Magnetism at the Nanoscale: Imaging - Fabrication - Physics

736. WE-Heraeus-Seminar

06 - 08 January 2021
ONLINE

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation that supports research and education in science with an emphasis on physics. It is recognized as Germany's most important private institution funding physics. Some of the activities of the foundation are carried out in close cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft). For detailed information see https://www.we-heraeus-stiftung.de

Aims and scope of the 736. WE-Heraeus-Seminar:

The development of new electronic devices with reduced dimensions, larger memory, faster data processing capabilities, and improved user experience requires new technological approaches. The development of magnetic materials with new functionality stands in the center of those approaches. Future advances rely on basic research in the fields of fabrication, imaging, and understanding of fundamental physical processes on short timescales and nanometer length scales.

In this seminar, we will discuss advances in magnetic devices fabrication, characterization techniques, and theoretical modeling, all with emphasison decreasing physical dimensions of the devices and increasing operation speed. With decreasing sizes, sample preparation becomes more and more complicated. In addition to this, magnetic signals become weaker and therefore require characterizing techniques and magnetic imaging to be driven to their limits. Besides this, the magnetic properties change and become more complex leading to new dynamic processes which play a significant role and need a deeper theoretical understanding to continue the quest for smaller and faster computing units. The fundamental physical effects occurring, at the nanoscale are currently investigated and a necessary building block for future spintronic applications. Miniaturization has led to a tremendous increase of information storage capabilities over the last decades shaping the transformation into a knowledge society. This success story can only be continued if new ideas, materials and methods contribute to global trends like digitalization and artificial intelligence.

The central objective of this seminar is to gather researchers working at the forefront of material research and fabrication, as well as others who develop and apply novel methods to image magnetic properties in such materials, with scientists who directly investigate the physics on a fundamental level and for applications. Moreover, we will provide a platform where emerging young scientists can meet established key figures in the field.

Introduction

Scientific Organizers:

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Program

Program

Wednesday, 06 January 2021

08:45	Jakob Walowski Felix Büttner Bastian Pfau	**Welcome & opening remarks**
09:00 – 09:35	Ho Pin	**Stability and manipulation of Skyrmions in multilayer nanostructures**
09:35 – 09:55	Erick Burgos Parra	**Field dependence of hybrid chiral textures in Ferromagnetic multilayers**
09:55 – 10:30	Giovanni Finocchio	**Skyrmion stabilization in hybrid multilayers and skyrmion-caloritronics**
10:30 – 10:45	***Networking***	
10:45 – 11:00	*COFFEE BREAK*	
11:00 – 11:35	Denys Makarov	**Curvilinear magnetism: From curvature induced magnetochirality to shapeable magnetoelectronics**
11:35 – 11:55	Michael Heigl	**Dipolar-stabilized first and second-order antiskyrmions in ferrimagnetic multilayers**
11:55 – 12:30	Yuriy Mokrousov	**Spin chirality: a functional variable of magnetic materials**
12:30 – 12:45	***Networking***	
12:45	*LUNCH BREAK*	
14:00 – 16:00	**Poster session 1**	
16:00 – 16:35	Tony Zhou	**A magnon scattering platform**
16:35 – 17:10	Hans Hug	**Coexistence of two Skyrmion phases in hybrid ferro/ferrimagnetic multilayers observed by quantitative MFM**
17:10 – 17:45	P. Chris Hammel	**Microscale characterization of ferromagnets: Dynamics and interfacial interactions**

Program

Thursday, 07 January 2021

09:00 – 09:35	Xiuzhen Yu	**Manipulation and control of nanometric topological spin textures**
09:35 – 09:55	Kenta Hagiwara	**Spin and orbital texture of the Weyl semimetal $MoTe_2$ studied by spin-resolved momentum microscopy**
09:55 – 10:30	Jeffrey McCord	**Magnetooptical imaging on different length- and timescales**
10:30 – 10:45	***Networking***	
10:45	*COFFEE BREAK*	
11:00 – 11:35	Simone Finizio	**Nucleation dynamics of chiral magnetic textures studied with time-resolved X-ray microscopy**
11:35 – 11:55	Aurore Finco	**Imaging non-collinear antiferromagnetic textures via single spin relaxometry**
11:55 – 12:30	Markus Weigand	**Advanced methods for magnetic scanning X-ray microscopy**
12:30 – 12:45	***Networking***	
12:45	*LUNCH BREAK*	
14:00 – 16:00	**Poster session 2**	
16:00 – 16:35	Kirsten von Bergman	**Zero-field magnetic skyrmions in model-type systems studied with STM**
16:35 – 17:10	Kai Litzius	**Universal high-speed dynamics of bubble skyrmions in an uncompensated amorphous ferrimagnet**
17:10 – 17:45	***Networking Event***	

Program

Friday, 08 January 2021

09:00 – 09:35	Timo Kuschel	**Impact of thermal conductivity in insulators on thermally induced spin currents**
09:35 – 09:55	Jonathan Kipp	**The chiral hall effect in canted ferromagnets and antiferromagnets**
09:55 – 10:30	Matthias Althammer	**Observation of antiferromagnetic magnon pseudospin dynamics and the Magnon Hanle effect**
10:30 – 10:45	***Networking***	
10:45	*COFFEE BREAK*	
11:00 – 11:35	Sangeeta Sharma	**Ultrafast spin dynamics: ab-initio description**
11:35 – 11:55	Martin Schultze	**Driving spin dynamics with the electric field of light**
11:55 – 12:30	Daniel Steil	**Optically induced intersite spin transfer in ferromagnetic alloys and compound systems**
12:30	Jakob Walowski Felix Büttner Bastian Pfau	**Closing remarks & awards**

Posters

Nr.		Posters session 1
1	Md. Shadab Anwar	**Irradiation-induced magneto-structural phase transition in Fe_60V_{40} alloy thin films**
2	Sanjay Ashok	**Influence of transport on the time-resolved MOKE signal during ultrafast demagnetization**
3	Riccardo Battistelli	**High resolution coherent X-ray magnetic imaging with holography-aided phase retrieval**
4	Benny Böhm	**Manipulation of laterally homogeneous vertical AF domain walls in synthetic antiferromagnets with perpendicular magnetic anisotropy**
5	Davide Bossini	**Ultrafast amplification and non-linear magneto-elastic coupling of coherent magnon modes in an antiferromagnet**
6	Claire Donnelly	**Mapping buried topological spin textures with 3D magnetic imaging**
7	Jonas Feldmann	**Epitaxial YIG nanofilms grown by metalorganic aerosol deposition**
8	Amalio Fernandez-Pacheco	**Investigation of new effects in 3D magnetic nanostructures with complex geometries**
9	Kathinka Gerlinger	**Optical Skyrmion Nucleation in Functional Co-based Multilayers**
10	Sumit Ghosh	**Ultrafast electronic generation of antiferromagnetic spin spiral states**
11	Dongwook Go	**Orbital transport in spintronics**
12	Mateusz Gołębiewski	**Demonstration and potential application of the spin-wave Talbot effect**

Nr.		Posters session 1
13	Olena Gomonay	**Dynamics of antiferromagnetic textures affected by inhomogeneous strains**
14	Hauke Heyen	**Skyrmion movement in Ta/CoFeB/MgO-trilayers**
15	Neha Jha	**Phenalenyl-based Organic Barriers for Tunnel Junctions**
16	Lisa-Marie Kern	**Nanopatterning to Control and Localize Optical Skyrmion Nucleation**
17	Tobias Kleinke	**2D Maps of Laser induced Photocurrents in Ferromagnet-Topological Insulator Heterostructures**
18	Deli Kong	**In situ transmission electron microscopy of magnetism in highly strained nanowires**
19	André Kubetzka	**Domain Walls in a Row-Wise Antiferromagnetic Manganese Monolayer**
20	Sina Ludewig	**Towards ultrafast optical excitation of propagating magnons on the nanoscale**
21	Maximilian Merte	**Nonlinear photocurrents in antiferromagnets**
22	Daniel Metternich	**DyCo – A Material for Ultrasmall Skyrmions at Room Temperature?**
23	Dennis Meyer	**Magnetism and thermal transport in LMO / SMO superlattices**
24	Mathieu Moalic	**Excitation of short wavelength spin waves in ferromagnetic conduit with microwave pumped perpendicularly magnetized nanodot**

Nr.		Poster session 2
25	Manuel Müller	**Temperature-dependent spin-transport and current-induced torques in superconductor/ferromagnet heterostructures**
26	Maximilian Paleschke	**Plasmon-like fringe patterns on permalloy nanostructures in femtosecond photoemission electron microscopy**
27	Henrike Probst	**Study of ultrafast element-specific magnetization dynamics by use of extreme ultraviolet light**
28	Oleksandr Pylypovskyi	**Geometrically driven chiral effects in curvilinear antiferromagnetic spin chains**
29	Levente Rózsa	**Temperature scaling of spin model parameters**
30	Ruslan Salikhov	**Reversal of the domain wall magnetization in perpendicular anisotropy stripe and bubble domains of Co/Pt multilayers**
31	Fabian Samad	**Magnetic microstructure investigations of focused ion beam irradiated synthetic antiferromagnets with perpendicular anisotropy**
32	Tom Saunderson	**Orbital decomposition of Yu-Shiba-Rusinov resonances from magnetic impurities in multiband superconducting Pb**
33	Boris Seng	**Direct imaging of chiral domain walls with Dzyaloshinskii-Moriya interaction in ferrimagnetic alloys at different temperatures**
34	Zahra Shomali	**Spin transfer torque in ferromagnetic Josephson junctions Including chiral P-wave ferromagnetic superconductor reservoirs**

Nr.		Poster session 2
35	Sibylle Sievers	**Quantum calibrated magnetic force microscopy**
36	Finn-Frederik Stiewe	**THz-2D scanning spectroscopy**
37	Karen Stroh	**Magnetic coupling in $La_{0.7}Sr_{0.3}MnO_3/La_2CoMnO_6$ superlattices**
38	Christian Strüber	**Tracing magnetization dynamics in Gd, Tb and Fe at the BZ edge by TR-ARPES**
39	Xin Liang Tan	**Spin-resolved Fermi Surface of ultrathin ferromagnetic FePd alloy monolayers**
40	Phoebe Tengdin	**Ultrafast manipulation of order in compound and textured magnetic materials**
41	Nele Thielemann-Kühn	**Optical driven 4*f*-spin and orbital transitions in rare-earth metals**
42	Clemens von Korff Schmising	**Element-specificity in resonant spectroscopy of complex magnetic systems in the extreme ultraviolet spectral range**
43	Jonathan Weber	**Lorentz imaging in an ultrafast transmission electron microscope**
44	Teresa Weßels	**Quantitative analysis of magnetic states in an artificial spin ice by off-axis electron holography**
45	Steffen Wittrock	**Photo-induced magnetization dynamics with spin-currents: spin wave manipulation and ultrafast phenomena**
46	Lena Wysocki	**Tailoring the magnetic anisotropy of $La_{0.7}Sr_{0.3}Mn_{1-y}Ru_yO_3$ epitaxial thin films**

Nr.		Poster session 2
47	Lin Yang	**Magnetic anisotropy and anomalous Hall effect of $SrRuO_3$/$LaNiO_3$ superlattices grown on $SrTiO_3$(100)**
48	Lichuan Zhang	**Imprinting and driving electronic orbital magnetism using magnons**

Abstracts of Talks

(in alphabetical order)

Observation of Antiferromagnetic Magnon Pseudospin Dynamics and the Magnon Hanle effect

M. Althammer[1,2]

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The spin-1/2 of an electron makes it an archetypal two-level system and inspires the description of other two-level systems using an analogous pseudospin. The quantized spin excitations of an ordered antiferromagnet are such pairs of spin-up and -down magnons and can be characterized by a magnonic pseudospin, which has eluded experiments thus far. The similarity between electronic spin and magnonic pseudospin has triggered the prediction of exciting phenomena like emergent spin-orbit coupling and topological states in antiferromagnetic magnonics. As a first step we will introduce the concept of magnon pseudospin and description of magnon pseudospin dynamics and discuss similarities to electron spin transport [1]. In the second part, we show our recent experiments demonstrating control of magnon spin transport and pseudospin dynamics in a 15 nm thin film of the antiferromagneticinsulator hematite (α-Fe_2O_3) utilizing two Pt strips for all-electrical magnon injection and detection [2]. We observe an oscillation in polarity of the magnon spin signal at the detector as a function of the externally applied magnetic field. We quantitatively explain our experiments in terms of diffusive magnon transport. In particular, we observe a coherent precession of the magnon pseudospin caused by the easy-plane anisotropy and the Dzyaloshinskii-Moriya interaction. This observation can be viewed as the magnonic analogue of the electronic Hanle effect and the Datta-Das transistor, unlocking the high potential of antiferromagnetic magnonics towards the realization of electronics-inspired phenomena.

References

[1] A. Kamra et al., (2020) accepted for publication in PRB.
[2] T. Wimmer et al., arXiv 2008.00440 (2020) accepted for publication in PRL.

Field Dependence of Hybrid Chiral Textures in Ferromagnetic Multilayers

E. Burgos Parra[1,2], S. Flewett,[3], Y. Sassi[2], F. Ajejas[2], W. Legrand[2] C. Leveille[1], P. Gargiani[4], M. Valvidares[4], N. Reyren[2], V.Cros[2], N. Jaouen[1]

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Chiral magnetic structures induced by Dzyaloshinskii-Moriya interaction (DMI) [1] have been proposed as the cornerstone of new technology applications such as high-density data storage devices or neuromorphic computing [2], due their room temperature stability and efficient current induced motion. Recent studies of the amplitude of magnetic satellites of a crystal Bragg peak by Zhang et al. [3] showed that x-ray resonant magnetic scattering (XRMS) is a powerful tool to access to the relevant topological parameters of these magnetic structures.
In this work, we use small angle reflectivity XRMS to reveal directly the chiral properties of FM multilayers with tailored magnetic chiralities driven by spin-orbit-related effects at interfaces [4,5]. We show that it can straightforwardly and unambiguously determine the main characteristics of chiral magnetic distributions in perpendicularly magnetized multilayers [4]: its chiral nature, the quantitative winding sense (clockwise or counterclockwise), and its type, i.e. Néel (cycloidal) or Bloch (helical). Moreover, we prove that this approach combined with micromagnetic simulations reveals hybrid chiral spin texture in multilayers [5]. Finally, we studied the in plane field dependence intensity of the dichroism and the appearance of second order diffraction peaks, usually forbidden on these systems. We have performed XRMS simulations on micromagnetic simulations in order to better understand the asymmetric change of the intensity of the magnetic asymmetry lobes the hysteretic behavior of these ones with the external field. As result, we have predicted the in-depth magnetization of these hybrid chiral spin textures, which suggest a complex interplay between the hybrid domain wall state existing in these systems and DMI fields.

