Magnetism Division
Fachverband Magnetismus (MA)

Heiko Wende
Universität Duisburg-Essen
Fakultät für Physik
Lotharstr. 1
D-47048 Duisburg
heiko.wende@uni-due.de

Overview of Invited Talks and Sessions

(Lecture halls H2 and H5; Poster P)

Invited Talks

MA 1.1	Mon	10:00–10:30	H5	**Utilizing Vacuum States above Surfaces for Imaging and Manipulation of Atomic-Scale Magnetism** — •Anika Schlenhoff
MA 2.1	Mon	13:30–14:00	H5	**Magnon-polarons in magnetic insulators** — •Benedetta Flebus
MA 2.2	Mon	14:00–14:30	H5	**Spin-phonon coupling in non-local spin transport through magnetic insulators** — •Rembert Duine
MA 2.3	Mon	14:30–15:00	H5	**Double accumulation and anisotropic transport of magneto-elastic bosons in yttrium iron garnet films** — •Alexander A. Serga
MA 2.5	Mon	15:15–15:45	H5	**Magnon polarons and the low-temperature spin-Seebeck effect** — •Piet Brouwer, Rico Schmidt
MA 2.6	Mon	15:45–16:15	H5	**Magnon-Polarons in different flavors: (anti)ferromagnetic to topological** — •Akashdeep Kamra
MA 2.7	Mon	16:15–16:45	H5	**Magnon polarons in antiferromagnetic insulator Cr2O3** — •Jing Shi
MA 4.1	Tue	10:00–10:30	H5	**2D Magnetic materials** — •Alberto Morpurgo
MA 6.1	Tue	13:30–14:00	H5	**Spin-charge interconversion with oxide 2-dimensional electron gases** — •Manuel Bibes
MA 6.2	Tue	14:00–14:30	H5	**Spin-to-charge current conversion for logic devices** — •Felix Casanova
MA 6.3	Tue	14:30–15:00	H5	**Electrical and thermal generation of spin currents by magnetic graphene** — •B.J van Wees, T.S. Ghiasi, A.A. Kaverzin, D.K. de Wal, A.H. Dismukes, Bart Wees
MA 6.4	Tue	15:15–15:45	H5	**Ferroelectric switching of spin-to-charge conversion in GeTe** — •Christian Rinaldi
MA 6.5	Tue	15:45–16:15	H5	**Theory of spin and orbital Edelstein effects in a topological oxide two-dimensional electron gas** — •Annika Johansson, Börge Göbel, Jürgen Henk, Manuel Bibes, Ingrid Mertig
MA 6.6	Tue	16:15–16:45	H5	**Nonlinear magnetoresistance and Hall effect from spin-momentum locking** — •Giovanni Vignale
MA 7.1	Wed	10:00–10:30	H5	**Anatomy of skyrmion-defect interactions and their impact on detection protocols** — •Samir Lounis
MA 10.1	Wed	13:30–14:00	H5	**Topological spin crystals stabilized by itinerant frustration** — •Yukitoshi Motome
MA 10.2	Wed	14:00–14:30	H5	**Formation of spin-hedgehog lattices and giant topological transport properties in chiral magnets** — •Naoya Kanazawa
MA 10.3	Wed	14:30–15:00	H5	**Topological-chiral magnetic interactions driven by emergent orbital magnetism** — •Sergii Grytsiuk, Jan-Philipp Hanke, Markus Hoffmann, Juba Bouaziz, Olena Gomonay, Gustav Bihlmayer, Samir Lounis, Yuriy Mokrousov, Stefan Blügel
MA 10.4	Wed	15:15–15:45	H5	**Complex spin structures in thin transition metals films and their oxides** — •Matthias Bode
MA 13.1	Thu	10:00–10:30	H5	**Magnetism and superconductivity: new physics one atom at a time** — •Alexander Balatsky

MA 13.3	Thu	10:45–11:15	H5	**Magnetic adatom chains on superconducting $NbSe_2$** — Eva Liebhaber, Lisa M. Rütten, Gael Reecht, Jacob F. Steiner, Sebastian Rohlf, Kai Rossnagel, Felix von Oppen, •Katharina J. Franke
MA 13.5	Thu	11:30–12:00	H5	**Yu-Shiba-Rusinov states and ordering of magnetic Impurities near the boundary** — •Jelena Klinovaja
MA 13.7	Thu	12:15–12:45	H5	**Resonance from antiferromagnetic spin fluctuations for spin-triplet superconductivity in UTe2** — •Pengcheng Dai
MA 14.1	Thu	13:30–14:00	H5	**The role of itinerant electrons and higher order magnetic interactions among fluctuating local moments in metallic magnets** — •Julie Staunton
MA 17.1	Fri	10:00–10:30	H5	**Emergent electromagnetic response of nanometer-sized spin textures** — •Max Hirschberger, Takashi Kurumaji, Leonie Spitz
MA 19.1	Fri	13:30–14:00	H5	**"Neuromorphic Computing": A Productive Contradiction in Terms** — •Herbert Jaeger
MA 19.2	Fri	14:00–14:30	H5	**Neuromorphic computing with radiofrequency spintronic devices** — •Alice Mizrahi, Nathan Leroux, Danijela Markovic, Dedalo Sanz Hernandez, Juan Trastoy, Paolo Bortolotti, Leandro Martins, Alex Jenkins, Ricardo Ferreira, Julie Grollier
MA 19.3	Fri	14:40–15:10	H5	**Data Storage and Processing in the Cognitive Era** — •Giovanni Cherubini
MA 19.4	Fri	15:10–15:40	H5	**Brain-inspired approaches and ultrafast magnetism for Green ICT** — •Theo Rasing

Invited talks of the joint symposium SKM Dissertation Prize 2021 (SYSD)

See SYSD for the full program of the symposium.

SYSD 1.1	Mon	10:00–10:25	Audimax 2	**Avoided quasiparticle decay from strong quantum interactions** — •Ruben Verresen, Roderich Moessner, Frank Pollmann
SYSD 1.2	Mon	10:25–10:50	Audimax 2	**Co-evaporated Hybrid Metal-Halide Perovskite Thin-Films for Optoelectronic Applications** — •Juliane Borchert
SYSD 1.3	Mon	10:55–11:20	Audimax 2	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYSD 1.4	Mon	11:20–11:45	Audimax 2	**The thermodynamics of stochastic systems with time delay** — •Sarah A.M. Loos
SYSD 1.5	Mon	11:50–12:15	Audimax 2	**First Results on Atomically Resolved Spin-Wave Spectroscopy by TEM** — •Benjamin Zingsem

Invited talks of the joint symposium Potentials for NVs sensing magnetic phases, textures and excitations (SYNV)

See SYNV for the full program of the symposium.

SYNV 1.1	Mon	13:30–14:00	Audimax 2	**Harnessing Nitrogen Vacancy Centers in Diamond for Next-Generation Quantum Science and Technology** — •Chunhui Du
SYNV 1.2	Mon	14:00–14:30	Audimax 2	**Nanoscale imaging of spin textures with single spins in diamond** — •Patrick Maletinsky
SYNV 1.3	Mon	14:30–15:00	Audimax 2	**Spin-based microscopy of 2D magnetic systems** — •Jörg Wrachtrup
SYNV 1.4	Mon	15:15–15:45	Audimax 2	**Exploring antiferromagnetic order at the nanoscale with a single spin microscope** — •Vincent Jacques
SYNV 1.5	Mon	15:45–16:15	Audimax 2	**Nanoscale magnetic resonance spectroscopy with NV-diamond quantum sensors** — •Dominik Bucher

Invited talks of the joint symposium Novel phases and dynamical properties of magnetic skyrmions (SYMS)

See SYMS for the full program of the symposium.

SYMS 1.1	Tue	10:00–10:30	Audimax 2	**Imaging skyrmions in synthetic antiferromagnets by single spin relaxometry** — •Aurore Finco

SYMS 1.2	Tue	10:30–11:00	Audimax 2	**Microwave spectroscopy of the skyrmionic states in a chiral magnetic insulator** — •Aisha Aqeel, Jan Sahliger, Takuya Taniguchi, Stefan Maendl, Denis Mettus, Helmuth Berger, Andreas Bauer, Markus Garst, Christian Pfleiderer, Christian H. Back
SYMS 1.3	Tue	11:15–11:45	Audimax 2	**Archimedean Screw in Driven Chiral Magnets** — •Nina del Ser
SYMS 1.4	Tue	11:45–12:15	Audimax 2	**Frustration-driven magnetic fluctuations as the origin of the low-temperature skyrmion phase in $Co_7Zn_7Mn_6$** — •Jonathan White, Victor Ukleev, Kosuke Karube, Peter Derlet, Chennan Wang, Hubertus Luetkens, Daisuke Morikawa, Akiko Kikkawa, Lucile Mangin-Thro, Andrew Wildes, Yuichi Yamasaki, Yuichi Yokoyama, Le Yu, Cinthia Piamonteze, Nicolas Jaouen, Yusuke Tokunaga, Henrik Rønnow, Taka-hisa Arima, Yoshinori Tokura, Jonathan White
SYMS 1.5	Tue	12:15–12:45	Audimax 2	**Magnetic Skyrmions as Topological Multi-Media Influencers** — •Sebastián A. Díaz

Invited talks of the joint symposium Facets of many-body quantum chaos (SYQC)

See SYQC for the full program of the symposium.

SYQC 1.1	Tue	13:30–14:00	Audimax 2	**Holographic interpretation of SYK quantum chaos** — •Alexander Altland
SYQC 1.2	Tue	14:00–14:30	Audimax 2	**Non-Fermi liquids and the lattice** — •Sean Hartnoll
SYQC 1.3	Tue	14:30–15:00	Audimax 2	**Dual-unitary circuits: non-equilibrium dynamics and spectral statistics** — •Bruno Bertini
SYQC 1.4	Tue	15:15–15:45	Audimax 2	**Post-Ehrenfest many-body quantum interferences in ultracold atoms** — •Steven Tomsovic
SYQC 1.5	Tue	15:45–16:15	Audimax 2	**Dynamics in unitary and non-unitary quantum circuits** — •Vedika Khemani

Invited talks of the joint symposium Curvilinear condensed matter (SYCL)

See SYCL for the full program of the symposium.

SYCL 1.1	Wed	10:00–10:30	Audimax 2	**Curvature Effects and Topological Defects in Chiral Condensed and Soft Matter** — •Avadh Saxena
SYCL 1.2	Wed	10:30–11:00	Audimax 2	**Topology and Transport in nanostructures with curved geometries** — •Carmine Ortix
SYCL 2.1	Wed	11:15–11:45	Audimax 2	**Superconductors and nanomagnets evolve into 3D** — •Oleksandr Dobrovolskiy
SYCL 2.2	Wed	11:45–12:15	Audimax 2	**Properties of domain walls and skyrmions in curved ferromagnets** — •Volodymyr Kravchuk
SYCL 2.3	Wed	12:15–12:45	Audimax 2	**X-ray three-dimensional magnetic imaging** — •Valerio Scagnoli

Prize talks of the joint Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:00	Audimax 1	**Organic semiconductors - materials for today and tomorrow** — •Anna Köhler
SYAW 1.2	Wed	14:00–14:30	Audimax 1	**PbTe/CdTe nanocomposite as an attractive candidate for room-temperature infrared detectors** — •Grzegorz Karczewski
SYAW 1.3	Wed	14:40–15:10	Audimax 1	**Fingerprints of correlation in electronic spectra of materials** — •Lucia Reining
SYAW 1.4	Wed	15:10–15:40	Audimax 1	**Artificial Spin Ice: From Correlations to Computation** — •Naëmi Leo
SYAW 1.5	Wed	15:40–16:10	Audimax 1	**From microwave optomechanics to quantum transport – carbon nanotubes as highly versatile hybrid devices** — •Andreas K. Hüttel

SYAW 1.6	Wed	16:20–16:50	Audimax 1	**Quantum spin dynamics of a spin-1/2 antiferromagnetic Heisenberg-Ising chain** — •Zhe Wang
SYAW 1.7	Wed	16:50–17:20	Audimax 1	**Imaging the effect of electron transfer at the atomic scale** — •Laerte Patera

Invited talks of the joint symposium Spain as Guest of Honor (SYES)

See SYES for the full program of the symposium.

SYES 1.1	Wed	13:30–13:40	Audimax 2	**DFMC-GEFES** — •Julia Herrero-Albillos
SYES 1.2	Wed	13:40–14:10	Audimax 2	**Towards Phononic Circuits based on Optomechanics** — •Clivia M. Sotomayor Torres
SYES 1.3	Wed	14:10–14:40	Audimax 2	**Adding magnetic functionalities to epitaxial graphene** — •Rodolfo Miranda
SYES 1.4	Wed	14:45–15:15	Audimax 2	**Bringing nanophotonics to the atomic scale** — •Javier Aizpurua
SYES 1.5	Wed	15:15–15:45	Audimax 2	**Hydrodynamics of collective cell migration in epithelial tissues** — •Jaume Casademunt
SYES 1.6	Wed	15:45–16:15	Audimax 2	**Understanding the physical variables driving mechanosensing** — •Pere Roca-Cusachs

Invited talks of the joint symposium Attosecond and coherent spins: New frontiers (SYAS)

See SYAS for the full program of the symposium.

SYAS 1.1	Thu	10:00–10:30	Audimax 2	**Ultrafast Coherent Spin-Lattice Interactions in Iron Films** — •Steven Johnson
SYAS 1.2	Thu	10:30–11:00	Audimax 2	**Ultrafast spin, charge and nuclear dynamics: ab-initio description** — •Sangeeta Sharma, John Kay Dewhurst
SYAS 1.3	Thu	11:15–11:45	Audimax 2	**Light-wave driven Spin Dynamics** — •Martin Schultze, Markus Münzenberg, Sangeeta Sharma
SYAS 1.4	Thu	11:45–12:15	Audimax 2	**All-coherent subcycle switching of spins by THz near fields** — •Christoph Lange, Stefan Schlauderer, Sebastian Baierl, Thomas Ebnet, Christoph Schmid, Darren Valovcin, Anatoly Zvezdin, Alexey Kimel, Rostislav Mikhaylovskiy, Rupert Huber
SYAS 1.5	Thu	12:15–12:45	Audimax 2	**Ultrafast optically-induced spin transfer in ferromagnetic alloys** — •Stefan Mathias

Invited talks of the joint symposium The Rise of Photonic Quantum Technologies – Practical and Fundamental Aspects (SYPQ)

See SYPQ for the full program of the symposium.

SYPQ 1.1	Fri	10:00–10:30	Audimax 2	**Quantum dots operating at telecom wavelengths for photonic quantum technology** — •Simone Luca Portalupi
SYPQ 1.2	Fri	10:30–11:00	Audimax 2	**Photonic graph states for quantum communication and quantum computing** — •Stefanie Barz
SYPQ 1.3	Fri	11:00–11:30	Audimax 2	**Rare-earth ion doped solids at sub-Kelvins: practical and fundamental aspects** — •Pavel Bushev
SYPQ 1.4	Fri	11:45–12:15	Audimax 2	**Quantum Light and Strongly Correlated Electronic States in a Moiré Heterostructure** — •Brian Gerardot
SYPQ 1.5	Fri	12:15–12:45	Audimax 2	**Quantum communication in fibers and free-space** — •Rupert Ursin

Sessions

MA 1.1–1.9	Mon	10:00–12:30	H5	**Surface Magnetism (joint session MA/O)**
MA 2.1–2.8	Mon	13:30–17:00	H5	**Focus Session: Magnon Polarons - Magnon-Phonon Coupling and Spin Transport (joint session MA/HL)**
MA 3.1–3.20	Mon	13:30–16:30	P	**Posters Magnetism I**

MA 4.1–4.4	Tue	10:00–11:15	H5	**Spin-Dependent 2D Phenomena**
MA 5.1–5.22	Tue	10:00–13:00	P	**Posters Magnetism II**
MA 6.1–6.6	Tue	13:30–16:45	H5	**Focus Session: Spin-Charge Interconversion (joint session MA/HL)**
MA 7.1–7.12	Wed	10:00–13:15	H5	**Skyrmions I (joint session MA/KFM)**
MA 8.1–8.4	Wed	10:00–12:10	H2	**INNOMAG e.V. Dissertationspreis / Ph.D. Thesis Prize (2020)**
MA 9.1–9.4	Wed	12:30–14:20	H2	**INNOMAG e.V. Diploma/Master Prize (2021)**
MA 10.1–10.7	Wed	13:30–16:30	H5	**Focus Session: Higher-Order Magnetic Interactions - Implications in 2D and 3D Magnetism I**
MA 11.1–11.34	Wed	13:30–16:30	P	**Posters Magnetism III**
MA 12.1–12.3	Wed	14:30–16:15	H2	**INNOMAG e.V. Dissertationspreis / Ph.D. Thesis Prize (2021)**
MA 13.1–13.7	Thu	10:00–12:45	H5	**PhD Focus Session: Symposium on Strange Bedfellows - Magnetism Meets Superconductivity" (joint session MA/AKjDPG) (joint session MA/TT)**
MA 14.1–14.6	Thu	13:30–15:15	H5	**Focus Session: Higher-Order Magnetic Interactions - Implications in 2D and 3D Magnetism II**
MA 15.1–15.47	Thu	13:30–16:30	P	**Posters Magnetism IV**
MA 16	Thu	17:30–18:30	MVMA	**General Assembly of the Division of Magnetism**
MA 17.1–17.12	Fri	10:00–13:15	H5	**Skyrmions II (joint session MA/KFM)**
MA 18.1–18.42	Fri	10:00–13:00	P	**Posters Magnetism V**
MA 19.1–19.5	Fri	13:30–16:30	H5	**PhD Focus Session: Symposium on "Magnetism - A Potential Platform for Big Data?" (joint session MA/O/AKjDPG)**

General Assembly of the Division of Magnetism

Thursday 17:30–18:30 MVMA

MA 1: Surface Magnetism (joint session MA/O)

Time: Monday 10:00–12:30 Location: H5

Invited Talk MA 1.1 Mon 10:00 H5

Utilizing Vacuum States above Surfaces for Imaging and Manipulation of Atomic-Scale Magnetism — •Anika Schlenhoff — Department of Physics, University of Hamburg, Germany

Non-collinear spin textures in ultra-thin films raise expectations for spintronic applications, demanding for atomic-scale, spin-sensitive, but yet robust probe techniques. Spin-polarized vacuum resonance states (sp-RS) are unoccupied electronic states in the vacuum gap between a probe tip and a magnetic sample. They exhibit the same local spin quantization axis as the surface, even when it rotates on the atomic scale [1]. In a spin-polarized scanning tunneling microscopy (SP-STM) setup, the sp-RS can be addressed by spin-polarized electrons tunneling resonantly from the magnetic tip via these states into the surface. As I will show, this technique allows for atomic-scale magnetic imaging at tip-sample distances of up to 8 nm, providing a loophole from the hitherto existing dilemma of losing spatial resolution when increasing the tip-sample distance in a scanning probe setup [2]. Experimental results will be discussed in terms of the sp-RS' spin-splitting and the magnetic contrast as a function of bias and tip-sample distance, and in terms of the atomic-scale nature of the resonant tunneling condition. In combination with thermally-assisted spin-transfer torque switching via sp-RS [3], our approach qualifies for a spin-sensitive read-write technique with ultimate lateral resolution in future spintronic applications. [1] A. Schlenhoff *et al.*, Phys. Rev. Lett. **123**, 087202 (2019). [2] A. Schlenhoff *et al.*, Appl. Phys. Lett. **116**, 122406 (2020). [3] A. Schlenhoff *et al.*, Phys. Rev. Lett. **109**, 097602 (2012).

MA 1.2 Mon 10:30 H5

The effect of trapped Helium atoms on spin polarized tunneling in an STM tunnel junction — •Christopher Trainer[1], Chi Ming Yim[1,2], Christoph Heil[3], Vladimir Tsurkan[4,5], Alois Loidl[4], Liam Farrar[1], and Peter Wahl[1] — [1]SUPA, School of Physics and Astronomy, University of St. Andrews, St. Andrews KY16 9SS, UK — [2]Tsung Dao Lee Institute & School of Physics and Astronomy,Shanghai Jiao Tong University, Shanghai, 200240, China — [3]Institute of Theoretical and Computational Physics, Graz University of Technology, NAWI Graz, 8010 Graz, Austria — [4]Center for Electronic Correlations and Magnetism, Experimental Physics V, University of Augsburg, D-86159 Augsburg, Germany — [5]Institute of Applied Physics, MD 2028 Chisinau, Republic of Moldova

I will present a study of the influence of a Helium probe particle on spin-polarized imaging with an STM. Helium was inserted into the junction between a magnetic Iron tip and an Iron Telluride sample. From tunneling spectra acquired at different tip-sample distances we have mapped out the binding energy of the Helium atom in the tunneling junction. We find that imaging with Helium trapped in the tunneling junction makes the STM sensitive to the magnetic exchange interaction between the tip and the sample. I will demonstrate that by changing the tip sample separation the intensity of the imaged magnetic order can be both enhanced and suppressed and that the overall spin polarization of the junction can be tuned by varying the bias voltage, effectively enabling voltage-control of the spin-polarization of the tunneling current across the junction.

MA 1.3 Mon 10:45 H5

Zero-point magnetic exchange interactions — •Juba Bouaziz[1,2], Julen Ibañez Azpiroz[3], Filipe S. M. Guimarães[1], and Samir Lounis[1,4] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich 52425, Germany — [2]Department of Physics, University of Warwick, Coventry CV4 7AL, United Kingdom — [3]Centro de Física de Materiales, Universidad del País Vasco/Euskal Herriko Unibertsitatea, 20018 Donostia, San Sebastián, Spain — [4]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany

Quantum fluctuations are ubiquitous in physics. Their emergence, magnitude and impact on various physical properties is a fascinating research topic of strong implications in nanotechnologies. They impact non-trivially the behaviour of nanostructures. Hinging on the fluctuation-dissipation theorem and the random phase approximation [1], we show that quantum fluctuations play an important role in determining the fundamental magnetic exchange interactions and account for the large overestimation of the magnetic interactions as obtained from conventional static first-principles frameworks, filling in an important gap between theory and experiment. Our analysis further reveals that quantum fluctuations tend to promote the noncollinearity and stability of chiral magnetic textures such as skyrmions. [1] J. Bouaziz et al. PRR 2, 043357 (2020).

This work was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (ERC-consolidator Grant No. 681405, DYNASORE)

MA 1.4 Mon 11:00 H5

Iron growth on Be(0001) studied by STM — •Hermann Osterhage, Karoline Oetker, Roland Wiesendanger, and Stefan Krause — Department of Physics, University of Hamburg, Germany

Under high pressure, bulk Fe undergoes a phase transition to the ϵ-phase in a hexagonal close-packed (hcp) structure [1]. To date, the need for anvil cells to create ϵ-Fe prohibits an experimental validation of the noncollinear or antiferromagentic ground states predicted theoretically [2]. In our approach, Be(0001) is used as a closely-spaced hcp substrate that may accommodate ϵ-Fe provided that pseudomorphic growth occurs.

The clean Be(0001) surface was characterized using scanning tunneling spectroscopy at low temperatures. It hosts a parabolically dispersing surface state that couples strongly to phonon modes as evidenced in inelastic tunneling spectroscopy [3].

Fe growth on this surface was studied in dependence of coverage and substrate temperature during deposition. The Fe grows in multilayer islands when deposited at room temperature. For elevated temperatures, a combination of high resolution scanning tunneling microscopy and Auger electron spectroscopy shows hints of the formation of a locally ordered alloy of Fe and Be. The morphology of the resulting films and scanning tunneling spectra acquired on this system will be presented and discussed.

[1] I. Leonov *et al.*, Phys. Rev. Lett. **106**, 106405 (2011).
[2] R. Lizárraga *et al.*, Phys. Rev. B **78**, 064410 (2008).
[3] H. Osterhage *et al.*, Phys. Rev. B **103**, 155428 (2021).

MA 1.5 Mon 11:15 H5

Spin-resolved Fermi Surface of Ultrathin Ferromagnetic FePd Alloy Monolayers — •Xin Liang Tan[1], Kenta Hagiwara[1], Ying-Jiun Chen[1,2], Vitaliy Feyer[1], Claus M. Schneider[1,2], and Christian Tusche[1,2] — [1]Forschungszentrum Jülich, Peter Grünberg Institut, Jülich — [2]Fakultät für Physik, Universität Duisburg-Essen, Duisburg

Magnetism in reduced dimensions is one of the preconditions for the realization of nanoscale spintronics. Despite the recent discovery of ferromagnetism in monolayers of two-dimensional materials, tunability and engineering on such systems are challenging. Here we have studied the electronic structure of ultrathin ferromagnetic iron-palladium alloy films using spin-resolved momentum microscopy. Momentum microscopy enables the two-dimensional detection of photoelectrons with an in-plane crystal momentum over the full Brillouin zone. By employing an imaging spin filter, spin-resolved momentum maps of the iron-palladium alloy were acquired. Breaking of time reversal symmetry by the remanent magnetization of the film manifests in a pronounced anisotropy of the electron states in the Fermi surface. In particular, the competition between exchange interaction and strong spin-orbit coupling in the FePd alloy leads to the formation of wave-vector dependent local gaps in the Fermi surface. Moreover, the spin-resolved maps recorded by the momentum microscope give evidence for a noncollinear spin texture of the electron states at the Fermi surface, where the local spin polarization vector points orthogonal to the remanent magnetization of the sample.

MA 1.6 Mon 11:30 H5

On-surface synthesis of magnetic organometallic chains on the superconducting Ag/Nb(110) substrate — •Jung-Ching Liu[1], Philipp D'Astolfo[1], Carl Drechsel[1], Xunshan Liu[2], Silvio Decurtins[2], Shi-Xia Liu[2], Rémy Pawlak[1], Wulf Wulfhekel[3], and Ernst Meyer[1] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, Basel, CH 4056 — [2]Department of Chemistry and Biochemistry, University of Bern, Freiestrasse 3, Bern, CH 3012 — [3]Physikalisches Institut, Karlsruhe Institute of Technology, Wolfgang-Gaede-Str. 1, D-76131 Karlsruhe, Germany

With proximity to s-wave superconductivity, spin texture arises on a magnetic chain and Majorana bound states (MBSs) can be found at two ends[1-3]. To study MBSs with diverse magnetic structures, we propose to conjugate magnetic atoms with organic molecules via on-surface reaction. Choosing Fe and PTO, we fabricate magnetic chains on the superconducting Ag/Nb substrate[4,5]. With the investigation with STM and AFM at 4.7K, we confirm the proximity-induced superconductivity on Ag from Nb, as well as the success in growing magnetic organometallic chains. We believe our work demonstrates the feasibility of growing tunable magnetic lattices by changing organic molecules. Above all, the direct synthesis on a superconductor offers a convenient way to study the interaction between magnetic lattices and superconductivity. [1]S. Nadj-Perge et al. Science 2014, 346, 602-607 [2]M. Ruby et al. Nano Lett. 2017, 17, 4473-4477 [3]R. Pawlak et al. Npj Quantum Inf. 2016, 2, 16035 [4]A. D. Pia et al. Chem. Eur. J. 2016, 22, 8105-8112 [5]T. Tomanic et al. Phys. Rev. B 2016, 94, 220503

MA 1.7 Mon 11:45 H5

Interplay of magnetic states and hyperfine fields of iron dimers on MgO(001) — •SUFYAN SHEHADA[1,2], MANUEL DOS SANTOS DIAS[1], MUAYAD ABUSAA[3], and SAMIR LOUNIS[1,4] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Department of Physics, Arab American University, Jenin, Palestine — [4]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany

Individual nuclear spin states can have very long lifetimes and could be useful as qubits. Progress in this direction was achieved on MgO/Ag(001) via detection of the hyperfine interaction (HFI) of Fe, Ti and Cu adatoms using scanning tunneling microscopy (STM) [1,2]. Previously, we systematically quantified from first-principles the HFI for the whole series of 3d transition adatoms (Sc*Cu) deposited on various ultra-thin insulators, establishing the trends of the computed HFI with respect to the filling of the magnetic s and d-orbitals of the adatoms and on the bonding with the substrate [3]. Here we take one step further by investigating the impact of the magnetic coupling between the dimer atoms on the HFI of Fe dimers on MgO(001) and its dependence on where the Fe atoms are located on the surface.

–Work funded by the Palestinian German Science Bridge (BMBF–01DH16027) and Horizon 2020–ERC (CoG 681405–DYNASORE).

[1] Willke *et al.*, Science **362**, 336 (2018); [2] Yang *et al.*, Nat. Nano. **13**, 1120 (2018); [3] Shehada *et al.*, Npj Comput. Mater. **7**, 87 (2021).

MA 1.8 Mon 12:00 H5

Pairwise magnetic exchange interaction tensor from tight-binding models of noncollinear magnetism — •KSENIIA VODENKOVA[1] and PAVEL BESSARAB[1,2] — [1]ITMO University, St. Petersburg, Russia — [2]University of Icelad, Reykjavik, Iceland

The microscopic origin of the exchange interactions for noncollinear ordering of atomic magnetic moments in itinerant-electron systems is a subject of ongoing scientific discussions. In this work, we derive by means of the multiple-scattering theory a general expression for pairwise magnetic exchange interaction parameters for an arbitrary noncollinear, nonstationary magnetic state. In contrast to previous approaches, our formalism takes into account the variation of the fast degrees of freedom such as charge density and magnetic moment length. Application of the formalism to a tight-binding model reveals a range of magnetic systems that can be described by a classical Heisenberg Hamiltonian reasonably well. For other systems, our approach makes it possible to systematically derive atomistic spin Hamiltonians beyond the Heisenberg model. Moreover, the expression for the pairwise interaction tensor describes a local curvature of the energy surface of the system as a function of the orientation of magnetic vectors. This can be used in various contexts including description of thermal stability of magnetic states within the harmonic transition state theory and efficient identification of stable magnetic configurations using the Newton-Raphson method.

MA 1.9 Mon 12:15 H5

The chiral Hall effect in canted ferromagnets and antiferromagnets — •JONATHAN KIPP[1], KARTIK SAMANTA[1], FABIAN LUX[1,2,3], MAXIMILIAN MERTE[1,2,3], DONGWOOK GO[1,3], JAN-PHILIP HANKE[1], MATTHIAS REDIES[1,2], FRANK FREIMUTH[1,3], STEFAN BLÜGEL[1], MARJANA LEZAIC[1], and YURIY MOKROUSOV[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum — [2]RWTH Aachen University, Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg-University Mainz

There are 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. 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. [1]L .Smejkal et al., Science Advances 6 (2020) [2]L. Smejkal et al., Nature Physics 14, 242-251 (2018) [3]J. Kipp et al., Comm. Phys. 4, 99 (2021)

MA 2: Focus Session: Magnon Polarons - Magnon-Phonon Coupling and Spin Transport (joint session MA/HL)

The coupling of spin waves and atomic lattice vibrations in solid magnetic states, so-called magnon polarons (MPs), can have large impact on spin transport properties as recently explored for spin Seebeck effect, spin pumping and nonlocal spin transport. This resonant enhancement can be reached when the magnon dispersion is shifted by a magnetic field and crosses the phonon dispersion with sufficient overlap. While initially observed at low temperatures and large magnetic fields, further material and device developments have led to MPs at room temperature and moderate magnetic fields. Thus, MPs become important for the manipulation and amplification of spin currents in spintronic and spin caloritronic devices, e.g. by carrying the spins much further than using uncoupled magnons. This focus session highlights the main important research outcomes for MPs, state-of-the-art techniques to detect MPs, such as Brillouin light scattering, and to study MP transport, e.g. by spin Seebeck effect and nonlocal spin transport, as well as the investigation of MPs in different material classes such as garnets, ferrites and antiferromagnets. In addition, the excessive theoretical work on MPs performed recently is addressed in this focus session.

Organizer: Timo Kuschel (Bielefeld University)

Time: Monday 13:30–17:00 Location: H5

Invited Talk MA 2.1 Mon 13:30 H5

Magnon-polarons in magnetic insulators — •BENEDETTA FLEBUS — Boston College, Chestnull Hill, USA

We theoretically study the effects of strong magneto-elastic coupling on the transport properties of magnetic insulators. We develop a Boltzmann transport theory for the mixed magnon-phonon modes, i.e., magnon-polarons, and determine transport coefficients of the composite quasi-particles. Magnon-polaron formation causes anomalous features in the magnetic field and temperature dependence of the spin Seebeck effect when the disorder scattering in the magnetic and elastic subsystems is sufficiently different. We discuss how experimental data by Kikkawa et al. [PRL 117, 207203 (2016)] on yttrium iron garnet films can be explained by an acoustic quality that is much better than the magnetic quality of the material.

Invited Talk MA 2.2 Mon 14:00 H5

Spin-phonon coupling in non-local spin transport through magnetic insulators — •Rembert Duine — Institute for Theoretical Physics, Utrecht University, The Netherlands

Long-range spin transport through ferromagnetic and antiferromagnetic insulators has recently been demonstrated. In this talk I will discuss how spin-phonon interactions influence this transport. In the first part of the talk I will discuss how bulk spin-phonon interactions lead to magnon-polaron formation and how this composite boson influences the non-local transport. In the second part, I will discuss how spin-phonon interactions across an interface give rise to long-distance spin transport that is carried purely by phonons.

Invited Talk MA 2.3 Mon 14:30 H5

Double accumulation and anisotropic transport of magnetoelastic bosons in yttrium iron garnet films — •Alexander A. Serga — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Kaisersalutern, Germany

Interaction between quasiparticles of a different nature, such as magnons and phonons, leads to mixing their properties and forming hybrid states in the areas of intersection of individual spectral branches. In garnet ferrite films, such hybridization results in a resonant increase in the efficiency of the spin Seebeck effect and the spontaneous bottleneck accumulation of hybrid magnetoelastic bosons—magnon polarons.

Similar to the Bose-Einstein magnon condensation (BEC), the latter phenomenon occurs in a yttrium iron garnet film exposed to microwaves. However, unlike the BEC, which is a consequence of the equilibrium Bose statistics, the bottleneck accumulation is determined by changing interparticle interactions. Studying the transport properties of accumulated quasiparticles, we found that such accumulation occurs in two frequency-distant groups: quasiphonons and quasimagnons. These quasiparticles propagate in the film plane as spatially localized beams with different group velocities. The developed theoretical model qualitatively describes the double accumulation effect, and the analysis of the two-dimensional quasiparticle spectrum makes it possible to determine the wavevectors and frequencies of each group.

