Saale), Germany

Tunneling anisotropic magnetoresistance (TAMR) [1] can appear in stacks with a single crystalline ferromagnetic electrode, a tunnel barrier and a non-magnetic counter electrode. Especially for fully epitaxial stacks an increase in magnetoresistance is expected because of increased k-parallel conservation. More complex effects may appear when a ferroelectric tunnel barrier is used. We present an optimization for the thin film pulsed laser deposition of $SrTiO_3$ and $BaTiO_3$ tunnel barriers on $La_{0,7}Sr_{0,3}MnO_3$ for (001)-oriented $SrTiO_3$ substrates. After deposition the layer stacks were processed by means of lithography, etching and electron beam evaporation. Besides structural characterization we will present magnetotransport measurements done at low temperatures in a cryostat equipped with a 3D vector magnet.

[1] C. Gould, C. Ruester, G. Schmidt, L. Molenkamp: "Tunnelling Anisotropic MagnetoResistance (TAMR)", INTERMAG 2006 - IEEE International Magnetics Conference 4261550 (2006), 116

[2] J. D. Burton, Evgeny Y. Tsymbal: "Tunneling anisotropic magnetoresistance in a magnetic tunnel junction with half-metallic electrodes", Physical Review B93, 024419, 2016

MA 15.83 Tue 10:00 Poster E

X-ray resonant magnetic reflectometry (XRMR) study of the interface between ferromagnetic transition metals and MgO — Daan Benjamin Boltje[1,2], •Sven Erik Ilse[1], Gisela Schütz[1], and Eberhard Goering[1] — [1]Max Planck Institute for Intelligent Systems, Stuttgart, Germany — [2]Delmic BV, Delft, Netherlands

Multilayer systems of ferromagnetic transition metals and MgO attract a lot of attention in the last years because of their application in STT-MRAMs. The chemical and magnetic properties at the interface between the transition metal and MgO are of exceptional interest in STT-MRAM cells. Those properties determine for example the strength of the interfacial perpendicular magnetic anisotropy and the thickness of possible magnetic dead layers, which are important parameters for the performance of MRAMs. With X-ray resonant magnetic reflectometry (XRMR) we combine the advantages reflectometry and X-ray magnetic circular dichroism (XMCD). Thus, we are able to determine element specific chemical and magnetic depth profiles including roughness at interfaces with XRMR. We performed X-ray absorption spectroscopy (XAS), XMCD and XRMR measurements on Ta|CoFeB|MgO|Al2O3|Au stacks. The chemical depth profile revealed a pronounced roughness at the Ta|CoFeB interface and that especially Fe intermixes largely with other species at the interfaces. The magnetic depth profile revealed a 10 Å and a 4 Å thick magnetic dead layer for Fe and Co, respectively, at the CoFeB|MgO interface.

MA 15.84 Tue 10:00 Poster E

Characterization of the exchange bias system Fe_3O_4/CoO via SQUID and VSM — •Kevin Ruwisch, Jari Rodewald, and Joachim Wollschläger — Fachbereich Physik, Universität Osnabrück, Barbarastraße 7, 49076 Osnabrück

Spintronics is a rising field of research in physics. Here, magnetite as a ferrimagnet and cobaltoxide as an antiferromagnet have become more important for industrial applications in spintronics over the years. For instance, magnetite is used in magnetoresistive random-access memory (MRAM) consisting of magnetic tunnel junctions (MTJ). Thus, improving the magnetic properties of ferrimagnetic/antiferromagnetic bilayers for spintronic devices is very important since antiferromagnetic films serve as pinning layers, e.g., for MTJs due to exchange bias.

Hence, in this work Fe_3O_4/CoO bilayers, grown by reactive molecular beam epitaxy (RMBE) on MgO(001), are investigated via temperature-dependent vibrating sample magnetometry (VSM) and superconducting quantum interference device (SQUID). Hysteresis as well as temperature dependent magnetization measurements were performed. The composition as well as the surface structure have been characterized by in-situ x-ray photoelectron spectroscopy (XPS) and low-energy electron diffraction (LEED), respectively. One approach of characterizing the magnetic features of Fe_3O_4/CoO is to evaluate the impact of CoO towards coercivity, remanence, magnetocrystalline anisotropy and especially the exchange bias. Additionally the blocking temperature with respect to the film thickness of the antiferromagnetic layer is investigated.

MA 15.85 Tue 10:00 Poster E

Metadynamics study on the reorientation transition in magnetic thin films — •László Udvardi[1,2], Balázs Nagyfalusi[1], and László Szunyogh[1,2] — [1]Department of Theoretical Physics, Buapest University of Technology and Economics — [2]MTA-BME Condensed Matter Research Group, Budapest University of Technology and Economics

The competition between different type of anisotropies often leads to a reorientation of the magnetization direction. The temperature driven spin reorientation transition in thin films is usually explained by competing uniaxial on-site anisotropy and shape anisotropy. In the study we present the results of Monte Carlo simulations based on a classical Heisenberg model. The free energy landscape is sampled along a path relevant for the reorientation by means of well tempered metadynamics[1]. The simulation has been performed using model parameters and exchange tensors and anisotropy parameters obtained from *ab-initio* calculations. We demonstrate that the competing magnetic anisotropies result in both first and second order transitions.

[1] Barducci, A. and Bussi, G. and Parrinello, M., Phys. Rev. Lett. **100**, 020603 (2008)

MA 15.86 Tue 10:00 Poster E

Temperature and angular dependence of the anisotropic magnetoresistance in epitaxial Mn5Ge3 film — •Yufang Xie[1,3], ye yuan[2], mao wang[1,3], chi xu[1,3], manfred helm[1,3], shengqiang zhou[1], and Slawomir Prucnal[1] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstrasse 400, D-01328 Dresden, Germany — [2]Physical Science and Engineering Division, King Abdullah University of Science and Technology, 23955-6900 Thuwal, Saudi Arabia — [3]Technische Universität Dresden, D-01062 Dresden, Germany

The (100) epitaxial ferromagnetic Mn5Ge3 films are made by ms-range diffusion of Mn into Ge (100) [1] . Temperature and angular dependent magnetoresistance (MR) measurements performed on the ferromagnetic Mn5Ge3 films reveal strong anisotropy when applied field is parallel to the film plane. More interestingly, the angular dependence of the MR at H =30 kOe change strongly with temperature. The characteristic feature of the angular dependent MR is a twofold symmetry at temperature below 170 K. As the temperature increases from 170 K to 270 K an additional set of peaks appears and the observed anisotropy becomes more and more prominent. At this temperature range the MR shows an overall fourfold symmetry. At the temperature higher than 270 K the angular dependent MR shows a twofold symmetry again.

[1] Y. Xie, Y. Yuan, M. Wang, C. Xu, R. Hübner, J. Grenzer, Y. Zeng, M. Helm, S. Zhou and S. Prucnal, Appl. Phys. Lett. 113, 222401 (2018)