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[2] A. Fert, N. Reyren and V. Cros, Nat. Rev. Mat. **2**, 17031 (2017)
[3] S. L. Zhang, G. van der Laan, and T. Hesjedal, Nat. Commun. **8**, 14619 (2017)
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Imaging non-collinear antiferromagnetic textures via single spin relaxometry

A. Finco[1]

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Antiferromagnets attract a great interest for spintronics owing to the robustness of magnetic textures and their fast dynamics. However, since they exhibit no net magnetization, antiferromagnets are challenging to work with. NV-center magnetometry, which provides a µT sensitivity combined with a nanoscale spatial resolution, has emerged in the last years as a powerful technique to investigate them [1].

Here we introduce a new imaging mode of the NV-center magnetometer which does not rely on the measurement of the static magnetic stray field but on the detection of magnetic noise originating from spin waves inside the non-collinear antiferromagnetic textures of interest. The presence of magnetic noise accelerates the NV spin relaxation. As a consequence, the emitted photoluminescence is reduced, allowing a simple detection of the noise sources [2].

We demonstrate this new technique on synthetic antiferromagnets (SAF) [3] consisting of two ferromagnetic Co layers antiferromagnetically coupled through a Ru/Pt spacer. We first image domain walls and prove that we perform noise-based imaging by measuring a shorter NV spin relaxation time above an antiferromagnetic domain than above a domain wall. Calculations of the spin waves dispersion both in the antiferromagnetic domains and in the domains walls as well as maps of simulated magnetic noise intensity enable us to conclude that the noise which we probe arises from spin waves channelled in the domain walls.

Going further, we tune the composition of the SAF stacks in order to stabilize spin spirals or antiferromagnetic skyrmions. In both cases, our relaxometry-based technique is able to image the non-collinear structures, demonstrating its efficiency and opening new avenues of exploration in the characterization of complex structures in magnetically-compensated materials.

This work was performed in collaboration with the UMR CNRS/Thalès and the Center for Nanoscience and Nanotechnology (C2N) in Palaiseau, France. It has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 846597 and from the DARPA TEE Program.

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[2] A. Finco et al, arXiv:2006.13130 (2020)
[3] W. Legrand et al, Nature Materials, **19**, 34 (2020)

Nucleation dynamics of chiral magnetic textures studied with time-resolved X-ray microscopy

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Chiral magnetic textures stabilized in perpendicularly magnetized materials exhibiting a non-negligible Dzyaloshinskii-Moriya interaction have recently attracted attention in the magnetism research community. Amongst the various chiral magnetic configurations, magnetic skyrmions have been one of the most extensively investigated ones, as they show a set of interesting properties, including an energy barrier against annihilation [1] and the possibility of manipulating them with low current densities [2], which has led to the proposal to employ these magnetic configurations as a digital information encoder.

Proposed designs of skyrmionic data processing devices usually rely on three components: nucleation/deletion [3], current-driven motion [4], and electrical detection [5] of the magnetic skyrmions. In this contribution, after an overview of time-resolved X-ray magnetic microscopy techniques, we present the time-resolved investigation of the dynamics of the current-induced nucleation of magnetic skyrmions in absence of external magnetic fields at a nano-engineered nucleator site fabricated on top of a Pt/CoB/Ir microwire [3]. With these measurements, we could demonstrate the reliable current-induced nucleation of magnetic skyrmions in absence of external magnetic fields with pulse widths down to 50 ps, and observe that the nucleation process is driven by a synergy between the spin orbit torque-induced switching of the magnetization and thermal effects due to the Joule heating of the current pulse.

Part of this work has received funding from the EU - H2020 programme (Grant No. 654360) having benefitted from the access provided by PSI in Villigen within the framework of the NFFA-Europe Transnational Access Activity.

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Skyrmion stabilization in hybrid multilayers and skyrmion-caloritronics

Giovanni Finocchio

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In this talk, I will discuss recent results in the field of magnetic skyrmions we achieved in Messina. Magnetic skyrmions are topological protected solitons with a chirality that can be stabilized by the Dzyaloshinskii-Moriya interaction (DMI). Understanding the physical properties of magnetic skyrmions is important for fundamental research with the aim to develop new spintronic device paradigms where both logic and memory can be integrated at the same level or for unconventional computing. We have recently studied different mechanism of stabilization of skyrmions in confined devices considering also hybrid multilayers [1]. In this seminary, it will be discussed the stability of magnetic skyrmion (complete vs incomplete) and the dynamical properties of skyrmions driven by a thermal gradient [2] and nonuniformities in material parameters.

References

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Spin and orbital texture of the Weyl semimetal $MoTe_2$ studied by spin-resolved momentum microscopy

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Momentum microscopy [1] is based on the principles of photoelectron emission microscopy (PEEM), which provides PEEM images in real space. Moreover, it also provides two-dimensional photonelectron maps of the in-plane crystal momentum over the whole Brillouin zone. Thus, we are able to measure the local electronic structure on nano-sized samples and individual domains. Together with an imaging spin filter [2], we have revealed the spin-resolved electronic structure of the unconventional type-II Weyl semimetal 1Td $MoTe_2$ in the full Brillouin zone. Weyl semimetals host chiral fermions in solids as a pair of non-degenerate linear dispersions with band crossing points in bulk [3]. These Weyl points are protected by topology, forming a Fermi arc, which is a connection between a pair of Weyl points with opposite chirality at the surface. Combined with the use of differently polarized light, we have revealed the spin texture and the orbital texture of the strongly tilted Weyl cones [4] in comparison with first-principles calculations. We give evidence that a pair of Weyl cones exhibits a strong circular dichroism with reversed sign, indicating the different chiral charge of the respective Weyl points in the Fermi surface.

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Microscale Characterization of Ferromagnets: Dynamics and Interfacial Interactions

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Development of sensitive local probes of magnon dynamics is essential to further understand the physical processes that govern magnon generation, propagation, scattering, and relaxation. Quantum spin sensors like the NV center in diamond have long spin lifetimes and their relaxation can be used to sense magnetic field noise at gigahertz frequencies. We discuss the mechanisms by NV relaxation arises from either individual or multiple spinwaves from various magnon scattering processes.[1] Multi-magnon processes enable sensitivity to magnons having frequencies exceeding the NV resonance frequency. A contrasting approach to microscopic FMR detection employs force detection using a scanned micromagnetic tip. Spatially resolved spectroscopic measurements obtained using ferromagnetic resonance force microscopy provide a route to detailed understanding of spin interactions at normal-metal/ferromagnet interfaces. We discuss an unexpected 32-G uniaxial anisotropy field generated in a 20-nm-thick $Y_3Fe_5O_{12}$ thin film as a consequence of such an interaction with a 5-nm Au overlayer. [2] The use of the low-damping ferrimagnetic insulator $Y_3Fe_5O_{12}$ enables imaging with multiple localized standing spin-wave modes (multimode imaging) confined by the micromagnetic tip.

References

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Dipolar-stabilized first and second-order antiskyrmions in ferrimagnetic multilayers

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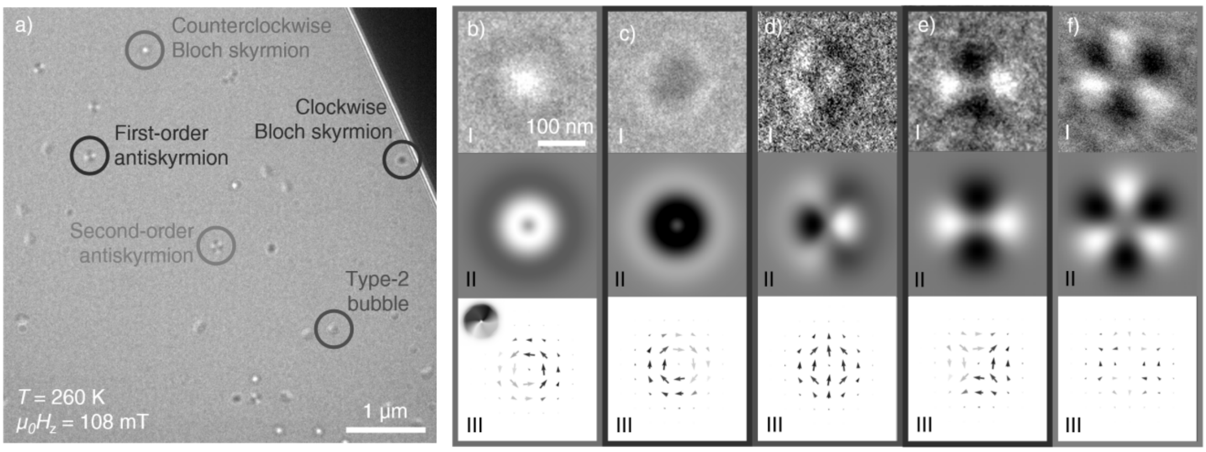
Skyrmions and antiskyrmions are topologically protected spin structures with opposite winding numbers. Particularly in coexisting phases, these two types of magnetic quasi-particles may show fascinating physics and potential for spintronic devices. While skyrmions are observed in a wide range of materials, until now antiskyrmions were exclusive to materials with D_{2d} symmetry. In this work, we show first and second order antiskyrmions stabilized by magnetic dipole-dipole interaction in Fe/Gd-based multilayers. We modify the magnetic properties of the multilayers by Ir insertion layers. Using Lorentz transmission electron microscopy imaging, we observe coexisting (Fig. a) antiskyrmions (Fig. e,f), Bloch skyrmions (Fig. b,c), and type-2 bubbles (Fig. d) and determine the range of material properties and magnetic fields where the different spin objects form and dissipate. We perform micromagnetic simulations to obtain more insight into the studied system and conclude that the reduction of saturation magnetization and uniaxial anisotropy leads to the existence of this zoo of different spin objects and that they are primarily stabilized by dipolar interaction.



Coexistence of two Skyrmion Phases in Hybrid Ferro/Ferrimagnetic Multilayers observed by quantitative MFM

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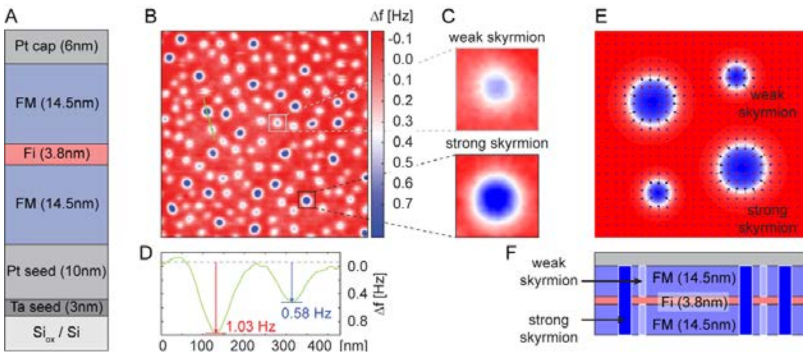
Zheng et al. have recently demonstrated the coexistence of (tubular) skyrmions with a new particle-like object, the chiral bobber (ChB) in thinned FeGe single crystals. These authors further pointed out that the two topologically protected spin textures, the tubular skyrmion and the ChB can be used as information carriers in racetrack applications. Here we report a thin film system consisting of three main layers (nominally identical top and bottom ferromagnetic layers with strong interfacial DMI, and an ferrimagnetic interlayer) that can support two different skyrmion phases at room temperature (Fig. 1A, B and C). In addition to the FM/Fi/FM heterostructure multilayer system, additional multilayer systems consisting of only one or two FM layers, one FM layer on the top of the Fi, and one system with two FM layers and a magnetically inactive Ta interlayer have been fabricated for comparison. All systems have been studied by in-vacuum quantitative magnetic force microscopy (qMFM). The MFM results allow the conclusion that two distinct skyrmion phases coexist. These are tubular skyrmions running through all layers and skyrmions located in the top and bottom FM layers only. Micromagnetic calculations (Fig. 1E) confirmed the coexistence of these spin textures governed by a delicate balance of the different magnetic energy density terms arising from the different multilayers and their exchange and magnetostatic coupling. Our results suggest that future skyrmionics devices make use of transitions between these distinct reservoirs of skyrmions possibly exploring information storage in 3-dimensions.



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The chiral Hall effect in canted ferromagnets and antiferromagnets

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The anomalous Hall effect (AHE) reflects the immense diversity of mechanisms for intrinsic or extrinsic current generation that can be found in the world of magnets. This world offers numerous exciting classes of antiferromagnets, where the anomalous and recently discovered crystal Hall [1] effect as well as the topological Hall effect in non-coplanar antiferromagnets [2] have been studied in the past decades. In this work, we uncover a novel type of Hall effect emerging in generic canted spin systems. Identifying a clear fingerprint of this chiral Hall effect (CHE) in discrete tight-binding models as well as ab-initio calculations is central in establishing a solid understanding of this new phenomenon closely tied to real space topology of magnetic textures. In this study, we provide robust numerical evidence for the CHE in a honeycomb lattice of canted spins and present a material candidate, SrRuO3. We uncover contributions to the Hall conductivity sensitive to the canting angle between neighboring spins which can be directly related to the imprinted vector chirality. Exploring the symmetry properties of the CHE we demonstrate the complex interplay of symmetry, topology and chirality in canted spin systems.