Funded by the ERC Advanced Grant 694709 SuperMagnonics and by the DFG within TRR 173 – 268565370 (project B04).

MA 2.4 Mon 15:00 H5

enhancement of the spin seebeck effect by magnon-phonon resonance in a partially compensated magnet — •R. Ramos[1,2], T. Hioki[3,4], Y. Hashimoto[1], T. Kikkawa[1,3,4], P. Frey[5], A.J.E. Kreil[5], V.I. Vasyuchka[5], A.A. Serga[5], B. Hillebrands[5], and E. Saitoh[1,3,4] — [1]WPI AIMR, Tohoku University, Japan — [2]CIQUS, Departamento de Química-Física, Universidade de Santiago de Compostela, Spain — [3]Department of Applied Physics, The University of Tokyo, Japan. — [4]IMR, Tohoku University, Japan — [5]Fachbereich Physik and Landesforshungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

The spin Seebeck effect (SSE) refers to the generation of a spin current in magnetic materials by the application of a thermal gradient. Recently, the effect of magnon-phonon hybridization, resulting from the crossing of the magnon and phonon dispersions, has been detected in the SSE and named magnon-polaron SSE. This is experimentally observed as spikes of the SSE-voltage at the magnetic field values for which the hybridization between the magnon and phonon dispersions is maximized over k-space. In this talk, we will report the detection of magnon-polaron SSE in a nonmagnetic-ion-substituted garnet system at room temperature and low magnetic fields [1]. The effect is 8 times larger than that observed in a YIG film. We show that the magnon dispersion can be strongly affected by the nonmagnetic-ion substitutions, thus resulting in a clear modification of the magnetic field condition for the observation of magnon-polarons. [1] R. Ramos et al. Nature Comm. 10, 5162 (2019).

Invited Talk MA 2.5 Mon 15:15 H5

Magnon polarons and the low-temperature spin-Seebeck effect — •Piet Brouwer and Rico Schmidt — Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany

Using a simplified microscopic model of coupled spin and lattice excitations in a ferromagnetic insulator we evaluate the magnetic-field dependence of the longitudinal spin Seebeck effect at low temperatures. We find that at low temperatures, large magnetic fields, and for not-too-large system sizes the spin Seebeck effect is almost completely mediated by magnon polarons, superpositions of magnon and phonon excitations, with frequency close to the crossing points of magnon and phonon dispersions. We find an enhancement of the spin-Seebeck effect for “critical” values of the magnetic field, for which magnon and phonon dispersions touch. Such an enhancement of the longitudinal spin-Seebeck effect was observed experimentally by Kikkawa et al. [Phys. Rev. Lett. 117, 207203 (2016)]. We find that the existence of this enhancement is independent of the relative strength of magnon-impurity and phonon-impurity scattering.

Invited Talk MA 2.6 Mon 15:45 H5

Magnon-Polarons in different flavors: (anti)ferromagnetic to topological — •Akashdeep Kamra — Condensed Matter Physics Center (IFIMAC) and Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, E-28049 Madrid, Spain

Due to magnetoelastic coupling, magnons and phonons in a magnet can combine to form hybrid quasiparticles, inheriting properties from both, called magnon-polarons. We will begin by examining and clarifying the essential requirements for their hybridization in terms of the spin conservation laws and the nature of the magnetoelastic coupling. This will allow us to deduce the properties, such as spin, of the magnon-polarons thus formed and provide guidance on how to engineer magnon-polarons. In carrying out this general discussion, we will analyze the cases of magnon-polarons in ferromagnets as examples. Then, we will apply the general principles developed to the cases of antiferromagnets and topological magnonic insulators thereby demonstrating magnon-polarons with novel, tunable, and chiral properties. We will conclude our discussion with recent experiments suggesting spin-phonon coupling to underlie collective quantum phenomena in the high-Tc superconductor YBCO.

References: [1] A. Kamra, H. Keshtgar, P. Yan, and G. E. W. Bauer. Phys. Rev. B 91, 104409 (2015). [2] H. T. Simensen, R. E. Troncoso, A. Kamra, and A. Brataas. Phys. Rev. B 99, 064421 (2019). [3] E. Thingstad, A. Kamra, A. Brataas, and A. Sudbø. Phys. Rev. Lett. 122, 107201 (2019).

Invited Talk MA 2.7 Mon 16:15 H5

Magnon polarons in antiferromagnetic insulator Cr2O3 — •Jing Shi — Department of Physics & Astronomy, University of California, Riverside, USA

While magnon polarons in ferrimagnetic materials have been experimentally investigated by various meanings including the spin Seebeck effect, nonlocal transport, inelastic neutron scattering, spin pumping, etc., similar hybridized excitations in antiferromagnets have not been well explored. For typical antiferromagnets, the magnon dispersion lies well above the acoustic phonon dispersion, which prevents the formation of magnon polarons under accessible magnetic fields. In this talk, I will first review the main magnon polaron results in yttrium iron garnet [1], a ferrimagnetic insulator. My focus will be on a special antiferromagnetic insulator: Cr2O3. In this uniaxial antiferromagnet, the left-handed magnon branch can be effectively lowered to zero at ~6 T, the spin-flop transition, allowing for thermodynamic measurements. In our study of Cr2O3 spin Seebeck effect [2], We observe magnon polaron anomalies right below the spin flop transition. where the left-handed magnon dispersion intersect both longitudinal and transverse acoustic phonon dispersions. I will present our experimental data and analysis in my talk.

[1] H.R. Man et al., Direct observation of magnon-phonon coupling in yttrium iron garnet. Phys. Rev B 96, 100406(R) (2017). [2] J.X. Li et al., Observation of magnon-polarons in a uniaxial antiferromagnetic insulator Cr2O3. Phys. Rev. Lett. 125, 217201(2020).

MA 2.8 Mon 16:45 H5

Revealing thermally driven distortion of magnon dispersion by spin Seebeck effect in Gd3Fe5O12 — •Bin Yang[1], Si Yu Xia[1], Hui Zhao[1], Gan Liu[1], Jun Du[1], Ka Shen[2], Zhiyong Qiu[3],

and Di Wu[1] — [1]National Laboratory of Solid State Microstructures, Jiangsu Provincial Key Laboratory for Nanotechnology, Collaborative Innovation Center of Advanced Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China — [2]Center for Advanced Quantum Studies and Department of Physics, Beijing Normal University, Beijing 100875, China — [3]School of Materials Science and Engineering, Dalian University of Technology, Dalian 116024, China

We report a systematic study of the temperature and field dependences of the spin Seebeck effect (SSE) in a bilayer of Pt/Gd3Fe5O12. An anomalous structure is observed in the magnetic field dependent measurements at temperatures between ~60 and ~210 K.We attribute these anomalies to the contribution from the quasiparticles hybridized between the Gd moment dominated spin wave (α mode) and the transversal acoustic phonon, known as the magnon polarons, and explain these rich phenomena by an increase of the group velocity of the α-mode magnon with increasing temperature and the nonparabolic magnon dispersion of Gd3Fe5O12. Our results demonstrate that the magnon polaron induced SSE is helpful for the investigation of the magnon dispersion evolution with a simple transport approach.

MA 3: Posters Magnetism I

Topics: Surface Magnetism (3.1-3.4), Thin Films: Magnetic Coupling Phenomena / Exchange Bias (3.5-3.11), Thin Films: Magnetic Anisotropy (3.12-3.13), Topological Insulators (3.14-3.15), Micro- and Nanostructured Magnetic Materials (3.16-3.20)

Time: Monday 13:30–16:30 Location: P

MA 3.1 Mon 13:30 P

Yu-Shiba-Rusinov states of Manganese atoms on proximitzed Silver layers — •Jennifer Hartfiel, Mira Kressler, Gaël Recht, and Katharina J. Franke — Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

The adsorption of a magnetic adatom on a superconducting substrate perturbes the Cooper pair condensate in close proximity to the surface. The unpaired magnetic moment induces localized bound states, so-called Yu-Shiba-Rusinov (YSR) states, inside the superconducting energy gap, which can be probed by scanning tunneling spectroscopy (STS). The coupling strength between the magnetic moment of the impurity and the Cooper pairs determines the energy needed for tunneling into the YSR state.

In this work we perform STS measurements on Mn adatoms on Ag islands on Vanadium. Vanadium is very reactive and widely reconstructed by oxygen on the surface. This makes it difficult to investigate a possible adsorption-site dependence of the YSR energies. We passivate the surface by expitaxially grown silver monolayers. The Ag is proximitized by the superconducting substrate, and we observe YSR states for Mn on Ag/V. As the coupling of the magnetic impurity with the superconductor depends strongly on the adsorption geometry, we compare the YSR states for Mn atoms on two different crystal orientations of the Vanadium, which influences the structure of the Ag islands grown on top and, hence, the YSR states.

MA 3.2 Mon 13:30 P

Tailoring magnetic anisotropy by graphene-induced skyhook effect of 4f metals — •Alexander Herman[1], Stefan Kraus[2], Shigeru Tsukamoto[3], Lea Spieker[1], Tobias Lojewski[1], Damian Günzing[1], Tobias Hartl[2], Jan Gui-Hyon Dreiser[4], Bernard Delley[4], Katharina Ollefs[1], Thomas Michely[2], Nicolae Atodiresei[3], and Heiko Wende[1] — [1]Faculty of Physics and Center for Nanointegration, Duisburg-Essen — [2]II. Physikalisches Institut, Universität zu Köln — [3]Peter Grünberg Institute and Institute for Advanced Simulation, FZ Jülich — [4]SLS, Paul Scherrer Institut (CH)

From macroscopic heavy-duty permanent magnets to nanodevices the precise control of the magnetic properties in rare-earth metals is crucial for many applications used in our daily life. Therefore, a detailed understanding and manipulation of the 4f-metals magnetic properties represent the key to further boost the functionalization and efficiency of practical applications. We present a proof-of-concept surface-alloy system in which graphene induces a skyhook effect on a 4f metal and therefore modifies its magnetic properties. We demonstrate that by adsorbing graphene onto a long-range ordered two-dimensional dysprosium-iridium surface alloy, the magnetic 4f metal atoms are selectively lifted from the surface alloy and a giant magnetic anisotropy is introduced in dysprosium atoms as a result of manipulating its geometrical structure within the surface alloy. Our combined theoretical simulations and experimental measurements provide an easy and unambiguous understanding of its underlying mechanism. Financial support by DFG through projects WE 2623/17-1, MI 581/23-1, and AT 109/5-1.

MA 3.3 Mon 13:30 P

Step-edge-induced anisotropic chiral spin coupling in ultrathin magnetic films — Anika Schlenhoff, •Stefan Krause, and Roland Wiesendanger — Department of Physics, University of Hamburg, Germany

Step edges represent a local break of lateral symmetry in ultrathin magnetic films. In our experiments, we investigate the spin coupling across atomic step edges on Fe/W(110) by means of spin-polarized scanning tunneling microscopy and spectroscopy.

As we show in our experiments, atomic step edges induce a chiral spin coupling, with outreaching consequences on the local spin texture in the film [1]. Local modifications of the spin texture toward step edges separating double from single layer areas of Fe on W(110) are observed, and selection rules indicate a chiral spin coupling that significantly changes with the propagation along different crystallographic directions. The experimental results will be presented, and the findings are explained in terms of anisotropic Dzyaloshinskii-Moriya interaction arising from the broken lateral symmetry at atomic step edges.

Our experiments strongly indicate that surface roughness and interface quality on the atomic scale is of high relevance for spin manipulation and transmission in terms of tailored magnetic coupling for future spintronic applications.

[1] A. Schlenhoff, S. Krause, and R. Wiesendanger, Phys. Rev. Lett. **123**, 037201 (2019).

MA 3.4 Mon 13:30 P

Cation- and lattice-site-selective magnetic depth profiles of ultrathin Fe_3O_4(001) films — Tobias Pohlmann[1,2], •Timo Kuschel[3], Jari Rodewald[1], Jannis Thien[1], Kevin Ruwisch[1], Florian Bertram[2], Eugen Weschke[4], Padraic Shafer[5], Joachim Wollschläger[1], and Karsten Küpper[1] — [1]Uni Osnabrück, Germany — [2]DESY, Hamburg, Germany — [3]Uni Bielefeld, Germany — [4]HZB Bessy II, Berlin, Germany — [5]ALS, Berkeley, USA

We present x-ray magnetic circular dichroism (XMCD) and x-ray resonant magnetic reflectivity (XRMR) measurements on ultrathin Fe_3O_4(001) films to obtain magnetic depth profiles of the different cation species Fe^{2+}_{oct}, Fe^{3+}_{tet}, and Fe^{3+}_{oct} located on octahedral and tetrahedral sites of the inverse spinel structure of Fe_3O_4. Performing XRMR on the three resonant XMCD energies yields magnetic depth profiles that each correspond to one specific cation species.

The depth profiles of both Fe^{3+} cations reveal a (3.9±1.0)-Å-thick surface layer of enhanced magnetization, which is likely due to an excess of these ions at the expense of the Fe^{2+}_{oct} species in the surface region. The magnetically enhanced Fe^{3+}_{tet} layer is additionally shifted about 2.9±0.4 Å farther from the surface than the Fe^{3+}_{oct} layer [1].

Moreover, we compare the depth profiles with the recently revealed cation vacancy reconstruction of the Fe_3O_4(001) surface [2] as well as the unreconstructed Fe_3O_4(111) surface that is Fe_{oct}-terminated [3].

[1] T. Pohlmann et al., Phys. Rev. B 102, 220411(R) (2020)
[2] R. Bliem et al., Science 346, 1215 (2014)
[3] S. Brück et al., Appl. Phys. Lett. 100, 081603 (2012)

MA 3.5 Mon 13:30 P

Interlinking ferro- and antiferromagnetic thickness dependencies of macroscopic magnetic characteristics with microscopic properties of polycrystalline exchange-biased bilayers — •Maximilian Merkel, Meike Reginka, Rico Huhnstock, and

Arno Ehresmann — Universität Kassel

A systematic investigation of the exchange bias shift and the coercive field exhibited by prototypical polycrystalline exchange-biased bilayers is conducted in dependence of the thicknesses of the participating ferro- and antiferromagnetic layer. Columnar grain growth is verified via thickness dependent grain size analysis by means of atomic force microscopy. Formulating analytic expressions for the named thickness dependencies allowed us to establish a quantitative link between the macroscopically observable magnetic characteristics and the microscopic properties. Relations depending on measurement conditions and parameters describing the microstructure of the granular antiferromagnetic layer in the context of a generalized description of polycrystalline exchange-bias systems were hereby thoroughly considered. This is facilitated by an extended time-dependent Stoner-Wohlfarth approach in combination with angular-resolved measurements of magnetization reversal curves utilizing magneto-optical Kerr magnetometry validating the consistency of the generalized model approach.

MA 3.6 Mon 13:30 P

Influence of strain on the magnetic ground state in multiferroic $BiFeO_3$ studied from First Principles — •Sebastian Meyer[1], Bin Xu[2,3], Matthieu Verstraete[1], Laurent Bellaiche[2], and Bertrand Dupé[1,4] — [1]Nanomat/Q-mat/CESAM, University of Liége, Belgium — [2]Physics Department and Institute for Nanoscience and Engineering, University of Arkansas, USA — [3]Jiangsu Key Laboratory of Thin Films, School of Physical Science and Technology, Soochow University, China — [4]Fonds de la Recherche Scientifique (FNRS), Bruxelles, Belgium

We study the influence of compressive and tensile strain on the magnetic ground state in thin films of the multiferroic $BiFeO_3$ by means of density functional theory. Using two different methods, we determine the strength of the magnetic exchange, the Dzyaloshinskii-Moriya interaction and the anisotropy energies. The first one is based on the generalized Bloch theorem which allows the self-consistent computation of the total energy of spin spirals. This has already been applied to successfully determine the magnetic ground state in *R*3*c* bulk $BiFeO_3$ [1]. The second one is based on the evaluation of a tight-binding Hamiltonian parameterized via Wannier functions and solved via Green functions methods as implemented in TB2J [2]. Using both methods, we explore the change of magnetic ground state of strained $BiFeO_3$ and compare the results with experimental findings.

[1] Xu, B., *et al.*, Phys. Rev. B **103**, 214423 (2021)
[2] He, Y., *et al.*, Comp. Phys. Comm. **264**, 107938 (2021)

MA 3.7 Mon 13:30 P

Tilted magnetization stripe domain reversal in Co/Pt multilayer systems — •Peter Heinig[1], Olav Hellwig[1,2], Ruslan Salikhov[2], Fabian Samad[2], Rico Ehrler[1], and Benny Böhm[1] — [1]Chemnitz University of Technology — [2]Helmholtz-Zentrum Dresden-Rossendorf

Co/Pt multilayer systems with total thickness above 10 nm are well-known for their highly periodic perpendicular stripe domain structures. Here we study $[Co(3.0\ nm)/Pt(0.6\ nm)]_X$ multilayers with constant Co and Pt thickness in the regime of tilted stripe domains, where we vary the number of repeats X to tune the remanent state from the well-known out-of-plane stripe domain via a tilted stripe domain to a purely in-plane domain state. Vibrating Sample Magnetometry (VSM) and Magnetic Force Microscopy (MFM) are used to study three characteristic samples with $X = 22$; 11 and 8, which represent the three above mentioned remanent states respectively. While for conventional perpendicular stripe domains the field reversal is characterized by irreversible hysteretic nucleation, propagation and annihilation of stripe domains across a broad field range, strikingly the tilted stripe domain regime reveals a collapse of all irreversible hysteretic switching down to a single point. The dramatically changed field reversal behavior will be discussed, also in the light of possible future applications.

MA 3.8 Mon 13:30 P

Nucleation site density & magnetization reversal in exchange-biased 1D nanostructures — •Sapida Akhundzada[1,3], Meike Reginka[1], Maximilian Merkel[1], Kristina Dingel[2,3], Bernhard Sick[2,3], Arno Ehresmann[1,3], and Michael Vogel[1,3] — [1]Institute of Physics & Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel — [2]Intelligent Embedded Systems, University of Kassel, Wilhelmshöher Allee 73, D-34121 Kassel — [3]AIM-ED - Joint Lab Helmholtzzentrum für Materialien & Energie, Hahn-Meitner-Platz 1, D-14109 Berlin

The interface-driven exchange bias (EB) effect [1] is a well-studied phenomenon observed in ferromagnetic (FM)/antiferromagnetic (AFM) thin film systems. In numerous studies, asymmetric hysteresis loops have been observed in EB thin films mainly caused by defects in the FM or AFM layer contributing to a locally inhomogeneous EB landscape. In full film samples, Romanens et al. [2] were able to correlate these asymmetries to higher domain nucleation densities for an antiparallel configuration of the applied field and the EB field. Here we report on the correlation between the nucleation site density and asymmetric remagnetization process in in-plane magnetized EB nanowires investigated by high-resolution optical Kerr microscopy. The influence of the structural dimensions, the EB material system, and additional modification of the interface by keV He ion bombardment are shown.

[1] W. H. Meiklejohn, J. Appl. Phys. 33, 1328 (1962)
[2] F. Romanens et al, Phys. Rev. B 72, 134410 (2005)

MA 3.9 Mon 13:30 P

Magnetic Coupling in YIG/GIG Heterostructures — •Sven Becker[1], Zengyao Ren[1,2,3], Felix Fuhrmann[1], Andrew Ross[1,4], Sally Lord[1,5], Shilei Ding[1,2,6], Rui Wu[1,7], Jinbo Yang[6], Jun Miao[3], Mathias Kläui[1,2,7], and Gerhard Jakob[1,2] — [1]University of Mainz, Germany — [2]Graduate School of Excellence 'MAINZ', Germany — [3]USTB, Beijing, China — [4]Université Paris-Saclay, France — [5]University of Manchester, UK — [6]Peking University, China — [7]University of Trondheim, Norway

We study the magnetic coupling in epitaxial $Y_3Fe_5O_{12}/Gd_3Fe_5O_{12}$ (YIG/GIG) heterostructures grown by pulsed laser deposition. From bulk sensitive magnetometry and surface sensitive spin Seebeck effect and spin Hall magnetoresistance measurements, we determine the alignment of the heterostructure magnetization as a function temperature and external magnetic field. The ferromagnetic coupling between the Fe sublattices of YIG and GIG dominates the overall behavior of the heterostructures. Because of the temperature-dependent gadolinium moment, a magnetic compensation point of the total bilayer system can be identified. This compensation point shifts to lower temperatures with increasing YIG thickness due the parallel alignment of the iron moments. We show that we can control the magnetic properties of the heterostructures by tuning the thickness of the individual layers, opening up a large playground for magnonic devices based on coupled magnetic insulators. These devices could potentially control the magnon transport analogously to electron transport in giant magnetoresistive devices.

MA 3.10 Mon 13:30 P

Growth, structure, and magnetic properties of artificially layered NiMn in contact to ferromagnetic Co on $Cu_3Au(001)$ — •Tauqir Shinwari[1], Ismet Gelen[1], Melek Villanueva[1], Ivar Kumberg[1], Yasser A. Shokr[1,2], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Faculty of Science, Department of Physics, Helwan University, 17119 Cairo, Egypt

Single-crystalline artificially layered [Ni/Mn] antiferromagnetic films with 1 atomic monolayer (ML) of Ni and 1, 2, or 3 ML of Mn have been deposited under ultrahigh-vacuum conditions on $Cu_3Au(001)$ and covered by ferromagnetic Co layers. Their structural and magnetic properties are characterized by low-energy electron diffraction (LEED) and magneto-optical Kerr effect (MOKE), respectively, and compared with disordered Ni_xMn_{100-x} alloy films with the same Ni/Mn ratio and the same film thickness. We find from LEED I(V) curves that the perpendicular interatomic lattice distance is decreased by 2% in the artificially layered [Ni/Mn] samples in comparison to the disordered Ni_xMn_{100-x} alloy films. This change in the structure causes higher coercivity, exchange bias, and stronger exchange coupling in artificially layered [Ni/Mn] samples compared to disordered Ni_xMn_{100-x} alloy films.

MA 3.11 Mon 13:30 P

Inverse proximity effects in superconductor/ferromagnet heterostructures studied by GISANS — •Annika Stellhorn[1,2], Emmanuel Kentzinger[1], Anirban Sarkar[1], Vitaliy Pipich[3], Kathryn Krycka[4], Patrick Schöffmann[1], Tanvi Bhatnagar-Schöffmann[1,5], and Thomas Brückel[1] — [1]Forschungszentrum Jülich GmbH, JCNS-2 and PGI-4, JARA-FIT, Jülich, GERMANY — [2]Lund University, Division of Synchrotron Radiation Research, Lund, Sweden — [3]Forschungszentrum Jülich GmbH, JCNS@MLZ, Garching, Germany — [4]National Institute of Standards and Technology, NIST-NCNR, Gaithersburg, USA — [5]Forschungszentrum Jülich GmbH, PGI-5, Jülich, GERMANY

Understanding the origin of proximity effects at the interfaces of superconducting and ferromagnetic materials is the key for an application in fluxonic devices and in spintronics. Depending on the ferromagnetic magnetocrystalline anisotropy, such proximity effects can lead to domain-wall-superconductivity or a generation of long-ranged spin-triplet Cooper pairs. This work presents a study of the depth-resolved lateral magnetic profile in the superconductor(S)/ferromagnet(F) thin film system Nb(S)/FePd(F) with perpendicular magnetic anisotropy by Grazing-Incidence Small-Angle Neutron Scattering (GISANS) with polarization analysis. In these systems, the transition from the normal-conducting state via a domain-wall-superconducting state to a complete-superconducting state is accompanied by an increase of the domain wall width.

MA 3.12 Mon 13:30 P

Impact of the separate variation of the sputter deposition pressure for seed and multilayer growth on the magnetic properties of Co/Pt multilayer films — •Rico Ehrler, Tino Uhlig, and Olav Hellwig — Chemnitz University of Technology, D-09107 Chemnitz, Germany

The pressure during the sputter deposition process greatly influences the structural as well as magnetic properties of Co/Pt multilayer films with perpendicular anisotropy. Already in 2013 Pierce et al. [1] tuned the lateral heterogeneity and structural order in such systems by changing the sputter deposition pressure for both the Pt seed as well as the multilayer simultaneously. By independent pressure variation of seed and multilayer we achieve an even higher degree of control over the magnetic properties. In a later work, a Ta adhesion layer between substrate and seed was used to achieve a highly oriented Pt(111) texture [2]. This is in accordance with our investigation, where the presence of such a layer greatly influences the growth of the seed.

In this study, a high and low deposition pressure was chosen independently for seed and multilayer, leading to 4 different seed/multilayer combinations. We repeated this variation with an added Ta adhesion layer between the substrate and the Pt seed and will highlight the impact of these systematic variations on the structural and magnetic properties.

[1] M. S. Pierce et al, Phys. Rev. B, vol. 87, no. 18, 2013
[2] Yu. Tsema et al., Appl. Phys. Lett., vol. 109, no. 7, 2016

MA 3.13 Mon 13:30 P

Effect of laser annealing on the magnetic properties of Co/Pt based multilayers — •Lokesh Rasabathina[1], Apoorva Sharma[1], Sandra Busse[3], Benny Böhm[1], Fabian Samad[1,2], Georgeta Salvan[1], Alexander Horn[3], and Olav Hellwig[1,2,4] — [1]Institute of Physics, Chemnitz University of Technology, 09107 Chemnitz, Germany — [2]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [3]Laserinstitut Hochschule Mittweida, Schillerstraße 10, 09648 Mittweida, Germany — [4]Center for Materials, Architectures and Integration of Nanomembranes (MAIN), Chemnitz University of Technology, 09107 Chemnitz, Germany

Two methods of laser annealing, namely, Continuous Wave (CW) and Pulsed Wave (PW) method, are used for modifying the magnetic properties of perpendicular magnetic anisotropy (PMA) multilayers in a controlled manner. For this we compare a set of two samples, a PMA $(Co/Pt)_{10}$ multilayer and an antiferromagnetically interlayer exchange coupled PMA $(Co/Pt)_4/Co/Ir/(Co/Pt)_5$ multilayer. Room temperature hysteresis loops using longitudinal MOKE magnetometry are measured for different laser annealing conditions. Thus, a relationship between the applied laser parameters and the magnetic properties is extracted, which provides insight into the processes that occur during the laser annealing process.

MA 3.14 Mon 13:30 P

Giant Topological Hall Effect in Noncollinear Phase of Two-dimensional Antiferromagnetic Topological Insulator MnBi4Te7 — •Subhajit Roychowdhury, Sukriti Singh, Satya N. Guin, Nitesh Kumar, Tirthankar Chakraborty, Walter Schnelle, Horst Borrmann, Chandra Shekhar, and Claudia Felser — Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany

Magnetic topological insulators provide an important platform for realizing several exotic quantum phenomena, such as the axion insulating state and quantum anomalous Hall effect, owing to the interplay between topology and magnetism. MnBi4Te7 is a two-dimensional Z_2 antiferromagnetic (AFM) topological insulator with a Néel temperature of ~13 K. In AFM materials, the topological Hall effect (THE) is observed owing to the existence of nontrivial spin structures. In this study, we observed that an unanticipated THE starts to develop in a MnBi4Te7 single crystal when the magnetic field is rotated away from the easy axis (c-axis) of the system. Furthermore, the THE resistivity reaches a giant value of ~7 microΩcm at 2 K when the angle between the magnetic field and c-axis is of 75°. This value is significantly higher than the values for previously reported systems with noncoplanar structures. The THE can be ascribed to the noncoplanar spin structure resulting from the canted state during the spin-flop transition in the ground AFM state of MnBi4Te7. The large THE at a relatively low applied field makes the MnBi4Te7 system a potential candidate for spintronic applications.

MA 3.15 Mon 13:30 P

High-throughput screening of the exchange interactions among magnetic impurities in a quantum spin Hall insulator — •Rubel Mozumder, Philipp Rüssmann, and Stefan Blügel — Peter Grünberg Institut (PGI) and Institute for Advanced simulation (IAS), Forschungszentrum Jülich, D-52424 Jülich, Germany

An internal magnetic field in Quantum Spin Hall Insulators (QSHI) breaks the time-reversal symmetry and transforms the QSHI into a Quantum Anomalous Hall insulator (QAHI). This topological phase transition also transforms 1D helical edge states of a QSHI into 1D chiral states, which are topologically protected single spin-transport channels at the edges of QAHIs.

Here we present a high-throughput study of a large number of magnetic impurities (3*d* and 4*d* transition-metal elements) in different combinations, which are embedded into the QSHI Bi_2Te_3. For this, we extend the AiiDA-KKR package [1] that allows to run high-throughput *ab initio* calculations using the JuKKR code [https://jukkr.fz-juelich.de] that is based on full-potential relativistic all-electron density functional theory calculations within the Korringa-Kohn-Rostoker Green-function method. We extract Heisenberg exchange coupling parameters as well as Dzyaloshinskii-Moriya vectors for pairs of impurities to study the tendency toward stable ferromagnetic order, which is a prerequisite for the QAHI state. Furthermore, we investigate the effect of co-doping on the magnetic interactions.

References

[1] P. Rüßmann *et al.*, npj Comput Mater **7**, 13 (2021).

MA 3.16 Mon 13:30 P

Complex nanostructured magnetic thin films investigated by x-ray absorption spectroscopy — •Damian Günzing[1], Shalini Sharma[2,3], Alexander Zintler[3], Johanna Lill[1], Debora Motta Meira[4], Harish K Singh[3], Ruiwen Xie[3], Georgia Gkouzia[3], Márton Major[3], Iliya Radulov[3], Philipp Komissinskiy[3], Hongbin Zhang[3], Konstantin Skokov[3], Yukiko K Takahashi[2], Lambert Alff[3], Leopoldo Molina-Luna[3], Heiko Wende[1], and Katharina Ollefs[1] — [1]Faculty of Physics, University of Duisburg-Essen — [2]National Institute for Materials Science, Tsukuba — [3]Institute of Materials Science, Technical University of Darmstadt — [4]Sector 20, Advanced Photon Source, Argonne National Laboratory

Understanding the interplay of the structural phase composition and the corresponding magnetic properties is at the heart of hysteresis design of e.g. hard magnetic materials. Here, we investigated a $SmCo_5$ Sm_2Co_{17} nano composite film manufactured via MBE on an Al_2O_3 substrate without additional buffer layers [1]. We established a multi-absorber fitting and simulation method for non-destructive extended x-ray fine structure (EXAFS) spectra of complex magnetic materials to quantify the two phases, $SmCo_5$ and Sm_2Co_{17}. In combination with transmission electron microscopy and magnetometry we found that the high magnetization and strong perpendicular anistropy originates from the nanoscale composition of these two phases with coherent interfaces. (Supported by the DFG Project-ID 405553726*CRC 270).

[1] S. Sharma et al., *ACS Appl. Mater. Interfaces* (2021) 13, 27, 32415-32423

MA 3.17 Mon 13:30 P

Topographic and magnetic characterization of periodically curved organic/metallic hybrid thin film systems — •Christian Janzen[1], Sekvan Bagatur[2], Maximilian Merkel[1], Meike Reginka[1], Michael Vogel[1], Thomas Fuhrmann-Lieker[2], and Arno Ehresmann[1] — [1]Institute of Physics and Center for Interdisciplinary Nanostrcuture Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel — [2]Institute of Chemistry and CINSaT, University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

In this work, a low-molecular azo-glass material (AZOPD [1]) is structured by a two-beam-interference-patterning process. Thereby, a periodically curved topography with a structure height and a structure wavelength at the nanoscale is obtained, whereby the latter is constant over the sample area. The periodically curved organic layer is used as a topographic template for the deposition of a ferromagnetic thin film. Non-contact atomic force microscopy measurements were conducted in order to investigate the alteration of the topography after sputter deposition. By spatially resolved magneto-optical Kerr magnetometry, a direct correlation between the local topography of the heterostructure and its coercive field is observed. The occurence of an uniaxial magnetic anisotropy, originating from the periodically curved topography, is examined by varying the ferromagnetic layer thickness. Finally, the influence of the sample topography on the alignment of magnetic domains is investigated via Kerr-microscopy.

[1] Fuhrmann *et al.* Chem. Mater. 1999, 11, 8, 2226-2232

MA 3.18 Mon 13:30 P

Simulation of the FEBID process — •Alexander Kuprava[1] and Michael Huth[2] — [1]Goethe Universität Frankfurt, Germany — [2]Goethe Universität Frankfurt, Germany

Focused electron beam induced deposition is a direct-write nanofabrication technology with unique advantages for free-form 3D deposition. However, a shape-true transfer from a 3D CAD model target structure to the actual nano-deposit is a non-trivial task. Here we present our modular computer simulation framework that was developed to simulate FEBID process in order to assist the study of the growth of 3D structures. The program includes an electron-beam generation and an electron-solid interaction module, a diffusion module and a reaction equation solver. A Monte Carlo (MC) simulation was utilized for scattered electron trajectories generation and inelastic electron-solid interaction on a cellular structured 3D grid. The simulation details are discussed which include applied structured grid-based simulation practices, the numerical solution of the reaction equation, the diffusion simulation concept and the MC simulation of primary and secondary electron flux. The program was used to simulate the growth of high aspect-ratio Pt-based nanoscale pillars with a stationary Gaussian electron beam using (CH3)3CpCH3Pt(IV) as a precursor. The simulation results were compared to the experimentally grown structures regarding shape trueness and growth rate.