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Impact of thermal conductivity in insulators on thermally induced spin currents

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Spin currents generated from thermal gradients in magnetic tunnel junctions via the tunnel magneto-Seebeck effect (TMS) [1] or in ferromagnetic insulators via the spin Seebeck effect (SSE) [2,3] have high potential for future nano-electronic devices [4]. Recent reports highlight the enhancement of thermally induced spin currents by the insertion of antiferromagnetic insulating (AFMI) layers [5]. However, quantitative determination and comparison of the TMS or SSE coefficients requires accurate knowledge of the temperature drop across the insulating tunnel barrier or AFMI, alternatively of the heat flux that passes the insulating material [6-8]. The key property here is the thermal conductivity, which determines both temperature drop and heat flux, but is experimentally difficult to access.

We present two new approaches to obtain the thermal conductivity in insulators and utilize laser-induced TMS in combination with finite element modeling [9] as well as ultrafast thermoreflectance and magnetooptic Kerr effect thermometry. We extract values of the thermal conductivity for MgAl2O4 and MgO barrier materials [10] that are in nice agreement with theoretical predictions for ultra-thin oxide barriers [11]. Furthermore, we experimentally found that the thermal conductivity does not significantly changes when an AFMI, such as NiO, is inserted in SSE devices. We thus confirm the enhanced spin conductivity induced by the AFMI insertion.

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Universal high-speed dynamics of bubble skyrmions in an uncompensated amorphous ferrimagnet

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Magnetic skyrmions are topologically stabilized spin configurations that, like domain walls (DWs), can be collectively displaced by current pulses and may thus be used in next-generation spintronic devices. [1] However, skyrmions in ferromagnets move at an angle with respect to the drive, complicating their use in wire devices. [2] Systems such as compensated ferrimagnets and natural antiferromagnets can reduce this skyrmion Hall effect to zero and provide high speeds for skyrmions and DWs. [3,4]
Besides the compensation of the skyrmion Hall effect, the predictability of skyrmion trajectories is of major importance. Analytical equations of motion describe straight 180° DWs in the one-dimensional (1D) model while rigid, circular bubble domains and skyrmions are predicted to move according to the Thiele equation. [5] However, DWs and skyrmions are often not perfectly straight or circular. Here, we study how deformed DWs and bubble skyrmions move in uncompensated ferrimagnetic CoGd in response to current pulses. We find that all 1D spin textures as well as all fully enclosed spin textures, reach speeds >500 m/s and display identical dynamics. While high speeds are indeed reached, the predicted differences between skyrmion and DW dynamics could not be observed. We attribute this deviation from the commonly used model to significant deformations of the skyrmions during their motion.

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Curvilinear magnetism: From curvature induced magnetochirality to shapeable magnetoelectronics

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Non-collinear magnetic textures like spin spirals, chiral domain walls or skyrmions are typically stabilized by the intrinsic spin-orbit induced Dzyaloshinskii-Moriya interaction (DMI) [1]. Curvature effects emerged as a novel mean to design chiral magnetic responses relying on extrinsic parameters, i.e. geometrical curvature of thin films [2-4]. The lack of an inversion symmetry and the emergence of a curvature induced effective anisotropy and DMI are characteristic of curved surfaces, leading to curvature-driven magnetochiral effects and topologically induced magnetization patterning [5-7]. Vast majority of activities are dedicated to curved ferromagnets, where recent achievements include the development of the theory of curvilinear micromagnetism [3] and the first experimental confirmation of curvature-driven chiral effects stemming from the exchange interaction [4]. Only very recently, the focus was put also on curvilinear antiferromagnets. Pylypovskyi et al. [8] demonstrated that intrinsically achiral one-dimensional curvilinear antiferromagnets behave as a chiral helimagnet with geometrically tunable DMI and orientation of the Neel vector.

The application potential of 3D-shaped magnetic thin films is currently being explored as mechanically shapeable magnetic field sensors [9] for automotive applications, magnetoelectrics for memory devices, spin-wave filters, high-speed racetrack memory devices as well as on-skin interactive electronics [10-12].

The fundamentals as well as application relevant aspects of curvilinear ferro- and antiferromagnets will be covered in this presentation.

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Magnetooptical imaging on different length- and timescales

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The role of magnetic domain formation and reorientation processes reveals fascinating physics and is as well of great relevance for technological applications. Magneto-optical microscopy, mostly Kerr microscopy, is an in-lab imaging technique for magnetic analysis. This allows for domain behavior to be studied on a wide range of lateral scales reaching from centimeters down to 200 nanometers and even below. Investigations are possible under static conditions but as well under dynamic excitations ranging beyond the microwave regime.

In the talk, we will explore the parameter-space in terms of spatial and temporal dimensions. We will show how in-operando time-resolved magnetic domain observation sheds light on the irreversible and hysteretic magnetization changes due to domain nucleation, domain wall resonances, precessional magnetization effects, and spin-wave and related phenomena.

A special emphasis on the formation of magnetic domains in magnetic thin films and thin film devices. Examples will range from skyrmion bubble analysis to magnetic field sensor structures operating at GHz excitations. Advanced techniques based on higher order magnetooptical effects will be touched and an outlook to future developments will be given.

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Spin chirality: a functional variable of magnetic materials

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Chiral magnetic materials steadily move to the center of attention owing to their unique properties which range from utter sensitivity to electrical currents, to a whole world of possible topological effects rooting in complex spin- and reciprocal-space behavior [1]. Here, I will show how the spin chirality, which is inherent to chiral magnets, emerges as a unique functional variable in magnetic materials. Conceptually, I will attempt to classify chirality-sensitive contributions to magneto-transport and magneto-optical properties of magnets based on the flavors of magnetic chirality, discussing possible applications of uncovered effects in the realm of spin "chirotronics" – the part of spintronics which deals with creation, control and manipulation of the spin chirality as the key observable [1-3]. Further, I will show that chiral orbital transport effects may give rise to novel exchange interactions among spins which pave the way to the realization of novel three-dimensional spin textures such as hopfions [4]. Finally, I will also make it clear that discussed effects are not limited to systems which exhibit finite spin chirality in their ground state, but are inherent to wide classes of collinear ferromagnets and antiferromagnets subject to thermal fluctuations or excited by optical means [5]. The possibility of imprinting spin chirality by ultrafast laser pulses, combined with its robust behavior in magnets taken out of equilibrium makes spin chirality a very promising platform for novel paradigms in the realm of spintronics applications [6].

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Stability and Manipulation of Skyrmions in Multilayer Nanostructures

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The topologically protected spin structure of skyrmions manifests in their emergent behaviour as magnetic quasiparticles with individual addressability and ease of manipulation [1, 2]. The discovery of room temperature (RT) skyrmions in industry-compatible multilayer films has generated immense interest towards investigating their behaviour in nanostructures, where myriad device concepts are built upon their manipulation in dots and mobility in wires.

First, we present the zero field stability of skyrmions in confined nanodots, with promise for perpendicular electrical reading [3]. Next, we outline the skyrmion dynamical phenomenology in nanowires – marked by distinct motion regimes and skyrmion Hall effect which is strongly reshaped by wire edge and skyrmion size [4]. Finally, we examine synthetic antiferromagnetic multilayer films as potential means of stabilizing zero field skyrmions and mitigating skyrmion Hall effect [5].

These results pivot efforts for tailoring the behaviour of nanoscale skyrmions in device-relevant configurations for their employment in skyrmion-based magnetic tunnel junctions, racetrack memories and synaptic computational electronics.

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Driving spin dynamics with the electric field of light

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This talk will introduce examples of the sub-femtosecond modification of optical, electronic and magnetic material properties in metallic and semiconducting samples with the goal to obtain reversible coherent state-switching.

By means of attosecond spectroscopy we show that the magnetic state of a ferromagnetic system can be directly controlled by the electric field of light without the need of mediating processes like electro-electron and electron-spin couplings. This suggests the feasibility of ultrafast light-field driving of carrier and spin dynamics that might allow future ultrafast optoelectronic and spintronic applications[1], [2].

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Ultrafast spin dynamics: ab-initio description

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I will talk about all-optical switching of long-range magnetic order. The type of coupling between the constituent atoms of a magnetic solid, usually ferromagnetic (FM) or anti-ferromagnetic (AFM), is a fundamental property of any magnetic material. This coupling is governed by the exchange interaction, for which the time scale of a typical magnetic material is of the order of a few 100s of femtoseconds. In our work, using time-dependent density functional theory (TDDFT), we demonstrate that a rich control over magnetization at sub-exchange time scales (of the order of few tens of femtoseconds) is possible[1,2,3,4,5,6,7]. This even includes changing the magnetic order from AFM to FM[8]. By investigating a wide range of multi-sublattice magnetic materials we are able to formulate three simple rules that predict the qualitative dynamics of magnetization for ferromagnetic, anti-ferromagnetic, and ferri-magnetic materials on sub-exchange time scales.

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Optically induced intersite spin transfer in ferromagnetic alloys and compound systems

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Optically induced intersite spin transfer (OISTR), theoretically first predicted in 2016, describes the fastest possible manipulation of spins by light [1,2]. In OISTR, a direct light-induced, spin-selective charge transfer between different magnetic sublattices allows for a change of the magnetic moment on timescales of the exciting light field itself, i.e., on the fastest timescales accessible today. In my presentation, I will discuss OISTR [1,2] and its first experimental realizations by us [3,4,5] and others [6,7] in different material systems ($Fe_{50}Ni_{50}$, Heusler compounds, magnetic multilayers) using both extreme ultraviolet (XUV) and visible light as a probe.

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Zero-field magnetic skyrmions in model-type systems studied with STM

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Magnetic skyrmions can be stabilized in thin films by interface-induced Dzyaloshinskii-Moriya interactions that compete with exchange interactions. Such skyrmions can become lowest energy states in applied magnetic fields but are often only metastable configurations in zero magnetic field. Spin-polarized scanning tunneling microscopy is a powerful tool to characterize such magnetic textures down to the atomic scale [1].

We have studied the magnetic properties of a Rh/Co atomic bilayer on Ir(111) using spin-resolved scanning tunneling microscopy. Depending on the stacking of the Rh monolayer we observe a significant number of domain walls with unique rotational sense in the otherwise out-of-plane magnetized film. We also identify small circular magnetic objects in the virgin state. They coexist in both oppositely magnetized ferromagnetic domains and resemble zero-field magnetic skyrmions with up- or down-pointing core. Ab-initio calculations in combination with spin dynamics simulations shed light on the origin of these unusual properties [2]. The domain walls and skyrmions can be imaged also with non-spin-polarized probe tips due to the contribution of the non-collinear magnetoresistance (NCMR) [3,4]. It arises from spin-mixing and leads to variations in the differential conductance depending on the details of the local spin texture.

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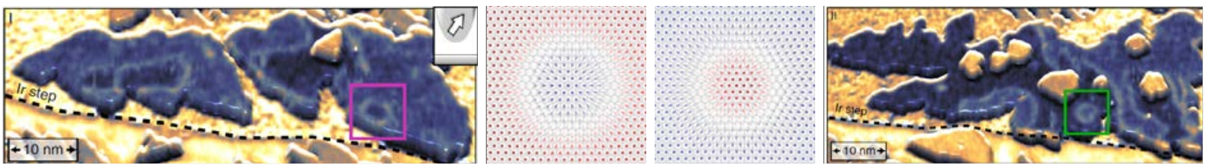

FIG: Maps of differential conductance, in which Rh/Co islands appear darker. At this bias voltage domain walls appear brighter compared to the out-of-plane domains due to the NCMR. The two boxes indicate meta-stable zero-field magnetic skyrmions of opposite direction, as sketched in the two central images. The diameter of the skyrmions is on the order of 4 nm, the sketches are to scale and each dot represents one atomic magnetic moment.

Advanced Methods for Magnetic Scanning X-ray Microscopy

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X-ray microscopy using X-ray circular magnetic dichroism (XMCD) as contrast mechanism has long been established as a powerful tool for investigation of magnetic materials on the nanometer scale. Not only is the effect quantitative and local, but also highly sensitive and element specific, which allows access to individual layers or sub-lattices in complex systems.

Scanning Transmission X-ray Microscopes (STXM) combine this with the ability to use a wide array of possible detectors and sample environments (bias fields, cryostats). In particular, fast single photon detectors for time resolved pump-and probe have been used to study a wide range of magnetic phenomena on them, like vortex core motions [1], magnonic behavior in real-space[2] or room temperature skyrmionics [3,4] with time resolutions down to 20ps.

As a scanning probe technique, STXM can also utilize total electron yield for surface sensitive measurements even under strong bias fields, which allows both the investigation of materials on bulk substrates as well as the comparing surface and bulk magnetism on thin films, which can also be combined with cryogenic sample environments [5].

Finally, x-ray ptychography has emerged as a method in recent years to improve the spatial resolution of scanning x-ray microscopes by using diffraction information at each sample points to reconstruct the sample, which can also be applied to magnetic materials [6]

We will present highlights of magnetic imaging on STXM utilizing a wide variety of non-conventional experimental setups and give an outlook how the method will profit from upcoming high brilliance light sources.

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Manipulation and control of nanometric topological spin textures

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Exotic topological spin textures1) and their dynamics attract much attention to fundamental physics2) and applications to novel electron-devices3) owing to their topological nature and emergent electromagnetic properties. Here, I will present how to control, drive and manipulate nanometer-scale topological spin textures and their lattice forms, such as (anti) skyrmion, (anti) meron and their transformations between antiskyrmions and skyrmions, merons and skyrmions, and transformations of their lattice forms between square lattice (sq.-ML) and triangular lattice (hex-SkL), with finely tuning the external magnetic field in several magnets4-6) with non-centrosymmetric crystalline structure. On the other hand, the minute (atomic-scale) skyrmions have been successfully manipulated in centrosymmetric magnets with Ruderman–Kittel–Kasuya–Yoshida (RKKY)-type electronic coupling7-8). To manipulate and track individual skyrmions and its lattice form using a relatively low electric current, we make a microdevice composed a thin helimagnet of FeG with a small notch9), which allowed the spin current to be localized in a specific area near the corner of the notch. Drift, Hall and torque motions of single 80-nm-size skyrmions and their clusters are tracked with directional current at low current density, a thousand times weaker than those used in that for drives of magnetic domain walls.

These works were done in collaborations with Profs. Yoshinori Tokura, Naoto Nagaosa, Masashi Kawasaki, Taka-hisa Arima, Yusuke Tokunaga, Shinichro Seki and Masahiko Mochizuki and Drs. Tasujiro Taguchi, Fumitaka Kagawa, Max Hirschberger, Wataru Koshibae, Naoya Kanazawa, Kosuke Karube, Jan Masell, Licong Peng, Fehmi Yasin, Khanh Nguyen Daisuke Morikawa, Masao Nakamura, Kiyou Shibata, and Rina Takagi.

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A Magnon Scattering Platform

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Scattering experiments have revolutionized our understanding of nature. Examples include the discovery of the nucleus, crystallography, and the discovery of the double helix structure of DNA. Scattering techniques[1] differ by the type of the particles used, the interaction these particles have with target materials and the range of wavelengths used. Magnons, quasi-particles in spin ordered systems, have shown tremendous potential in low-dissipation computing[2–4], and recent advances in the experimental study of magnons have strongly expanded our understanding of spin ordered systems[5,6]. Using magnons as a probe, we demonstrate a new 2-dimensional table-top scattering platform for exploring magnetic properties of materials on mesoscopic length scales. Long lived, coherent magnonic excitations are generated in a thin film of YIG and scattered off a magnetic target deposited on its surface. The scattered waves are then recorded using a scanning NV center magnetometer[7,8] that allows sub-wavelength imaging and operation under conditions ranging from cryogenic to ambient environment. While most scattering platforms measure only the intensity of the scattered waves, our imaging method allows for spatial determination of both amplitude and phase of the scattered waves thereby allowing for a reconstruction of the target scattering potential. Our results[9] establish magnon scattering experiments as a new platform for studying correlated many-body systems.

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Abstracts of Posters

(in alphabetical order)

Irradiation-induced magneto-structural phase transition in $Fe_{60}V_{40}$ alloy thin films

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Ion beam irradiation can lead to an increased saturation magnetization (M_s) in non-ferromagnetic precursors of $Fe_{60}Al_{40}$ [1], $Fe_{50}Rh_{50}$ [2] and $Fe_{60}V_{40}$ alloy thin films. $Fe_{60}V_{40}$ films of 40 nm thickness were prepared onto SiO_2 (270 nm)/Si substrates using magnetron sputtering at 300 K and at optimized growth temperature of 573 K. The as-grown films are weakly ferromagnetic with M_s < 20 kA/m for above mentioned growth temperatures. Irradiation with Ne^+ ions at 25 keV in a fluence range of 1×10^{15} – 1×10^{16} ions/cm^2 leads to a systematic increase of M_s with fluence. The irradiation with the highest fluence of 1×10^{16} ions/cm^2 increases M_s to 512 and 670 kA/m for films grown at 300 and 573 K respectively. X-ray diffraction of the as-grown films shows a broad peak at $2\theta \approx 44^\circ$, which suggests short range ordering. Ne^+-irradiation causes the formation of the A2 structure, which is ferromagnetic. This amorphous to crystalline structural phase transition can be conveniently controlled using ion-irradiation, thus leading to a drastic increase of M_s, which can be useful for magnetic pattering applications.

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Influence of transport on the time-resolved MOKE signal during ultrafast demagnetization

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Ultrafast demagnetization of itinerant ferromagnets is mediated by a variety of local and non-local processes such as spin-flip scattering and optically induced spin transport that both reduce the spin polarization in the probed area. [1, 2]. This microscopic picture is based on a number of theoretical and experimental investigations over the past two decades.

The majority of experimental studies so far followed the optically induced demagnetization dynamics in magnetic materials using the time-dependent magneto-optical Kerr response of the magnetic and non-magnetic materials. Using thin magnetic films with film thickness smaller than penetration depth of the laser light leads to a homogeneous optical excitation of the material which is reflected in a single Kerr responsible of the material.

In contrast, the situation becomes much more complicated when using materials with larger film thickness where the optically excited volume of the materials is no longer homogeneously heated by the laser pulse. The heat as well as the spin-dependent charge transport will affect the depth dependent magnetization dynamics of the material and, hence, the time-resolved MOKE signal. In particular, optically generated spin currents will propagate through the magnetic materials and will hence contribute to the magnetization dynamics at different vertical positions in the material at different timescales.

In this contribution, we theoretically and experimentally study the role of transport in the time-resolved MOKE signal of a 100nm thick Ni film. Starting with simulation based on the Thermodynamic μT-model [3] we determine the spatial and temporal evolution of magnetization. We take into account that the MOKE signal of such a 100nm magnetic film is determined by the sum of the Kerr responses from different material depths in the complex Kerr plane [4]. By integrating the depth sensitivity function [5] weighted by spatially resolved magnetization at various time instances we obtain the changes in the MOKE signal on a femtosecond timescale. To demonstrate the capability of this approach, we compare our theoretical predictions with the changes in Kerr-rotation and Kerr-ellipticity measured using the Complex-MOKE technique [6, 7].

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High resolution coherent X-ray magnetic imaging with holography-aided phase retrieval

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Fourier Transform Holography (FTH) is a lensless coherent X-ray imaging technique for nanoscale variations in thin-film materials. FTH is intrinsically drift-free, able to detect both amplitude and phase of the light transmitted through the sample and it is the only coherent imaging technique which has been productively employed in high-throughput magnetic imaging experiments [1-4].

Despite its advantages, FTH suffers from an intrinsic limitation, as the obtained image is a convolution between the actual sample transmission function and the exit wave of a reference hole, part of the optical setup. This generates an inconvenient tradeoff between contrast and resolution: large reference holes produce poorly resolved images with high contrast, while small reference holes ensure high resolution at the price of a reduced signal to noise ratio.

This limitation can be overcome by using more sophisticated algorithms, such as iterative phase retrieval algorithms. These algorithms and FTH perfectly complement each other: Holography provides an immediate feedback on the support to be used for phase retrieval increasing the algorithm stability, and phase retrieval allows to overcome the reference hole size limitation, eliminating the need of a compromise between image resolution and contrast. Holography-aided phase retrieval has been demonstrated in the extreme UV photon range at high harmonic generation sources with promising results [5]. However, this method so far relied on pristine data and was not successfully applied on holograms recorded with synchrotron light in a productive way.

Here we present the latest results obtained using holography-aided phase retrieval algorithms, comparing them to the original FTH results obtained with synchrotron light. The technique appears to be reliable, stable and can be effortless applied to improve the quality of FTH images on the run during magnetic imaging experiments.

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Manipulation of laterally homogeneous vertical AF domain walls in Synthetic Antiferromagnets with Perpendicular Magnetic Anisotropy

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Antiferromagnets (AFs) are of emerging interest due to their wide variety of useful properties at the micro and nanoscale. Despite the macroscopically vanishing magnetic remanent moment and therefore high stability with respect to external magnetic field, AFs may provide other unique static magnetic states as well as promising characteristics for dynamic applications like high domain wall velocities and excitation frequencies that reach up into the THz regime.

Synthetic antiferromagnets (SAFs), consisting of AF-coupled ferromagnetic layers via thin non-magnetic spacer layers, maintain the main characteristics of intrinsic AFs. Additionally, SAFs offer a high degree of tunability and easy integration, thus making them interesting for a wide range of applications.

One unique AF phenomenon, which can be observed and efficiently tuned in SAFs, is the Surface Spin Flop (SSF) [1, 2]. During the SSF-reversal, a laterally homogeneous vertical AF domain wall is nucleated. Combining the SAF with perpendicular magnetic anisotropy allows to easily manipulate even locally the magnetic properties of the system. Thereby, the vertical AF domain wall can be stabilized even at remanence, allowing to choose between multiple coexisting remanent states. Furthermore, the same approach can be extended to the coexistence of two vertical AF domain walls within a single SAF. Because of the laterally homogeneous nature of the vertical AF domain walls, the states may provide promising dynamic properties, which can be investigated by methods like ferromagnetic resonance, so far mainly operating at laterally homogeneous saturated states [3].

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Ultrafast amplification and non-linear magneto-elastic coupling of coherent magnon modes in an antiferromagnet

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Antiferromagnets have recently surged as candidates for a novel paradigm of spintronics devices able to outperform ferro- and ferrimagnetic materials in terms of operational frequency, storage density and resilience to external fields. Intrinsically the long-range antiferromagnetic order presents domains, which can hardly be manipulated. This magnetic texture and the magneto-elastic coupling - which is intimately interconnected to the domain structure - have been very recently shown to play a major role in the mechanism allowing electric manipulations of the Néel vector. The quest for an ever faster and more energy efficient control of antiferromagnets motivates the use of ultrashort light pulses as stimulus to drive (sub)-picosecond spin dynamics. However, the role of domain walls and magneto-elastic coupling on the ultrafast Néel vector dynamics has been hitherto barely addressed, if not totally neglected. Here we demonstrate that the domain walls can activate a novel functionality in an antiferromagnetic crystal, namely a non-linear magneto-elastic domain-walls-mediated coupling between coherent spin wave modes belonging to different branches of the magnon dispersion, affecting the ultrafast dynamics of the Néel vector. We realise experimentally the tailored amplification of coherent THz oscillations of the Néel vector pumping a magnon mode in an antiferromagnetic NiO crystal. This process is triggered by driving a combined electronic and magnetic transition and results even in the amplification of a different GHz magnon mode, via the aforementioned coupling. Our results prove the generation, non-linear manipulation and detection of coherent oscillations of the Néel vector via the optical generation and the subsequent non-linear coupling be- tween magnon modes, without the need for electric contacts, heavy metal layers and thus avoiding Joule heating.

Mapping buried topological spin textures with 3D magnetic imaging

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Three dimensional magnetic systems promise significant opportunities for applications, for example providing higher density devices and new functionality associated with complex topology and greater degrees of freedom [1,2].

To characterize three dimensional magnetic systems, we have developed X-ray magnetic nanotomography [3], combining a new iterative reconstruction algorithm [4] with a dual rotation axis experimental setup, therefore providing access to the three-dimensional magnetic configuration at the nanoscale. In a first demonstration, we have observed a configuration that contains vortices, antivortices, and Bloch point singularities [3]. In addition to the magnetic structure, the dynamic response of the 3D magnetic configuration to excitations is key to our understanding. With our recent development of X-ray magnetic laminography [5,6], it is now possible to determine the magnetisation dynamics of a three-dimensional magnetic system [5].

A final challenge concerns the identification of nanoscale topological objects within the complex reconstructed magnetic configurations. To address this, we have recently implemented calculations of the magnetic vorticity [7,8], that make possible the location and identification of 3D magnetic solitons, leading to the first observation of magnetic vortex rings [8].

These new experimental capabilities of X-ray magnetic imaging open the door to the elucidation of complex three-dimensional magnetic structures, and their dynamic behaviour.

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Epitaxial YIG nanofilms grown by metalorganic aerosol deposition

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Thin films of the ferrimagnetic insulator Yttrium Iron Garnet (YIG) show very low magnetic damping, rendering them a promising system for a multitude of future applications of magnonics [1-3]. In this study, epitaxial growth of YIG thin films of thickness 10 nm to 80 nm on (111)-oriented Gadolinium Gallium Garnet (GGG) is achieved via metal organic aerosol deposition, which provides a vacuum-free alternative to most commonly used pulsed laser deposition (PLD) or sputtering techniques. Excellent structural properties were examined by atomic force microscopy, X-ray reflectometry and diffraction, all showing the single crystal character and step-flow topology of the YIG films. Magnetic properties were studied by ferromagnetic resonance measurements (stripline-FMR) and SQUID magnetometry.

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Investigation of new effects in 3D magnetic nanostructures with complex geometries

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The expansion of nanomagnetism to three dimensions provides exciting opportunities to explore new physical phenomena, and at the same opens fascinating prospects to create 3D magnetic devices which could be exploited in future technologies [1].

In this contribution, I will present a selection of our recent work investigating new effects in 3D magnetic nanostructures with complex geometries.

First, I will introduce a new computational framework for the 3D printing of complex-shaped nanostructures using focused electron beam induced deposition [2, 3]. Second, I will show how we can create double-helix nanowire systems, where the combination of tunable geometrical chirality and magnetic interactions allows us to imprint non-trivial chiral spin textures and topological defects at precise locations of this 3D nano-geometry [4]. Finally, I will present results where the magnetoelectrical response of 3D spintronic nanowire devices has been investigated [5], observing a strong anomalous magnonic contribution to the total magnetoresistance signal, result of the non-collinear configuration of magnetic states and electrical currents.

I would like to acknowledge the work done by all my group members and collaborators responsible for the work I will be presenting.

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Optical Skyrmion Nucleation in Functional Co-based Multilayers

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Magnetic skyrmions are topological quasi-particles on the nanometer scale that can be created and annihilated in the presence of a symmetry-breaking applied magnetic field using single femtosecond IR laser pulses above a material dependent fluence threshold [1]. Until now, isolated skyrmions have mostly been studied in materials with high interfacial Dzyaloshinskii-Moriya interaction (DMI) like Pt/CoFeB/MgO multilayers. Skyrmions in materials with large DMI are homochiral [2]. They can be generated and moved deterministically by electrically generated spin-polarized currents [2, 3]. In these materials as well as in materials with weak DMI, such as symmetric Co/Pt multilayers, skyrmions can also be nucleated with an optical laser pulse [4]. Here we present a systematic study of the optical nucleation of skyrmions in magnetic materials with strong and weak DMI, respectively. In general, the number of nucleated skyrmions varies with the applied magnetic field. In contrast, both materials show no increase in the number of skyrmions nucleated if the fluence is increased beyond a certain critical value. We explain this observation based on time-resolved x-ray scattering measurements of the nucleation process combined with atomistic simulations. We find that the skyrmion nucleation process is mediated by a fluctuation phase enabling topological switching in short-range correlated magnetization patterns, leading to a homogeneous nucleation of skyrmions. The short-range ordered fluctuation phase emerges only above a certain excitation threshold independently from the applied field. Only in a subsequent coarsening phase, the skyrmion nuclei grow to their equilibrium size and distribution promoted by the applied field.