MA 3.19 Mon 13:30 P

Spray deposition of ferromagnetic $SrFe_{12}O_{19}$ nanoplates colloid at Si and cellulose substrate — •Andrei Chumakov[1], Calvin Brett[1,2], Artem Eliseev[3], Evgeny Anokhin[3], Lev Trusov[3], Lewis Akinsinde[4], Marc Gensch[1,5], Dirk Menzel[6], Matthias Schwartzkopf[1], Wei Cao[5], Shanshan Yin[5], Manuel Scheel[5], Micheal Rübhausen[4], Peter Müller-Buschbaum[5,7], Daniel Soederberg[2], Andrei Eliseev[3], and Stephan V. Roth[1,2] — [1]DESY, Hamburg, Germany — [2]KTH RIT, Stockholm, Sweden — [3]MSU, Moscow, Russia — [4]CFEL, Universität Hamburg, Hamburg, Germany — [5]TU München, Garching, Germany — [6]TU Braunschweig, Braunschweig, Germany — [7]TU München, MLZ, Garching, Germany

Ferromagnetic $SrFe_{12}O_{19}$ nanoparticles with a hard magnetic moment perpendicular to their plane and stabilized by a positive charge can form a self-ordered coating under the influence of magnetic fields drying from dispersion. We investigated the film formation of a stable colloid dispersion of ferromagnetic nanoplates and nanoblocks onto a silicon substrate and cellulose nanofilm without and under the action of an external magnetic field during scalable layer-by-layer spraying. The formation of a film of ferromagnetic particles from an aqueous colloid makes it possible to form a stable magnetic coating of agglomerates of nanoparticles. An external magnetic field in the deposition process leads to the appearance of residual magnetization in the film. Particles with a smaller aspect ratio form a periodic structure of agglomerates of nanoparticles with signs of an artificial opal-like structure.

MA 3.20 Mon 13:30 P

Magnetization switching of dipolar coupled elongated permalloy nanostructures of high shape anisotropy — Neeti Keswani[1], Yoshikata Nakajima[2], Neha Chauhan[2], Tomofumi Ukai[2], Himadri Chakraborti[3], Kantimoy Das Gupta[3], Tatsuro Hanajiri[2], Sakthi Kumar[2], Yukio Ohno[4], Hideo Ohno[4], and •Pintu Das[1] — [1]Department of Physics, Indian Institute of Technology Delhi, New Delhi-110016 — [2]Bio Nano Electronics Research Centre, Toyo University, Kawagoe, Saitama-3508585, Japan — [3]Department of Physics, Indian Institute of Technology Bombay, Mumbai-400076 — [4]Research Institute of Electrical Communications, Tohoku University, Sendai, Japan - 9808577

Behavior of nanomagnets of strong shape anisotropy can be studied by modelling them as Ising-like macrospins. Due to the potential use of such macrospin-like nanomagnets in devices such as in nanomagnetic logic etc., a detailed understanding of the exact switching behavior of such nanomagnets coupled via dipolar interaction is essential.

In this work, we have used 2-dimensional electron gas based micro-Hall magnetometry in ballistic transport regime to measure the stray fields emanating from the lithographically patterned elongated nanomagnets of $Ni_{80}Fe_{20}$ arranged in a double ring like structure. Our results demonstrate that although the magnetic images of the nanomagnets show single-domain behavior, however, their switching process may involve formation of other complex structures such as magnetic vortices, etc. The experimental results are analyzed by performing micro-magnetic simulations for the nanostructures.

MA 4: Spin-Dependent 2D Phenomena

Time: Tuesday 10:00–11:15 Location: H5

Invited Talk MA 4.1 Tue 10:00 H5

2D Magnetic materials — •Alberto Morpurgo — University of Geneva

Exfoliation of thin crystals from van der Waals bonded parent compounds allows the realization of atomically thin layers, exhibiting new phenomena, properties and functionality. For atomically thin magnetic materials, this strategy has been followed only recently, and has led to multiple interesting results. In my talk I will mainly focus on the investigation of 2D semiconducting magnetic materials by means of transport measurements. I will discuss how we use atomically thin layers to realize tunnel barriers, and measure the temperature and magnetic field dependence of the tunneling resistance to extract detailed information about their magnetic phase diagram. In a first generation of experiments we have demonstrated the principle for diferent anti-ferromagnetic semiconductors (CrI_3, $CrCl_3$, $MnPS_3$), and extracted important microscopic information about the phase transitions occurring in these systems (and in some cases about the relevant exchnage integrals). More recently we have shown that the technique also works for ferromagnets such as $CrBr_3$, using which we are able to infer detailed information about the magnetic field and temperature dependence of the tubnneling resistance (both in the ferromagnetic and in the paramagnetic state).

MA 4.2 Tue 10:30 H5

Spin-polarised imaging and quasi-particle interference of the van-der-Waals ferromagnet Fe_3GeTe_2 — •Olivia Armitage[1], Christopher Trainer[1], Luke Rhodes[1], Harry Lane[2], Edmond Chan[2], Chris Stock[2], and Peter Wahl[1] — [1]SUPA, School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews, Fife, KY16 9SS, United Kingdom — [2]SUPA, School of Physics and Astronomy, University of Edinburgh, United Kingdom

Van-der-Waals ferromagnets have enabled the development of heterostructures with spintronics functionalities. However, information about the magnetic properties of these systems has come largely from macroscopic techniques, with little being known about the microscopic magnetic properties. Here, we use spin-polarised scanning tunnelling microscopy and quasi-particle interference imaging to study the magnetic and electronic properties of the metallic 2D vdW ferromagnet Fe_3GeTe_2. From comparison with Density Functional Theory calculations we can assign the quasi-particle interference to be dominated by spin-majority bands. We find a dimensional dichotomy of the bands at the Fermi energy: bands of minority character are predominantly two-dimensional in character, whereas the bands of majority character are three-dimensional. We expect that this will enable new design principles for spintronics devices.

MA 4.3 Tue 10:45 H5

Photocurrents in single-layer Fe3GeTe2 from first principles — •Maximilian Merte[1,2,3], Frank Freimuth[3,1], Theodoros Adamantopoulos[1], Dongwook Go[3,1], Tom Saunderson[3,1], Matthias Kläui[3], Stefan Blügel[1], and Yuriy Mokrousov[1,3] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

We present a method for calculating laser induced currents [1], which are of second order in the electric field, by means of Wannier interpolation. Our method can be applied as a post-processing tool to the wannier90code [2], which is compatible with many ab-initio codes. We apply the developed method to study photocurrents in a single-layer of the van der Waals layered crystal Fe3GeTe2, which act as 2D ferromagnetic metals whose properties are being intensively explored nowadays [3]. Our calculations predict a very sizeable magnitude of photocurrents in this material, whose sign and properties can be tuned by doping or by the frequency of the pulse. We also uncover the importance of the scattering effects which are naturally taken care of within the Keldysh formalism that we use as the ground framework for our method. We acknowledge funding from Deutsche Forschungsgemeinschaft (DFG) through SFB/TRR 173 and 288. Simulations were performed with computing resources granted by JARA-HPC from RWTH Aachen University and Forschungszentrum Jülich under projects jara0161, jiff40 and jias1a [4]

[1] Frank Freimuth et al., arXiv: 1710.10480 (2017)
[2] www.wannier.org
[3] Y. Deng et al., Nature 563, 94 (2018).
[4] Jülich Supercomputing Centre. (2018). JURECA: Modular supercomputer at Jülich Supercomputing Centre. Journal of large-scale research facilities, 4, A132. http://dx.doi.org/10.17815/jlsrf-4-121-1

MA 4.4 Tue 11:00 H5

Charge density waves as enablers for chiral magnetism in two-dimensional $CrTe_2$ — •Nihad AbuAwwad[1,2], Manuel dos Santos Dias[1], Sascha Brinker[1], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany

The discovery of two-dimensional (2D) van der Waals magnets opened unprecedented opportunities for the fundamental exploration of magnetism in quantum materials and the realization of next generation spintronic devices. Recently, thin $CrTe_2$ films were demonstrated to be ferromagnetic up to room temperature, with an intriguing dependence of the easy axis on the thickness of the material [1,2]. Here, we demonstrate using first-principles that the charge-density waves characterizing a single $CrTe_2$ give rise to chiral magnetism through the emergence of the Dzyaloshinskii-Moriya interaction (DMI). Utilizing atomistic spin dynamics, we perform a detailed investigation of the complex magnetic properties pertaining to this 2D material impacted by the presence of various types of charge density waves.

–Work funded by the Palestinian-German Science Bridge (BMBF–01DH16027) and Priority Programme SPP 2244 2D Materials Physics of van der Waals Heterostructures of the DFG (project LO 1659/7-1).

[1] Zhang *et al.*, Nat. Commun. **12**, 2492 (2021); [2] Meng *et al.*, Nat. Commun. **12**, 809 (2021).

MA 5: Posters Magnetism II

Topics: Skyrmions (5.1-5.14), Non-Skyrmionic Magnetic Textures (5.15-5.20), Weyl Semimetals (5.21-5.22)

Time: Tuesday 10:00–13:00 Location: P

MA 5.1 Tue 10:00 P

Robust Formation of Nanoscale Magnetic Skyrmions in Easy-Plane Anisotropy Thin Film Multilayers with Low Damping — •Luis Flacke[1,2], Valentin Ahrens[3], Simon Mendisch[3], Lukas Körber[4,5], Tobias Böttcher[6], Elisabeth Meidinger[1,2], Misbah Yaqoob[1,2], Manuel Müller[1,2], Lukas Liensberger[1,2], Attila Kákay[4], Markus Becherer[3], Philipp Pirro[6], Matthias Althammer[1,2], Stephan Geprägs[1], Hans Huebl[1,2,7], Rudolf Gross[1,2,7], and Mathias Weiler[1,2,6] — [1]Walther-Meißner Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]Physics Department, Technical University of Munich, 85748 Garching, Germany — [3]Department of Electrical and Computer Engineering, Technical University of Munich, 80333 Munich, Germany — [4]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [5]Fakultät Physik, Technische Universität Dresden, 01062 Dresden, Germany — [6]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [7]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

We investigate magnetic superlattices based on the low-damping and high saturation magnetization binary alloy Co25Fe75. The formation of stable sub-100 nm diameter skyrmions is confirmed and analyzed by magnetic force microscopy within an $K_{\rm eff} < 0$. The relatively low damping of the superlattice spin dynamics is quantified by broadband ferromagnetic resonance measurements.

MA 5.2 Tue 10:00 P

Exchange- and Dzyaloshinskii-Moriya interactions in magnetic bilayers at surfaces — •Tim Drevelow, Mara Gutzeit, and Stefan Heinze — Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstraße 15, 24098 Kiel, Germany

Magnetic skyrmions in synthetic antiferromagnets exhibit favorable transport properties [1], e.g. the absence of the skyrmion Hall effect and have recently been stabilized at room temperature [2]. Here, we investigate synthetic antiferromagnets built from trilayers composed of Co and Fe layers coupled via a Rh spacer layer. *Ab initio* calculations using density functional theory were performed to obtain the strength of the inter- and intralayer exchange and Dzyaloshinskii-Moriya interactions which allows to parametrize an atomistic spin model. We studied freestanding trilayers as well as trilayers on the Ir(111) surface since both Rh/Co and Rh/Fe bilayers have previously been grown on this surface [3,4].

[1] Zhang *et al.* Nat. Com. **7**, 10293 (2016)
[2] Legrand *et al.* Nat. Mat. **19**, 34 (2020)
[3] Romming *et al.* Phys. Rev. Lett. **120**, 207201 (2018)
[4] Meyer *et al.* Nat. Com. **10**, 3823 (2019)

MA 5.3 Tue 10:00 P

The Skyrmion Radius Calculator — •Moritz Sallermann, Bernd Zimmermann, Fabian Lux, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The skyrmion radius is an important quantity for any skyrmion characterisation, motion and device concept. For technological applications – especially as a promising building block for future information technology – it is essential to determine those materials in which skyrmions assume a typical radius of 10 nm or even less.

We studied the energy contributions of the circular domain wall profile [1] in thin, infinite films of magnetic materials, employing the continuous, micromagnetic approximation. Notably, we also include the exact contribution of the magnetostatic interactions and thus go beyond the commonly applied thin-film approximation. We confirm our findings by comparing them with exact micromagnetic calculations that do not depend on any choice of trial functions. We provide an easy to use and fast online tool, the Skyrmion Radius Calculator [2], which computes an approximation to the skyrmion radius in fractions of a second. It is based on the minimization of the energy of the ansatz profile. The agreement with full micromagnetic simulations can be estimated from the resulting profile parameters and is excellent as long as the skyrmions are of domain-wall character.

Acknowledgement: DFG through SPP-2137 & SFB-1238 (project C1).

[1] F. Büttner, I. Lemesh and G.S. Beach, Sci.Rep., 8(1) (2018)
[2] https://juspin.de/skyrmion-radius/

MA 5.4 Tue 10:00 P

Modification of the DMI by He^+ ion bombardment characterized by high-resolution optical Kerr microscopy — •Sapida Akhundzada[1], Florian Ott[1], Maxwell Li[2], Tim Mewes[3], Arno Ehresmann[1], Vincent Sokalski[2], and Michael Vogel[1] — [1]Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Kassel, Germany — [2]Department of Materials Science and Engineering, Carnegie Mellon University, Pittsburgh, USA — [3]Department of Physics and Astronomy, University of Alabama, Tuscaloosa, USA

The Dzyaloshinkii-Moriya interaction (DMI) is an antisymmetric exchange interaction arising, e.g., from interfaces between ferromagnets and heavy metals with large spin-orbit coupling [1]. The DMI is topologically stabilizing chiral spin-structures like skyrmions which are promising candidates for nonvolatile magnetic memory technologies [2]. It has been recently demonstrated that the DMI can be tuned by bombardment with accelerated ions [3]. While altering the interfaces between the different material layers in total, the sign and magnitude of the DMI can be manipulated [3]. In a systematic study, we modified the DMI by keV He ion bombardment in perpendicularly magnetized ferromagnetic/heavy metal multilayer system. In order to characterize the interfacial DMI, we characterized the field-driven, asymmetric growth of the magnetic domains by high-resolution Kerr microscopy.

[1] T. Moriya, Phys. Rev. Lett. 4, 228 (1960)
[2] A. Fert, V. Cros and J. Sampaio, Nat. Nanotechnol. 8, 152 (2013)
[3] H. T. Nembach, et al., arXiv:2008.06762 (2020)

MA 5.5 Tue 10:00 P

Stability of the skyrmion lattice in $Fe_{1-x}Co_xSi$ — •Carolina Burger[1], Andreas Bauer[1], Alfonso Chacon[1], Marco Halder[1], Jonas Kindervater[1], Sebastian Mühlbauer[2], André Heinemann[2], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, D-85748 Garching, Germany

We report measurements of the magnetization, susceptibility, and electrical transport on single-crystal $Fe_{1-x}Co_xSi$, complemented by small-angle neutron scattering. In small magnetic fields, this compound hosts a hexagonal lattice of topologically non-trivial skyrmions that may persist metastably down to lowest temperatures when field-cooled. We show that signatures characteristic of the skyrmion lattice survive field values up to the field-polarized regime as well as field inversion. At low temperatures, the Hall effect is dominated by the anomalous contributions, with additional contributions emerging in the vicinity of the magnetic phase transitions hinting towards complex processes associated with the unwinding of the skyrmion lattice.

References: [1] A. Bauer, C. Pfleiderer, and M. Garst, Phys. Rev. B 93 (23), 235144 (2016), [2] A. Bauer, A. Chacon, M. Halder, C. Pfleiderer, Springer Series in Solid-State Sciences 192 (2018), [3] H. Oike, A. Kikkawa, N. Kanazawa, Y. Taguchi, M. Kawasaki, Y. Tokura, and F. Kagawa, Nature Phys. 12, 62 (2016)

MA 5.6 Tue 10:00 P

Topological Hall effect in thin films of noncollinear magnets — •Rebeca Ibarra[1,2], Anastasios Markou[1], Aleksandr Sukhanov[2], Dmytro Inosov[2], and Claudia Felser[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Technical University Dresden, Germany

Topological spin textures in quantum materials are of great interest, along with the associate transport signatures, for next-generation spintronic applications. Recently, the tetragonal (t) Heusler compounds show to host elliptical skyrmions and antiskyrmions [1], and the hexagonal (h) half-Heusler compound MnPtGa displays noncollinear magnetism [2]. Spin chirality in metallic materials with noncoplanar spin structure gives rise to a Berry phase-induced topological Hall effect. In addition, neutron diffraction is a powerful technique to study the magnetic structure of these chiral materials.

Here, we study the noncollinear spin textures in high-quality epitaxial thin films of the t-Mn_2RhSn and h-MnPtGa compounds. In t-Mn_2RhSn, we observe topological Hall signatures of two distinct chiral spin textures. Interestingly, we show with single-crystal neutron diffraction that the h-MnPtGa undergoes a magnetic phase transition from ferromagnetic to in-plane canted antiferromagnetic. With our thin film method, we can access a novel and fundamental understanding of these compounds not possible with other methods.

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MA 5.7 Tue 10:00 P

Spin-transfer torque driven motion, deformation, and instabilities of magnetic skyrmions at high currents — •Jan Masell[1], Davi R. Rodrigues[2], and Karin Everschor-Sitte[2] — [1]RIKEN CEMS, Wako, Japan — [2]University of Duisburg-Essen, Duisburg, Germany

Magnetic skyrmions are whirls which are characterized by a topological winding number. They have gained massive attention due to this real-space topological property and other features like possible nanometer size, extraordinary stability, or easy manipulation by electrical currents or other means. Therefore, various proposals emerged how skyrmions might serve as mobile information carriers in future information technology.

When considering skyrmions driven by spin-transfer torque (STT), it is usually assumed that distortions due to the current are small.

We have simulated STT-driven skyrmions with ultra high precision and quantitatively studied the distortion by STT in the entire stability regime up to the ferromagnetic instability. We find analytical expressions for the distortion of skyrmions, which is quadratic in the current, as well as for the STT-induced elliptical instability which destroys the skyrmion. We show numerically that for large enough Gilbert damping, however, stable but distorted "shooting star" skyrmion solutions are possible in regimes even above the elliptical instability. [1]

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MA 5.8 Tue 10:00 P

Skyrmion movement in Ta/CoFeB/MgO-trilayers — •Hauke Lars Heyen[1], Jakob Walowski[1], Christian Denker[1], Malte Römer-Stumm[2], Markus Münzenberg[1], and Jeffrey McCord[2] — [1]Institut für Physik, Universität Greifswald, Felix-Hausdorff-Straße 6, 17489 Greifswald, Germany — [2]Christian-Albrechts-Universität zu Kiel, Institute for Materials Science, Nanoscale Magnetic Materials and Magnetic Domains, 24143 Kiel, Germany

Skyrmion manipulation and dynamics control are promising tools for the realization of racetrack memory devices to increase data storage densities.

We use current pulses to experimentally investigate skyrmion dynamics in Ta/CoFeB/MgO-trilayers. Layer thickness control in CoFeB layers in the picometer range generated by very small thickness gradients allows to produce layers exhibiting a transition region from in-plane to out-of-plane magnetic anisotropy along the sample. This enables fine adjustment for optimal skyrmion nucleation. Skyrmions are created in the demagnetized CoFeB layer using magnetic field pulses tilted slightly out of the plane direction. Afterwards stabilized by a small out-of-plane field, skyrmion dynamics are generated with microsecond current pulses and recorded by Kerr-microscopy.

By using a specially developed tracking software to follow the motion after each current pulse, we analyze the skyrmion dynamics. The movement shows a Skyrmion-Hall-effect and a superdiffusive distribution. Further the skyrmions seem to get stuck, generated or annihilated at pinning centers.

MA 5.9 Tue 10:00 P

Ab-initio investigation of intrinsic antiferromagnetic skyrmions in magnetic thin films — •Amal Aldarawsheh[1,2], Imara Fernandes[1], Sascha Brinker[1], Moritz Sallersmann[1], Muayyad Abusaa[3], and Samir Lounis[1,2] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany — [3]Physics Department, Arab American University, Jenin, Palestine.

Skyrmions are topologically protected spin textures that are envisioned to be the next generation of bits. However, conventional ferromagnetic (FM) skyrmions are deflected when an electric field is applied, which limits their use in spintronic devices. In contrast, antiferromagnetic (AFM) skyrmions, which consist of two FM solitons coupled antiferromagnetically, are predicted to have zero net magnus force [1], and this makes them promising candidates for spintronic racetrack memories. So far these have been stabilized in synthetic AFM structures [2], i.e.

multilayers hosting FM skyrmions, which couple antiferromagnetically through a non-magnetic spacer. Using *ab initio* calculations in conjunction with atomistic spin dynamics, we investigate systematically and predict the presence of chiral intrinsic AFM structures in specific and realistic combination of thin films deposited on heavy substrates. [1] X. Zhang *et al.* Sci. Rep. **6**, 24795 (2016), [2] Legrand *et al.* Nat. Mat., **19**, 34 (2020). Work funded by the PGSB (BMBF–01DH16027) and Horizon 2020–ERC (CoG 681405–DYNASORE).

MA 5.10 Tue 10:00 P

First-principles study of DMI mechanisms and exchange frustration in Rh/Co/Fe/Ir multilayers — •Felix Nickel, Sebastian Meyer, and Stefan Heinze — Institute of Theoretical Physics and Astrophysics, University of Kiel

Magnetic skyrmions are promising for the usage in data storage and logic devices. Materials, which can host small diameter skyrmions in zero magnetic field at room temperature, are suitable for such applications. Recently, it has been shown that ultrathin Rh/Co films on Ir(111) exhibit skyrmions with diameters below 10 nm at zero magnetic field [1]. On the other hand, room temperature skyrmions with diameters of 30 nm - 90 nm have been found in magnetic multilayers [2].The Dzyaloshinskii-Moriya Interaction (DMI), exchange frustration and magnetocrystalline anisotropy are the main characteristics that make materials capable of hosting such complex spin structures. We performed density functional theory calculations for different transition-metal multilayer systems consisting of Co, Fe, Ir and Rh and determined those magnetic interactions to investigate if properties of ultra thin film systems, like in Ref. [1], can be transferred to multilayer systems. We present how the magnetic interactions depend on the structural properties of the multilayer systems. Further we predict multilayers which are very promising for the stabilisation of magnetic skyrmions.

[1] Meyer *et al.*, Nat. Commun. **10**, 3823 (2019)
[2] Moreau-Luchaire *et al.*, Nat. Nanotechnol. **11**, 444 (2016)

MA 5.11 Tue 10:00 P

Skyrmion braids — Fengshan Zheng[1], Filipp N. Rybakov[2], •Nikolai S. Kiselev[3], Dongsheng Song[1,4], András Kovács[1], Haifeng Du[5], Stefan Blügel[3], and Rafal E. Dunin-Borkowski[1] — [1]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons and Peter Gr\"unberg Institute, Forschungszentrum J\"ulich, 52425 J\"ulich, Germany — [2]Department of Physics, KTH-Royal Institute of Technology, Stockholm, SE-10691 Sweden — [3]Peter Gr\"unberg Institute and Institute for Advanced Simulation, Forschungszentrum J\"ulich and JARA, 52425 J\"ulich, Germany — [4]Institutes of Physical Science and Information Technology, Anhui University, Hefei 230601, China — [5]High Magnetic Field Laboratory, Chinese Academy of Science (CAS), Hefei, Anhui Province 230031, China

Skyrmions are vortex-like spin textures that form strings in magnetic crystals. Due to the analogy to elastic strings, skyrmion strings are naturally expected to braid and form complex three-dimensional patterns, but this phenomenon has not been explored yet. We found that skyrmion strings can form braids in cubic crystals of chiral magnets [1]. Our finding is confirmed by direct observations of skyrmion braids in B20-type FeGe using transmission electron microscopy. The theoretical analysis predicts that the discovered phenomenon is general for a wide family of chiral magnets. These findings have important implications for skyrmionics and propose a solid-state framework for applications of the mathematical theory of braids.

[1] F. Zheng et al., arXiv:2104.01682.

MA 5.12 Tue 10:00 P

Antiskyrmions and sawtooth surface textures in an S4 symmetric magnet — Kosuke Karube[1], Licong Peng[1], •Jan Masell[1], Xiuzhen Yu[1], Fumitaka Kagawa[1,2], Yoshinori Tokura[1,2], and Yasujiro Taguchi[1] — [1]RIKEN CEMS, Wako, Japan — [2]University of Tokyo, Tokyo, Japan

Magnetic skyrmions are vortex-like textures in the magnetization. By now, skyrmions are found in many systems ranging from bulk chiral magnets to thin films and monolayers. Their anti-vortex-like antiparticles, consequently dubbed "antiskyrmions", were theoretically predicted to exist in magnets with D_{2d} or S_4 symmetry [1], but were observed only in a family of D_{2d}-symmetric Heuslers. [2]

We report the first observation of antiskyrmions in a magnet with S_4 symmetry. We prepared Pd-doped Schreibersite which shows a weak uniaxial anisotropy and weak antisymmetric DMI. Thus, domain walls with opposite handedness are stabilized along two orthogonal directions. In thin films, LTEM reveals square-shaped antiskyrmions, elliptical skyrmions, and trivial bubbles, as a consequence of dipolar interactions. For thicker systems, MFM shows that the domain wall textures fractalize with sawtooth patterns. These novel patterns arise from the weak antisymmetric DMI in combination with dominant dipolar interactions, as shown by our micromagnetic simulations. [3]

[1] A.N. Bogdanov & D.A. Yablonskii, JETP **68,** 101-103 (1989)
[2] A.K. Nayak *et al.*, Nature **548,** 561-566 (2017)
[3] K. Karube, L.C. Peng, J. Masell, *et al.*, Nature Materials **20,** 335-340 (2021)

MA 5.13 Tue 10:00 P

Real-Space Observation of Topological Defects in Extended Skyrmion-Strings — •Jan Masell[1], Xiuzhen Yu[1], Fehmi S. Yasin[1], Kosuke Karube[1], Naoya Kanazawa[2], Kiyomi Nakajima[1], Takuro Nagai[3], Koji Kimoto[3], Wataru Koshibae[1], Yasujiro Taguchi[1], Naoto Nagaosa[1,2], and Yoshinori Tokura[1,2] — [1]RIKEN CEMS, Wako, Japan — [2]University of Tokyo, Tokyo, Japan — [3]National Institute for Materials Science, Tsukuba, Japan

Skyrmions are whirls in the magnetization which are characterized by a 2d topological winding number. Due to their topology, large skyrmions are protected by a high energy barrier [1] which makes them interesting objects for potential future applications. However, in 3d bulk materials or thin films, skyrmions are strings (SkS) which can have singular topological defects [2], known as Bloch points.

We use Lorentz Transmission Microscopy (LTEM) on thin films of chiral magnets to obtain a sideview of SkS that extend in the film plane. We obtain high resolution images of various defects, including Bloch points which terminate SkS or fuse them, but also SkS which annihilate smoothly by escaping through the surface. These objects can be discerned by comparing them to the results of micromagnetic simulations. [3]

[1] B. Heil, A. Rosch & J. Masell, Phys. Rev. B **100,** 134424 (2019)
[2] P. Milde *et al.*, Science **340**, 1076-1080 (2013)
[3] X.Z. Yu*, J. Masell* *et al.*, Nano Lett. **20,** 7313-7320 (2020)

MA 5.14 Tue 10:00 P

Mode following method for magnetic systems — •Stephan von Malottki[1,2], Moritz A. Goerzen[2], Hendrik Schrautzer[1,2], Pavel F. Bessarab[1], and Stefan Heinze[2] — [1]Science Institute, University of Iceland, Reykjavík — [2]ITAP, University of Kiel, Germany

The average lifetime of metastable magnetic states is commonly determined by harmonic transition state theory (HTST) [1] or the related Langer's theory [2], resulting in an Arrhenius-law depending on the thermal energy, the energy barrier and the pre-exponential factor. The latter contains information about the dynamics and entropic effects of the transition and is often challenging to obtain. In the past, the application of HTST calculations to magnetic skyrmions has been limited to cases in which the harmonic and zero-mode approximations are justified [1-3]. Other cases, such as the collapse of magnetic skyrmions via the chimera transition [2-4] or the collapse of antiskyrmions [4] were not always accessible. Here, we present a numerical method to evaluate the entropic contribution of individual Eigenmodes beyond the harmonic approximation. With this method, not only the quality of the harmonic and zero-mode approximations can be evaluated, but also the direct numerical calculation of the entropic contributions becomes feasible, which allows access to intermediate temperature regimes that could not be treated with conventional HTST.

[1] P. Bessarab *et al.* Sci. Rep. **8**, 3433 (2018) [2] L. Desplat *et al.* PRB **99**, 174409 (2019) [3] F. Muckel *et al.* Nat. Phys. **17**, 395-402 (2021) [4] S. Meyer *et al.* Nat. Commun. **10** 3823, (2019)

MA 5.15 Tue 10:00 P

Single-Crystal Growth and Low-Temperature Properties of Er_2 — •Christoph Resch[1], Georg Benka[1,2], Andreas Bauer[1], and Christian Pfleiderer[1] — [1]Physik Department E51, Technische Universität München, 85748 Garching, Germany — [2]Kiutra GmbH Rupert-Mayer-Str. 4481379 Munich, Germany

Single crystals of the hexagonal rare-earth diboride ErB_2 were synthesized by means of the self-adjusted flux travelling solvent optical floating zone technique. The magnetic phase diagram was inferred from measurements of the magnetization and the ac susceptibility as a function of magnetic field and temperature for fields up to 14 T applied along major crystallographic axes. We find behavior characteristic of a hard-axis-easy-plane antiferromagnet. Magnetoresistivity and hall effect measurements up to 20 T exhibit a field dependence that may not be accounted for by standard normal and anomalous contributions, suggesting non-collinear antiferromagnetic order as potential origin.

MA 5.16 Tue 10:00 P

Topological-chiral magnetic interactions in ultrathin films at surfaces — •Soumyajyoti Haldar[1], Sebastian Meyer[2], André Kubetzka[3], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstr. 15, 24098 Kiel, Germany — [2]Nanomat/Q-mat/CESAM, Université de Liège, B-4000 Sart Tilman, Belgium — [3]Department of Physics, University of Hamburg, 20355 Hamburg, Germany

Non-collinear spin structures are of fundamental interest in magnetism since they allow to obtain insight into the underlying microscopic interactions and are promising for spintronic applications [1,2]. Here, we demonstrate that recently proposed topological-chiral magnetic interactions [3] can play a key role for magnetic ground states in ultrathin films at surfaces [4]. Based on density functional theory we show that significant chiral-chiral interactions occur in hexagonal Mn monolayers due to large topological orbital moments which interact with the emergent magnetic field. Due to the competition with higher-order exchange interactions superposition states of spin spirals such as the 2Q state or a distorted 3Q state can arise. Simulations of spin-polarized scanning tunneling microscopy images suggest that the distorted 3Q state could be the magnetic ground state of a Mn monolayer on Re(0001).

[1] A. Fert *et al.*, Nat. Rev. Mater. **2**, 17031 (2017). [2] J. Grollier *et al.*, Nat. Electron. **3**, 360 (2020). [3] S. Grytsiuk *et al.*, Nat. Commun. **11**, 511 (2020). [4] S. Haldar *et al.*, arXiv:2106.08622 (2021).

MA 5.17 Tue 10:00 P

Creation of reconfigurable stray field landscapes in synthetic antiferromagnets via focused ion beam irradiation — •Fabian Samad[1,2], Gregor Hlawacek[1], Sri Sai Phani Kanth Arekapudi[2], Xiaomo Xu[1], Leopold Koch[2], Miriam Lenz[1], and Olav Hellwig[1,2] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany

Synthetic antiferromagnets (SAFs) with perpendicular magnetic anisotropy (PMA) can exhibit different magnetic phases depending on the magnetic history and energy balance [1]. By using focused He^+ ion beam (FIB) irradiation, the antiferromagnetic (AF) interlayer exchange coupling (IEC) and PMA can be reduced on a lateral (sub-)micron scale, such that different magnetic textures can be "written" with FIB [2,3]. Due to the depth-dependent ion damage, AF domains are stabilized at low fluences, typically around 10 ions/nm^2. When using a fluence gradient, the AF domains can be further manipulated in a directional fashion by applying external magnetic fields. Thus, a well-defined and reconfigurable stray field landscape is created, which can act on a suitable functional overlayer, such as a spin wave conducting or superconducting layer.

[1] Hellwig et al., J. Magn. Magn. Mater. 319, 13 (2007)
[2] Koch et al., Phys. Rev. Applied 13, 024029 (2020)
[3] Samad et al., Appl. Phys. Lett. 119 (2021)

MA 5.18 Tue 10:00 P

Ab initio exploration of hopfion hosting magnets — •Imara Lima Fernandes, Roman Kováčik, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany

Topological magnetic textures are currently of great interest in condensed matter physics due to their rich science and potential applications in information technology. In contrast to two-dimensional magnetic skyrmions, which are currently under intense scrutiny both theoretically and experimentally, their three-dimensional (3D) counterpart, known as Hopfions, were only recently observed experimentally [1]. Hopfions are stable solutions of the magnetization field with a knotted topological structure. In particular, their simplest spin texture can be described as a closed torus with a topologically nontrivial spin texture in the cross-section profile.

In the current work, using *ab initio* calculations, we explore suitable classes of materials to host magnetic hopfions based on analytical conditions of Heisenberg exchange parameters derived in Ref. [2]. We address systematically the case of chemical disorder and temperature in order to approach the optimal magnetic parameter field. The present study may give a guidance to identify suitable materials.

– Funding is provided by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (Grant 856538 – 3D MAGiC).

[1] Kent, N. *et al*, Nat. Commun. **12**, 1562 (2021).
[2] Rybakov, F. N. *et al*, arXiv:1904.00250

MA 5.19 Tue 10:00 P

Combing the helical phase of chiral magnets with electric currents — •Jan Masell[1], Xiuzhen Yu[1], Naoya Kanazawa[2], Yoshinori Tokura[1,2], and Naoto Nagaosa[1,2] — [1]RIKEN CEMS, Wako, Japan — [2]University of Tokyo, Tokyo, Japan

In chiral magnets, the competition between the ferromagnetic exchange interaction and the small Dzyaloshinskii-Moriya interaction can form long-ranged helical modulations as the ground state. This helical phase has been extensively studied and chiral magnets gained extra attention when the skyrmion lattice was discovered in the chiral magnet MnSi a decade ago. However, in contrast to particle-like skyrmions, the helical phase seemed useless for spintronic applications as it is strongly pinned and hard to manipulate.

We have recently managed to unpin the helical phase in thin films of the chiral magnet FeGe by using electrical currents. Our theoretical analytical and numerical analysis predicts that the unpinned helical phase shows a variety of interesting dynamical phenomena, including distinct reorientation processes which can be driven by defects deep in the bulk or by the edge of the material, and predict numerous instabilities. Our results pave the way for "helitronics" and potential application in memory devices or unconventional computing.

[1] J. Masell, X.Z. Yu, N. Kanazawa, Y. Tokura & N. Nagaosa, Phys. Rev. B **102,** 180402(R) (2020)

MA 5.20 Tue 10:00 P

Magnetic ordering in CePdAl$_3$ and CePtAl$_3$ — •Michal Stekiel[1], Petr Cermak[4,5], Wolfgang Simeth[1,2], Martin Meven[4,3], Christian Franz[1,4], Stefan Weber[1], Rudolf Schönmann[1], Vivek Kumar[1], Kirill Nemkovskiy[4], Hao Deng[4,3], Andreas Bauer[1], Christian Pfleiderer[1], and Astrid Schneidewind[4] — [1]Technische Universität München, Garching, Germany — [2]Paul-Scherrer-Institut, Villigen, Switzerland — [3]RWTH Aachen at MLZ, Garching, Germany — [4]JCNS at MLZ, Garching, Germany — [5]Charles University, Praha, Czech Republic

In cerium-based intermetallic compounds the interplay of localized 4f electrons with itinerant d electrons may result in a wide range of magnetic and electronic ordering phenomena. Here, we report a comprehensive neutron diffraction study on single crystals of the non-centrosymmetric compounds CePdAl$_3$, crystallizing in the orthorhombic space group $Cmc2_1$, and CePtAl$_3$, crystallizing in the tetragonal space group $I4/mmm$. In CePdAl$_3$, a collinear antiferromagnetic structure is observed below T_N = 5.3 K with an ordered moment of 1.64 μ_B/Ce pointing along the a direction. In CePtAl$_3$, an amplitude-modulated cycloidal structure with an ordering vector $(\frac{2}{3}00)$ emerges below T_N = 3.2 K. A symmetry analysis and its connection to the magnetic structures of measured compounds will be presented.

MA 5.21 Tue 10:00 P

Spin and orbital texture of the Weyl semimetal MoTe$_2$ studied by spin-resolved momentum microscopy — •Kenta Hagiwara[1], Xin Liang Tan[1], Philipp Rüssmann[1], Ying-Jiun Chen[1,2], Koji Fukushima[3], Keiji Ueno[3], Vitaliy Feyer[1], Shigemasa Suga[1,4], Stefan Blügel[1], Claus M. Schneider[1,2], and Christian Tusche[1,2] — [1]Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich — [2]Fakultät für Physik, Universität Duisburg-Essen, 47057 Duisburg — [3]Saitama University, 338-8570, Saitama, Japan — [4]Osaka University, 567-0047, Osaka, Japan

Weyl semimetals host chiral fermions in solids as a pair of non-degenerate linear dispersions with band crossing points in their bulk electronic structure. 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. Momentum microscopy provides two dimensional photoelectron maps of the in-plane crystal momentum over the whole Brillouin zone, simultaneously. Together with an imaging spin filter, we have revealed the spin-resolved electronic structure of the type-II Weyl semimetal 1T$_d$ MoTe$_2$ in the full Brillouin zone. Supported by first-principles calculations, we clarified the spin texture and the orbital texture of the Weyl cones, which reflect the chirality of the Weyl points. We give evidence that a pair of

Weyl cones exhibits a strong circular dichroism with reversed sign, indicating the different charge of the respective Weyl points in the Fermi surface.

MA 5.22 Tue 10:00 P

Giant anomalous Hall and Nernst eff ect in magnetic cubic Heusler compounds — •Jonathan Noky[1], Yang Zhang[2], Claudia Felser[1], and Yan Sun[1] — [1]Max Planck Institute for Chemical Physics of Solids, Dresden, Germany — [2]Massachusetts Institute of Technology, Cambridge, USA

There is an ongoing search for materials with large anomalous Hall and Nernst effects. These effects can be utilized in applications for data storage, thermoelectric power generation, and a high temperature quantum anomalous Hall effect, when preparing them as thin films. A promising class of materials for this purpose are the Heusler compounds because they can be grown in thin films and have a high Curie temperature. In these systems, the interplay between magnetism and topological band structures leads to a strongly enhanced Berry curvature. This can consequently create large anomalous Hall and Nernst effects.

In this work, we provide a comprehensive study of the intrinsic anomalous transport properties for magnetic cubic full Heusler compounds and we illustrate that several Heusler compounds outperform the best so far reported materials. Additionally, the results reveal the general importance of mirror planes in combination with magnetism for giant anomalous Hall and Nernst effects, which should be valid for all linear responses (spin Hall effect, spin orbital torque, etc.) dominated by intrinsic contributions.

MA 6: Focus Session: Spin-Charge Interconversion (joint session MA/HL)

While classical spintronics has traditionally relied on ferromagnetic metals as spin generators and spin detectors, a new approach called spin-orbitronics exploits the interplay between charge and spin currents enabled by the spin-orbit coupling (SOC) in non-magnetic systems. Efficient spin-charge interconversion can be realized through the direct and inverse Edelstein effects at interfaces where broken inversion symmetry induces a Rashba SOC. Although the simple Rashba picture of split parabolic bands is usually used to interpret such experiments, it fails to explain the largest conversion effects and their relation to the actual electronic structure.

Organizer: Ingrid Mertig (University Halle-Wittenberg)

Time: Tuesday 13:30–16:45 Location: H5

Invited Talk MA 6.1 Tue 13:30 H5

Spin-charge interconversion with oxide 2-dimensional electron gases — •Manuel Bibes — Unité Mixte de Physique CNRS/Thales

Oxide 2-dimensional electron gases (2DEGs) display a wide range of functionalities including Rashba spin-orbit coupling (SOC), which offers exciting opportunities for spintronics. In this talk, I will show that the 2DEG that forms at the interface of SrTiO3 (STO) with LaAlO3[1] or reactive metals such as Al[2,3] may be exploited to efficiently interconvert spin and charge currents. By applying a gate voltage, we tune the position of the Fermi level in the complex multi-orbital structure of STO, which results in a strong variation of the conversion amplitude[4]. This can be related to the band structure through ARPES experiment and tight-binding calculations. I will present results from both spin-charge conversion where spins are injected by spin pumping in a FMR cavity and detected as a transverse voltage[5], and from charge-spin conversion probed through the bilinear magnetoresistance (BMR). Using a semi-classical model, the analysis of the BMR amplitude yields a good estimate of the Rashba coefficient[6]. In a second part, I will present gate-controlled, all-electrical spin current generation and detection in planar nanodevices only based on a STO 2DEGs[7].

[1] Ohtomo et al, Nature 2004, 427, 423. [2] Rödel et al, Adv. Mater. 2016, 28, 1976. [3] Vicente-Arche et al, PR Mater. 2021, 5, 064005. [4] Lesne et al, Nat. Mater 2016, 15, 1261. [5] Vaz et al, Nat. Mater. 2019, 18, 1187. [6] Vaz et al, PR Mater. 2020, 4, 071001. [7] Trier et al, Nano Lett. 2020, 20, 395.

Invited Talk MA 6.2 Tue 14:00 H5

Spin-to-charge current conversion for logic devices — •Felix Casanova — CIC nanoGUNE, San Sebastian, Basque Country, Spain

The integration of logic and memory in spin-based devices, such as the recent MESO proposal by Intel [1], could represent a post-CMOS paradigm. A key player is the spin Hall effect (SHE), which allows to electrically create or detect pure spin currents without using ferromagnets (FM). Understanding the different mechanisms giving rise to SHE allows to optimize spin-to-charge conversion (SCC) in heavy metals. With this knowledge, we developed a novel and simple FM/Pt nanodevice to readout the in-plane magnetic state of the FM electrode using SHE [2]. The spin-orbit based detection allows us to independently enhance the output voltage (needed to read the in-plane magnetization) and the output current (needed for cascading circuit elements) with downscaling of different device dimensions, which are necessary conditions for implementing the MESO logic [1].

Finally, I will present a radically different approach to further enhance SCC. By engineering a van der Waals heterostructure which combines graphene with a transition metal dichalcogenide, we first demonstrated SHE in graphene due to spin-orbit proximity [3]. The combination of long-distance spin transport and SHE in the same material gives rise to an unprecedented SCC efficiency, making graphene-based systems excellent candidates for MESO logic [1,2].

[1] Manipatruni et al., Nature 565, 35 (2019); [2] Pham et al., Nature Electron. 3, 309 (2020); [3] Safeer et al., Nano Lett. 19, 1074 (2019); Herling et al., APL Mater. 8, 071103 (2020).

Invited Talk MA 6.3 Tue 14:30 H5

Electrical and thermal generation of spin currents by magnetic graphene — •B.J van Wees[1], T.S. Ghiasi[1], A.A. Kaverzin[1], D.K. de Wal[1], A.H. Dismukes[2], and Bart Wees[2] — [1]Zernike Institute for Advanced Materials, Groningen, The Netherlands — [2]Department of Chemistry, Colombia University, New York, NY, USA

I will introduce proximity effects in Van der Waals heterostructures of graphene and materials with strong spin orbit interaction or magnetic 2D materials. Then I will discuss recent experiments [1] where we demonstrate with (non)local spin transport experiments that the proximity of the antiferromagnet CrSBr introduces a strong spin dependent conductivity (with a polarization of about 24%) in (bilayer) graphene. The strength of the exchange field is estimated to be about 170T, implying that the graphene has become magnetic by proximity. This also resulted in the observation of a spin-dependent Seebeck effect. These results were recently confirmed using non-magnetic injector/detector electrodes [2] Fimally I will indicate some new (device) functionalities made possible by this strong proximity inducedspin-charge coupling in graphene [1] T.S. Ghiasi et al., Nature Nanotech. 16, 788, Vol 18, 2021 [2] A.A. kaverzin et al., in preparation

15 min. break.

Invited Talk MA 6.4 Tue 15:15 H5

Ferroelectric switching of spin-to-charge conversion in GeTe — •Christian Rinaldi — Dipartimento di Fisica, Politecnico di Milano, 20133 Milano, Italy

Scalable and energy efficient magneto-electric spin-orbit (MESO) logic has been recently proposed by Intel as technologically suitable computing alternative to CMOS devices, towards attojoule electronics [1]. The MESO device comprises a magnetoelectric unit to drive a magnetic memory, while the read-out is perfomed exploiting spin-to-charge conversion in materials with large spin-orbit coupling.

Here we show that the ferroelectric Rashba semiconductor germanium telluride offers memory as well as spin-orbit read-out in a single material compatible with silicon, thus offering the opportunity for a great simplification of the MESO structure. Here we first demonstrate the robust control of ferroelectricity through gating. Then, by spin pumping measurements in Fe/GeTe, we reveal the ferroelectric control of its sizeable spin-to-charge conversion. These results pave the way to low power spin-orbit logic devices beyond-CMOS. [1] S. Manipatruni, Nature 565, 35 (2019); [2] S. Varotto et al., arXiv preprint, arXiv:2103.07646 (2021).

Invited Talk MA 6.5 Tue 15:45 H5

Theory of spin and orbital Edelstein effects in a topological oxide two-dimensional electron gas — •Annika Johansson[1], Börge Göbel[1,2], Jürgen Henk[1], Manuel Bibes[3], and Ingrid Mertig[1] — [1]Martin Luther University Halle-Wittenberg, Halle, Germany — [2]Max Planck Institute of Microstructure Physics, Halle, Germany — [3]Unité Mixte de Physique CNRS/Thales, Université Paris-Sud, Université Paris-Saclay, Palaiseau, France

$SrTiO_3$ (STO)-based two-dimensional electron gases (2DEGs) provide a highly efficient spin-to-charge conversion [1], also known as inverse Edelstein effect [2,3]. Recently, an extremely large spin-to-charge conversion efficiency was demonstrated in the 2DEG at the interface between STO and Al [4]. The application of a gate voltage leads to a strong variation and even sign changes of the spin-to-charge conversion.

We explain this unconventional gate dependence of the (inverse) spin Edelstein effect from a theoretical perspective by Boltzmann transport calculations within a multiorbital tight-binding model. Further, we report on the electrically induced magnetization originating from the orbital moments, known as orbital Edelstein effect [5]. At STO interfaces the orbital Edelstein effect exceeds the spin Edelstein effect by more than one order of magnitude.

[1] E. Lesne *et al.*, Nat. Mater. **15**, 1261 (2016)
[2] V. M. Edelstein, Solid State Commun., **73**, 233 (1990)
[3] K. Shen *et al.*, Phys. Rev. Lett. **112**, 096601 (2014)
[4] D. Vaz *et al.*, Nature Materials **18**, 1187 (2019)
[5] A. Johansson *et al.*, Phys. Rev. Research **3**, 013275 (2021)

Invited Talk MA 6.6 Tue 16:15 H5

Nonlinear magnetoresistance and Hall effect from spin-momentum locking — •Giovanni Vignale — University of Missouri

Surface states of topological insulators exhibit the phenomenon of spin-momentum locking, whereby the orientation of an electron spin is determined by its momentum. Recently a link has been discovered between the spin texture of these states and a new type of nonlinear magnetoresistance, which depends on the relative orientation of the current with respect to the magnetic field as well as the crystallographic axes, and scales linearly with both the applied electric and magnetic fields. The nonlinear magnetoresistance originates from the conversion of a non-equilibrium spin current into a charge current under the application of an external magnetic field. Additionally, it has been found that the nonlinear planar Hall effect, manifested as a transverse component of the nonlinear current, exhibits a Pi/2 phase shift with respect to the nonlinear longitudinal current, in marked contrast to the usual Pi/4 phase difference that exists between the linear planar Hall current and the linear longitudinal current in typical topological insulators and transition metal ferromagnets. In this talk I review the development of the theory vis-a-vis experiments done on the surface of topological insulator Bi_2Se_3 films and other materials.

MA 7: Skyrmions I (joint session MA/KFM)

Time: Wednesday 10:00–13:15 Location: H5

Invited Talk MA 7.1 Wed 10:00 H5

Anatomy of skyrmion-defect interactions and their impact on detection protocols — •Samir Lounis — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Magnetic skyrmions are topological swirling spin-textures with enormous potential for new technologies that store, transport and read information. However, imperfections intrinsic to any real device lead to pinning or repulsion of skyrmions, generate complexity in their motion and challenge their application as future bits of information. I will discuss our first-principles investigations of the electronic, magnetic and transport properties of single skyrmions interacting with 3d and 4d impurities embedded in PdFe/Ir(111). We found that the skyrmions energy landscapes have a universal shape as function of the defect's electron filling, enabling predictions of the repulsive or attractive nature of the impurity [1]. This finding can be used to design complex energy profiles with targeted properties via atom-by-atom manufacturing of multi-atomic defects [2,3]. Finally, I address how the latter affect the electronic structure and the chiral orbital magnetism, with consequences for the efficiency of skyrmion detection protocols [4], either all-electrical or optical.

– Work funded by Horizon 2020–ERC (CoG 681405–DYNASORE).

[1] Fernandes et al., Nat. Commun. 9, 4395 (2018); [2] Arjana et al. Sci. Rep. 10, 14655 (2020); [3] Fernandes et al., JPCM 32, 425802 (2020); [4] Fernandes et al., Nat. Commun. 11, 1602 (2020).

MA 7.2 Wed 10:30 H5

In the eye of the storm – A high resolution view at the details of the 3D magnetic texture of Skymions tubes — S. Schneider[1,2], D. Wolf[2], A. Lubk[2], U.K. Rössler[1], A. Kovács[3], M. Schmidt[4], R.E. Dunin-Borkowski[3], B. Büchner[2], and •B. Rellinghaus[1] — [1]Dresden Center for Nanoanalysis, TU Dresden, Dresden, Germany — [2]IFW Dresden, Dresden, Germany — [3]FZ Jülich, Jülich, Germany — [4]MPI CPfS, Dresden, Germany

Low temperature holographic vector field electron tomography in an external magnetic field was used to quantitatively reconstruct the 3D magnetic texture of skyrmion tubes (SkTs) in an FeGe needle [1]. The resulting high-resolution 3D magnetic images reveal various previously unseen details of the SkTs in FeGe. Our findings include the occurrence of local deviations from a homogeneous Bloch character within the tubes. They highlight the collapse of the skyrmion texture upon approaching the surfaces of the needle, provide evidence for the coexistence of longitudinal and transverse skyrmion textures, and reveal an axial modulation of the SkTs that is found to be strongly correlated among neighboring tubes in the needle. Based on the quantitative 3D magnetic induction data, we have calculated spatially resolved energy density maps across the SkTs that provide experimental evidence for the energetic stabilization of these magnetic solitons through an energy gain due to the Dzyaloshinskii-Moryia interaction, which overcompensates the exchange energy in the tube centers. Details of the novel experimental setup and limitations of the approach will be discussed.

[1] D. Wolf et al., arXiv:2101.12630 [cond-mat.mtrl-sci]

MA 7.3 Wed 10:45 H5

Real-space observation of skyrmion dynamics in an insulating magnet with a small heat gradient — Xiuzhen Yu[1], Fumitaka Kagawa[1,2], Shinichiro Seki[2], Masashi Kubota[1], •Jan Masell[1], Fehmi S. Yasin[1], Kiyomi Nakajima[1], Masao Nakamura[1], Masashi Kawasaki[1,2], Naoto Nagaosa[1,2], and Yoshinori Tokura[1,2] — [1]RIKEN CEMS, Wako, Japan — [2]University of Tokyo, Tokyo, Japan

Magnetic skyrmions are whirls in the magnetization with a non-trivial real-space topology. They are frequently discussed as potential building blocks for future information technology devices due to their topological protection and high mobility: Skyrmions can be moved by electrical currents and magnetic field gradients. It was also proposed to move skyrmions by magnons or thermal gradients [1].

We report the first observation of skyrmion dynamics in a linear thermal gradient. While nanometer-sized skyrmions remain pinned even with large thermal gradients [2], we observe a depinning threshold on the order of only 10 K/m in the insulating chiral magnet Cu_2OSeO_3 where skyrmions are 60nm large and the Gilbert damping is low. The observed velocity on the scale of 1μm/s agrees with our estimates for skyrmion motion due to a thermally activated magnon current.

[1] L. Kong & J. Zang, PRL **111,** 067203 (2013)
[2] M. Hirschberger, J. Masell, *et al.*, PRL **125,** 076602 (2020)
[3] X.Z. Yu, J. Masell, *et al.*, preprint: https://doi.org/10.21203/rs.3.rs-156692/v1

MA 7.4 Wed 11:00 H5

Screw dislocations in chiral magnets — •Maria Azhar[1], Volodymyr Kravchuk[1,2], and Markus Garst[1] — [1]Institut für Theoretische Festkörperphysik, Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Bogolyubov Institute for Theoretical Physics of National Academy of Sciences of Ukraine, 03680 Kyiv, Ukraine

The Dyzaloshinskii-Moriya interaction stabilizes helimagnetic order in cubic chiral magnets for a large range of temperatures and applied magnetic field. In this helimagnetic phase the magnetization varies only along the helix axis, that is aligned with the applied field, giving rise to a one-dimensional periodic magnetic texture. This texture shares many similarities with generic lamellar order like cholesteric liquid crystals, for example, it possesses disclination and dislocation defects [1]. Here, we investigate both analytically and numerically screw dislocations of helimagnetic order. Whereas the far-field of these defects is universal, we find that various core structures can be realized even for the same Burgers vector of the screw dislocation. In particular, we identify screw dislocations with smooth magnetic core structures, that close to the transition to the field-polarized phase continuously connect either to vortices of the XY-order parameter or to skyrmion strings. In addition, close to zero fields we find singular core structure comprising a chain of Bloch points with alternating topological charge.

[1] P. Schoenherr et al. Nature Physics 14, 465 (2018).

MA 7.5 Wed 11:15 H5

Skyrmion Diffusion in Confined Geometries — •Jan Rothörl[1], Chengkun Song[2], Nico Kerber[1], Yuqing Ge[1], Klaus Raab[1], Boris Seng[3], Maarten Alexander Brems[1], Florian Dittrich[1], Robert Reeve[1], Jianbo Wang[2], Qingfang Liu[2], Peter Virnau[1], and Mathias Kläui[1] — [1]Institute of Physics Johannes Gutenberg-University Mainz — [2]Key Laboratory for Magnetism and Magnetic Materials of the Ministry of Education Lanzhou University China — [3]Institut Jean Lamour Université de Lorraine France

Magnetic skyrmions are topologically stabilized quasi-two-dimensional whirls of magnetization. Diffusion of skyrmions in continuous films [1] can be exploited for novel computing approaches, which often require understanding the behavior of skyrmions in confined geometries. We were studying this behavior in different confined geometries like circles, triangles and squares using experiments and coarse-grained computer simulations. Our results indicate that mobility is not only governed by skyrmion density but also by the interplay between skyrmion numbers and geometry. For triangular or square geometries, we found that this behavior is drastically dependent on the commensurability of the skyrmion number with the shape of the confinement [2].

[1] Zázvorka et al., Nat. Nanotechnol. 14, 658 (2019) [2] Song et al., Adv. Funct. Mater. 31, 2010793 (2021)

MA 7.6 Wed 11:30 H5

Effects of interlayer exchange on collapse mechanisms and stability of magnetic skyrmions — •Hendrik Schrautzer[1,2], Stephan von Malottki[1,2], Pavel F. Bessarab[2,3], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel,Germany — [2]University of Iceland, Reykjavik, Iceland — [3]ITMO University, St. Petersburg, Russia

Despite the great success of realizing magnetic skyrmions in multilayers, even at room temperature [1], very little is known about the thermal stability of skyrmions in these systems. In this study, we investigate by means of minimum energy path calculations and harmonic transition state theory the skyrmion decay mechanisms, corresponding energy barriers, and thermal collapse rates in systems incorporating several magnetic monolayers as a function of interlayer exchange coupling (IEC). The magnetic interactions within each layer are chosen so as to mimic the well-established Pd/Fe/Ir(111) system parametrized by first principles density functional theory calculations. We find that skyrmions in different monolayers collapse successively (simultaneously) for weak (strong) IEC. For intermediate IEC regime, we find a rich diversity of decay mechanisms, including the chimera collapse stabilized by IEC. Counter-intuitively, an optimal value of the IEC strength exists for a certain stacking of the magnetic layers. It corresponds to maximum skyrmion stability. We use the determined skyrmion collapse mechanisms to ultimately evaluate the skyrmion lifetime in magnetic multilayers.

[1] Moreau-Luchaire, *et al.*, Nat. Nanotechnol. 11, 444 (2016).

MA 7.7 Wed 11:45 H5

Exploring the phase diagram of thin film MnSi — •Grace Causer[1], Maria Azhar[2], Alfonso Chacon[1], Andreas Bauer[1], Thorsten Hesjedal[3], Markus Garst[2], and Christian Pfleiderer[1] — [1]Physics Department, Technical University of Munich, Garching, Germany — [2]Institute for Theoretical Solid State Physics, Karlsruhe Institute of Technology, Karlsruhe, Germany — [3]Clarendon Laboratory, University of Oxford, Oxford, United Kingdom

We have charted the magnetic phase diagram of thin film MnSi grown on a Si substrate via the magnetisation, magnetic susceptibility, planar Hall, and small-angle neutron scattering data, tracking carefully the field and temperature history. Our experimental results are supported by micromagnetic simulations, which jointly reveal a magnetic phase diagram dominated by a field-induced unwinding of an out-of-plane propagating helical wavevector. Below 2 K a discrete phase regime can be discerned unambiguously. These observations provide insights into the integral role of magnetic anisotropy and dimensionality on the low-temperature phase diagram of thin film MnSi.

MA 7.8 Wed 12:00 H5

Optimizing the skyrmion profile for technological applications — •Markus Hoffmann, Sarina Lebs, Moritz Sallermann, and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

Chiral magnetic skyrmions are of great scientific interest and of potential relevance in information technology. Important properties – such as their lifetime, mobility, and robustness with respect to external influences – depend hereby on the specific application. Thus, skyrmion properties must be tuned to outperform existing technologies.

Based on a combination of micromagnetic arguments and atomistic spin-dynamics simulations carried out with `Spirit` (https://spirit-code.github.io), we investigate the dependence of aforementioned properties on the skyrmion profile, *i.e.*, on the spatial dependence of the magnetization field, and analyze how the skyrmion profile can be tuned to optimize the skyrmion's properties. To obtain static properties, we perform LLG and GNEB simulations, which provide us the energy barrier and the corresponding saddle point structure, and combine those with HTST calculations to determine the lifetime prefactor [1]. Additionally, we perform LLG simulations to investigate the dynamics of skyrmions, including their velocity as well as the skyrmion Hall angle.

We acknowledge funding from the DARPA TEE program through grant MIPR (#HR0011831554) from DOI, and DFG through SPP-2137 and SFB-1238 (project C1).

[1] M. Hoffmann *et al.*, Phys. Rev. Lett. **124**, 247201 (2020).

MA 7.9 Wed 12:15 H5

Emergence of Magnetic Skyrmions in Ultrathin Films of Manganese on W(001) at High Magnetic Fields — •Reiner Brüning, Kirsten von Bergmann, André Kubetzka, and Roland Wiesendanger — Festkörper- und Nanostrukturphysik, Hamburg, Deutschland

Topological spin textures like skyrmions with diameters on the order of a few nanometers are promising objects for the application in the field of spintronics. Whereas typical skyrmion systems like Pd/Fe bilayers on Ir(111) [1] have a hexagonal crystal symmetry, here, we investigate a monolayer of Mn on the square lattice of W(001) using spin-polarized scanning tunneling microscopy at 4.2 K. In absence of an external magnetic field, the known magnetic ground state of a 2.2 nm spin spiral is observed [2]. Between 90° rotational domains two types of magnetic domain walls can be identified.

The measurements at 9 T show that the external magnetic field leads to a decrease in the size of the domains and initializes the transition from the spin spiral to small skyrmion areas which results in a coexistence state of the spin spiral and skyrmion phase. Inside the small skyrmionic areas, the skyrmions arrange in a hexagonal-like order, in agreement with recent simulations [3]. By high voltage pulses of 1-2 V, we can locally induce transitions between spiral phase and skyrmion phase.

[1] N. Romming *et al.*, Science, **341**, (2013)
[2] P. Ferriani *et al.*, Phys. Rev. Lett. **101**, 027201 (2008)
[3] A. K. Nandy *et al.*, Phys. Rev. Lett. **116**, 177202 (2016)

MA 7.10 Wed 12:30 H5

Application of Thermal and Induced Skyrmion Diffusion in Non-Conventional Computing — •Maarten A. Brems, Mathias Kläui, and Peter Virnau — Institute of Physics, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany

Magnetic skyrmions are two-dimensional magnetic quasi-particles with interesting properties for possible future applications in memory storage devices and non-conventional computing. We have shown that skyrmions in thin film magnetic multilayers exhibit thermal diffusion [1]. These properties make skyrmions promising candidates for signal carriers (tokens) in Brownian computing, which exploits thermal fluctuation for computations. We design a crossing-free layout for a composite half-adder module to overcome the problem that crossings generate for the fabrication of circuits [2]. To address the key issue of slow computation based on thermal excitations, we propose to combine artificial diffusion induced by an external excitation mechanism [2,3]. For magnetic skyrmions, induced diffusion by spin-orbit torques or other mechanisms can increase the computation speed by several orders of magnitude. This method can be employed to accelerate conventional Brownian computing as necessary and thereby greatly enhance the application scenarios of token-based computing for instance for low power devices such as autonomous sensors.

[1] J. Zázvorka et al., Nat. Nanotechnol. 14, 658 (2019). [2] M. A. Brems, P. Virnau and M. Kläui, ArXiv: 2107.02097 [Cond-Mat] (2021). [3] M. A. Brems, P. Virnau and M. Kläui, European patent disclosure, EP21164676.5 (2021).

MA 7.11 Wed 12:45 H5

Solitary-waves excitations and current-induced instabilities of skyrmion strings — •Volodymyr Kravchuk[1,3], Shun Okumura[2], and Markus Garst[1] — [1]Karlsruhe Institute of Technology, Germany. — [2]The University of Tokyo, Japan. — [3]Bogolyubov Institute for Theoretical Physics, Kyiv, Ukraine

Field-polarized chiral magnets possess topological line excitations where the magnetization within each cross-section perpendicular to the applied field forms a skyrmion texture. We introduce and discuss an effective field-theoretical description for the low-energy dynamics of such a skyrmion string. It predicts, in particular, that skyrmion strings support solitary waves that propagate along the string while maintaining their shape. Using integrals of motion, we derive the profile of these waves analytically, and we find quantitative agreement with numerical micromagnetic simulations [1]. In addition, we discuss the influence of a spin-polarized current on the string. Whereas it is well-known that a current flowing perpendicular to the string results in a skyrmion string motion, we demonstrate that a longitudinal current destabilizes the string. This destabilization occurs via the pumping of the Goldstone mode of the string that results in a helical-shaped string deformation that increases with time. Whereas in a clean system an infinitesimal current suffices, a finite threshold current is required to destabilize the string in the presence of disorder. Moreover, we show that this current-induced instability also holds for skyrmion lattices.

[1] V. Kravchuk, U. Rößler, J. van den Brink, M. Garst, PRB, 102, 220408(R) (2020).

MA 7.12 Wed 13:00 H5

Magnetoelastic coupling and phases in the skyrmion lattice magnet Gd_2PdSi_3 discovered by high-resolution dilatometry — •Sven Spachmann[1], Rüdiger Klingeler[1], Ahmed Elghandour[1], Matthias Frontzek[2], and Wolfgang Löser[3] — [1]Kirchhoff Institute for Physics, Heidelberg University, Germany — [2]Oak Ridge National Laboratory, Oak Ridge, USA — [3]Leibniz Institute for Solid State and Materials Research (IFW), Dresden, Germany

We report high-resolution capacitance dilatometry measurements on single crystals of the centrosymmetric skyrmion-hosting intermetallic Gd_2PdSi_3 in magnetic fields up to 15 T which are complemented by specific heat and magnetization studies. Our data enable us to complete the magnetic phase diagram and to establish yet unreported phase boundaries. We find strong magnetoelastic effects associated with antiferromagnetic order at T_{N1}= 22.3 K and T_{N2} = 19.7 K as well as an additional feature at $T^* \approx 13$ K. Grüneisen analysis shows the onset of magnetic contributions around 60 K, i.e., well above T_{N1}, and strong field effects in an applied magnetic field of 15 T are found up to 200 K (150 K) for B $\parallel$ c (B $\parallel$ a^*, i.e., B $\perp$ c). Our data allow us to extract the uniaxial pressure dependence of the different phase boundaries. We elucidate thermodynamic properties of the recently discovered skyrmion lattice phase and show that it is strongly enhanced by uniaxial pressure.

MA 8: INNOMAG e.V. Dissertationspreis / Ph.D. Thesis Prize (2020)

The Working Group Magnetism (Arbeitsgemeinschaft Magnetismus der DPG) awards a dissertation prize whose aim is to recognise outstanding research done within the framework of a doctorate and communication of this research in an excellent way, both verbally and in writing. The prize is kindly supported by INNOMAG e.V. In this finalists session, pre-selected nominees will present and defend their dissertation. Afterwards, the prize committee decides on the winner of the INNOMAG e.V. Dissertation Prize 2020 and the award of 1000 EURO.

Time: Wednesday 10:00–12:10 Location: H2

MA 8.1 Wed 10:00 H2

Spin-orbit driven transport: Edelstein effect in Rashba systems and topological materials — •Annika Johansson — Martin Luther University Halle-Wittenberg, Halle, Germany

A charge current driven through a system with broken inversion symmetry can generate a spatially homogeneous spin polarization. This phenomenon is known as Edelstein effect [1,2]. Using semiclassical Boltzmann transport theory, I investigate the Edelstein effect in two- and three-dimensional Rashba systems and topological materials. Whereas the current-induced spin density in conventional isotropic Rashba systems is in-plane and perpendicular to the charge current, I show that the direction as well as the magnitude of the induced spin density can be strongly modified in systems with reduced symmetry, which provides new opportunities to control and manipulate the electrically induced magnetization [3].

Further, I predict a highly efficient Edelstein effect in three-dimensional Weyl semimetals, mainly originating from their topological surface states due to their favorable Fermi surface geometry, their strong spin polarization and the enhanced momentum relaxation time [4]. In comparison to Rashba systems, the Edelstein effect in Weyl semimetals is enhanced by at least one order of magnitude.

[1] A. Aronov and Y. Lyanda-Geller, JETP Lett. **50**, 431 (1989).
[2] V. Edelstein, Solid State Commun. **73**, 233 (1990).
[3] A. Johansson et al., Phys. Rev. B **93**, 195440 (2016).
[4] A. Johansson et al., Phys. Rev. B **97**, 085417 (2018).

MA 8.2 Wed 10:25 H2

Highly Efficient Domain Wall Motion in Ferrimagnetic Bilayer Systems at the Angular Momentum Compensation Temperature — •Robin Bläsing — RWTH Aachen University, Aachen, Germany

Within the last decade, the efficiency of current-induced motion of magnetic domain walls (DWs) has been enhanced tremendously by utilizing the exchange coupling torque (ECT) in synthetic antiferromagnetic structures. The focus of the present study is on exploring this mechanism in ferrimagnetic layers consisting of a transition metal layer and a rare earth metal layer which couple antiferromagnetically. The DWs are moved by nanosecond-long current pulses and their velocity is determined by using Kerr microscopy at various temperatures. It is shown here that the motion is most efficient at a certain temperature T_A at which the angular momenta of both layers compensate each other and the ECT is maximized. Since the device temperature is significantly increased by the current pulses, taking into account Joule heating is of major importance when determining T_A. The results of current-induced domain wall motion in the present thesis can be used for the development of novel storage devices and improving their efficiency.