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Orbital Transport in Spintronics

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Spin current is one of the central concepts in spintronics. While early studies of giant magnetoresistance and spin-transfer torque have shown good agreement between the theory and experiment, recent experiments of current-induced torques in spin-orbit coupled systems imply that we need a theory which goes beyond “spin current picture”. In general, angular momentum can be carried by other degrees of freedom as well as the spin. For electrons, the angular momentum is encoded in not only the spin but also orbital part of the wave function, thus one can think of transport of orbital angular momentum carried by electrons in analogy to the spin transport.

In this poster, I will explain how to electrically generate orbital current and utilize it to exert a torque on the magnetization. As a way to generate the orbital current, I introduce a mechanism of orbital Hall effect, which is defined as orbital current response along transverse directions to an external electric field [1]. Then I show that injection of the orbital current to a ferromagnet can excite magnetization dynamics, which we call orbital torque [2]. One advantage of utilizing the orbital current is that it does not require spin-orbit coupling for electrical generation, which is in contrast to spin current generation, e.g., by spin Hall effect. Thus, the orbital torque mechanism predicts sizable current-induced torque even for weakly spin-orbit coupled materials. However, since the spin and orbital angular momenta transform in the same way upon symmetry operations, it is challenging to disentangle the orbital transport effect from the spin transport effect in experiments. For this purpose, we recently developed a general theory which can track angular momentum transfer between different angular-momentum-carrying degrees of freedom, which include not only the spin and orbital of the electron but also crystal lattice and local magnetic moment [3]. From a first-principles implementation of the formalism, we show that the orbital torque mechanism behaves qualitatively different from the “conventional” contribution caused by the spin Hall effect. This provides microscopic understanding of the orbital torque in terms of the electronic structure. Finally, I discuss further experimental implications and conceptual difference between the orbital transport and spin transport.

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Demonstration and potential application of the spin-wave Talbot effect

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The Talbot effect has been known in linear optics since the 19th century and has found various technological applications. With micromagnetic simulations, we demonstrate the self-imaging phenomenon for spin waves (SWs), in three basic configurations: (i) out-of-plane magnetized thin film (forward volume, FV), and in-plane magnetized thin film (ii) parallel (Damon-Eshbach, DE) and (iii) perpendicular (backward volume, BV) to the grating. The first scenario is the closest to the textbook Talbot effect due to an isotropic dispersion. However, for the second and third scenario, SW dynamics is anisotropic what is especially prominent for lower frequencies. We demonstrate that the properties of SW self-imaging are consistent with the theoretical predictions based on the general formalism of wave optics. This compliance cannot be introduced in advance, rather, Landau-Lifshitz nonlinear equation describing SW propagation must be solved for this purpose. This has systematically been done in our study. By performing micromagnetic simulations in permalloy film, we show that the observation of the first Talbot images shall be feasible with standard micro-focused BLS. We expect, that in Yttrium Iron Garnet (YIG) thin films, also the primary images can be reached due to 10 times smaller damping than in permalloy. We have also shown that the Talbot effect is obtainable for smaller, in-plane aligned external magnetic fields for which SW wavelengths depend on the direction of propagation. It gives a lot of application possibilities, as well as ways of manipulating and adapting the effect to specific needs thanks to additional anisotropic and caustic effects. To prove that, we demonstrate logical function performed with SWs in finite width ferromagnetic waveguide. The obtained results help to better understand SW interference and scattering processes at the diffraction gratings. Moreover, our findings open an avenue to practical application of the Talbot effect in future magnonic devices.

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Dynamics of antiferromagnetic textures affected by inhomogeneous strains

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Searching for the efficient ways to control and manipulate antiferromagnetic states in spintronic devices we study dynamics of antiferromagnetic textures in presence of inhomogeneous strain fields. We demonstrate that the inhomogeneous spontaneous strains and strains created at interfaces, defects, and sample edges define the shape and size of the domains, and orientation of the domain walls. We further show that the frozen spontaneous strains strongly affect fast dynamics of the magnetic texture. In particular, inhomogeneous strain field pins the domain wall and modifies spin-wave spectra. We calculate the eigen-modes of multidomain sample and show that the frequencies of the localized magnon modes related with oscillations of the domain walls separating spin (S) and twin (T) domains scale with the values of magnetoelastic constants. In addition, the domain walls induce reflection of the propagating spin-waves and in case of the T domains can also result in a birefringes effect. Moreover, coupling between the propagating and localized modes mediated by the magnetic nonlinearity modifies the magnetic response of a multidomain antiferromagnet. We believe that our results open a way for efficient manipulation of antiferromagnetic textures in the materials with pronounced magnetoelastic interactions.

Ultrafast electronic generation of antiferromagnetic spin spiral states

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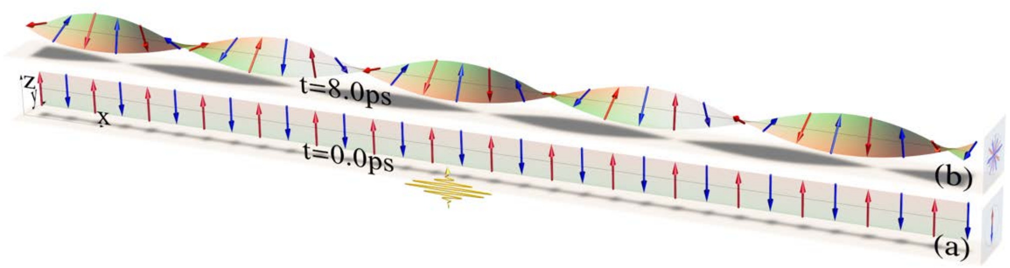
Ultrafast optical control of magnetism is one of the most promising aspects of modern spintronics for its potential application in fast and low power consumption devices. The recent experimental demonstration of generating topologically non trivial chiral structure with ultrashort laser pulses [1] has opened a new field of possibilities in this regard. However the theoretical understanding of the underlying mechanisms is still under mist which is one of the main hurdles in controlled optical generation and manipulation of chiral magnetic order. In our contribution we provide a comprehensive picture of how to induce magnetisation dynamics by combining both quantum mechanical evolution and classical magnetisation dynamics on equal footing and demonstrate how a stable chiral spin spiral can be generated from a collinear antiferromagnetic chain [2]. We systematically show how this hybrid dynamical evolution depends on different system parameter as well as on the external factors such as the strength of the electric field or the ambient temperature. Our finding reveals several crucial aspects of ultrashort opto-spintronics which is equally important in optical generation of various chiral spin structures as well as in exploring different aspects of ultrafast demagnetisation.



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Skyrmion movement in Ta/CoFeB/MgO-trilayers

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We investigate experimentally the movements of skyrmions with current pulses in Ta/CoFeB/MgO-trilayers. The magnetic CoFeB layer has a very small thickness gradient resulting in areas with in-plane and out-of-plane magnetic anisotropy and an area with both components. The CoFeB thickness deviating from 1 nm in both directions allows to create a rich playground for magnetic effects by annealing the sample and crystallization at the MgO interface. The skyrmions are created in the demagnetized CoFeB layer using a magnetic field pulse tilted slightly out of the plane direction. The skyrmions dynamics are generated using microsecond current pulses. During this time, the skyrmions are stabilized by a small out-of-plane field. The skyrmion motion is recorded by Kerr-microscopy.

We analyze the recorded skyrmion dynamics using a specially developed tracking software to follow the motion after each current pulse. The movement shows a superdiffusive distribution and allows for an identification of a pinning center distribution as well as the Skyrmion-Hall-effect. Furthermore, we identify areas where skyrmions are generated and annihilated. This allows to determine the skyrmion life time, velocity and moving directions. Further, we can identify how the skyrmion density varies.

Phenalenyl-based Organic Barriers for Tunnel Junctions

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Phenalenyl (PLY) based molecules are appealing for spintronic applications as demonstrated by the formation of a spinterface, showing tunnel magneto resistance close to room temperature (RT). The spinterface formation leads to the unique property, that a magnetic tunnel junction (MTJ) with a PLY barrier requires only one ferromagnetic metal layer (FM), while the other ferromagnetic layer is formed in the organic barrier directly at the FM/organic barrier interface [1].

In the present study, we compare three different kinds of PLY molecules (PLY, zinc methyl phenalenyl (ZMP), Cu-PLY [2]) as barrier material for tunnel junctions. In addition, we introduce a new 3-D shadow mask technology allowing for reducing the junction size of in-situ structured devices down to 3x 6 µm². Further investigations reveal an AFM rms-roughness of less than 0.7 nm and TEM imaging indicates sharp and well-defined interfaces. Consequently, the current depends non-linearly on the voltage for average barrier thicknesses exceeding 4.8 nm measured by a calibrated quartz micro balance (QCM), the resistance depends exponentially on the barrier thickness and the resistance shows no significant temperature dependence. This evidences tunneling as conduction mechanism. Magneto-resistive characteristics appear applying a few mV, while memristive properties require voltages in the Volt range. The memristive resistance change is found for all three types of PLY and can be up to a factor of 2. Furthermore, it is stable and reproducible for at least about 100 cycles. Extremely high MR signals are observed at room temperature up to 1000% for FM/Cu-PLY/FM and FM/Cu-PLY/non-magnetic metal layer (NM), but only for some junctions and with improvable stability.

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Nanopatterning to Control and Localize Optical Skyrmion Nucleation

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Magnetic skyrmions are topological quasi-particles of small size and high stability that are potential candidates for next-generation spintronics applications. The basic operations required for data storage devices – writing, deleting and shifting – have already been realized using spin-polarized currents [1]. Femtosecond laser pulses offer an alternative way of manipulating magnetization in a potentially faster and more energy efficient fashion. This kind of excitation has already led to the observation of femtosecond demagnetization and all-optical magnetic switching in ferri- and ferromagnetic materials. The optically induced nucleation of skyrmions in thin magnetic multilayer films was recently demonstrated [2]. In view of applications in spintronics devices, the nucleation sites of skyrmions need to be well-defined and reproducible. Here, we follow new routes to localize optically-induced skyrmions on the nanometer scale: In our first approach, we demonstrate that a proximity mask can be designed to locally affect the excitation amplitude enabling spatial control of skyrmion nucleation sites. Our second approach relies on He+-ion irradiation. Here, we locally apply a focused He+ -ion beam to achieve tailored magnetic patterning of the multilayers without affecting their topography. We investigate the patterning impact on the magnetic anisotropy and pinning landscape, locally influencing the magnetic hysteresis and the optical fluence threshold for skyrmion nucleation.

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2D Maps of Laser induced Photocurrents in Ferromagnet-Topological Insulator Heterostructures

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Topological insulators provide theoretically dissipationless and 100 % spin polarized conduction channels for electrons. This property make them appealing for spintronic applications [1]. We will present 2D polarization dependend maps of laser induced photocurrents with fixed applied external magnetic field of +/- 30 mT. The sample consists of a topological insulator rectangle with a small 3 nm thick CoFeB rectangle on top. We used a laser with a wavelength of λ=785nm. For the edges of the ferromagnet we found a lateral accumulation of spin polarization due to the spin Nernst effect [2]. We can also show that the spin-polarized current is dependend of the direction of the magnetization. Furthermore we did measurements of the laser induced photocurrents on topological insulator hall-bar structure. Therefore we used an infrared laser with a wavelength of λ=1560nm. In these measurements similar results were found.

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In situ transmission electron microscopy of magnetism in highly strained nanowires

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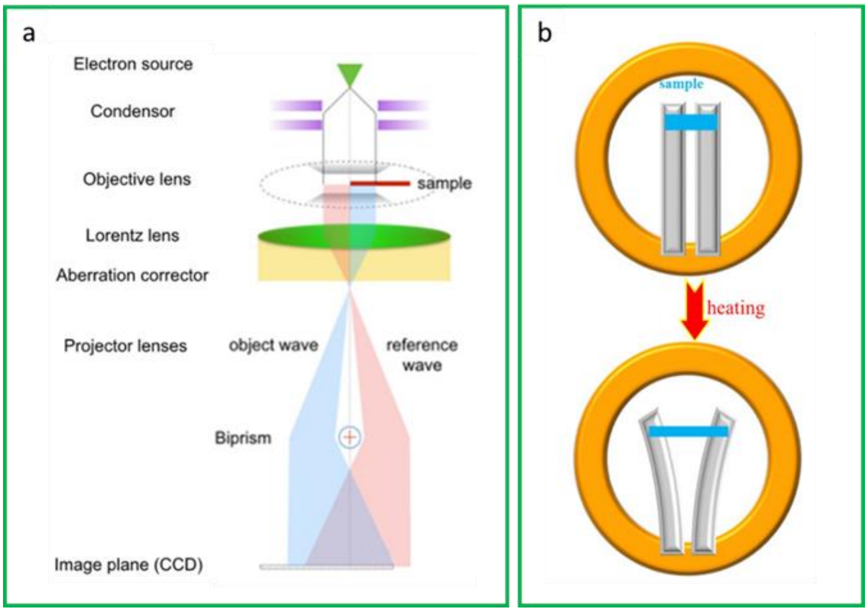
This work aims to investigate the relationship between the microstructure (such as morphology, defect distribution, etc.) of strained NWs and their electrical transport/magnetic properties. Previous study reported the NWs can sustain very large strain. [1] The atomic-scale mechanisms of how strain affects the magnetic properties of nanomaterials is an unsettled issue. With Lorentz transmission electron microscope, the axis-off electronic holography(as shown in Figure a) [2] and our lab-made deformation device (as shown in Figure b), the nanoscale magnetic properties of NWs under straining can be in situ measured.



a. Schematic diagram of axis-off electronic holography; [2] b. Schematic diagram of lab-made in situ TEM deformation device

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Domain Walls in a Row-Wise Antiferromagnetic Manganese Monolayer

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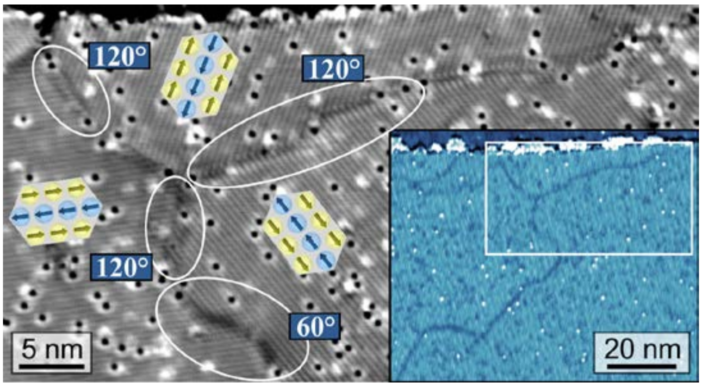

SP-STM image of three adjacent 1*Q* rotational domains on fcc Mn/Re(0001); *U* = -30 mV, *I* = 7 nA, *T* = 4.2 K. The inset shows a larger field of view (*dI/dU* map, *U* = +500 mV, *I* = 3 nA) where the DWs are imaged without resolving the AFM spin texture [2].