MA 8.3 Wed 10:50 H2

Spintronics with Terahertz Radiation: Probing and driving spins at highest frequencies — •Tom Sebastian Seifert — Freie

Universität Berlin, Berlin, Germany

Spin-orbit interaction (SOI) will be of central importance for future spin-based electronics (spintronics) as it permits, for example, the conversion of charge into spin currents and vice versa via the spin Hall effect. It is highly interesting to study spin dynamics at terahertz (THz) frequencies because spintronic devices should eventually operate at THz rates. In our experiments, we employ femtosecond optical and THz pulses to trigger ultrafast spin and charge dynamics in magnetic thin-film stacks featuring a strong SOI. In particular, we study THz emission from multilayers consisting of magnetic and a nonmagnetic materials [1,2,3]. By varying the magnetic layer material, we aim at identifying the different mechanisms that can lead to the ultrafast generation of spin currents. Such mechanisms include spin-voltage-driven transport [4] by conduction-band electrons in metal-metal stacks and magnon-mediated transfer of spin angular momentum in insulator-metal stacks [5]. Finally, we turn from probing to driving spins at highest speeds by demonstrating the picosecond writing speed of an antiferromagnetic memory element based on CuMnAs employing strong THz pulses[6]. References: [1] T. Seifert et al., Nat. Phot. 10 (2016). [2] T. Kampfrath et al., Nat. Nanotech. 8 (2013). [3] T. Seifert et al., APL, 110, 252402 (2017). [4] R. Rouzegar et al., ArXiv 2103.11710 (2021) [5] T. Seifert et al., Nat. Commun. 9 (2018). [6] K. Olejnik et al., Science Adv. 4 (2018).

MA 8.4 Wed 11:15 H2

Linear and nonlinear spin waves in nanoscale magnonic structures for data processing — •Qi Wang — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern, Germany

Spin waves, and their quanta magnons, attract attention as novel data carriers instead of electrons in future low-energy data processing units due to their short wavelength, low losses, and abundant nonlinear phenomena. Although separated spin-wave logic gates have already been demonstrated, the smallest sizes of these elements are in the ranges of a few micrometers and are not competitive with the current state-of-the-art CMOS technology. Moreover, the realization of an integrated magnonic circuit is still an unresolved challenge.

The objective of this talk is to present a nanoscale magnon directional coupler as a universal data processing unit for performing different logic operations and suitable for the integration into a magnonic circuit. First, the spin-wave characteristics in the nanoscale waveguides were studied theoretically and experimentally. Based on this knowledge, a nanoscale directional coupler was designed and its linear and nonlinear functionalities were studied using Brillouin Light Scattering spectroscopy. Following, the first integrated magnonic circuit consisting of two couplers and performing half-adder functionality was studied numerically. Finally, we introduced the inverse-design method into the field of magnonics and demonstrated its high performance, flexibility, and potential. These studies were supported by ERC StG MagnonCircuits.

Short break followed by bestowal of INNOMAG e.V. Dissertationspreis / Ph.D. Thesis Prize (2020)

MA 9: INNOMAG e.V. Diploma/Master Prize (2021)

Die Arbeitsgemeinschaft Magnetismus der DPG hat einen Diplom-/Masterpreis ausgeschrieben, welcher auf der Online-Tagung der DPG 2021 vergeben wird. Ziel des Preises ist die Anerkennung herausragender Forschung im Rahmen einer Diplom-/Masterarbeit und deren exzellente Vermittlung in Wort und Schrift. Im Rahmen dieser Sitzung tragen die besten der für ihre an einer deutschen Hochschule durchgeführten Masterarbeit Nominierten vor. Im direkten Anschluss entscheidet das Preiskommittee über den Gewinner bzw. die Gewinnerin des INNOMAG e.V. Diplom/Master-Preises 2021 in Höhe von 500 EURO. Talks will be given in English!

Time: Wednesday 12:30–14:20 Location: H2

MA 9.1 Wed 12:30 H2

Orbital Magnetic Moment of Magnons — •Robin R. Neumann[1], Alexander Mook[1,2], Jürgen Henk[1], and Ingrid Mertig[1] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany — [2]Department of Physics, University of Basel, Basel, Switzerland

It is commonly accepted that magnons—collective excitations in a magnetically ordered system—carry a spin of $1\hbar$ or, phrased differently, a magnetic moment of $g\mu_\mathrm{B}$. In this talk, I demonstrate that magnons carry magnetic moment beyond their spin magnetic moment. Our rigorous quantum theory uncovers a magnonic orbital magnetic moment brought about by spin-orbit coupling. We apply our theory to two paradigmatic systems where the notion of orbital moments manifests itself in novel fundamental physics rather than just quantitative differences. In a coplanar antiferromagnet on the two-dimensional kagome lattice the orbital magnetic moment gives rise to an orbital magnetization. While the spin magnetization is oriented in the kagome plane, the orbital magnetization also has a finite out-of-plane component leading to 'orbital weak ferromagnetism.' The insulating collinear pyrochlore ferromagnet $Lu_2V_2O_7$ exhibits a 'magnonic orbital Nernst effects,' i. e. transversal currents of orbital magnetic moment induced by a temperature gradient. The orbital magnetization and the orbital Nernst effect in magnetic insulators are two signatures of the orbital magnetic moment of magnons.

MA 9.2 Wed 12:50 H2

Angle-Dependent Magnetotransport in Semimetals — •Felix Spathelf[1,2,3], Benoît Fauqué[2], and Kamran Behnia[1] — [1]LPEM (CNRS), ESPCI Paris, Université PSL, Paris, France — [2]JEIP, USR 3573 CNRS, Collège de France, Université PSL, Paris, France — [3]Universität Heidelberg

We report on studies of the electrical and thermoelectric transport properties of semimetals with high mobilities at temperatures down to 2 K and in magnetic fields up to 13.8 T to understand their remarkable amplitude. The Seebeck effect, magnetoresistance and the Hall effect of bismuth were measured and compared to the results of a theoretical model, which was developed on the basis of semiclassical theory. The model perfectly describes the zero field Seebeck coefficient from 10 K to 300 K and agrees well with experimental data in a large part of the (T, B, Θ)-space. It is shown that the contribution of the Nernst coefficient to the Seebeck effect has to be taken into account when explaining the latter. In addition, the Seebeck effect of bismuth is at least up to a temperature of 120 K significantly affected by Landau quantisation. Furthermore, the influence of the sample shape on the angle-dependent magnetoresistance is studied in bismuth and antimony. At 40 K, magnetoresistance shows the symmetry inherited from the Fermi surface topology. Upon cooling below 20 K, this symmetry is lost in bismuth, but not in antimony. The loss of symmetry is sample-dependent and can be traced back to a robust surface contribution to conductivity. Besides, the highest magnetoresistance ever observed was measured in bismuth, amounting to $1.56 \cdot 10^8$ under a magnetic field of 12.8 T.

MA 9.3 Wed 13:10 H2

Optimizing the magnetocaloric effect in all-d-metal Ni-Co-Mn-Ti Heusler alloys — •Benedikt Beckmann and Oliver Gutfleisch — TU Darmstadt, 64287 Darmstadt, Germany

Magnetocaloric refrigeration is a promising cooling technology which could be an environmentally friendly and more energy efficient alternative to conventional vapor compression refrigeration. Among magnetocaloric materials, Ni-Mn based Heusler alloys, showing a first-order magnetostructural phase transition, are promising candidates. In this study, a systematic analysis of all-d-metal $Ni_{50\text{-}x}Co_xMn_{50\text{-}y}Ti_y$ Heusler alloys is carried out [1]. Due to their enhanced mechanical stability, these alloys can also be utilized in cooling cycles that apply magnetic field and pressure as external stimuli to induce the phase transition. A systematic heat treatment optimization is carried out, resulting in a substantial decrease of the transition width down to only 4 K. The microstructural differences between as-cast and differently annealed alloys are analyzed in detail by *in-situ* polarized light microscopy. As a result, large isothermal entropy changes up to 38 $Jkg^{-1}K^{-1}$ are achieved in 2 T. The adiabatic temperature change is measured directly for this material system and values up to -3.8 K for the first field application and -0.8 K under cyclic conditions are obtained in moderate magnetic field changes of 1.93 T.

We acknowledge financial support from DFG (CRC/TRR 270) and ERC (Adv. Grant No. 743116).

[1] A. Taubel & B. Beckmann et al., Acta Materialia 201, 425-434 (2021)

MA 9.4 Wed 13:30 H2

High-Resolution Dilatometry Studies on Transition Metal Oxides — •Marco Hoffmann, Kaustav Dey, Sven Spachmann, and Rüdiger Klingeler — Kirchhoff Institute for Physics, Heidelberg University, INF 227, D-69120 Heidelberg, Germany

The thermodynamic properties of the transition metal oxides $CoTiO_3$ and $R_4Ni_3O_{10}$ (R = La, Pr, Nd) were studied by means of high-resolution capacitance dilatometry. Thermal expansion and magnetostriction measurements were performed in temperatures down to 2 K and fields up to 15 T. For $CoTiO_3$ a strong magnetoelastic coupling is found and its phase diagram is constructed [1]. A phenomenological domain model is applied to explain its magnetostriction and magnetization data. Furthermore, a hydrostatic pressure dependence of the Néel temperature ($T_N = 37\,K$) of $dT_N/dp = 0.8\,K/GPa$ is derived by a Grüneisen analysis. This analysis also shows a single dominant energy scale in $CoTiO_3$ below 50 K. For the $R_4Ni_3O_{10}$ compounds, on the other hand, Grüneisen analyses indicate competing interactions just below the metal-to-metal transition temperatures T_M and pressure dependencies of $dT_M/dp = -8\,K/GPa$, $-4\,K/GPa$ and $-3\,K/GPa$ for R = La, Pr, Nd, respectively [2]. Clear anomalies in the thermal expansion at T_M for all three compounds show strong coupling between the electronic and lattice degrees of freedom. [1] M. Hoffmann, K. Dey, J. Werner, R. Bag, J. Kaiser, H. Wadepohl, Y. Skourski, M. Abdel-Hafiez, S. Singh, and R. Klingeler, Phys. Rev. B (accepted 2021) [2] D. Rout, S. R. Mudi, M. Hoffmann, S. Spachmann, R. Klingeler, and S. Singh, Phys. Rev. B **102**, 195144 (2020).

Short break followed by bestowal of INNOMAG e.V. Diploma/Master Prize (2021)

MA 10: Focus Session: Higher-Order Magnetic Interactions - Implications in 2D and 3D Magnetism I

Materials in which the magnetic moments order or cooperate in unusual ways underpin a plethora of physical phenomena, from strong magnetoelectric effects to topological quasiparticles, thus holding great promise for future spintronic and quantum computing applications. Magnetic interactions are the fundamental quantities that explain the complex magnetic phase diagrams and exotic excitation spectra of these intriguing materials. Recent theoretical and experimental developments have led to a realization of a pivotal role played by higher-order magnetic interactions in stabilizing intricate magnetic structures. The 4-spin 3-site interaction stabilizes an up-up-down-down state, which can become chiral. Theoretically, novel 4-spin chiral interactions and even 6-spin (chiral-chiral) couplings might explain the emergence of complex short-period 3D magnetic structures, and could open a path to the discovery of materials hosting 3D topological magnetization textures, such as magnetic hopfions. Experimentally, 4-spin interactions are conjectured to play a central role in skyrmions lattice formation in frustrated centrosymmetric materials. This area of research will make a strong impact in the field of magnetism in the upcoming years.

Organizers: Samir Lounis (University of Duisburg-Essen and Forschungszentrum Jülich), Manuel dos Santos Dias and Stefan Blügel (Forschungszentrum Jülich), Jonathan White (Paul Scherrer Institut)

Time: Wednesday 13:30–16:30 Location: H5

Invited Talk MA 10.1 Wed 13:30 H5

Topological spin crystals stabilized by itinerant frustration — •Yukitoshi Motome — The University of Tokyo, Tokyo, Japan

Topological spin crystals, which are periodic arrays of topological spin textures such as vortices, skyrmions, and hedgehogs, have attracted numerous attention for the potential use of their magnetic, transport, and optical properties for future spintronics and quantum computing. For materializing such unconventional magnetism, it is crucially important to understand the relevant magnetic interactions. Widely known is the Dzyaloshinskii-Moriya interaction, which stabilizes swirling spin textures in competition with ferromagnetic exchange interactions. Here, we theoretically study a different mechanism driven by effective magnetic interactions arising from itinerant nature of electrons. We show that, in addition to the well-known Ruderman-Kittel-Kasuya-Yosida interaction, multiple-spin interactions naturally arise as higher-order contributions from the spin-charge coupling in itinerant magnets. They are intrinsically long-ranged and have characteristic wave numbers specified by the Fermi surfaces, like the Ruderman-Kittel-Kasuya-Yosida interaction. We find that frustration among such long-range multiple-spin interactions, which we call itinerant frustration, can stabilize a variety of topological spin crystals with unique features, even in centrosymmetric systems where the Dzyaloshinskii-Moriya interaction is absent. We discuss our results with recent advances in experiments.

Invited Talk MA 10.2 Wed 14:00 H5

Formation of spin-hedgehog lattices and giant topological transport properties in chiral magnets — •Naoya Kanazawa — University of Tokyo, Tokyo, Japan

The last few years have seen remarkable progress in the discovery of versatile topological spin crystals with different topology, dimensionality and density. In parallel, the crucial role of higher-order magnetic interactions among multiple spins has been gradually recognized. In this talk, we report the formation of three-dimensional topological spin texture, i.e., the lattices of spin hedgehogs in a chiral magnet MnGe and its relatives. Their nature of twisting spins in short periods imply the relevance of such higher-order interactions. We also introduce various giant transport properties, such as topological Hall and thermoelectric effects, which may originate from the effective monopole field and dynamical fluctuations of spin hedgehogs.

This work is done in collaboration with K. Akiba, T. Arima, R. Arita, S. Awaji, C. D. Dewhurst, Y. Fujishiro, M. Ichikawa, K. Ishizaka, H. Ishizuka, F. Kagawa, K. Kakurai, Y. Kawamura, M. Kawasaki, A. Kikkawa, S. Kimura, K. Kindo, T. Koretsune, A. Kitaori, Y. Kozuka, R. Kurihara, A. Matsuo, H. Mitamura, A. Miyake, D. Morikawa, T. Nakajima, A. Nakamura, N. Nagaosa, K. Ohishi, H. M. Rønnow, K. Shibata, T. Shimojima, J. Shiogai, Y. Taguchi, M. Tokunaga, Y. Tokura, A. Tsukazaki, V. Ukleev, J. S. White, X. Z. Yu.

Invited Talk MA 10.3 Wed 14:30 H5

Topological-chiral magnetic interactions driven by emergent orbital magnetism — •Sergii Grytsiuk[1], Jan-Philipp Hanke[1], Markus Hoffmann[1], Juba Bouaziz[1], Olena Gomonay[2], Gustav Bihlmayer[1], Samir Lounis[1], Yuriy Mokrousov[1,2], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg University Mainz, 55099 Mainz, Germany

Based on microscopic arguments and a systematic total energy expansion, further validated by electronic structure calculations, we discover a new class of magnetic interactions of chiral nature originating from the so-called topological orbital moment (TOM) of electrons in noncoplanar magnets [1]. The TOMs, $\mathbf{L}^{\mathrm{TO}}$, emerge from the scalar spin chirality of three magnetic moments, $\mathbf{S}_i \cdot (\mathbf{S}_j \times \mathbf{S}_\mathbf{k})$. As a result of a six-spin– or a four-spin interaction, they can interact with each other and interact with the spins of the underlying lattice. In the context of B20-type chiral magnet MnGe, these novel interactions can dominate over the Dzyaloshinskii-Moriya interaction in selecting the chiral ground state, providing possibly a key for solving the open question of the recently observed complex 3D magnetic structures. By providing a mechanism for the physical realization of the Faddeev model with hopfion solutions, topological-chiral interactions might play a key role in triggering the formation of 3D magnetic solitons without the assistance of an external magnetic field.

[1] S. Grytsiuk *et al.*, Nature Commun **11**, 511 (2020).

15 min. break.

Invited Talk MA 10.4 Wed 15:15 H5

Complex spin structures in thin transition metals films and their oxides — •Matthias Bode — Physikalisches Institut, Experimentelle Physik II, Universität Würzburg, Germany

The term "magnetism" subsumes a plethora of interactions originating from various physical mechanisms. Their competition often results in highly complex spin structures, such that the specific origin is masked and can only be unraveled by combining experiment and theory. For example, for an Fe monolayer on Rh(111) an up-up-down-down (↑↑↓↓) spin structure was predicted by DFT [1] which was only later understood to originate from the previously unconsidered four-spin–three-site beyond-Heisenberg interaction [2]. We could indeed confirm this ↑↑↓↓ spin structure experimentally by spin-polarized STM. Three orientational domains were observed, the field-dependent behavior of which is surprisingly complex, potentially due to uncompensated spins at domain boundaries. Furthermore, in a recent survey of submonolayer transition metal oxides on Ir and Pt(001) we observed highly complex spin structures which appears to be driven by a Dzyaloshinskii-Moriya-enhanced Ruderman-Kittel-Kasuya-Yosida (RKKY) interaction [3]. However, the orientation of the Dzyaloshinskii-Moriya vector and the observation of a long-wavelength spin rotation have not yet been adequately explained [4].

[1] A. Al-Zubi *et al.*, Phys. Status Solidi B **248**, 2242 (2011)
[2] A. Krönlein *et al.*, Phys. Rev. Lett. **120**, 207202 (2018)
[3] M. Schmitt *et al.*, Nature Comm. **10**, 2610 (2019)
[4] M. Schmitt *et al.*, Phys. Rev. B **100**, 054431 (2019)

MA 10.5 Wed 15:45 H5

Two-dimensional atomic-scale spin textures in Fe monolayers — André Kubetzka, Roland Wiesendanger, and •Kirsten von Bergmann — Department of Physics, University of Hamburg, Germany

Higher-order interactions can induce two-dimensionally modulated magnetic ground states at zero magnetic field, and spin-polarized scanning tunneling microscopy (SP-STM) is a powerful tool to characterize such spin structures down to the atomic scale [1-3].

Using SP-STM we have recently observed several different square or hexagonal magnetic ground states in Fe monolayers in contact with Rh and Ir layers. The details of the resulting states with magnetic periods on the order of one nanometer depend critically on the stacking of the Fe layer and the number of adjacent Rh or Ir layers [1,4-7].

[1] S. Heinze *et al.*, Nature Phys. **7**, 713 (2011).
[2] Y. Yoshida *et al.*, Phys. Rev. Lett. **108**, 087205 (2012).
[3] J. Spethmann *et al.*, Phys. Rev. Lett. **124**, 227203 (2020).
[4] K. von Bergmann *et al.*, Nano Lett. **15**, 3280 (2015).
[5] N. Romming *et al.*, Phys. Rev. Lett. **120**, 207201 (2018).
[6] A. Kubetzka *et al.*, Phys. Rev. Materials **4**, 081401(R) (2020).
[7] M. Gutzeit *et al.*, (in preparation).

MA 10.6 Wed 16:00 H5

Three- and four-spin interactions from first-principles: calculations and properties — •Sergiy Mankovsky, Svitlana Polesya, and Hubert Ebert — Dept. Chemistry, LMU Munich, Butenandtstrasse 11, D-81377 Munich, Germany

We discuss an extension of the Heisenberg Hamiltonian by accounting for the contributions of higher order interactions calculated on a first-principles level, that can play a crucial role for the stabilization of various types of non-collinear magnetic structure, as for example skyrmions. All calculations are performed by making use of the fully relativistic Korringa-Kohn-Rostoker (KKR) Green function method. We focus on the three-spin and four-spin interaction parameters concerning their calculation and properties. In particular, we discuss their controversial interpretation and the origin of the three-spin chiral interaction (TCI) represented by an expression worked out recently (Phys. Rev. B, **101**, 174401 (2020)). An interpretation of the TCI is suggested, showing explicitly its dependence on the relativistic spin-orbit coupling and on the topological orbital susceptibility (TOS). This is based on an expression for the TOS that is worked out on the same footing as the expression for the TCI. Using first-principles calculations we demonstrate in addition numerically the common topological properties of the TCI and TOS.

MA 10.7 Wed 16:15 H5

Role of higher-order exchange interactions for skyrmion stability — •Souvik Paul[1,2], Soumyajyoti Haldar[2], Stephan von Malottki[2], and Stefan Heinze[2] — [1]Peter Grünberg Institute (PGI-1) and Institute for Advanced Simulation (IAS-1), Forschungszentrum Jülich, Germany — [2]Institute of Theoretical Physics and Astrophysics, Christian-Albrechts-Universität zu Kiel, Germany

Magnetic skyrmions have recently become a research focus as they show promise for future magnetic memory and logic devices. One key obstacle for applications is the stability of skyrmionic bits against thermal fluctuations. The importance of Heisenberg exchange interaction, Dzyaloshinskii-Moriya interaction, magnetocrystalline anisotropy and dipole-dipole interactions in skyrmion stability has been reported. However, due to their origin from a fourth-order perturbation theory, non-Heisenberg higher-order exchange interactions (HOI) – the biquadratic, the three-site-four-spin and the four-site-four-spin interaction – have so far been neglected. Using *ab-initio* parametrized atomistic spin dynamics simulations in ultrathin films, we demonstrate that the HOI play an important role for skyrmion stability. We find that the effect of the first two HOI, to a large extent, can be included in the effective Heisenberg exchange constants. However, the four-site four spin interaction behaves qualitatively in a different way and has a large contribution on the energy barrier stabilizing skyrmions and antiskyrmions against annihilation. Our study opens up a new avenue for increasing the stability of topological spin structures.

MA 11: Posters Magnetism III

Topics: Magnonics (11.1-11.16), Terahertz Spintronics (11.17-11.23), Spintronics (other effects) (11.24-11.26), Spin Transport and Orbitronics, Spin-Hall Effects (11.27-11.32), Cooperative Phenomena: Spin Structures and Magnetic Phase Transitions (11.33-11.34)

Time: Wednesday 13:30–16:30 Location: P

MA 11.1 Wed 13:30 P

Formation of magnon polarons in ferromagnetic nanogratings — •Felix Godejohann[1], Alexey Scherbakov[1,2], Serhii Kukhtaruk[1,3], Alexander Poddubny[2], Dmytro Yaremkevych[1], Mu Wang[5], Achim Nadzeyka[4], Dmitri Yakovlev[1,2], Andrew Rushforth[5], Andrey Akimov[5], and Manfred Bayer[1,2] — [1]Experimentelle Physik 2, Technische Universität Dortmund, 44227 Dortmund, Germany — [2]Ioffe Inst., RAS, St. Petersburg, Russia — [3]Dept. of Theo. Phys., V.E. Lashkaryov Inst. of Semiconductor Phys., Kyiv, Ukraine — [4]Raith GmbH, 44263 Dortmund, Germany — [5]School of Phys. and Astronomy, Univ. of Nottingham, UK

In our time-resolved experiments with ferromagnetic nanogratings (NGs), the formation of coherent magnon polarons is confirmed by direct evidence of the avoided crossing effect, as well as by several bright indirect manifestations. The NGs have been produced by focused ion beam milling into a 105 nm-thick Fe0.81Ga0.19 film. They have a lateral period of 200 nm and consist of parallel grooves of 100 nm width and 7-21 nm depth milled along the [100]-crystallographic direction. We perform transient magneto-optical measurements in a conventional pump-probe scheme with micron spatial resolution, where the femtosecond pump pulse excites the NGs, while the probe pulse serves to detect coherent lattice and magnetic responses. Using an external magnetic field, the magnon modes can be brought into resonance with the localized phonon modes of the NG resulting in the formation of magnon polarons, where the coupling strength is determined by the spatial overlap of the interacting modes.

MA 11.2 Wed 13:30 P

Topological magnon-polaron in a two-dimensional ferromagnet — •Gyungchoon Go, Se Kwon Kim, and Kyung-Jin Lee — Department of Physics, KAIST, Daejeon 34141, Republic of Korea

We theoretically investigate the topological aspects of the magnon-phonon hybrid excitation in a simple two-dimensional (2D) square-lattice ferromagnet with perpendicular magnetic anisotropy. In our 2D model, the Berry curvature we find requires neither a special spin asymmetry such as the DM interaction nor a special lattice symmetry: Our 2D model description is applicable for general thin-film ferromagnets. We show that even without such long-range dipolar interaction, DM interaction, or special lattice symmetry, the nontrivial topology of a magnon-phonon hybrid can emerge by taking account of the well-known magnetoelastic interaction originates from the magnetocrystalline anisotropy. Because the magnetocrystalline anisotropy is ubiquitous in ferromagnetic thin-film structures, our result does not rely on specific preconditions and thus is quite generic. Furthermore, we show that the topological structures of the magnon-polaron bands can be manipulated by effective magnetic fields via topological phase transition. We uncover the origin of the nontrivial topological bands by mapping our model to the well-known two-band model for topological insulators, where the Chern numbers are read by counting the number of topological textures, called skyrmions, of a certain vector in momentum space. In this picture, the magnon-phonon hybridization induces the chiral texture of the momentum space vector. As an experimental probe for our theory, we propose the thermal Hall conductivity.

MA 11.3 Wed 13:30 P

Magnetization Dynamics in Hybrid Ferromagnetic Systems — •Misbah Yaqoob[1,2,3], Lukas Liensberger[1,2], Luis Flake[1,2], David Weffling[3], Vitaliy Vasyuchka[3], Matthias Althammer[1,2], Rudolf Gross[1,2], and Mathias Weiler[1,3] — [1]Walther-Meißner-Institut, Garching, Germany — [2]Physik- Department, TU München, Germany — [3]Fachbereich Physik, TU Kaiserslautern, Germany

Thin film heterostructures consisting of several magnetically ordered layers are a promising platform for magnon spintronics because they can host complex magnetic textures, hybrid spin dynamics and spin torques [1,2].
We have investigated the magnetization dynamics of purely metallic ferromagnetic thin film multilayers and insulating magnet/metallic magnet thin film hybrid systems using broadband ferromagnetic resonance (FMR) and microfocused frequency-resolved magneto-optic Kerr effect (μFR-MOKE) at room temperature. With FMR, we find that the anisotropy of all-metallic systems can be tuned from $\mu_0 M_{\mathrm{eff}} \approx 300\,\mathrm{mT}$ to $\mu_0 M_{\mathrm{eff}} \approx 0$ by varying the number of multilayer repeats without affecting magnetic damping. We extract the spinwave dispersion using μFR-MOKE and find μm scale spinwave propagation lengths and group velocities in the order of 10 km/s. We compare these findings to those obtained in hybrid metallic ferromagnet/insulating yttrium iron garnet thin film heterostructures.

[1] Klingler et al. Phys. Rev. Lett. 120, 127201 (2018)
[2]Flacke et al. arXiv:2102.11117 (2021)

MA 11.4 Wed 13:30 P

Amplification of Propagating Spin Waves by Rapid Cooling — •David Breitbach[1], Michael Schneider[1], Bert Lägel[1], Carsten Dubs[2], Andrei N. Slavin[3], Vasyl Tyberkevych[3], Philipp Pirro[1], Burkard Hillebrands[1], and Andrii Chumak[4] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany — [2]Innovent e.V. Technologieentwicklung, Jena, Germany — [3]Department of Physics, Oakland University, Rochester, MI, United States — [4]Faculty of Physics, University of Vienna, Vienna, Austria

Recently, the formation of a magnon Bose-Einstein Condensate (BEC) triggered by the rapid cooling of magnonic nano-structures has been reported [1]. A rapid decrease of the phonon temperature achieved after heating with an applied DC pulse in a nano-sized YIG|Pt sample leads to a non-equilibrium between the phonon and the magnon system. This results in a redistribution of magnons to the lowest frequencies of the spectrum and, finally, to the formation of a BEC. Building on this mechanism, we show the coherent amplification of externally excited, propagating spin waves in a YIG-waveguide using time-resolved BLS microscopy. This amplification is maximal when the spin-wave packet propagates through the Pt-region during the process of rapid cooling. This study shows the applicability of the rapid cooling mechanism to compensate for the intrinsic damping in spintronic devices and also gives insight into new physics, namely the interaction of a prepared coherent state with a magnon BEC. [1] M. Schneider, et. al., Nat. Nanotechnol. 15, 457-461 (2020)

MA 11.5 Wed 13:30 P

Theory of quantum entanglement and the structure of two-mode squeezed antiferromagnetic magnon vacuum — •Dennis Wuhrer, Niklas Rohling, and Wolfgang Belzig — Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany

Recent investigations of the quantum properties of an antiferromagnet in the spin wave approximation have identified the eigenstates as two-mode squeezed sublattice states. The uniform squeezed vacuum and one-magnon states were shown to display a massive sublattice entanglement. Here we expand this investigation and study the squeezing properties of all sublattice Fock states throughout the magnetic Brillouin zone.

We derive the full statistics of the sublattice magnon number with wave number $\vec{k}$ in the ground state and show that magnons are created in pairs with opposite wave vectors, hence, resulting in entanglement of both modes. To quantify the degree of entanglement we apply the Duan-Giedke-Cirac-Zoller inequality and show that it can be violated for all modes. The degree of entanglement decrease towards the corners of the Brillouin zone. We relate the entanglement to measurable correlations of components of the Néel and the magnetization vectors, thus, allowing to experimentally test the quantum nature of the squeezed vacuum.

The distinct k-space structure of the probabilites shows that the squeezed vacuum has a nonuniform shape that is revealed through the $\vec{k}$-dependent correlators for the magnetization and the Néel vectors.

MA 11.6 Wed 13:30 P

Combined tr-MOKE, BLS and THZ-radiation setup for the

investigation of magnetization dynamics on different time scales — •Akira Lentfert[1], Benjamin Stadtmüller[1], Martin Aeschlimann[1], Georg von Freymann[1,2], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern — [2]Fraunhofer Institute for Industrial Mathematics ITWM

Two separate models commonly describe spin and magnetization dynamics on different time scales. Systems in the sub-picosecond regime in ultrafast demagnetization processes are dominated by single-particle excitations. Here, a femtosecond laser pulse induces a loss of the magnetic order, which can be observed with time-resolved pump-probe spectroscopy based on the magneto-optical Kerr effect (tr-MOKE). In the nanosecond time scale, dynamics are described by collective excitations in terms of spin waves. However, due to the nature of the measurement technique mentioned above, it is impossible to detect incoherent collective dynamics. Therefore, the role of spin-waves up to the THz regime on ultrashort time scales could not be studied sufficiently. In this work, a combined setup of tr-MOKE with Brillouin-Light-Scattering spectroscopy (BLS) is presented, which allows the simultaneous investigation of magnetization dynamics on different time scales, from 1 ns down to 10 fs. Furthermore, using electromagnetic THz radiation to excite spin waves in this frequency regime resonantly gives further insight into the magneto-optical interactions. This research has been supported by DFG (TRR 173: Spin+X).

MA 11.7 Wed 13:30 P

Influence of Spatial Confinement on Spin-Wave Frequency Combs — •Christopher Heins[1], Tobias Hula[1,2], Katrin Schultheiss[1], Francisco Goncalves[1], Lukas Körber[1,3], Mauricio Bejarano[1,3], Luis Flacke[4,5], Lukas Liensberger[4,5], Aleksandr Buzdakov[1], Attila Kákay[1], Mathias Weiler[4,5,6], Jürgen Fassbender[1,3], and Helmut Schultheiss[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]TU Chemnitz, Germany — [3]TU Dresden, Germany — [4]Walther-Meißner-Institut, Garching, Germany — [5]TU München, Germany — [6]TU Kaiserslautern, Germany

Recently, it has been shown that four-magnon scattering in a stripe-shaped magnonic waveguide can be stimulated and utilized to generate spin wave frequency combs [1].

Here, we demonstrate that by restricting possible eigenstates via a two-dimensional spatial confinement the stimulated four-magnon scattering can be enhanced and a single RF excitation leads to the spontaneous formation of a frequency comb. We determine the frequency spacing of the spin wave modes in a $Co_{25}Fe_{75}$ rectangular microconduit with micromagnetic simulations and explore the formation of spin-wave frequency combs experimentally by means of micro-focused Brillouin light scattering. Further, we show that the spontaneously generated frequency comb can be resonantly amplified by a second RF excitation.

The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within program SCHU 2922/1-1.

[1] Hula et al., arXiv:2104.11491 (2021)

MA 11.8 Wed 13:30 P

Magnon condensates in magnetization landscapes — •Matthias R. Schweizer, Alexander J.E. Kreil, Georg von Freymann, Alexander A. Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany

In this study, we demonstrate the potential to control a magnon condensate by spatial modulation of the saturation magnetization.

As shown in previous studies, a magnon condensate can be created via parallel parametric pumping in a stripline-resonator. We use a 458 nm laser in combination with a phase-based wavefront modulation technique to create confined temperature patterns in an yttrium-iron-garnet film of 5 μm thickness, which result in a decrease of the local saturation magnetization and in modify the local frequency of the condensate. The magnon density is measured by means of k-vector-resolved Brillouin-light-scattering-spectroscopy. We provide evidence of strong, directed magnon accumulation by magnon supercurrents [1] and anomalous decay behavior for several distances between heated positions.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - TRR 173 - 268565370.

[1] *D. A. Bozhko et al.*, Nat Commun **10**, 2460 (2019)

MA 11.9 Wed 13:30 P

Parametric pumping in out-of-plane magnetized ferrite films towards magnon Bose-Einstein condensation — •Andra Pirktina, Timo B. Noack, Vitaliy I. Vasyuchka, Alexander Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

The Bose–Einstein condensate (BEC) in a parametrically overpopulated gas of spin-wave quanta—magnons—manifests itself as a spontaneous formation of a coherent spin wave state at the energy minimum of the magnon spectrum. Magnon BECs, which are observed at gigahertz frequencies in tangentially magnetized yttrium iron garnet (YIG) films even at room temperature, can be used as signal sources for microwave applications and as information carriers in wave and quantum computing. However, due to the wavelength of the order of a few micrometers, the magnon BEC is detected mainly by the Brillouin light scattering spectroscopy, which is hardly applicable to real devices.

Here, we report on the spontaneous BEC formation in the out-of-plane magnetization geometry, where the magnon spectrum has a minimum at zero wavenumber, and the BEC frequency coincides with the ferromagnetic resonance frequency. In this case, the BEC was detected as a microwave electromagnetic signal by an inductive microstrip antenna. A small signal line width of 1.4 MHz was measured after the pump power exceeded the parametric instability threshold by 34 dB.

Funded by the ERC Advanced Grant 694709 SuperMagnonics and by the DFG within TRR 173 – 268565370 (project B04).

MA 11.10 Wed 13:30 P

Electric phase control of magnon currents — •Rostyslav O. Serha, Vitaliy I. Vasyuchka, Alexander A. Serga, and Burkard Hillebrands — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany

New findings of interactions between electric fields and magnons are promising for novel magnonic applications. They would allow the control of the phase of magnon currents by applying a voltage to the magnetic waveguides. In our work, we investigated the influence of a strong electric field on the phase of propagating spin waves in yttrium iron garnet (YIG) films. The experiment was performed in different spin-wave excitation geometries when volume and surface magnetostatic spin waves were excited. With the help of a vector network analyzer, the phase shift of the transmitted wave, which is sensitive to different external influences, was precisely measured. It was found that the phase shift owing to the electric field influence is relatively strong in the case of magnetostatic surface spin waves but is also observable for backward volume magnetostatic waves. By comparing results obtained for different spin-wave geometries, we discuss the physical nature of the observed phase shift, including possible contributions from the magnetoelectric effect in YIG and from the Aharonov-Casher effect. Funding by the ERC Advanced Grant 694709 SuperMagnonics is gratefully acknowledged.

MA 11.11 Wed 13:30 P

Dipolar interactions and spin dynamics in the itinerant ferromagnets Fe and Ni — •Lukas Beddrich[1,2], Steffen Säubert[3,4], Johanna K. Jochum[1], Christian Franz[1,5], and Peter Böni[2] — [1]Research Neutron Source Heinz Maier-Leibnitz (FRM II) | TU München — [2]Physics Department | TU München — [3]Chair for Topology of Correlated Systems (E51) | Physics Department | TU München — [4]Department of Physics | Colorado State University — [5]Jülich Center for Neutron Science (JCNS)

The spin wave dispersion of an isotropic ferromagnet is comprehensively described by the Holstein-Primakoff theory, which takes dipolar interactions into account. The dispersion follows a quadratic form for large q values $E_{SW} \propto q^2$, whereas for small q the dispersion shows linear behavior. This is attributed to the long-range dipolar interaction between the magnetic moments. The subtle influence of these interactions on the magnon spectrum are expressed by the dipolar wave vector q_D. The dipolar interactions are primarily probed for $q \leq q_D$. Utilizing the modern MIEZE method, a neutron resonance spin echo technique, we investigated the spin wave dispersion in iron and the paramagnetic spin fluctuations in nickel at small momentum and energy transfer with high resolution, never achieved before by neutron scattering. The results show excellent agreement with previously conducted triple-axis measurements by Collins et al. in the overlapping q regime, while extending the investigated range of the spin wave dispersion down to a momentum transfer of $q = 0.015A^{-1}$ with unprecedented energy resolution.

MA 11.12 Wed 13:30 P

Integration and characterization of micron-sized YIG structures with very low Gilbert damping on arbitrary substrates — •Philip Trempler[1], Rouven Dreyer[1], Philipp Geyer[1], Georg Woltersdorf[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther Universität Halle-Wittenberg, 06099 Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther Universität Halle-Wittenberg 06099 Halle (Saale), Germany

We present a process that allows the transfer of monocrystalline yttrium-iron-garnet microstructures onto virtually any kind of substrate. The process is based on a recently developed method that allows the fabrication of freestanding monocrystalline YIG bridges on gadolinium-gallium-garnet. Here, the bridges' spans are detached from the substrate by a dry etching process and immersed in a watery solution. Using drop-casting, the immersed YIG platelets can be transferred onto the substrate of choice, where the structures finally can be reattached and, thus, be integrated into complex devices or experimental geometries. Using time-resolved scanning Kerr microscopy and inductively measured ferromagnetic resonance, we find a ferromagnetic resonance linewidth of 195 μT at room temperature and we were even be able to inductively measure magnon spectra on a single micrometer-sized YIG platelet at a temperature of 5 K. In the future, this approach will allow for types of spin dynamics experiments until now unthinkable.

MA 11.13 Wed 13:30 P

Local and nonlocal spin Seebeck effect in lateral Pt-Cr_2O_3-Pt devices at low temperatures — •Prasanta Muduli[1], Richard Schlitz[1], Tobias Kosub[2], René Hübner[2], Artur Erbe[2], Denys Makarov[2], and Sebastian T. B. Goennenwein[1] — [1]Institut für Festköper- und Materialphysik and Würzburg-Dresden Cluster of Excellence ct.qmat, Technische Universiät Dresden, 01062 Dresden, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany

We have studied thermally driven magnon spin transport (spin Seebeck effect, SSE) in heterostructures of antiferromagnetic α-Cr_2O_3 and Pt at low temperatures. Monitoring the amplitude of the local and nonlocal SSE signals as a function of temperature, we found that both decrease with increasing temperature and disappear above 100 K and 20 K, respectively. Additionally, both SSE signals show a tendency to saturate at low temperatures. The nonlocal SSE signal decays exponentially for intermediate injector-detector separation, consistent with magnon spin current transport in the relaxation regime. We estimate the magnon relaxation length of our α-Cr_2O_3 films to be around 500 nm at 3 K. This short magnon relaxation length along with the strong temperature dependence of the SSE signal indicates that temperature-dependent inelastic magnon scattering processes play an important role in the intermediate range magnon transport. Our observation is relevant to low-dissipation antiferromagnetic magnon memory and logic devices involving thermal magnon generation and transport.

MA 11.14 Wed 13:30 P

Nonlinear relaxation of quantized propagating magnons in nanodevices — •Morteza Mohseni[1], Qi Wang[2], Björn Heinz[1], Michael Schneider[1], Felix Kohl[1], Carsten Dubs[3], Andrii V. Chumak[2], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [3]INNOVENT e.V., Technologieentwicklung, Prüssingstraße 27B, 07745 Jena, Germany

The use of spin waves and their quanta, the magnons, opens many opportunities in designing novel data processing units. Relaxation of linear spin waves is well described by viscous Gilbert damping processes. However, for strong excitations, nonlinear damping processes such as the decay via magnon-magnon interactions emerge and trigger additional relaxation channels. Such nonlinear dynamics are essential for the generation of magnon Bose-Einstein condensates, although their characteristics are not well investigated in magnonic nanostructures. We investigate the nonlinear relaxation of strongly generated spin waves in yttrium iron garnet nanodevices. We show that the nonlinear magnon relaxation in this highly quantized system possesses intermodal features, i.e., magnons scatter to other quantized modes through a cascade of scattering events. A further discussion of the phenomenon in the regime of its fundamental limitations is given.

MA 11.15 Wed 13:30 P

Mode selective excitation of spin waves — •Takuya Taniguchi and Christian Back — Technische Universität München

In a magnetic stripe, spin waves have eigenmodes which are energetically separated due to the geometry of the device. However, it has been difficult to selectively excite one eigenmode of spin wave. In this work, we performed micromagnetic simulation to study spin wave propagation in a T-shaped device and found that the spin wave mode in the device is controllable by varying the resonant frequency and the device structure.

MA 11.16 Wed 13:30 P

Spin-wave frequency combs — •Tobias Hula[1,2], Katrin Schultheiss[1], Francisco Goncalves[1], Lukas Körber[1,3], Mauricio Bejarano[1,3], Matthew Copus[4], Luis Flacke[5,6], Lukas Liensberger[5,6], Aleksandr Buzdakov[1], Attila Kakay[1], Mathias Weiler[5,6,7], Robert Camley[5], Jürgen Fassbender[1,3], and Helmut Schultheiss[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]TU Chemnitz, Chemnitz, Germany — [3]TU Dresden, Dresden, Germany — [4]Center for Magnetism and Magnetic Nanostructures, University of Colorado, USA — [5]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Germany — [6]TU München, Munich, Germany — [7]TU Kaiserslautern, Kaiserslautern, Germany

We present experimental observations on the generation of a spin wave frequency comb in a low damping Co25Fe75 conduit measured using Brillouin light scattering microscopy. By driving the magnetization to large precession angles, nonlinear interactions such as four magnon scattering can be observed. When applying two RF signals with tunable frequencies and amplitudes to our microstructure, we can actively control the final states populated by these scattering processes. Our results show the generation of a frequency comb, consisting of several spin wave modes with adjustable frequency spacing and amplitude. Our observations are in qualitative agreement with micromagnetic simulations. We acknowledge financial support from the DFG within programs SCHU 2922/1-1, WE5386/4-1 and WE5386/5-1. K. S. acknowledges funding within the Helmholtz Postdoc Programme.

MA 11.17 Wed 13:30 P

Identification and characterization of plastics using THz-spectroscopy — •Tobias Kleinke, Finn-Frederik Stiewe, Ulrike Martens, Jakob Walowski, and Markus Münzenberg — Institute of Physics, University Greifswald, Germany

THz-spectroscopy is an attractive tool for scientific research, especially in life science, offering non-destructive interaction with matter due to its low photon energies [1]. Current research investigates the impact of plastic nanoparticles on cell tissue in several aspects, because those particles are highly abundant in the environment and also enter the human body potentially causing harmful interactions [2]. THz spectroscopy offers the opportunity to discover and study the influence of microplastics in living human cells.

Our project aims to identify and characterize different types of plastics in the human body or even in cells. Therefore it is necessary to set up a database with THz-spectra of the most abundant polymers. We analyze transmission spectra of several plastics with a commercial THz spectrometer (bandwidth from 0.1 to 6 THz) and identified specific absorption peaks for the individual studied materials. Furthermore, by determining the refractive index and the absorption coefficient, specific polymers can be characterized and identified.

Funding by BMBF: MetaZik PlasMark-T (FKZ:03Z22C511) is acknowledged.

[1] W. Shi et al., Journal of Biophysics, Vol. 14, 2021 [2] A. Ragusa et al., Environment International, Vol. 146, 2021

MA 11.18 Wed 13:30 P

THz-2D Scanning Spectroscopy — •Finn-Frederik Stiewe, Tobias Kleinke, Tristan Winkel, Ulrike Martens, Jakob Walowski, Christian Denker, and Markus Münzenberg — Institute of Physics, University Greifswald, Germany

THz-spectroscopy offers attractive imaging capabilities for scientific research, especially in life science. Its low photon energies lead to non-destructive interaction with matter [1,2]. However, wavelengths above 100 μm principally limit its spatial resolution by diffraction. Near-field-imaging using spintronic emitters offers the most feasible approach to overcome this restriction. In our study, we investigate THz-pulses generated by fs-laser-excitations in CoFeB/Pt heterostructures, based on spin currents together with a LT-GaAs Auston switch as detector.

The spatial resolution is tested by applying a 2D scanning technique with motorized stages allowing scanning steps in the sub-micrometer range. For this purpose, the spintronic emitter is directly evaporated on a gold-test pattern separated by a several hundred nanometer thick insulating spacer layer. Moving these structures with respect to the THz wave generation spot allows for resolution determination using the knife-edge method. We observe a THz beam FWHM of 4.86 *0.37 μm at 1 THz by using near-field imaging, which are in the dimension of the laser spot. Due to its simplicity, our technical approach offers a large potential for wide-ranging applications.

Funding by: MetaZIK PlasMark-T (FKZ:03Z22C511), BMBF

[1] A. G. Davies et al., Materials Today, Vol. 11 (2008) 18. [2] A. Y. Pawar et al., Drug Invention Today, Vol. 5 (2013).

MA 11.19 Wed 13:30 P

Spin-Hall-Angle measurements on magnetic heterostructures using THz-spectroscopy — •Tristan Winkel, Finn-Frederik Stiewe, Tobias Kleinke, Ulrike Martens, Jakob Walowski, and Markus Münzenberg — Institute of Physics, University Greifswald, Germany

Spin Hall angle measurements are important for spin device design. The data is used to build optimized spin Hall nano-oscillators for the fabrication of a neuromorphic computer chip [1]. THz spectroscopy provides effective means to measure spin Hall angles. In our study, we investigate THz pulses generated by fs laser excitations in magnetic heterostructures based on spin currents, together with an LT-GaAs Auston switch as a detector. The magnetic heterostructures consist of a CoFeB layer and a heavy metal layer. From the THz measurement, we can extrapolate the spin Hall angle of the heavy metal. Our technical approach offers great potential for wide-ranging applications due to its simplicity.

[1] M. Zahedinejad et al., Appl. Phys. Lett. 112, 132404 (2018)

Funding by: EU Horizon 2020, Spinage

MA 11.20 Wed 13:30 P

Microstructured spintronic terahertz emitters — •Rieke von Seggern[1], Christopher Rathje[1], Leon Gräper[1], Nina Meyer[2], Markus Münzenberg[2], and Sascha Schäfer[1] — [1]Institute of Physics, University of Oldenburg, Germany — [2]2Institute of Physics, University of Greifswald, Germany

In recent years, spintronic terahertz (THz) emitters have become a well-established source for strong single-cycle THz pulses [1]. In those metallic multilayer systems, an optically induced spin-polarized current pulse is converted into a transverse charge current, resulting in a broadband emission of THz radiation. In this work, we investigate different strategies for coupling the transverse current to micro-resonators on, or in close proximity, to the THz emitter surface and their influence on the detected THz spectrum. Various designs of resonator arrays were fabricated by electron beam lithography with expected resonance frequencies in the range of 0.5-4 THz. The resonances are visible as a decreased spectral THz amplitude at the corresponding resonance frequencies. A transition from a field- to a current-coupled regime is identified for decreasing distance between the resonator and the emitter, and compared to numerical modelling based on finite-element simulations.

[1] Seifert et al., Nat. Photonics 10, 483-488 (2016)

MA 11.21 Wed 13:30 P

Nutation resonance in antiferromagnets — •Ritwik Mondal[1,2], Levente Rózsa[3], Sebastian Grossenbach[3], and Ulrich Nowak[3] — [1]Institute of Physics of the Czech Academy of Sciences, Prague 6, Czech Republic — [2]Department of Physics and Astronomy, Uppsala University, Sweden — [3]Fachbereich Physik, Universität Konstanz, DE-78457 Konstanz, Germany

At ultrafast timescales, an additional spin torque term has to be supplemented within Landau-Lifshitz-Gilbert spin dynamics, to account for magnetic inertial dynamics causing spin nutation [1]. The experimental observation of the nutation resonance has only been achieved very recently [2]. In this work, we compare the effect of spin nutation in ferromagnets, antiferromagnets and ferrimagnets using linear response theory [3]. We identify the precession and nutation resonance peaks, and demonstrate that the precession resonance frequencies are reduced by the spin nutation, while the lifetime of the excitations is enhanced. We find the interplay between precession and nutation resonances to be more prominent in antiferromagnets compared to the ferromagnets, where the timescale of the exchange-driven sublattice dynamics is comparable to inertial relaxation times. Consequently, antiferromagnetic resonance techniques should be better suited for the search for intrinsic inertial spin dynamics on ultrafast timescales than ferromagnetic resonance [3].

[1] M.-C. Ciornei, J. M. Rubí, and J.-E. Wegrowe, Phys. Rev. B **83**, 020410(R) (2011) [2] K. Neeraj *et al.*, Nature Phys. **17**, 245 (2021) [3] R. Mondal *et al.* Phys. Rev. B **103**, 104404 (2021)

MA 11.22 Wed 13:30 P

Spintronic THz emitters tuned with Ta and modified interface qualities — •Laura Scheuer[1], Dominik Sokoluk[2], Garik Torosyan[3], René Beigang[1], Marco Rahm[2], and Evangelos Papaioannou[4] — [1]Fachbereich Physik and Landesforschungszentrum Optimas, TUK, Kaiserslautern, Germany — [2]Fachbereich Elektrotechnik, TUK, Kaiserslautern, Germany — [3]Photonic Center Kaiserslautern, Kaiserslautern, Germany — [4]Institut of Physics, MLU, Halle-Wittenberg, Germany

THz emission from metallic thin film multilayers interlinked the field of ultrafast spintronics and the field of THz optics, raising new fascinating research subjects. In principle, the THz pulse is generated by a spin current. This spin current is excited in a ferromagnetic layer by a fs laser pulse and diffuses into the adjacent layers. Usually their material is chosen to have a high spin-orbit coupling to provide a strong spin-to-charge conversion via the spin-Hall effect, resulting in a transient charge current. These accelerated electrons emit a radiation in the THz range.

Our recent experiments concentrate on materials different from our well-studied Fe/Pt-bilayers: Firstly, as Ta is a material with high spin-orbit coupling and a spin-Hall angle opposite to Pt's, we did not only replace Pt in bilayers but also added Ta as a second non-magnetic layer. Additionally we extended our investigations regarding the role of the interface to interfaces 'dusted' with Au and Cu, meaning they are grown thin enough not to form a whole monolayer.

MA 11.23 Wed 13:30 P

Modulation of Terahertz radiation by current confinement in patterned Ferromagnetic Emitters — •Bikash Das Mohapatra[1], Evangelos Th. Papaioannou[1], Reza Rouzegar[3], Tobias Kampfrath[3], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, D-06120 Halle, Germany — [2]Interdisziplinäres Zentrum für Meterialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Heinrich-Damerow-Straße 4, D-06120 Halle, Germany — [3]Department of Physical Chemistry, Fritz Haber Institute, Faradayweg 4-6, 14195 Berlin, Germany

Spintronic Ferromagnetic Emitters are novel sources for generation of THz radiation. Various studies have shown the generation of ultrafast transverse charge current from spin current by the Inverse Spin Hall Effect resulting in THz electromagnetic pulses. We have fabricated THz emitters into arrays of geometrical structures using Sputter deposition and e-beam lithography. The structures were micron or sub-micron sized squares and rectangles. Upon fs laser irradiation these emitters show an emission spectrum which is different than for large area reference emitters. We suggest that the confinement[1] results in local charge accumulation that creates additional currents that counteract the initial inverse spin Hall effect.

[1] Z. Jin et al., "Terahertz Radiation Modulated by Confinement of Picosecond Current Based on Patterned Ferromagnetic Heterostructures ", Phys. Stat. Sol. 13, 1900057 (2019).

MA 11.24 Wed 13:30 P

Strain effect in the anomalous Hall effect of SrRuO3 thin films : a first principles study — •Kartik Samanta[1], Marjana Ležaić[2], Stefan Blügel[2], and Yuriy Mokrousov[2] — [1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany — [2]Peter Grunberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

We investigate the effect of strain-induced oxygen octahedral distortion in the electronic structure and anomalous Hall response of the ferromagnetic SrRuO3(SRO) ultra-thin films by virtue of density functional theory calculations. We find a strong deformation of the oxygen octahedra (RuO6) with an increasing amount of substrate induced compressive strain. Our Berry curvature calculations predict a positive value of the anomalous Hall conductivity of +76 S/cm at -1.7% strain, whereas it is found to be negative (-156 S/cm) at -0.47% strain. We attribute the observed behavior of the anomalous Hall effect to the nodal point dynamics in the electronic structure arising in response to tailoring the oxygen octahedral distortion driven by the substrate induced strain. Our calculation of the strain-mediated anomalous Hall conductivity as a function of reduced magnetization obtained by scaling down the magnitude of the exchange field inside Ru atoms, shows a good qualitative agreement with experimental observations, which indicates a strong impact of longitudinal thermal fluctuations of Ru spin moments on the anomalous Hall effect in this system.

MA 11.25 Wed 13:30 P

Anisotropy of $4f$ states in $3d$-$4f$ single molecular magnets — Andreas Rauguth[1], Ahmed Alhassanat[1], Hebatalla Elnaggar[3], Angeliki A. Athanasopoulou[1], Chen Luo[2], Hanjo Ryll[2], Florin Radu[2], Torge Mashoff[1], Frank M.F. de Groot[3], Eva Rentschler[1], and •Hans-Joachim Elmers[1] — [1]Johannes Gutenberg-Universität Mainz, Mainz, Germany — [2]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — [3]University Utrecht, Utrecht, Netherlands

Using X-ray magnetic circular dichroism, we determined element-specific magnetic moments in $3d$-$4f$ metallacrown single molecular magnets at low temperature (7 K) and large field (7 Tesla). The magnetic moment of the molecule is dominated by the rare earth moment revealing a large contribution of orbital moment. Angular-dependent spectra on oriented molecules in single crystals allow to disentangle magnetic and orbital anisotropies. X-ray natural linear dichroism reveals the anisotropic charge distribution of the rare earth $4f$ state in the tetragonal crystal field despite the small $4f$ crystal field splitting. The angular dependence of the spin and orbital magnetic moments are compared to theory using multiplet calculations. We determined magnetic anisotropies from the angular dependence of the orbital magnetic moment.

MA 11.26 Wed 13:30 P

Numerical dynamic study of two coupled vortex-based spin transfer oscillator — •Abbass Hamadeh[1], Milan Ender[1], Vitally Lomakin[2], and Philipp Pirro[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern, Kaiserslautern, Germany — [2]Center for Magnetic Research, University of California at San Diego, La Jolla, CA, USA.

The magnetic vortex state in nano-magnetic structures is a subject of intensive research since it offers many applications. To gain key insight into engineering and manipulating the vortex core (VC) orientation reversal, it is crucial to fully understand their coupled dynamics. For this purpose, we have studied micromagnetically the auto-oscillating modes in a spin-transfer vortex oscillator with vortices in two coupled thin and thick layers for different applied magnetic fields and currents. We find that for the anti-parallel vortex polarity configurations, a region with downward/upward magnetization appears at the inner side of the vortex core resembling a deformation of the vortex profile. This deformation, induced by the vortex core's accelerating motion, breaks the lateral magnetization symmetry between the two layers of the oscillator. Our results reveal the origin of the signal measured experimentally [N. Locatelli et al., Appl. Phys. Lett. 98, 062501 (2011)] for a system based on two coupled vortices and provide key insights into engineering the vortex core orientation using DC currents.

MA 11.27 Wed 13:30 P

First principles design of Ohmic spin diodes based on quaternary Heusler compounds — •Thorsten Aull, Ersoy Sasioglu, and Ingrid Mertig — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06099 Halle (Saale) Germany

The Ohmic spin diode is a new concept in spintronics whose operation principle relies on the transport properties of spin-gapless semiconductors (SGSs) and half-metallic magnets (HMMs). [1] Due to the spin-dependent filtering of electrons Ohmic spin diodes exhibit linear current-voltage characteristics in the on-state and zero threshold voltage due to the absence of an energy barrier at the interface between the SGS and HMM electrode. Quaternary Heusler compounds offer a platform to design SGSs and HMMs within the same family and these materials possess high Curie temperatures which makes them favorable for room temperature applications. By applying first-principles DFT calculations combined with the non-equilibriums Green's function method we design four different OSDs using quaternary Heusler compounds. [2] We demonstrate that these diodes exhibit zero threshold voltage and possess linear current-voltage characteristics. Moreover, we reveal that the small leakage currents can be attributed to the overlap of the conduction and valance band edges in opposite spin channels at the Fermi energy in the SGS material.

[1] E. Şaşıoğlu *et al.*, Phys. Rev. Appl. **14**, 014082 (2020)
[2] T. Aull *et al.*, Appl. Phys. Lett. **118**, 052405 (2021)

MA 11.28 Wed 13:30 P

Bipolar Spin Hall Nano-Oscillators — •Toni Hache[1], Yancheng Li[2], Tillmann Weinhold[3], Bernd Scheumann[1], Francisco T. J. Goncalves[1], Olav Hellwig[1,4], Jürgen Fassbender[1,3], and Helmut Schultheiss[1,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Johns Hopkins University, United States — [3]Technical University Dresden, Germany — [4]Technical University Chemnitz, Germany

Spin Hall nano-oscillators (SHNO) convert dc currents in microwave oscillations of the magnetization. The frequency can be tuned by external magnetic fields, the applied dc current magnitude or by injection locking if an additional microwave magnetic field is applied to the SHNO. Here, we demonstrate another approach to extend the frequency range of an SHNO by adding a second ferromagnetic layer. An SHNO with a layer stack NiFe/Pt/CoFeB is used. By applying a charge current a pure spin current is generated by the spin Hall effect in the Pt. It has opposite spin polarization at both interfaces being in contact with the ferromagnetic layers. Therefore, only in one of both the Gilbert damping can be compensated by the spin-orbit torque to achieve auto-oscillations. By switching the charge current polarity the spin current polarizations switch as well and the second ferromagnetic material shows auto-oscillations. In this way two frequency ranges can be accessed by switching the applied charge current. The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within programme SCHU 2922/1-1.

MA 11.29 Wed 13:30 P

Asymmetric modification of the magnetic proximity effect in Pt/Co/Pt trilayers — •Ankan Mukhopadhyay[1], Sarathlal Koyiloth Vayalil[1], Dominik Graulich[2], Imran Ahamed[3], Sonia Francoual[4], Arti Kashyap[3], Timo Kuschel[2], and Anil Kumar P S[1] — [1]Indian Institute of Science, Bangalore, India — [2]Center for Spinelectronic Materials and Devices, Bielefeld University, Germany — [3]Indian Institute of Technology, Mandi, India — [4]Deutsches Elektronen-Synchrotron, Hamburg, Germany

Interfacial spin-orbit coupling in ferromagnet/nonmagnet systems promotes remarkable spin-related phenomena and interactions which simultaneously provide the electrical manipulation of the magnetic moments up to the point of magnetization switching by current-driven domain wall motion. The phenomenon of a nominally paramagnetic material getting spin-polarized in presence of an adjacent ferromagnetic material by the exchange interaction is known as the magnetic proximity effect (MPE). The MPE in the top and bottom Pt layers induced by Co in Ta/Pt/Co/Pt and Ta/Pt/Co/Cu/Pt multilayers has been studied by interface sensitive, element-specific x-ray resonant magnetic reflectivity at the Pt L_3 absorption edge with an in-plane magnetic field. It has been observed that the Ta buffer layer with increasing thickness modifies the bottom Pt growth which in turn reduces the induced magnetic moment in the bottom Pt layer in Ta/Pt/Co/Pt[1], while it decreases in the top Pt layer in Ta/Pt/Co/Cu/Pt if the thickness of the Cu spacer is increased.

[1]A. Mukhopadhyay et al., Phys. Rev. B **102**, 144435 (2020).

MA 11.30 Wed 13:30 P

Magnon transport in YIG/Pt nanostructures with reduced effective magnetization — •Janine Gückelhorn[1,2], Tobias Wimmer[1,2], Manuel Müller[1,2], Stephan Geprägs[1], Hans Hübl[1,2,3], Rudolf Gross[1,2,3], and Matthias Althammer[1,2] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik-Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany

The transport of information via spin waves (magnons) in magnetically ordered insulators provides novel paths for information processing. For applications based on pure magnonic spin currents damping effects resulting in a decrease of the corresponding conductivity, have to be minimized. Here, we investigate the magnon transport through an yttrium iron garnet (YIG) thin film with strongly reduced effective magnetization. Utilizing three-terminal Pt strip devices allow us to manipulate the magnon transport between the two outer strips via an additional charge current applied to the center electrode. Most importantly, above a certain threshold current, where damping compensation via spin torque is reached, the effective magnon conductivity can be enhanced by a factor of up to six. Another major observation is the linear dependence of the threshold current on the applied magnetic field. We attribute these observations to the reduced effective magnetization and the associated nearly circular mangetization precession.

Financial support by the DFG via project AL2110/2-1 and Germany's Excellence Strategy – EXC-2111 – 390814868 is acknowledged.

MA 11.31 Wed 13:30 P

Agility of spin Hall nano-oscillators — •Francisco Gonçalves[1], Toni Hache[1], Mauricio Bejarano[1,2], Tobias Hula[1,3], Olav Hellwig[1,3], Jürgen Fassbender[1,2], and Helmut Schultheiss[1,2] — [1]HZDR, Institute of Ion Beam Physics and Materials Research, Germany — [2]Technische Universität Dresden, Germany — [3]Institut für Physik, Technische Universität Chemnitz, Germany

Spin Hall nano-oscillators (SHNOs) have the ability to convert a direct current input to magnetisation auto-oscillations (AOs) in the gigahertz regime, by means of spin Hall effect and spin orbit torque [1-2]. We report the temporal response of nano-constriction SHNOs driven by voltage pulses, measured using time-resolved Brillouin light scattering microscopy. The SHNOs consist of a double-disk constriction of NiFe(5 nm)/Pt(7 nm). First, we show how few-nanosecond voltage pulses can efficiently induce AOs. Then, we show how the AOs synchronise to external microwave pulses by means of injection-locking [3]. Our findings suggest that the operation time of processes such as synchronisation and logic using SHNOs can be reduced to the nanosecond timescale and that multi-level microwave outputs can be achieved by combination of voltage and RF pulses. Financial support by the Deutsche Forschungsgemeinschaft is gratefully acknowledged within program SCHU2922/1-1.

[1] A. Manchon et al., Rev. Mod. Phys., vol. 91, p. 035004, Sep 2019. [2] T. Hache et al., Applied Physics Letters, vol. 116, no. 19, p. 192405, May 2020. [3] T. Hache et al., Applied Physics Letters, vol. 114, no. 10, p. 102403, Mar 2019.

MA 11.32 Wed 13:30 P

Monte Carlo simulation of ultrafast nonequilibrium spin and charge transport in iron — •Johan Briones, Hans Christian Schneider, and Bärbel Rethfeld — Department of Physics and Optimas Research Center, TU Kaiserslautern, Germany

Spin transport and spin dynamics after femtosecond laser pulse irradiation of iron (Fe) are studied using a kinetic Monte Carlo model. This model simulates spin dependent dynamics by taking into account elastic electron-lattice scattering, where only the direction of the excited electrons changes, and inelastic electron - electron scattering, where secondary electrons are generated. An analysis of the particle kinetics inside the material shows that a smaller elastic scattering time affects the spin dynamics by leading to a larger spatial spread of electrons in the material, whereas generation of secondary electrons affects the spin transport by increasing the propagation length of homogeneous spin polarization.

MA 11.33 Wed 13:30 P

Magnetic Transitions in Synthetic Antlerite, $Cu_3SO_4(OH)_4$ — •Darren C. Peets[1], Anton A. Kulbakov[1], Quirin Stahl[1], Pavlo Portnichenko[1], Maxim Avdeev[2], Sebastian Gass[3], Laura Teresa Corredor Bohorquez[3], Anja U. B. Wolter[3,4], Manuel Feig[5], Hagen Poddig[6], Inés Puente-Orench[7,8], Jochen Geck[1,4], and Dmytro S. Inosov[1,4] — [1]IFMP, TU Dresden, 01069 Dresden, Germany — [2]ANSTO, Lucas Heights, NSW 2234, Australia — [3]IFW-Dresden, 01069 Dresden, Germany — [4]ct.qmat, TU Dresden, 01069 Dresden, Germany — [5]IEP, TU Bergakademie Freiberg, 09596 Freiberg, Germany — [6]Anorganische Chemie II, TU Dresden, 01069 Dresden, Germany — [7]INMA, CSIC-Universidad de Zaragoza, Zaragoza 50009, Spain — [8]ILL, 38042 Grenoble, France

In frustrated magnetic systems, geometric constraints or the competition amongst interactions introduce extremely high degeneracy and prevent the system from readily selecting a low-temperature ground state. In the mineral antlerite, $Cu_3SO_4(OH)_4$, Cu^{2+} ($S = \frac{1}{2}$) quantum spins populate triangular-lattice three-leg ladders in a novel highly-frustrated quasi-one-dimensional structural motif. We demonstrate that this mineral hosts four distinct magnetically-ordered phases in zero field alone, including an incommensurate phase and a multiple-**q** phase. Multiple-**q** phases are extremely uncommon in centrosymmetric compounds of 3d and lighter elements, and the discovery of such a phase in antlerite opens a new route to finding new materials platforms for exotic magnetic order.

MA 11.34 Wed 13:30 P

Unconventional magnetism in the $RE_3Fe_3Sb_7$ spin system — •Sabrina Palazzese[1,2], Falk Pabst[3], Sumanta Chattopadhyay[1], Shingo Yamamoto[1], Thomas Herrmannsdörfer[1], Denis Gorbunov[1], Eugen Weschke[4], Oleksandr Prokhnenko[4], Hiroyuki Nojiri[5], Thomas Doert[3], Bella Lake[4,6], Joachim Wosnitza[1,2], and Michael Ruck[3] — [1]Hochfeld-Magnetlabor Dresden (HLD-EMFL), HZDR, Dresden, Germany — [2]Institut für Festkörper- und Materialphysik, TU Dresden, Germany — [3]Fakultät für Chemie und Lebensmittelchemie, TU Dresden, Germany — [4]Helmholtz-Zentrum Berlin für Materialien und Energie (HZB), Berlin, Germany — [5]Institute for Materials Research, Tohoku University, Sendai, Japan — [6]Institut für Festkörperphysik, TU Berlin, Germany

Here we present a detailed magnetization and electrical-transport study of novel $RE_3Fe_3Sb_7$ compounds. We find a number of spontaneous magnetic phase transitions in a wide temperature range and a pronounced magnetic anisotropy. $RE_3Fe_3Sb_7$ shows an emergent spontaneous magnetization in zero field and a kink in the temperature-dependent resistivity at the spin-reorientation transition SRT. In the ground state, $RE_3Fe_3Sb_7$ displays a large uniaxial magnetic anisotropy that changes to planar at SRT. Our neutron scattering results reveal an unusual antiparallel alignment of Pr and Fe magnetic moments. In addition, XMCD measurements in pulsed magnetic fields up to 28 T indicate a continuous rotation of the Nd moment towards the Fe moment.

MA 12: INNOMAG e.V. Dissertationspreis / Ph.D. Thesis Prize (2021)

The Working Group Magnetism (Arbeitsgemeinschaft Magnetismus der DPG) awards a dissertation prize whose aim is to recognise outstanding research done within the framework of a doctorate and communication of this research in an excellent way, both verbally and in writing. The prize is kindly supported by INNOMAG e.V. In this finalists session, pre-selected nominees will present and defend their dissertation. Afterwards, the prize committee decides on the winner of the INNOMAG e.V. Dissertation Prize 2021 and the award of 1000 EURO.