We investigate magnetic domain walls in a row-wise antiferromagnetic (AFM) system, the fcc-stacked manganese monolayer on Re(0001) [1]. To identify and understand the details of the domain wall spin texture we employ spin-polarized STM, atom manipulation, and spin dynamics simulations [2]. In contrast to traditional AFM domain walls, which can be described by a coherent spin rotation, we find that the low symmetry of the row-wise AFM state facilitates a new type of domain wall which connects rotational domains by an opposite rotation of adjacent spin pairs across the wall. This leads to a characteristic non-collinear spin texture with 90° angles in the wall center, a so-called 2*Q* state [3]. Surprisingly, the wall width of about 2 nm is determined by a balance of Heisenberg and higher-order exchange interactions and independent of crystal anisotropy. Based on the mathematical equivalence of uniaxial anisotropy and fourth-order exchange interactions, we can establish simple formulas for domain wall width and energy. Furthermore, we employ magnetic atom manipulation to image the domain wall structure with atomic spin-resolution and demonstrate as a proof of principle that the wall positions can be controlled by manipulating individual atoms, opening new possibilities to investigate AFM systems and prepare AFM spin configurations.

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Towards ultrafast optical excitation of propagating magnons on the nanoscale

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Recent experimental reports have demonstrated that optically induced femtosecond spin currents can excite coherent magnon dynamics in the THz frequency range. [1,2] On this poster we present a simple micromagnetic (numerical and analytical) model for this process. [3] The basic ingredient of this practically 1d model is a Slonczewski-like spin-transfer torque term. With this, we can reproduce the salient features of the experiments presented in reference [1]. Furthermore, the model provides insight into the factors which govern the spin wave mode-specific excitation efficiency.
Building up on these findings, we propose a sample design which allows to overcome the diffraction limit of the beam spot size when exciting in-plane propagating spin waves by femtosecond laser pulses. This is achieved by nanostructuring the toplayer of a CoFeB/Au/CoFeB trilayer film into stripes using focused ion beam milling. This structure results in a lateral spatial profile of the spin current injected into the bottom FM layer, giving rise to lateral radiation of spin waves away from the excitation spot. We present the current progress towards measuring these dynamics using our TR-MOKE setup.
HU and SL acknowledge financial support by the DFG within project A06 of the SFB 1073.

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Nonlinear photocurrents in antiferromagnets

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In the field of spintronics, the interaction of antiferromagnets with external electromagnetic fields plays a crucial role for future prospects related to fundamental understanding and technological applications. In materials of reduced symmetry a photocurrent which is of second order in the electric field can occur. Recently a response tensor describing these currents was derived based on the non-equilibrium Keldysh formalism [1]. Here we want to report on the implementation of this second order response tensor by means of Wannier interpolation, which can be applied as a postprocessing step to first-principles calculations performed with the Jülich DFT code FLEUR [2], an implementation of the FLAPW method. We apply the developed method to study photocurrents and their physical origins in complex oxides with antiferromagnetic ordering. Cases of linear and circular polarized light are considered.
We acknowledge funding from Deutsche Forschungsgemeinschaft (DFG) through SFB/TRR 173. Simulations were performed with computing resources granted by JARA-HPC from RWTH Aachen University and Forschungszentrum Jülich under projects jara0161, jiff40 and jias1a [3]

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DyCo – A Material for Ultrasmall Skyrmions at Room Temperature?

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Magnetic skyrmions are topologically-twisted solitonic states in the spin system of magnetic materials. Even though all skyrmions, by definition, share the same topology, one can distinguish between skyrmions that are stabilized by stray field effects and those stabilized by the Dzyaloshinskii–Moriya interaction (DMI). Only the latter ones can be ultrasmall (~10 nm in diameter), which is paramount for realizing spintronic devices. However, these DMI-Skyrmions require negligible stray fields, strong DMI and a large film thickness to be stable, which are mutually exclusive conditions in materials with interfacial DMI.
A promising solution to this problem is the recently discovered bulk-like DMI of rare earth – transition metal GdFeCo films [1]. Due to the strong spin-orbit coupling of Dy, we anticipate that DyCo exhibits even stronger bulk DMI and therefore stabilize ultrasmall skyrmions at room temperature at film thicknesses beyond 30 nm.
Here, we explore $Dy_{1-x}Co_x$ (50 nm) as a promising host for such ultrasmall skyrmions at room temperature. By systematically varying the Co content x, we tune the magnetic compensation temperature from room temperature to cryogenic temperatures. We will show our first direct imaging of stray field skyrmions in this material and discuss strategies of how to also realize ultrasmall skyrmions formed by DMI.

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Magnetism and thermal transport in LMO / SMO superlattices

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Superlattices with well-defined and controllable thickness of individual layers are a popular meta-material system to study electric, phononic and magnetic effects on the nanoscale.

On this poster we present our investigations of highly correlated perovskite $(LaMnO_3)_m/(SrMnO_3)_n$ superlattices (SLs). These include sample characterization by XRR, XRD, and SQUID magnetometry, thermal conductivity measurements by transient thermo-reflectivity, as well as an analytical description of the system. It is theoretically well known that the thermal conductivity of SLs decreases with an increasing interfacial density, and should increase again when the SL period drops below the phonon mean free path. In agreement with this expectation, we show a minimal thermal conductivity for SLs with m=n=2. This minimal thermal conductivity is actually more than 50% below the theoretically expected value and accompanied by a reduction of the phonon mean free path (MFP) below the layer thickness.

A possible cause of this reduction is revealed by SQUID measurements, which show a transition from ferromagnetic coupling to antiferromagnetic (AFM) coupling between the layers when their thickness is reduced. In our ongoing studies we therefore currently investigate if the MFP reduction is caused by magnetoelastic coupling at the SL interfaces and if external magnetic field can break the AFM coupling, and thereby reversibly control the thermal conductivity.

We acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - 217133147/SFB 1073, project A02.

Excitation of short wavelength spin waves in ferromagnetic conduit with microwave pumped perpendicularly magnetized nanodot

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One of the main research directions in magnonics focuses on excitation of the short wavelength spin waves (SWs). Recently, a few approaches have been proposed, but each of them have some limitations, while lack of the efficient source of SWs limits further development of magnonic applications. We propose local excitation of SWs in a thin ferromagnetic waveguide with the help of nanodot, that possesses perpendicular magnetic anisotropy. Our idea is to use confined SW modes in nanodot pumped by a global microwave magnetic field directed along the magnetization of the waveguide, which will emit propagating SW due to direct static and dynamic coupling with the waveguide. Two study cases are put against each other: a nanodot inscribed with a skyrmion and a nanodot in a fully saturated state along out-of-plane direction. We found the propagating SWs can be excited in a broad frequency band from a few to dozen GHz, in both scenarios. Interestingly, the propagating SW modes are antisymmetric across the waveguide width and their wavelength can be shorter than 100 nm. Furthermore, our studies look for the magnetic parameters and geometry that would be most suitable for an efficient conversion of global electromagnetic radiation to short wavelength SWs. We believe, that the demonstrated in micromagnetic simulations local, limited to the size of the nanodot, excitation of SWs in soft ferromagnetic conduit strongly support further development of magnonics.

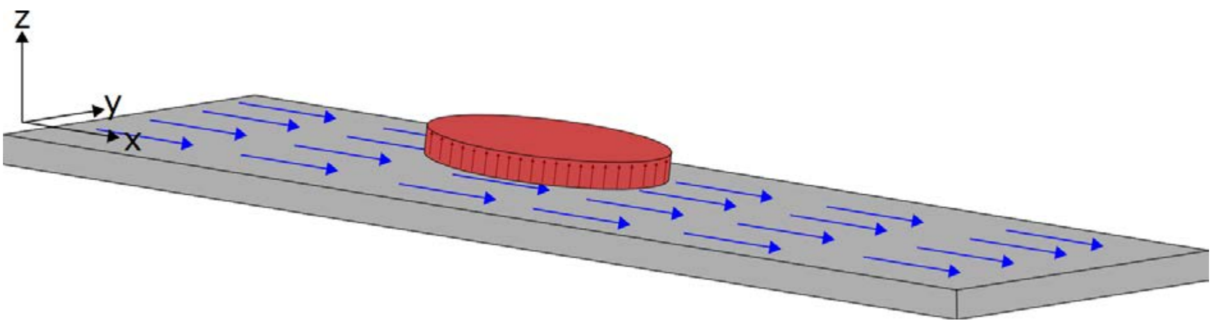

Figure 1: The waveguide and the disk, separated by a vacuum layer, the system used in micromagnetic simulations.

The work was supported by National Science Centre of Poland, Project SHENG No. UMO-2018/30/Q/ST3/00416.

Temperature-dependent spin-transport and current-induced torques in superconductor/ferromagnet heterostructures

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Proximity effects at superconductor(SC)/ferromagnet(FM) interfaces provide novel functionality in the field of superconducting spintronics. We investigate the injection of quasiparticle spin currents in a NbN/Permalloy (Py) heterostructures with a Pt spin sink layer. To this end, we excite ferromagnetic resonance in the Py-layer via the microwave driving field of a coplanar waveguide (CPW). A phase sensitive detection of the microwave transmission signal is used to quantitatively extract the inductive coupling strength between sample and CPW as a function of temperature [1]. Below the superconducting transition temperature Tc, we observe a blocking effect of pure spin current transport in the NbN layer. Moreover, below Tc we find a large field-like current-induced torque. Our findings, reveal symmetry and strength of spin-to-charge current conversion in SC/FM heterostructures and provide guidance for future superconducting spintronics devices [2].

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Acknowledgement

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Plasmon-like fringe patterns on permalloy nanostructures in femtosecond photoemission electron microscopy

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The remarkable progress of ultrafast microscopy and spintronics over the last decades has opened the development of several experimental and theoretical methods for the investigation and control of spin transport and magnetization dynamics in a wide variety of materials.[1] Supported by the "Collaborative Research Center / Transregio 227 Ultrafast Spin Dynamic" we investigate magnetic thin films and nanostructures on nanometer-femtosecond scales with a freshly built setup. Our approach is to combine state-of-the-art time-resolved photoemission electron microscopy (PEEM) with a back-side pumping geometry.[2]

In this poster, we will present the capabilities of our new setup as well as first experimental results for permalloy and silver nanostructures. In general, fringe fields surrounding their edges reveal interesting properties. Whereas it is well established that surface plasmon polaritons (SPP) in silver nanostructures can be imaged by PEEM [3] due to the material's exceptional low plasma frequency, similar observations have not been reported for iron, nickel or permalloy. Here, we report on dichroism images in threshold photoemission which show clear edge-induced standing waves with sub-micrometer wavelength. Difficulties arise from separating ordinary diffraction phenomena and plasmon dynamics since the used excitation energies lie way below the material's plasma frequency. However, careful analysis of the appearing moiré patterns as well as the coupling of the photon's spin-angular momentum to the observed fringe fields hint to propagation characteristics exclusive to evanescent waves, such as SPPs.[4, 5] This implies the possibility, that, although very weak, many materials with a high plasma frequency allow for excitation and experimental observation of SPPs at the dielectric/metal interface, especially opening many magnetic materials to the exciting field of magnetoplasmonics.[6]

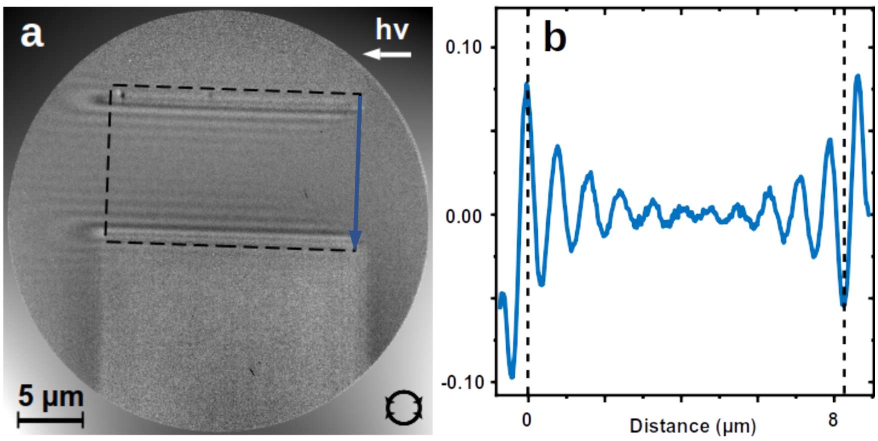

Figure 1: (a) Femtosecond laser PEEM image (30 fs, 1.23 MHz repetition rate, 3.32 eV) with circular dichroism contrast of permalloy nanostructures on a GaAs surface, revealing strong intensity oscillations at the edges. (b) Line profile of the area marked in (a) with the edge position marked as dashed lines.