Time: Wednesday 14:30–16:15 Location: H2

MA 12.1 Wed 14:30 H2

Emergent electrodynamics in non-collinear spin textures: skyrmions and beyond — •Börge Göbel — Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany

Magnetic skyrmions have attracted an enormous research interest since their discovery a decade ago. Especially the non-trivial real-space topology of these nano-whirls leads to fundamentally interesting and technologically relevant consequences like an enormous stability and the emergence of a topological Hall effect [1]. One issue, which is hindering the realization of spintronic applications, is the so-called skyrmion Hall effect: A skyrmion does not move parallel to an applied spin-polarized current. Instead, the skyrmion is pushed towards the edge of the sample where it annihilates. In this talk, I will present several ways, how this effect can be suppressed. Therefore, I will give an overview about observed or proposed alternative magnetic quasiparticles [1]. The stabilization, as well as the emergent electrodynamic effects will be discussed for the antiferromagnetic skyrmion [2], the bimeron [3] and the antiskyrmions. For the latter object I will present the observed coexistence with conventional skyrmions [4] which allows to suggest an advanced, less susceptible version of the racetrack data storage device.

References: [1] B. Göbel et al. Physics Reports 895, 1 (2021) [2] B. Göbel et al. PRB 96, 060406 (2017) [3] B. Göbel et al. PRB 99, 060407 (2019) [4] J. Jena*, B. Göbel* et al. Nature Communications 11, 1115 and Science Advances 6, eabc0723 (2020)

MA 12.2 Wed 14:55 H2

Complex magnetism of nanostructures on surfaces: from orbital magnetism to spin excitations — •Sascha Brinker — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — Department of Physics, RWTH Aachen University, D-52056, Aachen, Germany

Magnetic nanostructures deposited on surfaces not only offer a promising route towards the miniaturization of future information technology devices, but also serve as ideal prototypes to explore fundamental physics at the nanoscale. In this theoretical thesis, I explore a wide range of fundamental magnetic properties in this class of materials ranging from a new component to the orbital degrees of freedom, and a new chiral interaction, which is the biquadratic equivalent of the well-known Dzyaloshinskii-Moriya interaction, to the complex dependence of the so-called Gilbert damping, which can be observed for example in the spin excitation spectrum, on the non-collinear magnetic structure. The fundamental theoretical studies are complemented by fruitful collaborations with experimental colleagues using scanning tunneling microscopy. Theoretical methods were developed and applied to describe the magnetic stability of coupled nanostructures and the emergence of boundary states in magnetic chains proximity-coupled to a superconducting substrate.

This work was supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (ERC Consolidator Grant No. 681405 DYNASORE).

MA 12.3 Wed 15:20 H2

Robustness and Variation of Low-Dimensional Signal Transmission in Topological Phases — •Maik Malki and Götz Uhrig — Lehrstuhl Theoretische Physik I, TU Dortmund, 44221 Dortmund, Germany

The signal transmission based on topological materials represents an important issue for the future. To this end, we investigate the variation of signal transmission in topological phases as well as their robustness in one- and two-dimensional systems by pursuing different approaches. By modifying the boundaries we show the possibilities to control the speed of signal transmission in various topological systems. Furthermore, the triplon excitations in $BiCu_2PO_6$ provide a non-trivial Zak phase while no localized edge states are present. Thus the bulk-boundary correspondence is put into perspective. Finally, present ferromagnetic Shastry-Sutherland model in order to realize topological magnon excitations.

Short break followed by bestowal of INNOMAG e.V. Dissertationspreis / Ph.D. Thesis Prize (2021)

MA 13: PhD Focus Session: Symposium on Strange Bedfellows - Magnetism Meets Superconductivity" (joint session MA/AKjDPG) (joint session MA/TT)

At first sight, it seems that the phenomena of magnetism and superconductivity do not go along, as indicated by the Meissner effect, when a magnetic field is completely expelled from the interior of a conventional superconductor. However, the synergy of these two manifestations of nature in condensed matter does occur and can be rather interesting! Theoretical works have predicted the existence of exotic states at the interface between a superconductor and a magnet, such as the sought-after Majorana fermions and spin-triplet superconductivity. The first have been predicted to route an efficient way to implement quantum computers (currently a European scientific flagship), while the latter allows the creation of spin-polarized supercurrents, opening up fundamentally new possibilities for spintronics. Therefore, our symposium aims at putting together experts to provide a fundamental and practical understanding of the subject to discuss most recent developments from the theoretical and experimental sides, and to show perspectives for applications.

Organizers: Annika Stellhorn, Flaviano José dos Santos, Markus Hoffmann (Forschungszentrum Jülich and Peter Grünberg Institut)

Time: Thursday 10:00–12:45 Location: H5

Invited Talk MA 13.1 Thu 10:00 H5

Magnetism and superconductivity: new physics one atom at a time — •Alexander Balatsky — NORDITA — UCONN

In this tutorial I will review the effects of magnetism and electronic defect in conventional and unconventional superconductors. The extreme case of quantum engineering where one builds magnetic and electronic features one atom at a time has proved to be a versatile approach. Impurities and defects are pair breakers in superconductors. I will discuss how defects can also enable new features in superconductors like intragap resonances, topological Majorana modes and seed new superconducting phases. Looking forward I will discuss how we might induce novel physics in superconductors with precise quantum impurity band engineering

MA 13.2 Thu 10:30 H5

Magnetic exchange interactions at proximity of a superconductor — •Uriel Aceves[1,2], Sascha Brinker[1], Filipe Guimaraes[3], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany — [3]Jülich Supercomputing Centre, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany

The coupling of magnetic impurities to superconductors prompts the arise of exciting physics such as sub-gap states like Yu-Shiba-Rusinov states and Majorana zero modes, which constitute key mechanisms on the road towards a topological quantum computer. The interplay of spin-orbit coupling and (non-collinear) magnetism enriches the complexity and topological nature of the in-gap states hosted in proximity-induced superconductors. However, little is known about the impact of superconductivity on the different contributions to the magnetic exchange interactions, like the bilinear isotropic exchange and the Dzyaloshinskii-Moriya interaction — and in turn the impact on the magnetic textures. In this work, we propose a method for the extraction of the tensor of exchange interactions in the superconducting regime as described by the Bogoliubov-de Gennes equations. Finally, with our multi-orbital tight-binding code TITAN, we investigate a Mn (110) monolayer deposited on the Nb (110) surface and analyze the magnetic interactions of the superconducting and metallic phases.

–Work funded by Horizon 2020–ERC (CoG 681405–DYNASORE).

Invited Talk MA 13.3 Thu 10:45 H5

Magnetic adatom chains on superconducting $NbSe_2$ — Eva Liebhaber[1], Lisa M. Rütten[1], Gael Reecht[1], Jacob F. Steiner[2], Sebastian Rohlf[3], Kai Rossnagel[3], Felix von Oppen[2], and •Katharina J. Franke[1] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Germany — [3]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Germany

Magnetic adatom chains on superconducting substrates constitute a fascinating platform to study the interplay of quantum magnetism and superconductivity. Here, we investigate magnetic adatom chains in the dilute limit. This means that the atoms are sufficiently far spaced that direct hybridization of their d orbitals is negligible, but close enough for sizeable substrate-mediated interactions. We build these chains from individual Fe atoms on a 2H-$NbSe_2$ substrate. Using scanning tunneling microscopy and spectroscopy we first characterize the exchange coupling between the magnetic adatoms and the superconductor by detecting their Yu-Shiba-Rusinov states within the superconducting energy gap. We then use the tip of the STM to assemble dimers, trimers and chains of these Fe atoms. In each step, we track the evolution of the Yu-Shiba-Rusinov states and identify magnetic interactions, hybridization and band formation.

MA 13.4 Thu 11:15 H5

Tuning the interaction between spins coupled to a superconductor on the atomic level — •Felix Küster[1], Ana M. Montero[2], Filipe S. M. Guimarães[2], Sascha Brinker[2], Samir Lounis[2], Stuart S. P. Parkin[1], and Paolo Sessi[1] — [1]Max Planck Institute of Microstructure Physics, Halle, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, Jülich, Germany

Magnetic impurities coupled to superconducting condensates induce sharp in-gap resonances, the so-called Yu-Shiba- Rusinov (YSR) states. By reducing the distance between impurities, YSR quasiparticles can interact, hybridize, and eventually form bands. Here, we scrutinize the behavior of 3d atoms coupled to niobium by scanning tunneling microscopy and spectroscopy. We demonstrate how the coupling between spins and a superconducting condensate hosting an anisotropic Fermi surface can be tuned by varying the direction and distance between the impurities. We verify the existence of long range coupling as well as the crossing through a quantum phase transition, providing a promising platform for the emergence of topological superconductivity.

Invited Talk MA 13.5 Thu 11:30 H5

Yu-Shiba-Rusinov states and ordering of magnetic Impurities near the boundary — •Jelena Klinovaja — University of Basel, Basel, Switzerland

In my talk, I will discuss properties of one and two magnetic impurities near the boundary of a one-dimensional nanowire in proximity to a conventional s-wave superconductor. We showed that the energies of the subgap states, supported by the magnetic impurities, are strongly affected by the boundary for distances less than the superconducting coherence length. When the impurity is moved towards the boundary, multiple quantum phase transitions periodically occur in which the parity of the superconducting condensate oscillates between even and odd. The magnetic ground-state configuration of two magnetic impurities depends not only on the distance between them, but also explicitly on their distance away from the boundary of the nanowire. As a consequence, the magnetic ground state can switch from ferromagnetic to antiferromagnetic while keeping the interimpurity distance unaltered by simultaneously moving both impurities away from the boundary.

[1] O. Deb, S. Hoffman, D. Loss, and J. Klinovaja, Phys. Rev. B 103, 165403 (2021). [2] H. Ding, Y. Hu, M. T. Randeria, S. Hoffman, O. Deb, J. Klinovaja, D. Loss, and A. Yazdani, Proc. Natl. Acad. Sci. USA 118, 14 (2021). [3] S. Hoffman, J. Klinovaja, T. Meng, and D. Loss, .Phys. Rev. B 92, 125422 (2015). [4] T. Meng, J. Klinovaja, S. Hoffman, P. Simon, and D. Loss, Phys. Rev. B 92, 064503 (2015).

MA 13.6 Thu 12:00 H5

Temperature-Dependent Spin Transport and Current- Induced Torques in Superconductor-Ferromagnet Heterostructures — •Manuel Müller[1,2], Lukas Liensberger[1,2], Luis Flacke[1,2], Hans Huebl[1,2,3], Akashdeep Kamra[4], Wolfgang Belzig[5], Rudolf Gross[1,2,3], Mathias Weiler[1,2,6], and Matthias Althammer[1,2] — [1]Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]Physik- Department, Technische Universität München, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [4]Norwegian University of Science and Technology, Trondheim, Norway — [5]Physik-Department, Universität Konstanz, Konstanz, Germany — [6]Fachbereich Physik, TU Kaiserslautern, Kaiserslautern, Germany

Proximity effects at superconductor(SC)/ferromagnet(FM) interfaces provide novel functionality in superconducting spintronics. We investigate the injection of spin currents in NbN/permalloy (Py) heterostructures with and without a Pt spin sink layer. Spin currents are excited by broadband ferromagnetic resonance in the Py-layer coupled inductively to a coplanar waveguide and quantitative information on the spin current physics is obtained by measuring the complex microwave transmission as a function of temperature. Our findings, reveal the symmetry and strength of spin-to-charge current conversion in SC/FM heterostructures and provide guidance for future superconducting spintronics devices. Our results are published in Phys. Rev. Lett. **126**, 087201 (2021). We acknowledge financial support by the DFG.

Invited Talk MA 13.7 Thu 12:15 H5

Resonance from antiferromagnetic spin fluctuations for spin-triplet superconductivity in UTe2 — •Pengcheng Dai — Rice University

Superconductivity has its universal origin in the formation of bound (Cooper) pairs of electrons that can move through the lattice without resistance below the superconducting transition temperature Tc. While electron Cooper pairs in most superconductors form anti-parallel spin-singlets with total spin S = 0, they can also form parallel spin-triplet Cooper pairs with S = 1 and an odd parity wavefunction. Spin-triplet pairing is important because it can host topological states and Majorana fermions relevant for fault tolerant quantum computation. However, spin-triplet pairing is rare and has not been unambiguously identified in any solid state systems. Since spin-triplet pairing is usually mediated by ferromagnetic (FM) spin fluctuations, uranium based heavy-fermion UTe2, which has a Tc * 1.6 K, has been identified as a strong candidate for chiral spin-triplet topological superconductor near a FM instability. Here we use inelastic neutron scattering (INS) to show that superconductivity in UTe2 is coupled with a sharp magnetic excitation at the Brillouin zone (BZ) boundary near AF order, analogous to the resonance seen in other exotic superconductors. We find that the resonance in UTe2 occurs below Tc at an energy Er = 7.9kBTc. Since the resonance has only been found in spin-singlet superconductors near an AF instability, its discovery in UTe2 suggests that AF spin fluctuations can also induce spin-triplet pairing for superconductivity.

MA 14: Focus Session: Higher-Order Magnetic Interactions - Implications in 2D and 3D Magnetism II

Materials in which the magnetic moments order or cooperate in unusual ways underpin a plethora of physical phenomena, from strong magnetoelectric effects to topological quasiparticles, thus holding great promise for future spintronic and quantum computing applications. Magnetic interactions are the fundamental quantities that explain the complex magnetic phase diagrams and exotic excitation spectra of these intriguing materials. Recent theoretical and experimental developments have led to a realization of a pivotal role played by higher-order magnetic interactions in stabilizing intricate magnetic structures. The 4-spin 3-site interaction stabilizes an up-up-down-down state, which can become chiral. Theoretically, novel 4-spin chiral interactions and even 6-spin (chiral-chiral) couplings might explain the emergence of complex short-period 3D magnetic structures, and could open a path to the discovery of materials hosting 3D topological magnetization textures, such as magnetic hopfions. Experimentally, 4-spin interactions are conjectured to play a central role in skyrmions lattice formation in frustrated centrosymmetric materials. This area of research will make a strong impact in the field of magnetism in the upcoming years.

Organizers: Samir Lounis (University of Duisburg-Essen and Forschungszentrum Jülich), Manuel dos Santos Dias and Stefan Blügel (Forschungszentrum Jülich), Jonathan White (Paul Scherrer Institut)

Time: Thursday 13:30–15:15 Location: H5

Invited Talk MA 14.1 Thu 13:30 H5

The role of itinerant electrons and higher order magnetic interactions among fluctuating local moments in metallic magnets — •Julie Staunton — University of Warwick, Coventry CV4 7AL, U.K.

When external stimuli or varying temperature alter its magnetic properties, a metal's complex electronic fluid, with its emergent magnetic 'local moments', transforms. The itinerant electrons, coupled to these more localised spin degrees of freedom, have a profound effect on structure, electronic transport, and so on. The ab initio Density Functional Theory-based Disordered Local Moment method successfully describes this physics. It can locate and characterise magnetic phase transitions and calculate temperature and field-dependent magnetic properties. It will be shown how the theory provides a Gibbs free energy function of local moment order parameters with two central objects - local moment correlation functions in the paramagnetic state and local internal magnetic fields as functions of magnetic order. The potentially most stable magnetic phases and dominant 'exchange' interactions between pairs of local moments or effective 'spins' are identifiable from the first. Higher order magnetic interactions are extracted from the second and depend on how the electronic structure evolves with the state and extent of magnetic order. The approach will be illustrated by applications to the magnetic order and its link to the Fermi surfaces of rare earth metals and their compounds, permanent magnetic properties and the rich magnetic-strain phase diagrams and associated caloric effects of some transition metal antiferromagnets.

MA 14.2 Thu 14:00 H5

Short period magnetization texture of B20-MnGe explained by thermally fluctuating local moments — •Eduardo Mendive Tapia[1,2], Manuel dos Santos Dias[1], Sergii Grytsiuk[1], Julie Staunton[3], Stefan Blügel[1], and Samir Lounis[1] — [1]Peter Grünberg Institute and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Max-Planck-Institut für Eisenforschung, 40237 Düsseldorf, Germany — [3]University of Warwick, CV4 7AL, Conventry, UK

B20-type compounds, such as MnSi and FeGe, host helimagnetic and skyrmion phases at the mesoscale, which are canonically explained by the combination of ferromagnetic isotropic interactions with weaker chiral Dzyaloshinskii-Moriya ones. Mysteriously, MnGe evades this paradigm as it displays a noncollinear magnetic state at a much shorter nanometer scale [1]. Using a Disordered Local Moment theory within the KKR method [2,3], here we show that the length scale and volume-dependent magnetic properties of MnGe stem from purely isotropic exchange interactions generally obtained in the paramagnetic state. Our approach is validated by comparing MnGe with the canonical B20-helimagnet FeGe. The free energy of MnGe is calculated, from which we show how triple-q magnetic states can stabilize by adding higher-order interactions. –Work funded by the DAAD and EU Horizon 2020 via ERC-consolidator Grant No. 681405-DYNASORE.

[1] Fujishiro et al., Nat. Commun. **10**, 1059 (2019)
[2] Gyorffy et al., J. of Phys. F: Metal Phys. **15**, 1337 (1985)
[3] Jülich KKR codes (https://jukkr.fz-juelich.de)

MA 14.3 Thu 14:15 H5

Symmetry analysis of multi-spin interactions — •Levente Rózsa — University of Konstanz, Konstanz, Germany

Two-spin interactions including the isotropic exchange and Dzyaloshinsky-Moriya (DM) interactions or the magnetocrystalline anisotropy play a fundamental role in the formation of non-collinear spin structures. Going beyond the two-spin approximation enables the stabilization of, e.g., the zero-field nanoskyrmion lattice attributed to four-spin isotropic interactions [1]. A four-spin generalization of the DM interaction has also been proposed recently [2,3,4].

Multi-spin interactions are conventionally derived based on a perturbative expansion [2,4], which becomes cumbersome if many spins or higher orders of the spin-orbit coupling are involved. Here we present a systematic way of constructing multi-spin interaction terms based on a symmetry analysis. In the case of four spins, besides the isotropic and DM interactions, we identify symmetric second-order and fourth-order anisotropies, as well as a DM-like asymmetric anisotropy term. It is discussed how these coupling terms transform under point group operations, analogously to the Moriya rules; how they can be fitted based on the energies of specific spin configurations; and which types of non-collinear structures emerge based on these interactions.

[1] S. Heinze et al., Nat. Phys. 7, 713 (2011).
[2] S. Brinker et al., New J. Phys. 21, 083015 (2019).
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[4] S. Grytsiuk et al., Nat. Commun. 11, 511 (2020).

MA 14.4 Thu 14:30 H5

Spontaneous atomic-scale hexagonal spin lattices driven by higher-order exchange interactions — •Mara Gutzeit[1], André Kubetzka[2], Soumyajyoti Haldar[1], Henning Pralow[1], Roland Wiesendanger[2], Stefan Heinze[1], and Kirsten von Bergmann[2] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstraße 15, 24098 Kiel, Germany — [2]Department of Physics, University of Hamburg, 20355 Hamburg, Germany

Higher-order exchange interactions (HOI) beyond the pair-wise Heisenberg exchange can be the origin of a variety of complex magnetic structures such as conical spin spirals [1], multi-Q states [2,3], or nanoskyrmion lattices [4]. Here, using spin-polarized scanning tunneling microscopy we explore uniaxial spin states as well as two-dimensionally modulated spin structures in ultrathin Fe/Rh films on the Ir(111) surface. Density functional theory calculations elucidate how HOI stabilize spontaneous atomic-scale hexagonal spin lattices exhibiting only a small deviation from collinearity in these systems which are characterized by a weak Dzyaloshinskii-Moriya interaction. We demonstrate that a subtle interplay of HOI is responsible for the transition between different magnetic ground states.

[1] Yoshida *et al.* PRL **108**, 087205 (2012)
[2] Krönlein *et al.* PRL **120**, 207202 (2018)
[3] Spethmann *et al.* PRL **124**, 227203 (2020)
[4] Heinze *et al.* Nat. Phys. **7**, 713 (2011)

MA 14.5 Thu 14:45 H5

Dzyaloshinskii-Moriya Interaction revisited — •Hiroshi Katsumoto and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

In recent years, the Dzyaloshinskii-Moriya interaction (DMI) has received enormous attention. New materials, new physical issues, and new measurement methods have led to new questions. *E.g.*, recent theoretical studies have proposed higher-order interaction terms for this DMI [1]. Introduced by Dzyaloshinskii [2] on the basis of phenomenological and group-theoretical arguments in combination with classical axial vectors and substantiated by Moriya [3] for the first time microscopically based on the quantum mechanical spin-orbit interaction, in systems where the inversion symmetry is locally broken, the DMI affects the magnetic properties. We reiterate the cause of weak ferromagnetism in centrosymmetric materials and investigate the relationship between the Lifshitz invariant associated with macroscopic chiral symmetry breaking and microscopic DMI. We will discuss how to uniquely write down the interaction term in the spin Hamiltonian from the irreducible representation depending on the size of the spin.

We acknowledge funding from the DARPA TEE program through grant MIPR (#HR0011831554) from DOI, and Deutsche Forschungsgemeinschaft (DFG) through SPP-2137 and SFB-1238 (project C1).

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[3] T. Moriya, Phys. Rev. **120**, 91 (1960).

MA 14.6 Thu 15:00 H5

Chiral multi-site interactions in prototypical magnetic systems — •Sascha Brinker[1], Manuel dos Santos Dias[1], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced

Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Atomistic spin models can successfully explain the properties of magnetic materials once the relevant magnetic interactions are identified. Recently, new types of chiral interactions that generalize the Dzyaloshinskii-Moriya interaction have been proposed [1,2,3,4]. Here, we present a systematic construction of a generalized spin model containing isotropic and chiral multi-site interactions, motivated by a microscopic model, and their symmetry properties are established. We show that the chiral interactions arise solely from the spin-orbit interaction and that the multi-site interactions do not have to follow Moriya's rules, unlike the Dzyaloshinskii-Moriya interaction [1,4]. We then report on density functional theory calculations for prototypical magnetic systems, finite magnetic nanostructures on heavy metal substrates and two-dimensional systems with inversion symmetry.

[1] S. Brinker, M. dos Santos Dias and S. Lounis, New J Phys **21**, 083015 (2019); [2] A. Lászlóffy *et al.*, Phys Rev B **99**, 184430 (2019); [3] S. Grytsiuk *et al.*, Nat Commun **11**, 511 (2020); [4] S. Brinker, M. dos Santos Dias and S. Lounis, Phys Rev Research **2**, 033240 (2020)
–Work funded by Horizon 2020–ERC (CoG 681405–DYNASORE).

MA 15: Posters Magnetism IV

Topics: Ultrafast Magnetization Effects (15.1-15.15), Caloric Effects in Ferromagnetic Materials (15.16-15.22), Spin Calorics (general) (15.23), Functional Antiferromagnetism (15.24-15.25), Magnetic Heuslers (15.26-15.31), Complex magnetic oxides (15.32), Bulk Materials: Soft and Hard Permanent Magnets (15.33-15.35), Disordered Magnetic Materials (15.36-15.39), Multiferroics and Magnetoelectric Coupling (15.40-15.44), Magnetic Domain Walls (non-skyrmionic)(15.45-15.47)

Time: Thursday 13:30–16:30 Location: P

MA 15.1 Thu 13:30 P

Coherent all-optical switching of an antiferromagnet — •Tobias Dannegger[1], Marco Berritta[2], Karel Carva[3], Severin Selzer[1], Ulrike Ritzmann[2,4], Peter M. Oppeneer[2], and Ulrich Nowak[1] — [1]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz, Germany — [2]Department of Physics and Astronomy, Uppsala University, Box 516, SE-75120 Uppsala, Sweden — [3]Charles University, Faculty of Mathematics and Physics, Department of Condensed Matter Physics, Ke Karlovu 5, CZ-121 16 Prague, Czech Republic — [4]Dahlem Center of Complex Quantum Systems and Department of Physics, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

The physics of ultrafast magnetisation switching holds great potential for future magnetic storage applications. Much research has been conducted on ferro- and ferrimagnetic switching but more recent progress in spintronics has begun to utilise the advantages of antiferromagnets, such as robustness against external magnetic fields and high-frequency spin dynamics. Based on density functional theory calculations and atomistic spin dynamics simulations, we show, using the example of the easy-plane antiferromagnet CrPt, that the properties of antiferromagnets allow for a coherently induced ultrafast all-optical switching process that does not require the thermally induced demagnetisation of the material. This process is facilitated by the inverse Faraday effect, which, as our calculations reveal, induces staggered magnetic moments in the material. This can be used to achieve controllable switching between two perpendicular magnetisation states.

MA 15.2 Thu 13:30 P

Spin Dynamics in Magnetic Nanojunctions — •Rudolf Smorka[1], Martin Žonda[2], and Michael Thoss[1] — [1]Institute of Physics, Albert-Ludwigs-Universität Freiburg, Germany — [2]Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University Prague, Czech Republic

Recent experimental advances of atomic and nanoscale magnetism motivate the study of spin dynamics on ultrafast time scales. In this contribution, we use a quantum-classical hybrid approach to study current-driven magnetization dynamics in systems consisting of tight-binding electrons and localized classical spins. Using this approach, we show that both the electronic structure of the central system and the self-consistent feedback of spin and electron dynamics play a significant role in the dynamical properties of magnetic nano-junctions with applied dc voltage. Specifically, relaxation dynamics can be enhanced by tuning the dc voltage in resonance with electronic levels of the central system. We analyze this characteristic in nano-junctions containing a single classical Kondo impurity. Furthermore, we investigate current-induced spin-transfer-torques (STT) in a ferromagnetic spin valve far away from equilibrium and show that electronic levels in the bias window lead to an enhancement of the STT.

MA 15.3 Thu 13:30 P

Tuning all-optical magnetization switching efficiency by laser pulse wavelength variation — •Marcel Kohlmann[1], Krystina Hvorakova[1], Jakob Walowski[1], Robin John[1], Cai Müller[2], Marco Berrita[3], Deninse Hinzke[4], Pablo Nieves[5], Oksana Chubykalo-Fesenko[5], Tiffany Santos[6], Henning Ulrichs[7], Ritwik Mondal[3,4], Peter M Oppeneer[3], Ulrich Nowak[4], Jeffrey McCord[2], and Markus Münzenberg[1] — [1]Greifswald University — [2]Kiel University — [3]Uppsala University — [4]Konstanz University — [5]CISC Madrid — [6]HGST Western Digital — [7]Göttingen University

The annual growth of created, transferred and stored data demands the development of new storage media with higher data storage density. Heat-assisted magnetic storage devices (HAMR) present a promising candidate for this application. Hence investigation of magnetization manipulation remains a topic of interest for research and development. We therefore study all-optical-helicity-dependent switching of FePt granular media which is a prominent candidate material for the development of HAMR devices. We calculated the switching rates for individual FePt nanoparticles in ab-initio calculations of inverse Faraday effect and magnetic dichroism induced heating which provided us with a model to describe the switching as a stochastic process. With this theoretical description we optimize the number of laser shots, fluence and wavelengths to all-optically switch FePt grains. First experiments show, that tuning wavelengths requires simultaneous fluence adjustment due to the increased photon absorption for larger wavelengths.

MA 15.4 Thu 13:30 P

Investigation of ultrafast laser-induced toggle-switching and domain wall motion in GdF — •Rahil Hosseinifar[1], Ivar Kumberg[1], Evangelos Golias[1], Sangeeta Thakur[1], Karl Frischmuth[1], Florian Kronast[2], Mario Fix[3], Manfred Albrecht[3], and Wolfgang Kuch[1] — [1]Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [2]Helmholtz-Zentrum Berlin, Albert-Einstein-Straße 15, 12489 Berlin, Germany — [3]Institut für Physik, Universität Augsburg, Universitätsstraße 1, Building R, Level 4, 86159 Augsburg, Germany

Using purely optical means to manipulate the magnetization direction is an exciting way to introduce new potential applications in spintronic devices. We study 15 nm thin films of ferrimagnetic $Gd_{26}Fe_{74}$ with out-of-plane easy axis of magnetization by x-ray magnetic circular dichroism photoelectron emission microscopy. Individual linearly polarized laser pulses of 800 nm wavelength above a specific threshold fluence reverse the sample magnetization, independent of the magnetization direction, the so-called toggle switching. Local deviations from this deterministic behavior close to magnetic domain walls are studied. Reasons for nondeterministic toggle switching are related to extrinsic effects caused by pulse-to-pulse variations of the exciting laser system and intrinsic effects related to the magnetic domain structure of the sample. We point out intrinsic effects such as laser-induced domain-wall motion in the toggle switching and magnetic domain-wall elasticity, which cause local deviations from purely deterministic toggle switching.

MA 15.5 Thu 13:30 P

Ultrafast demagnetization dynamics including spin-, charge- and heat-transport. — •Sanjay Ashok, Sebastian T. Weber, Christopher Seibel, Johan Briones, and Bärbel Rethfeld — Fachbereich Physik and OPTIMAS Research Center, TU Kaiserslautern, Kaiserslautern, Germany

Ultrafast Demagnetization of metallic ferromagnets induced by femtosecond laser is usually studied in homogeneously heated thick films. In such cases, due to absence of temperature and density gradients within the material, there are no heat- or charge-currents. For thicker magnetic metals, the heating is not uniform and spin-, charge- and heat-transport contribute to ultrafast de- and re- magnetization. Here we study the role of spin-resolved charge and heat transport in ultrafast demagnetization of thick magnetic metal using the thermodynamic μT-model [1] and obtain spatial and temporal evolution of magnetization. We also study the role of transport for the relation between quenching and quenching time. Further, we analyze the different transport mechanisms and their contributions to measureable quantities.

[1] B. Y. Mueller and B. Rethfeld, Phys. Rev. B 90, 144420 (2014).

MA 15.6 Thu 13:30 P

Electron-magnon scattering dynamics in a two-band Stoner model — •Felix Dusabirane, Marius Weber, and Hans Christian Schneider — TU Kaiserslautern, Kaiserslautern, Germany

We theoretically study electronic scattering dynamics in a Stoner model with two spin-split bands. We include electron-magnon scattering together with Coulomb electron-electron scattering in order to describe incoherent hot-electron dynamics at sub-picosecond and picosecond timescales after ultrashort-pulse excitation in an itinerant ferromagnet. The optical excitation process is assumed to be instantaneous and the electronic dynamics is described at the level of equations of motion for momentum-dependent distribution functions together with time-dependent Fermi's Golden rule scattering rates. The magnons are treated as a bosonic bath.

We analyze the effect on the electronic spin-polarization dynamics of phase-space filling at different excitation conditions, as well as the magnitude of the Stoner splitting.

MA 15.7 Thu 13:30 P

Wavelength dependency in ultrafast magnetization dynamics of Nickel — •Martin Stiehl, Marius Weber, Christopher Seibel, Jonas Hoefer, Bärbel Rethfeld, Hans Schneider, Benjamin Stadtmüller, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Kaiserslautern, Germany

We revisit the problem of the influence of optical excitation conditions on ultrafast magnetization dynamics. In this contribution, we combined a theoretical analysis of the excitation and electron dynamics with time-resolved magneto-optical Kerr effect (tr-MOKE) studies to uncover the role played by the different pump-photon energies for ultrafast demagnetization in thin Ni films (10nm) on the insulating substrate MgO. We use a time-dependent Fermis Golden Rule approach to model the absorption and the temperature-based μ-T model for the subsequent incoherent electron dynamics. For a fixed absorbed energy one obtains rather different minority and majority carrier distributions for pump photon energies in the range from 0.5eV to 2.5eV. In contrast, we find identical tr-MOKE dynamics for all corresponding pump photon energies. The shape and fluence dependence of these photon energy dependent traces can be described well by our theoretical model. Our observations suggest a negligible influence of the details of the excited hot carrier distributions on the ultrafast demagnetization. Rather, the photon energy dependence of ultrafast demagnetization of Ni seems to be dominated by the deposited energy and quasi-thermal behavior of the electron system.

MA 15.8 Thu 13:30 P

Disentangling the Ultrafast Magnetization Dynamics in Magnet/Non-Magnet Bilayer Systems — •Jonas Hoefer, Martin Stiehl, Benjamin Stadtmüller, and Martin Aeschlimann — Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Kaiserslautern, Germany

In the last 20 years, different all-optical techniques based on the magneto-optical Kerr effect (MOKE) were employed to study the ultrafast magnetization dynamics of magnetic thin films, alloys and multilayer structures. While conventional time-resolved (tr) MOKE studies provided the insights into the microscopic mechanisms governing the loss of magnetic order in simple materials, tr-MOKE experiments with fs-XUV radiation provided an understanding of the element specific magnetization dynamics of composite materials. The most recent progress in tr-MOKE experiments is the implementation of the so-called C-MOKE approach. It utilizes the complex nature of the material specific Kerr response (KR) to disentangle the magnetization dynamics of magnetic/non-magnetic multilayer structures. A crucial ingredient for the separation of the magnetization dynamics of all layers is, however, the precise value of the KR of the transiently spin-polarized non-magnetic layers that is often only available from theory.

Here we present a new strategy to experimentally determine the KR of a transiently magnetized gold layer in a Permalloy (Py)/gold (Au) heterostructure after optical excitation. This allows us to disentangle the layer specific magnetization dynamics of both materials and thus to discuss the spin transport across the Py/Au interface.

MA 15.9 Thu 13:30 P

Efficient spin excitation via ultrafast damping torques in antiferromagnets — •Christian Tzschaschel[1,2], Takuya Satoh[3], and Manfred Fiebig[1] — [1]Department of Materials, ETH Zurich, Switzerland — [2]Department of Chemistry and Chemical Biology, Harvard University, USA — [3]Department of Physics, Tokyo Institute of Technology, Japan

Damping effects form the core of many emerging concepts for high-speed spintronic applications. Important characteristics such as device switching times and magnetic domain-wall velocities depend critically on the damping rate. While the implications of spin damping for relaxation processes are intensively studied, damping effects during impulsive spin excitations are assumed to be negligible because of the shortness of the excitation process. Here we show that, unlike in ferromagnets, ultrafast damping plays a crucial role in antiferromagnets because of their strongly elliptical spin precession. In time-resolved measurements, we find that ultrafast damping results in an immediate spin canting along the short precession axis. The interplay between antiferromagnetic exchange and magnetic anisotropy amplifies this canting by several orders of magnitude towards large-amplitude modulations of the antiferromagnetic order parameter. Exemplarily, we consider optical spin excitations in antiferromagnetic hexagonal $R\mathrm{MnO_3}$ via the inverse Faraday effect. We find that a so far overlooked damping torque can even provide the dominant excitation mechanism. We thus disclose a highly efficient route towards the ultrafast manipulation of magnetism in antiferromagnetic spintronics.