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Study of Ultrafast Element-specific Magnetization Dynamics by Use of Extreme Ultraviolet Light

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The seminal work of Beaurepaire in 1996 has paved the way for a wealth of subsequent experimental and theoretical works in the field of ultrafast magnetism [1]. However, despite these efforts little is known about the magnetization dynamics of complex magnetic systems such as alloys, strongly correlated electron systems and their heterostructures. To get a microscopic understanding of ultrafast magnetism in complex systems, an element-specific probe of the magnetic subsystems is necessary [2, 3].

Our new experimental setup makes use of the resonant magneto-optical Kerr effect in the extreme-ultraviolet (EUV) regime. The high-harmonic beamline is driven by a high-repetition-rate fiber laser and spans the energies of the M-absorption edges of Ni, Fe, Mn, Ru and Co. Due to the high stability and excellent EUV flux, it provides an increased sensitivity to detect the pure magnetic signals. Further, the possibility to apply magnetic fields (B=0-1T) and cooling capabilities (T=4-400K) to control the magnetic state of the sample surpasses the abilities of previous EUV-based MOKE setups.

Here, we would like to illustrate the improved functionality and good signal quality of our new setup by presenting first element-specific MOKE measurements of a Fe/Ni alloy and manganite films.

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Geometrically driven chiral effects in curvilinear antiferromagnetic spin chains

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Antiferromagnets are technologically promising materials for spintronic and spinorbirtonic devices [1]. An efficient manipulation of antiferromagnetic textures requires the presence of the Dzyaloshinskii-Moriya interaction (DMI), which is present in crystals of special symmetry, and thus limits the number of available materials. In contrast to antiferromagnets, it is already established that in ferromagnetic thin films and nanowires chiral responses can be tailored relying on curvilinear geometries [2].

Here, we explore curvature effects in curvilinear antiferromagnets [3]. We demonstrate theoretically that intrinsically achiral curvilinear antiferromagnetic spin chains behave as a biaxial chiral helimagnet with a curvature-tunable anisotropy and DMI. In contrast to ferromagnetic spin chains, this system possesses the hard-axis anisotropy stemming from the dipolar interaction, which allows to observe the effects of geometry even in chains with small curvature and torsion. The geometry-driven easy axis anisotropy determines the homogeneous antiferromagnetic state at low curvatures and the gap for spin waves. The geometry-driven DMI determines the helimagnetic phase transition and leads to the appearance of the region with the negative group velocity at the dispersion curve.

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Temperature scaling of spin model parameters

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Spin models play a fundamental role in describing the properties of nanoscale spintronic devices. The perpendicular easy-axis magnetocrystalline anisotropy in thin films enhances the stability of bits of information, thereby contributing to their miniaturization. The Dzyaloshinsky-Moriya interaction gives rise to chiral domain walls and skyrmions, while also inducing non-reciprocal spin-wave propagation. Understanding the influence of thermal fluctuations on these model parameters is essential for the design of novel room-temperature applications.

Here we present a theoretical model for calculating the temperature dependence of Heisenberg and Dzyaloshinsky-Moriya interactions, as well as single-ion and two-ion anisotropies in ferromagnets. Scaling exponents as a function of dimensionless parameters are derived from an analytical method based on Green's function theory, and are found to be in good agreement with the results of atomistic spin simulations. The role of thermally induced magnon-magnon interactions is highlighted, leading to the emergence of phenomena that are unexpected on a mean-field level. It is shown that the Dzyaloshinsky-Moriya interaction gives rise to an effective anisotropy term only present at finite temperature [1], which may compete with single-ion and demagnetization contributions and induce a temperature-driven spin reorientation transition in thin films [2]. Fluctuation corrections affect isotropic and anisotropic exchange terms differently, and the interplay between the two-ion anisotropic exchange and the single-ion anisotropy is demonstrated to cause a non-monotonic dependence of the total anisotropy on the temperature [3].

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Reversal of the domain wall magnetization in perpendicular anisotropy stripe and bubble domains of Co/Pt multilayers

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Magnetic objects at the nanoscale, such as skyrmions and bubble domains, are considered to be suitable units for nonvolatile, energy efficient computing elements, as they provide superior memory capability and minimize undesired heat losses [1, 2]. It is argued that in bubble skyrmions the interfacial Dzyaloshinskii-Moriya interaction (iDMI) supports the Neel component of domain walls (DWs) to be preferred over the Bloch component with some intermediate or hybrid states, depending on the iDMI strength [3]. When it comes to determining the type of the DW present in such systems, then it is usually identified using Lorentz transmission electron microscopy (LTEM), which requires special sample preparation and complex data analysis [4].
In the current study we report on the controlled manipulation of magnetic DWs polarization in aligned stripe and bubble domain systems, stabilized in [Co (0.44 nm)/Pt (0.7 nm)]$_X$ (X = 48, 100, 150) multilayers. We show that the remanent in-plane magnetization in the magnetometry data originates from the polarization of the Bloch-type DWs. Thus, the high in-plane remanent moment, measured parallel to the stripe DW direction, confirms dominating Bloch type DWs in our system. We demonstrate that the magnetization reversal process within the DWs does not influence the overall stripe and bubble domain morphology. Therefore our approach allows to study and control the magnetization reversal inside the DW by performing in-plane minor hysteresis loop sequences with field applied parallel to the magnetization of the DW Bloch component. The DW magnetization switching mechanisms will be discussed in detail, and compared with studies of domain structures in garnet film [5].

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Magnetic microstructure investigations of focused ion beam irradiated synthetic antiferromagnets with perpendicular anisotropy

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The magnetic ground state of layered synthetic antiferromagnets (SAFs) mainly depends on the interlayer exchange (IEC), demagnetization and perpendicular anisotropy energy. Due to their competitive nature, various magnetic phases can be stabilized in this system by changing the ratios of the respective energies. Previously, this was achieved by means of altering the layer thicknesses and repetition numbers, leading to different magnetic phases on either different samples or large areas of wedge-samples [1]. Here, in contrast, we irradiate the sample post-deposition with a nanometer-focused He+ ion beam, introducing intermixing of the thin layer interfaces, which yields a weakening of IEC and anisotropy. By this, various laterally coexisting magnetic phases can be stabilized on pre-defined areas of nanometer to micrometer scale. Areas irradiated with intermediate He+ ion fluences exhibit a ferromagnetic stripe domain phase due to the weakened IEC. For low He+ ion fluences, an antiferromagnetic (AF) remanent domain is nucleated, which exhibits an inverse magnetization structure as compared to the naturally preferred non-irradiated AF remanent state. Hence, with focused ion beam irradiation we can introduce well defined AF domains on the nanoscale into our SAF system. These domains can be further manipulated with an external out-of-plane magnetic field, yielding a continuous and directional annihilation from the high to the low fluence side of domains irradiated with a fluence gradient. This could be utilized for engineering a controllable and local stray field landscape within the stray field free environment provided by the as prepared SAF ground state.

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Orbital decomposition of Yu-Shiba-Rusinov resonances from magnetic impurities in multiband superconducting Pb

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Scanning tunnelling microscopy applied to superconductors has seen a flourish of activity in the last few years. Quasi-particle interference at impurities has become a powerful tool for determining the underlying fundamental properties of the gap structures in unconventional superconductors [1]. Additional analysis of pair-breaking induced by magnetic impurities in conventional superconductors further supported the deeper understanding of the superconducting state and the formation of Yu-Shiba-Rusinov bound states [2]. Extending those results to chains of magnetic impurities on a surface of superconductors with high spin-orbit coupling can be understood as one possible path towards Majorana Fermions [3].
Here, we present the implementation of the Bogoliubov-de Gennes (BdG) equation into a Green's function (KKR) first principles method [4], incorporating substitutional impurities [5]. This method combines the full complexity of the underlying electronic structure and Fermi surface geometry with a simple phenomenological parametrisation of the superconducting state. At the same time it enables us to model impurities as well as interfaces. We present calculations for the bulk as well as the surface of superconducting Pb in the presence of magnetic impurities, and assess the orbital character of the ensuing Yu-Shiba-Rusinov bound states making contact to experimental observations.

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Direct imaging of chiral domain walls with Dzyaloshinskii-Moriya interaction in ferrimagnetic alloys at different temperatures

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Magnetic skyrmions are topological spin textures that can be stabilized by the Dzyaloshinskii-Moriya interaction [1,2]. There are particularly suitable for next generation spintronics devices, like the skyrmion-based racetrack memory [3]. Recent studies confirmed their current-driven skyrmion dynamics in ultrathin ferromagnets via spin-orbit torques [4,5], where the chirality and spin texture of the skyrmions are key. However, the topological Magnus effect leads to a transverse motion of ferromagnetic skyrmions due to their non-zero topological charge [5], which is disadvantageous for devices. Antiferromagnetically exchange-coupled skyrmions or compensated ferrimagnets could suppress this effect owing to an overall zero topological charge.

Here we explore the chiral character as a function of the temperature of a GdFeCo-based ferrimagnet system with perpendicular magnetic anisotropy. We demonstrate that in this system homochiral spin textures such as magnetic skyrmions and skyrmionium [6] can be observed using scanning electron microscopy with polarization analysis. The high spatial resolution magnetic imaging technique reveals the domain wall spin structure as a function of temperature, with the observed structures found to be pure Néel-type spin textures, which is promising for devices. From the images, we extract the domain wall width as a function of the temperature and we calculate the exchange stiffness for the system.

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Spin Transfer Torque in Ferromagnetic Josephson Junctions Including chiral P-wave Ferromagnetic Superconductor Reservoirs

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The spin transfer torque (STT) in the Ferromagnetic Josephson junctions containing the interesting cases of ballistic-triplet chiral/p-wave ferromagnetic superconductor (FS) materials and the normal (N) interlayer, is investigated. The mentioned ballistic $FS_1|N|FS_2$ structure is dealt with solving the 16×16 Bogoliubov–de-Gennes equation. It is found that although the exchange fields of the FS are laid in the z and y direction, the STT interestingly exists in all three directions of x, y and z. This exciting finding suggests that the favourable equilibrium configuration concerning the least exchange coupling occurs in the relative exchange field direction different from 0 or π. Moreover, the ferromagnetic Josephson junction $FS_1|F_2|FS_3$ has been also investigated. Our study reveals the notable increase of the value of the STT in comparison to that of the $FS_1|N|FS_2$. On the other hand, the new relation for the bound state energy spectrum of these structures have been obtained.

Quantum calibrated magnetic force microscopy

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Magnetic force microscopy (MFM) can be considered a standard tool for nano-scale investigations of magnetic structures. MFM data can be quantified based on a calibration approach that allows to measure field and magnetization distributions in units of A/m with a spatial resolution down to the 30 nm scale under ambient conditions [1]. Calibrating the MFM means determining the MFM tip's stray field distribution. Together with the mechanical properties of the MFM cantilever it gives the instruments point spread function which constitutes the Instrument's Calibration Function (ICF). MFM data of unknown samples can be quantified by a deconvolution with the ICF. The MFM calibration standard approach is based on the measurement of a reference sample, followed by a deconvolution with the reference sample stray field, that, however, cannot be validated independently.

We here present a direct quantum calibration approach for the tip stray field distribution which gets along without reference sample. To this end we measure the tip stray field distribution directly with a single NV-center in diamond as an atomic magnetometer. The tip is scanned over the NV-center while the tip stray field is measured by optically detected magnetic resonance (ODMR). The thus calibrated MFM can be used to quantitatively measure magnetic fields over a broad range of length and field scales. Exemplarily, the calibrated MFM tip is used to quantitatively measure the stray field of a Co/Pt multilayer with nano-scale stripe domains and stray field amplitudes around 100 mT at a measurement height of 80nm.

The direct calibration overcomes reference sample related problems that arise not only from uncertainties of its stray field but also from its limited magnetic feature size spectrum. Beyond that it allows to transfer the quantum traceability of direct NV-center based measurements, as can be achieved via scanning NV-magnetometers, to MFM with its higher field tolerance.

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THz-2D Scanning Spectroscopy

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THz radiation has become an increasingly important tool for quality control in the food industry as well as in the medicine sector [1,2].
Since most seald plastic packaging compounds are transparent to THz radiation, it is possible to verify the food or drug ingredients by detecting their absorption lines even without unpacking the investigated substances [1].
We customized a standard commercial THz Fourier Transform spectrometer based on an LT-GaAs Auston switch emitter and detector from Menlo systems by adding a motorized 2D scanning unit. To test this 2D THz spectrocopy scanning system, we investigated a test stripe pattern of Au on glass with decreasing slitwidth and pitch. The measured resolution is very close to the diffraction limit and at 1 THz (300 μm) we can distinguish two points separated by a distance around 338 μm.
The next step is to replace the commercial system by a spintronic emitter and a ZnTe detector so that we reach a higher bandwidth.
With this setup we want to develop a THz based noninvasive detection scheme for microplastics accumulating in human and animal cell tissue. To identify the plastic, we need to create a database of plastic materials with either the commercial system or our own build setup.

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Magnetic coupling in $La_{0.7}Sr_{0.3}MnO_3$/La_2CoMnO_6 superlattices

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Perovskite manganites with strong coupling of electron, spin, and lattice degrees of freedom possess rich magnetic, electric, and structural phase diagrams. By arranging them into heterostructures, even more interesting phenomena emerge. Here we studied superlattices (SLs) of classical double exchange ferromagnetic (FM) metallic $La_{0.7}Sr_{0.3}MnO_3$ (LSMO, $T_{C1} \approx 350$ K) and A-site ordered superexchange FM insulating double perovskite La_2CoMnO_6 (LMCO, $T_{C2} \approx 220$ K) grown by the metalorganic aerosol deposition (MAD) technique on STO substrates. The thickness of the individual layers d_L was systematically varied from 1 to 24 unit cells (u.c.), whereas the overall thickness of the SLs was kept constant at $d_{SL} \approx 75$ nm.

We observed that at their interfaces, the FM layers with $d_L > 6$ u.c. were antiferromagnetically coupled as detected by a characteristic reduction of the measured SQUID magnetic moment at T_{C2} of LMCO. The coupling was found to be increasingly suppressed by an external magnetic field H of up to 10 kOe. Furthermore, first measurements of ultrafast magnetisation dynamics by excitation with ultrashort laser pulses at different temperatures and fields have been performed.

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Tracing magnetization dynamics in Gd, Tb and Fe at the BZ edge by TR-ARPES

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Time- and angle-resolved photoemission spectrocopy (TR-ARPES) allows for the investigation of magnetization dynamics by observing shifts in the electronic band structures and transient changes of the electronic population [1]. The focus of previous experiments often lay on the centre of the Brillouin zone (BZ). However, large parts of the electrons contributing to magnetism are distributed over the whole BZ. We prepare thin single-crystalline layers of the 3d-transmission metal Fe and the rare earth elements Gd and Tb on W(110) at room temperature and measure TR-ARPES signals at cryogentic temperatures (<100°C). In a pump-probe experiment photelectrons are excited by ultrashort monochromatic XUV pulses generated via HHG in an Argon target at a repetition rate of 10 KHz. We pump the demagnetization dynamics of the thin-film samples by intense IR pulses at 770 nm centre wavelength. We measure the electronic excitation and trace the photo-induced change of the exchange splitting and compare the results with the demagnetization observed at the centre of the BZ.

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Spin-resolved Fermi Surface of Ultrathin Ferromagnetic FePd Alloy Monolayers

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Magnetism in reduced dimensions is one of the preconditions for the realization of nanoscale spintronics. Despite recent discovery of ferromagnetism in monolayers of two-dimensional materials, tunability and engineering on such systems are usually very limited [1]. Therefore, the studies on the fundamental physics involved in the emergence of ferromagnetism in reduced dimensions remain scarce. In this presentation, the ultrathin ferromagnetic Iron-Palladium alloy film at atomic thickness will be explored using the state-of-the-art spin-resolved momentum microscopy [2]. Momentum microscopy enables the two-dimensional detection of photoelectrons of in-plane crystal momentum over the range of a full Brillouin zone or more. Furthermore, by employing an imaging spin filter, we have acquired the spin-resolved momentum maps of the Iron-Palladium alloy including the Fermi surface [2,3]. Breaking of time reversal symmetry across the Fermi surface was clearly observed upon remanent magnetization and is easily reversible by an opposite magnetization direction. Interaction and competition between exchange interaction and strong spin-orbit coupling are predicted to give rise to non-collinear spin textures in the electronic structure and enhanced band hybridization [4,5]. Evidence of a non-collinear spin texture across the Fermi surface is given, where the local spin polarization points orthogonal to the remanent magnetization of the sample.

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Ultrafast manipulation of order in compound and textured magnetic materials

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The interactions between electrons, spins, and phonons in magnets and other strongly correlated electron materials hold the key to their emergent properties and provide a route to manipulating their phases. While the fundamental length- and time-scales for these phenomena are nanometers (exchange length) and femtoseconds (exchange splitting), tools that enable the exploration of their interactions and functional properties have only recently become available. Using a combination of ultrafast lasers, electron, and x-ray pulses, we can go beyond merely observing the static lattice and band structure, to manipulating a material as it undergoes a light-induced phase transition. In this poster I will describe advances in ultrafast X-ray and electron beam spectroscopy and imaging that allow us to directly observe and manipulate new phases of matter in magnetic and other strongly correlated electron materials. Specifically, I will show examples of how we can drive nonequilibrium phase transitions and observe new material physics in a half-metallic heusler alloy Co2MnGe and skyrmion hosting ferrimagnetic insulator Cu2OSeO3.

Optical driven 4*f*-spin and orbital transitions in rare-earth metals

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Identifying the role of spin and orbital degrees of freedom is essential for understanding ultrafast magnetism. For separating S and L dynamics, we followed a new approach by probing time-resolved X-ray absorption (XA) spectra at the M_5 ($3d \rightarrow 4f$) resonance of lanthanide metals. For Tb we observed pump-induces changes of the multiplet structure after excitation with 800-nm laser pulses. The pump-effect follows the temperature of the laser excited valance electrons, which reveals a so far unknown channel for energy and angular momentum transfer: we found that 5*d* and 4*f* subsystems interact directly via inelastic electron scattering and charge transfer, initiating transitions to higher energetic 4*f* configurations. As a consequence, the 4*f* atomic magnetic moment including spin and orbital degrees of freedom is altered. In contrast to Tb with a $4f^8$ configuration, Gd with a half-filled $4f^7$ shell is not affected by the pump pulse and remains in its $^8S_{7/2}$ ground state. Being strongly material dependent and with its direct effect on magnetization, magneto-crystalline anisotropy and exchange coupling, we expect the 5*d*-4*f* excitation channel to be of crucial importance for the initial ultrafast dynamics.

Element-specificity in resonant spectroscopy of complex magnetic systems in the extreme ultraviolet spectral range

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The vision to manipulate and control magnetism with light is driven on the one hand by fundamental questions of direct and indirect photon-spin interactions and on the other hand by the necessity to cope with ever growing data volumes, requiring radically new approaches how to write, read and process information.
Here, we present two types of experimental geometries in the extreme ultraviolet spectral range to probe optically driven ultrafast magnetization dynamics with element specificity. First, we employ linearly polarized radiation of a free electron laser facility to demonstrate decoupled dynamics of the two sublattices of an FeGd alloy [1], a prerequisite for all-optical magnetization switching. Second, we use circularly polarized radiation generated in a laboratory based high harmonic generation setup to show optical intersite spin transfer in a CoPt alloy [2,3], a mechanism which only very recently has been predicted to mediate ultrafast metamagnetic phase transitions. Finally, we will also address a recent discussion in literature on spectral reshaping of magnetic circular dichroism because of a non-equilibrium electron distribution after femtosecond optical excitation [4].

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Lorentz Imaging in an Ultrafast Transmission Electron Microscope

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Recent progress in the development of laser-pulse driven, high-brightness photocathodes offers a path to investigate magnetization dynamics with a simultaneous fs-temporal and nm-spatial resolution by employing a Lorentz imaging scheme in an ultrafast transmission electron microscope (UTEM).

Lately, the ultrafast demagnetization of a magnetic vortex structure in a thin permalloy film after optical excitation was mapped spatiotemporally by the Göttingen UTEM project, yielding results in agreement with previous ultrafast optical spectroscopy experiments [1].

Further demonstrating the capabilities of ultrafast Lorentz microscopy, the formation of a metastable magnetic vortex-antivortex texture in thin iron films upon ultrafast optical excitation was recently reported [2]. When optically exciting the sample to a peak temperature above the Curie temperature, critical fluctuations of the paramagnetic phase manifest as topological defects upon rapid cooling back into the symmetry-broken phase. Investigations of such nanoscale ordering mechanisms may give access to a variety of hitherto unreported metastable phases and provide opportunities to gain a deeper understanding of transient magnetic states in optically excited systems.

The new UTEM project in Oldenburg is aiming for an improved beam brightness and advanced magnetic excitation schemes, in order to further establish ultrafast Lorentz microscopy as a powerful technique to characterize magnetic dynamics on the nanoscale.

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Quantitative analysis of magnetic states in an artificial spin ice by off-axis electron holography

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Frustration refers to the inability of a system to simultaneously satisfy competing interactions and can give rise to complex physical properties [1]. In this work, we studied an artificial spin ice that consisted of elongated single-domain patterned nanomagnets, which provided frustration by design. We used off-axis electron holography in the transmission electron microscope to quantitatively measure the magnetic phase shift induced by the sample [2]. The microscope was operated in magnetic field-free conditions using a Lorentz lens, while the conventional microscope objective lens was used to apply magnetic fields of up to 1.5 T to the sample. The phase shift of the electron wave was measured using an electron biprism and interpreted using a model-based iterative reconstruction algorithm to retrieve the projected in-plane magnetisation. The three-dimensional magnetic stray field surrounding the sample was calculated and the experimental results were compared with micromagnetic simulations.

The permalloy nanomagnets were patterned into a chiral ice geometry on a SiN membrane using lift-off lithography. Magnetic interactions between them were studied by applying in-plane magnetic fields to the sample. The resulting magnetic fields were recorded at remanence. The measurements revealed a zig-zag magnetization distribution, with stray fields that became more complex at the edges of the array. The results showed that the pattern of stray magnetic stray field in the plane of the particles is different from that integrated in a direction perpendicular to the plane of the sample, emphasizing the need to take its three-dimensional nature into account.

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Photo-induced magnetization dynamics with spin-currents: spin wave manipulation and ultrafast phenomena

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Spin currents offer a way to control static and dynamic magnetic properties, and hence, they are crucial for next-generation magnetic devices. In typical 3*d* transition metal ferromagnets like CoFeB, the lifetime of light-induced coherent dynamics is restricted to about 1 ns, which strongly limits the exploitation of the wave nature in magnonic devices. Here, we report on the potential of spin-currents to increase the spin wave lifetime in a heterostructure consisting of a heavy metal (8 nm of β-Tantalum (Platinum)) and 5 nm CoFeB. Patterned conduction strips facilitate the exploitation of the Spin Hall effect in Ta (Pt) in order to inject a spin current into the magnetic layer. We investigate how this spin current affects the magnetization dynamics in the adjacent CoFeB layer. Using time-resolved all-optical pump-probe spectroscopy allows us accessing not only the nanosecond but also the sub-picosecond timescales. On the longer timescales, we find the dependence of the Kittel mode's Gilbert damping parameter on the injected spin torque and determine the systems' Spin Hall angles and spin-mixing conductance [1]. Furthermore, we detect a strongly damped, ultrafast spin wave excitation with strong dependence on the spin current and, on the sub-picosecond timescales, we demonstrate the manipulation of the ultrafast demagnetization time. Thus, along with the lifetime enhancement of magnetic dynamics, spin currents might provide a way to push ultrafast magnetic effects to the limits and, for instance, to increase the speed of optical bit writing techniques.

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Tailoring the magnetic anisotropy of $La_{0.7}Sr_{0.3}Mn_{1-y}Ru_yO_3$ epitaxial thin films

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Ferromagnetic perovskite oxide thin films offer a rich platform to tailor the magnetic ordering of the system by external parameters such as layer thickness, epitaxial strain or interfacial engineering[1-3]. One of the key ingredients that influences the magnetic ground state of a thin film system is the effective magnetic anisotropy. Of particular interest for applications is how to obtain perpendicular magnetic anisotropy (PMA) in ferromagnetic perovskite oxide epitaxial thin films and multilayers. For example, topologically non-trivial magnetic textures can be induced when the perpendicular magnetic anisotropy is of comparable strength with interfacial Dzyaloshinskii-Moriya interaction and the Heisenberg exchange. Such moderate perpendicular magnetic anisotropy was realized in thin films of the ferromagnetic oxide $La_{0.7}Sr_{0.3}Mn_{1-y}Ru_yO_3$ by strain engineering and variation of the Mn/Ru ratio[3]. Here we present our results of the magnetic and magneto-transport study of epitaxial $La_{0.7}Sr_{0.3}Mn_{1-y}Ru_yO_3$ thin films. The effective magnetic anisotropy was tailored by the variation of epitaxial strain imposed by two types of substrates, by modifications of the Ru content and by the film thickness. PMA was observed for the $La_{0.7}Sr_{0.3}Mn_{0.9}Ru_{0.1}O_3$ films grown on LSAT(100) substrates, under small compressive strain, for thicknesses between 5 and 40 nm. For lower Ru content, in case of $La_{0.7}Sr_{0.3}Mn_{0.95}Ru_{0.05}O_3$ films, the magnetic easy axis was dominantly in-plane when the layer thickness was 30 nm and turned out-of-plane for 40-50 nm thick films. Growth of $La_{0.7}Sr_{0.3}Mn_{0.9}Ru_{0.1}O_3$ films on $SrTiO_3$(100) substrates, under tensile strain, resulted in in-plane magnetic anisotropy.

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Magnetic anisotropy and anomalous Hall effect of $SrRuO_3$/$LaNiO_3$ superlattices grown on $SrTiO_3$(100)

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Magnetic anisotropy and anomalous Hall effect resistance in ferromagnetic heterostructures have attracted much attention recently for spintronic applications. We investigated the magnetic anisotropy tunability of $SrRuO_3$/$LaNiO_3$ superlattices by means of structural changes of the RuO_6 octahedra at $SrRuO_3$/$LaNiO_3$ interfaces. The $SrRuO_3$ layers in the superlattices with 4 monolayers (ML) $LaNiO_3$ show lower octahedral tilting angle and higher titling angle for that of superlattices with 2 ML $LaNiO_3$. The $SrRuO_3$/$LaNiO_3$ superlattices were investigated by global SQUID magnetometry, by Hall effect resistance measurements and magneto-optical Kerr effect (MOKE) in polar geometry. The SQUID magnetometry data, in accord with the MOKE data, indicate that ferromagnetic $SrRuO_3$ layers epitaxially interfaced with 2 ML thick $LaNiO_3$ show stronger out-of-plane aniotropy than in superlattices with 4 ML thick $LaNiO_3$. The Hall effect transverse resistance loops of the $SrRuO_3$/$LaNiO_3$ superlattices show intriguing humplike features. These features are similar to what we observed also for $SrRuO_3$/$SrIrO_3$ superlattices and are debated to be a possible fingerprint of a topological Hall effect.

Imprinting and driving electronic orbital magnetism using magnons

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Magnons, as the most elementary excitations of magnetic materials, have recently emerged as a prominent tool in electrical and thermal manipulation and transport of spin, and magnonics as a field is considered as one of the pillars of modern spintronics. On the other hand, orbitronics, which exploits the orbital degree of freedom of electrons rather than their spin, emerges as a powerful platform in efficient design of currents and redistribution of angular momentum in structurally complex materials.
Here, we uncover a way to bridge the worlds of magnonics and electronic orbital magnetism, which originates in the fundamental coupling of scalar spin chirality, inherent to magnons, to the orbital degree of freedom in solids. We show that this can result in efficient generation and transport of electronic orbital angular momentum by magnons, thus opening the road to combining the functionalities of magnonics and orbitronics to their mutual benefit in the realm of spintronics applications.

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