MA 15.10 Thu 13:30 P

Dispersion relation of nutation surface spin waves in ferromagnets — •Mikhail Cherkasskii[1], Michael Farle[1,2], and Anna Semisalova[1] — [1]Faculty of Physics, University of Duisburg-Essen, Duisburg, 47057, Germany — [2]Kirensky Institute of Physics, Federal Research Center KSC SB RAS, Russia

Recently, it has been theoretically and experimentally demonstrated that the effects of inertia of magnetization should be considered in the full description of spin dynamics at pico- and femtosecond timescales [1-4]. The nutation motion of magnetization is a manifestation of inertia of the magnetic moments. A rigorous derivation including inertia in the Landau-Lifshitz-Gilbert equation was carried out by Mondal et al. in the Dirac-Kohn-Sham framework [3]. In this presentation, we show that inertia effect in magnetization dynamics results in a new type of spin waves, i.e. nutation surface spin waves, which propagate at terahertz frequencies in in-plane magnetized ferromagnetic thin films. Considering the magnetostatic limit, i.e. neglecting exchange coupling, we calculate dispersion relation and group velocity, which we find to be slower than the velocity of conventional (precession) spin waves. In addition, we find that the nutation surface spin waves are backward spin waves [1].

[1]*M. Cherkasskii, M. Farle, and A. Semisalova, Phys. Rev. B 103, 174435 (2021). [2]*M. Cherkasskii, M. Farle, and A. Semisalova, Phys. Rev. B 102, 184432 (2020). [3]*R. Mondal, M. Berritta, A. K. Nandy, and P. M. Oppeneer, Phys. Rev. B 96, 024425 (2017). [4]*K. Neeraj et al, Nat. Phys. 17, 245 (2021).

MA 15.11 Thu 13:30 P

Imprinting chirality in an antiferromagnetic spin chain with ultrafast laser — •Sumit Ghosh[1,2], Frank Freimuth[1,2], Olena Gomonay[2], Stefan Blügel[1], and Yuriy Mokrousov[1,2] — [1]PGI-1 and IAS-1, Forschungszentrum Jülich, Jülich, Germany — [2]Institute of Physics, Johannes Gutenberg-University Mainz, Germany

Recent experimental generation of skyrmions with ultrafast laser pulses [1] has opened new horizons in ultrafast generation of chiral magnetic order. However, the theoretical understanding of the underlying physics is still under mist which poses a hurdle in further manipulation of laser induced chirality. We present here a complete picture of the laser induces chirality generation by combining the classical magnetisation dynamics with quantum evolution of states which reveals the pertinent features of fast electron dynamics as well as slow magnetisation dynamics leading to the formation of a chiral structure [2]. We have successfully identified the emergent electronic interactions resulting the formation of the chiral structure which can survive for nanoseconds. We demonstrate the distinction between the dynamics initiated by a thermal re-population, and the laser excited dynamics and also show how to manipulate the end states by tuning the laser parameter. Our findings are fairly robust against thermal fluctuation which makes them feasible for experimental realisation and thus open new ways to explore the intertwined optical and magnetisation dynamics.

[1] F. Büttner et al. Nat. Mater. 20, 30-37 (2021).
[2] S. Ghosh, F. Freimuth, O. Gomonay, S. Blügel, Y. Mokrousov, arXiv:2011.01670.

MA 15.12 Thu 13:30 P

Ultrafast light-induced torques and Hall effects driven by laser pulses in thin films — •Hanan Hamamera[1,2], Filipe Souza Mendes Guimaraes[3], Mnauel dos Santos Dias[1], and Samir Lounis[1,4] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [2]Department of Physics, RWTH Aachen University, 52056 Aachen, Germany — [3]Jülich Supercomputing Centre, Forschungszentrum Jülich & JARA, 52425 Jülich, Germany — [4]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Effective control of the magnetization at ultrafast timescale using lasers have the capacity to revolutionize future technology devices. Based on realistic time-dependent electronic structure simulations [1], we have shown that the polarization of laser pulses are determinant to switch the magnetization via the inverse-Faraday like effect [1]. Even the magnetization of an elementary magnet such as bulk Ni can be reversed due to ultrafast light-induced torques. We extended this work to Co films on Pt(001), where various ultrafast Hall effects in conjunction with the inverse-Faraday effect dictate the observed complex magnetization dynamics. We discuss these phenomena in the light of the unveiled mechanisms and proceed to a systematic comparison with previous works.

— Work funded by the Palestinian-German Science Bridge (BMBF–01DH16027) and Horizon 2020–ERC (CoG 681405–DYNASORE).

[1] H. Hamamera *et al.*, arXiv:2104.13850 (2021).

MA 15.13 Thu 13:30 P

Nutational switching in ferromagnets and antiferromagnets — •Lucas Winter, Levente Rózsa, Sebastian Grossenbach, and Ulrich Nowak — University of Konstanz , Konstanz, Germany

For magnetic memory devices, precessional switching is a promising new way of writing data. However, on ultra-short timescales, recent research[1] indicates that the magnetization does not only exhibit precession but also nutation. Here, we investigate how nutation can contribute to spin switching. We use analytic theory and atomistic spin simulations to discuss the behavior of ferromagnets and antiferromagnets in high-frequency magnetic fields. In ferromagnets, linearly polarised fields align the magnetization perpendicular to the external field, enabling 90° switching. For circularly polarized fields in the xy plane, the magnetization tilts to the z direction. During this tilting, it rotates around the z axis, allowing 180° switching. In antiferromagnets, external fields with frequencies higher than the nutation frequency align the order parameter parallel to the magnetic field direction, while for lower frequencies it is oriented perpendicular to the field.

The switching frequency increases with higher magnetic field strengths, but it deviates from the Larmor frequency characteristic for precessional switching. High field strengths are required to outpace precessional switching. Furthermore, nutational switching requires low temperatures to be observable.

[1] K. Neeraj et al., Nat. Phys. 17, 245 (2021).

MA 15.14 Thu 13:30 P

Spectroscopic Analysis of the Ultrafast Non-Equilibrium Dynamics in Nickel at the European X-Ray Free-Electron Laser — •T. Lojewski[1], N. Rothenbach[1], Y. Kvashnin[2], L. Le Guyader[3], B. Van Kuiken[3], R. Carley[3], J. Schlappa[3], R. Gort[3], G. Mercurio[3], A. Yaroslavtsev[3], N. Gerasimova[3], M. Teichmann[3], L. Mercadier[3], R. Y. Engel[4], P. Miedema[4], L. Spieker[1], F. Döring[5], B. Rösner[5], F. De Groot[6], P. Thunström[2], O. Granäs[2], J. Jönsson[2], C. Lambert[7], I. Pronin[8], J. Rezvani[9], M. Pace[10], C. Boeglin[10], C. Stamm[7,11], M. Beye[4], C. David[5], O. Eriksson[2], A. Scherz[3], U. Bovensiepen[1], H. Wende[1], K. Ollefs[1], and A. Eschenlohr[1] — [1]Univ. Duisburg-Essen and CENIDE — [2]Uppsala Univ. — [3]European XFEL — [4]DESY — [5]PSI — [6]Utrecht Univ. — [7]ETH Zürich — [8]ITMO Univ. — [9]INFN — [10]Univ. of Strasbourg — [11]FHNW

X-ray absorption spectroscopy has become a valuable technique to study non-equilibrium dynamics due to its sensitivity to electronic and lattice dynamics combined with its element-specificity. The SCS instrument of the European X-ray free-electron laser offers unprecedented energy resolution and dynamic range in X-ray absorption spectra and their pump-induced changes. We report the time-resolved, spectroscopic analysis at the $L_{2,3}$-edges of nickel-metal obtained in transmission geometry. This spectroscopic analysis was combined with *ab initio* DFT calculations. We find redshifts and reduced peak intensities of the pumped spectra, which can be related to a reduction of the magnetic moment and an electronic redistribution, respectively.

MA 15.15 Thu 13:30 P

Wavelength-dependent magnetization dynamics in Ni|Au bilayers — •Christopher Seibel, Marius Weber, Martin Stiehl, Sebastian T. Weber, Martin Aeschlimann, Benjamin Stadtmüller, Hans Christian Schneider, and Baerbel Rethfeld — Department of Physics and Research Center OPTIMAS, TU Kaiserslautern, Germany

Existing experimental and theoretical studies of ultrafast demagnetization in ferromagnets rely mostly on only one fixed wavelength to excite the sample. However, recent experiments indicate that the dynamics of the demagnetization and remagnetization process depend on the wavelength of the exciting laser pulse [V. Cardin et al., Phys. Rev. B **101**, 054430 (2020); U. Bierbrauer et al., JOP: Cond. Mat. **29**, 244002 (2017)].

We extend the temperature-based μT-model to describe the ultrafast magnetization dynamics of magnetic/non-magnetic bilayer systems. Our theoretical model relies on realistic densities of states of both materials. It includes energy and spin transfer at the interface as well as the layer and wavelength dependent absorption of the pump pulses.

For the exemplary case of a thin nickel layer on a gold substrate, we find a faster and larger loss of the magnetic order of Ni when increasing the wavelength from 360 nm to 800 nm. Our theoretical predictions are confirmed by time-resolved MOKE experiments. This allows us to discuss the influence of energy and spin transfer processes for the photon energy dependent magnetization dynamics of magnetic bi- and multilayer structures.

MA 15.16 Thu 13:30 P

The local magnetic moment and vibrational properties of Sn in NiMnSn-Heusler alloys during magnetostructural phase transition — •Benedikt Eggert[1], Benedikt Beckmann[2], Johanna Lill[1], Tobias Lojewski[1], Simon Rauls[1], Franziska Scheibel[2], Andreas Taubel[2], Olga Miroshkina[1], Katharina Ollefs[1], Richard Brand[1], Michael Hu[3], Markus Gruner[1], Oliver Gutfleisch[2], and Heiko Wende[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen — [2]Functional Materials, TU Darmstadt — [3]Argonne National Laboratory, USA

Materials with first-order magnetostructural phase transition exhibit a large magnetocaloric effect and may lead to environmentally friendly and more energy efficient alternative to conventional vapor compression refrigeration. The investigated NiMnSn Heusler alloy exhibits a first order phase transition from low temperature ferrimagnetic martensite to high temperature ferromagnetic austenite phase. We performed ^{119}Sn nuclear resonant inelastic X-ray scattering (NRIXS) and ^{119}Sn Mössbauer spectroscopy along the phase transition to track the evolution of lattice dynamics and the local magnetic moment, respectively, during this transition. Sn-NRIXS indicates variations in the phonon density of states that lead to a reduction of the Sn-selective vibrational entropy and a softening of the lattice in the austenite phase. On the other side, Sn-Mössbauer spectroscopy indicates an increase of the induced Sn-moment, showing that the magnetic structure changes. We acknowledge the financial support through the DFG (CRC/TRR270) and the U.S. DOE.

MA 15.17 Thu 13:30 P

Ferromagnetic to paramagnetic transition of $SrRuO_3$ under pressure — •Anh Tong[1], Pau Jorba[1], Marc Seifert[1], Stefan Kunkemöller[2], Kevin Jenni[2], Markus Braden[2], James S. Schilling[1], and Christian Pfleiderer[1] — [1]Technische Universität München, James-Franck-Str.1, D-85748 Garching — [2]Universität zu Köln, Zülpicher Str.77, D-50937 Köln

In the Ruddlesden-Popper perovskite series, $Sr_{n+1}Ru_nO_{3n+1}$, intense experimental and theoretical efforts have been dedicated to unravel the nature of unconventional superconductivity in single-layer Sr_2RuO_4 ($n = 1$) as well as a putative electronic nematic phase masking the quantum critical end-point in the double-layer itinerant metamagnet $Sr_3Ru_2O_7$ ($n = 2$). We report an experimental study of the zero temperature ferromagnetic to paramagnetic transition under pressures up to 20 GPa in high quality single crystals of the infinite layer itinerant ferromagnet SrRuO3 ($n = \infty$). Our study aims to reconcile the properties of $Sr_3Ru_2O_7$ and Sr_2RuO_4 with the generic temperature-pressure-magnetic field phase diagram of itinerant ferromagnets.

MA 15.18 Thu 13:30 P

Microstructural aspects of multicaloric cooling using magnetic fields and unaxial stress in Ni-Mn-In Heusler compounds — •Lukas Pfeuffer[1], Adrìa Gràcia-Condal[2], Tino Gottschall[3], David Koch[1], Enrico Bruder[1], Jonas Lemke[1], Andreas Taubel[1], Franziska Scheibel[1], Konstantin Skokov[2], Lluís Mañosa[2], Antoni Planes[1], and Oliver Gutfleisch[1] — [1]Technical University of Darmstadt, 64287 Darmstadt, Germany — [2]Universitat de Barcelona, 08028 Barcelona, Catalonia, Spain — [3]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

Ni-Mn-based Heusler compounds exhibit giant magneto- and elastocaloric effects, but suffer from irreversibilities during cyclic operation due to their large thermal hysteresis. A promising way to improve cyclic performance is the sequential combination of magnetic field and uniaxial stress in an "exploiting-hysteresis cycle" which utilizes thermal hysteresis rather than avoiding it.

We have studied the influence of microstructure on the caloric response to magnetic fields, uniaxial stress and their combination in an exploiting-hysteresis cycle for Ni-Mn-In. By correlating XRD, EBSD and stress-strain data, a significant effect of grain orientation on the stress-induced martensitic transformation is revealed. Strain measurements in pulsed magnetic fields exhibit a substantial impact of grain size on the magnetic-field-induced transformation dynamics. We show that for an optimized microstructure, the maximum cyclic effect in magnetic fields of 1.9 T can be increased by more than 200 % to -4.1 K when a moderate sequential stress of 55 MPa is applied.

MA 15.19 Thu 13:30 P

Functional Properties of Ni-Mn-based Heusler alloys — •Olga Miroshkina[1,2], Markus Ernst Gruner[1], Vasiliy Buchelnikov[2], and Vladimir Sokolovskiy[2] — [1]Faculty of Physics, University of Duisburg-Essen, 47048 Duisburg, Germany — [2]Condensed Matter Physics Department, Chelyabinsk State University, 454001 Chelyabinsk, Russia

Multifunctional materials exhibiting the magnetocaloric effect (MCE) at first-order phase transitions are subject to intense fundamental and applied research as a more efficient and ecologically friendly alternative to conventional compressor devices. The combination of density functional theory and empirical models has proven as a useful tool in the theory-guided search for optimized MCE materials with large entropy and temperature change together with low temperature hysteresis. In this work, we consider a statistical model based on the theory of diffuse phase transitions, the Bean-Rodbell model of first-order phase transitions, and the molecular mean-field approach. The proposed model is applied to Ni-Mn-(Ga,In) Heusler alloys demonstrating different sequences of the magnetic and structural phase transitions. We modeled the temperature dependence of magnetization and magnetic entropy change under externally applied magnetic field and pressure and perform the comparison with available experimental data.

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MA 15.20 Thu 13:30 P

Non-hysteretic first-order ferromagnetic transitions by itinerant electron feedback and Fermi surface topology change — •Eduardo Mendive Tapia[1,2], Durga Paudyal[3], Leon Petit[4], and Julie Staunton[2] — [1]Max-Planck-Institut für Eisenforschung, 40237 Düsseldorf, Germany — [2]University of Warwick, CV4 7AL, Coventry, UK — [3]The Ames Laboratory, U.S. Dept of Energy, Iowa State University, USA — [4]Daresbury Laboratory, Warrington, UK

Refrigeration and air conditioning are crucial in modern life and in adapting to climate change. Discontinuous magnetic phase transitions have great promise for new, energy efficient and environmentally friendly solid-state cooling technology. Huge exploitable entropy and temperature changes typically result from the coupling between a material's spin polarized interacting electrons and the crystal structure. Such magnetostructurally driven cooling, however, is nearly always degraded by hysteresis. We present an *ab-initio* theory which can find mechanisms for first-order magnetic phase transitions that are purely electronic in origin [1], thus avoiding the need for magnetostructural effects. We show that this electronic mechanism arises from an itinerant electron feedback to magnetic order. In particular, it is demonstrated that a topological change of the Fermi surface explains the hysteresis free giant cooling properties recently measured in Eu_2In [2]. This work is funded by the EPSRC (UK) and the U.S. Dept of Energy, and forms part of the PRETAMAG project (University of Warwick).

[1] E Mendive-Tapia and J Staunton, PRB **101**, 174437 (2020)
[2] F Guillou et al., Nat. Comm. **9**, 2925 (2018)

MA 15.21 Thu 13:30 P

Large magnetic entropy change in Nd2In near the boiling temperature of natural gas — •Wei Liu[1], Franziska Scheibel[1], Tino Gottschall[2], Eduard Bykov[2], Imants Dirba[1], Konstantin Skokov[1], and Oliver Gutfleisch[1] — [1]Funktionale Materialien, Technische Universität, TU Darmstadt, Germany — [2]Hochfeld- Magnetlabor Dresden, Helmholtz-Zentrum Dresden-Rossendorf, Germany

In the great transformation from fossil fuels to CO2-neutral renewable energies, the woldwide comsumption of liquid natural gas (LNG) is rising to facilitate the transition. Here we report a new firtst-order magnetocaloric material Nd2In with a negligible thermal hysteresis for magnetocaloric natural gas liquefaction. Nd2In shows a maximum magnetic entropy change of 7.42 J/kg K in fields of 2 T at 109 K with a fully reversible adiabatic temperature change of 1.13 K under a magnetic field change of 1.95 T. Studying thermal expansion and magnetostriction, a two-stage magnetic transition with a negligible volume change is observed. The longitudinal strain increases with magnetic fields and then decreases. This phenomenon may be a result of a pure electromic mechanism which may be the reason for the negligible thermal hysteresis. These interesting properties are useful for the practical design of a magnetocaloric natural gas liquefaction system. [1]

The work is supported by the Helmholtz-RSF joint research group (Project No. HRSF-0045) and DFG (Project No. 405553726-TRR 270, Germany).

[1] W. Liu et al., Appl. Phys. Lett. 119, 022408 (2021)

MA 15.22 Thu 13:30 P

Magnetocaloric effect in the $Ho_{1-x}Dy_xAl_2$ family in high magnetic fields — •Eduard Bykov[1,2], Wei Liu[3], Konstantin Skokov[3], Franziska Scheibel[3], Oliver Gutfleisch[3], Sergey Taskaev[4], Catalina Salazar Mejia[1], Joachim Wosnitza[1,2], and Tino Gottschall[1] — [1]Hochfeld-Magnetlabor Dresden, Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]Institut für Festkörper- und Materialphysik, Technische Universität Dresden, Germany — [3]Funktionale Materialien, Technische Universität, TU Darmstadt, Germany — [4]Chelyabinsk State University, Russia

Hydrogen has the largest gravimetric energy density among all chemical fuels. At the same time, the density of gaseous H_2 is extremely low. For storage and transportation reasons it can be liquified. But it requires energy-intensive cooling down to 20 K. Magnetocaloric materials have the great potential to revolutionize gas liquefaction in order to make liquid hydrogen more competitive as fuel. We investigated a series of Laves-phase materials regarding their structural, magnetic, and magnetocaloric properties in high magnetic fields. The three compounds $HoAl_2$, $Ho_{0.5}Dy_{0.5}Al_2$, and $DyAl_2$ are suited for building a stack for cooling from liquid-nitrogen temperature (77 K) down to the boiling point of hydrogen at 20 K. This is evident from our direct measurements of the adiabatic temperature change in pulsed magnetic fields, which we compare with calorimetric data measured in static field. With this methodology, we are now able to study the suitability of magnetocaloric materials down to low temperatures up to the highest magnetic fields.

MA 15.23 Thu 13:30 P

Role of NiO in the nonlocal spin transport through thin NiO

films on $Y_3Fe_5O_{12}$ — Geert R. Hoogeboom[1], Geert-Jan N. Sint Nicolaas[1], Andreas Alexander[2], Olga Kuschel[2], Joachim Wollschläger[2], Inga Ennen[3], Bart J. van Wees[1], and •Timo Kuschel[3] — [1]Zernike Institute for Advanced Materials, University of Groningen, The Netherlands — [2]Osnabrück University, Germany — [3]Bielefeld University, Germany

In spin-transport experiments with spin currents propagating through an antiferromagnetic (AFM) material, the AFM is mainly treated as a passive spin conductor not generating nor adding any spin current to the system. To study the role of AFMs in local and nonlocal spin-transport experiments, we have sent spin currents through NiO of various thicknesses placed on $Y_3Fe_5O_{12}$. The spin currents are injected either electrically or by thermal gradients and measured at a wide range of temperatures and magnetic field strengths [1].
The transmissive role of NiO is reflected in the sign change of the local electrically injected spin transport and the reduction of all other signals by lowering the temperature. The thermally generated response, however, shows an additional upturn below 100 K that is unaffected by an increased NiO thickness. The temperature and magnetic field dependencies are similar to those for bulk NiO [2], indicating that NiO itself contributes to thermally induced spin currents.

[1] G. R. Hoogeboom et al., Phys. Rev. B 103, 144406 (2021)
[2] G. R. Hoogeboom et al., Phys. Rev. B 102, 214415 (2020)

MA 15.24 Thu 13:30 P

High quality antiferromagnetic Mn2Au (001) thin films for spintronics — •S. P. Bommanaboyena[1], T. Bergfeldt[2], R. Heller[3], M. Kläui[1], and M. Jourdan[1] — [1]Institut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, D-55099 Mainz, Germany — [2]Institut für Angewandte Materialien, Karlsruher Institut für Technologie, 76344 Eggenstein-Leopoldshafen, Germany — [3]Institut für Ionenstrahlphysik und Materialforschung, Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany

The recent experimental demomonstration of Néel order manipulation via current induced Néel spin-orbit torques in antiferromagnetic Mn2Au [1] has sparked a huge interest in this compound. We report the preparation of high-quality epitaxial Mn2Au(001) thin films using molecular beam epitaxy and compare them with magnetron sputtered films [2]. Mn and Au were co-evaporated in ultra-high vacuum onto a heated epitaxial Ta(001) buffer layer deposited on an Al2O3 substrate. Structural and morphological characterization of the thin films was carried out using in-situ reflective high energy electron diffraction, X-ray diffraction, X-ray reflectometry and temperature dependent resistance measurements. The films were found to be highly crystalline and smooth with a low defect concentration which is desirable for reduced domain wall pinning and will be useful for next generation antiferromagnetic spintronics devices which require smooth interfaces between the various active layers. [1] S. Yu. Bodnar et al, Nat. Commun. 9, 348 (2018). [2] S. P. Bommanaboyena et al, J. Appl. Phys. 127, 243901 (2020).

MA 15.25 Thu 13:30 P

Large exchange coupling of Mn2Au/Ni81Fe19 for antiferromagnetic spintronics — •S. P. Bommanaboyena[1], D. Backes[2], L. Ishibe Veiga[2], S. S. Dhesi[2], Y. R. Niu[3], B. Sarpi[3], T. Denneulin[4], A. Kovacs[4], T. Mashoff[1], O. Gomonoy[1], J. Sinova[1], K. Everschor-Sitte[1], D. Schönke[1], R. M. Reeve[1], M. Kläui[1], H.-J. Elmers[1], and M. Jourdan[1] — [1]Institut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, D-55099 Mainz, Germany — [2]Diamond Light Source, Chilton, Didcot, Oxfordshire, OX11 0DE, United Kingdom — [3]MAX IV Laboratory, Fotongatan 8, 22484 Lund, Sweden — [4]Ernst Ruska-Centre for Microscopy and Spectroscopy with Electrons, FZ Jülich, D-52425 Jülich, Germany

Mn2Au is a prominent antiferromagnet (AFM) which possesses the requisite crystallographic symmetry to exhibit a current induced Néel spin-orbit torque [1]. We demonstrate an exceptionally strong exchange coupling of Mn2Au films with very thin Permalloy (Py) overlayers [2]. The AFM Mn2Au domain pattern is perfectly imprinted on the Py, which is attributed to a specific atomic termination of the Mn2Au(001) thin film. Ferromagnetic hysteresis loops of exchange coupled 2nm Py overlayers reveal a large coercive field of 0.5 T. This is associated with a coupled rotation of both the Py magnetization and the Néel order of the underlying Mn2Au. Our results unlock novel possibilities for the readout of next generation antiferromagnetic spintronics devices. [1] S. Yu. Bodnar et al, Nat. Commun. 9, 348 (2018). [2] S.P. Bommanaboyena et al, arXiv:2106.02333 (2021).

MA 15.26 Thu 13:30 P

A quantum-mechanical study of pressure-induced changes in magnetism of austenitic stoichiometric Ni_2MnSn with point defects — •Martin Friák[1], Martina Mazalová[1,2], and Mojmír Šob[2,1] — [1]Institute of Physics of Materials, Czech Academy of Sciences, Brno, Czech Republic — [2]Department of Chemistry, Faculty of Science, Masaryk University, Brno, Czech Republic

We have performed a quantum-mechanical study of a series of stoichiometric Ni_2MnSn structures focusing on pressure-induced changes in their magnetic properties. Our study concentrated on the role of point defects, in particular Mn-Ni, Mn-Sn and Ni-Sn swaps. For most defect types we also compared states with both ferromagnetic (FM) and anti-ferromagnetic (AFM) coupling between (i) the swapped atoms and (ii) those on the original sublattice. Our calculations show that the swapped Mn atoms can lead to magnetic moments nearly twice smaller than those in the defect-free Ni_2MnSn. Further, the defect-containing states exhibit pressure-induced changes up to three times larger (but also smaller) than those in the defect-free Ni_2MnSn. Importantly, we find both qualitative and quantitative differences in the pressure-induced changes of magnetic moments of individual atoms even for the same global magnetic state. Lastly, despite of the fact that the FM-coupled and AFM-coupled states have often very similar formation energies (the differences only amount to a few meV per atom), their structural and magnetic properties can be very different. For details see M. Friák *et al.*, Materials 14 (2021) 523, doi:10.3390/ma14030523.

MA 15.27 Thu 13:30 P

Magnetisation dynamics and transport properties of epitaxial Co_2MnSi Heusler thin films — Claudia de Melo[1,2], •Anna M. Friedel[1,3], Charles Guillemard[1,4], Victor Palin[1,4], Philipp Pirro[3], Sébastien Petit-Watelot[1], and Stéphane Andrieu[1] — [1]Institut Jean Lamour, UMR CNRS 7198, Université de Lorraine, Nancy, France — [2]Chair in Photonics, LMOPS EA 4423 Laboratory, CentraleSupélec, Université de Lorraine, Metz, France — [3]Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany — [4]Synchrotron SOLEIL-CNRS, L'Orme des Merisiers, Gif-sur-Yvette, France

Co_2Mn-based Heusler compounds form a family of promising candidates for spintronic and magnonic applications combining desirable properties such as a high saturation magnetisation, low Gilbert damping and high Curie temperatures. Epitaxial half-metallic Co_2MnSi thin films are of particular interest since they have been shown to exhibit a 100% spin polarisation at the Fermi level and an associated ultralow Gilbert damping in the 10^{-4} range [1]. Yet, downscaling towards ultrathin films or microstructures is a critical necessity for applications known to impact the properties of magnetic materials. In this contribution, we report on the magnetisation dynamics and transport properties of epitaxially grown Co_2MnSi thin films [2] with thicknesses in the range of 4-44 nm, where ultralow Gilbert damping was maintained down to a film thickness of 8 nm.

[1] C. Guillemard, *et al.*, Phys. Rev. Applied **11**, 064009 (2019)
[2] C. Guillemard, *et al.*, J. Appl. Phys. **128**, 241102 (2020)

MA 15.28 Thu 13:30 P

Exploration of the magnetic structure of the shape-memory Heusler alloy Mn2NiGa — •Alistair Cameron[1], Sanjay Singh[2], Robert Cubitt[3], and Dmytro Inosov[1] — [1]Institut fuer Festkoerper- und Materialphysik, Technische Universitaet Dresden, D-01069 Dresden, Germany — [2]IIT, Banaras Hindu University, Varanasi, India — [3]Institut Laue-Langevin, 71 avenue des Martyrs, CS 20156, F-38042 Grenoble Cedex 9, France

The material Mn2NiGa is an example of one of the shape-memory Heusler alloys which have been predicted to show a skyrmion lattice. The Mn2YZ Heusler compounds undergo a cubic to tetragonal phase transition with decreasing temperature, and while most of these compounds possess a centrosymmetric low-temperature phase, this phase in Mn2NiGa is noncentrosymmetric. This opens up the possibility of the presence of the anisotropic Dzyaloshinskii-Moriya interaction, which can lead to the formation of skyrmion lattices. Both simulations and AC susceptibility measurements predicted the presence of a skyrmion lattice in this system, and so we performed small-angle neutron scattering measurements in order to search for this. The lattice was predicted to emerge below the Martensitic transition, and in a field of up to 1 T. However, while we saw a clear redistribution of spectral weight, we did not see any sign of a skyrmion lattice across a large range in temperature, field and scattering vector beyond those predicted for this lattice. We conclude that other magnetic behaviour dominates this material within the noncentrosymmetric tetragonal phase.

MA 15.29 Thu 13:30 P

Structural and magnetic properties of Co(Fe)-Ni-Al(Ga) Heusler alloys — •Olga Miroshkina[1,2], Markus Ernst Gruner[1], Vasiliy Buchelnikov[2], and Vladimir Sokolovskiy[2] — [1]Faculty of Physics, University of Duisburg-Essen, 47048 Duisburg, Germany — [2]Condensed Matter Physics Department, Chelyabinsk State University, 454001 Chelyabinsk, Russia

Ferromagnetic shape memory alloys (FSMA) are promising candidates for application as actuators, sensors, magnetomechanical devices, harvesters, and magnetic cooling systems. In their low-temperature, low-symmetry phases they may also posses a considerable magnetocrystalline anisotropy, which is necessary for the FSMA but may make them useful as low-cost permanent magnets. Co(Fe)-Ni-Al(Ga) alloys are an interesting subgroup, as these materials are ductile, cheap, and easily synthesized, while possessing a high Curie and martensitic transformation temperature. In this work, we report on a systematic first-principles study of the structural and magnetic properties of Co-Ni-Al, Fe-Ni-Al, and Fe-Ni-Ga Heusler alloys. We compared ground state energy and magnetic properties for different structural motives and degree of order and predict the structural stability at zero and finite temperatures.

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MA 15.30 Thu 13:30 P

Quadratic magnetooptic Kerr effect spectroscopy on partially ordered Co_2MnSi Heusler compounds — •Robin Silber[1], Daniel Král[2], Ondřej Stejskal[2], Lukáš Beran[1], Jaromír Pištora[2], Martin Veis[3], Timo Kuschel[2], and Jaroslav Hamrle[2] — [1]IT4Innovations,VŠB - Technical University of Ostrava, Czech Republic — [2]Charles University, Prague, Czech Republic — [3]Bielefeld University, Germany

The Heusler compound Co_2MnSi provides a crystallographic transition from B2 to $L2_1$ structure with increasing annealing temperature [1]. Here, we present linear and quadratic magnetooptic Kerr effect (LinMOKE and QMOKE) spectroscopy [2] for a set of Co_2MnSi thin-film samples annealed from 300°C to 500°C. Two interesting features were observed: (i) For photon energy below 3.0 eV, the shape of QMOKE spectra has resonance features, an unusual behaviour for metallic systems. (ii) The amplitude of these peaks is proportional to the annealing temperature and thus, to the amount of $L2_1$ ordering. While this dependence has been shown for a single wavelength before (1.95 eV) [3], we present this proportionality for the whole studied spectral range. The $L2_1$ ordering affects the interband contributions of the LinMOKE and QMOKE spectra, which are compared to ab-initio calculations [4].

[1] O. Gaier et al., J. Appl. Phys. 103, 103910 (2008)
[2] R. Silber et al., Phys. Rev. B 100, 064403 (2019)
[3] G. Wolf et al., J. Appl. Phys. 110, 043904 (2011)
[4] R. Silber et al., Appl. Phys. Lett. 116, 262401 (2020)

MA 15.31 Thu 13:30 P

Shell-ferromagnetism: a revised model — •Nicolas Josten[1], Sakia Noorzayee[1], Mehmet Acet[1], Franziska Scheibel[2], Asli Çakir[3], and Michael Farle[1] — [1]Faculty of Physics and Center for Nanointegration (CENIDE), University Duisburg Essen, Duisburg, 47057, Germany — [2]Institute of Material Science, Technische Universität Darmstadt, Alarich-Weiss-Str. 16, 64287 Darmstadt, Germany — [3]Department of Metallurgical and Materials Engineering, Mugla University, 48000 Mugla, Turkey

Shell-ferromagnetism denotes a strong pinning of magnetic moments in off-stoichometric $Ni_{50}Mn_{45}X_{05}$ (X= Al, Ga, In, Sn, Sb) Heusler alloys after decomposition into full Heusler Ni_2MnX and antiferromagnetic $Ni_{50}Mn_{50}$ above 550K [1]. The pinning is induced through magnetic annealing during decomposition resulting in coercive fields larger than 6 Tesla. The origin of this effect has been identified as ordering of excess Ni in the Mn-sublattice of the binary alloy $Ni_{50+x}Mn_{50-x}$ [2]. While the magnetic and thermal stability of the induced unidirectional anisotropy is already extremely high, maximizing the pinned magnetization is key for any technological application.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 405553726 - TRR 270.

[1] A. Cakir et al., Sci. Rep.6, 28931 (2016) [2] L. Pál et al., Phys. Stat. Sol. 42, 49-59 (1970).

MA 15.32 Thu 13:30 P

First Principles study of spin spirals in the multiferroic $BiFeO_3$ — •Sebastian Meyer[1], Bin Xu[2,3], Matthieu Verstraete[1], Laurent Bellaiche[2], and Bertrand Dupé[1,4] — [1]Nanomat/Q-mat/CESAM, University of Liége, Belgium — [2]Physics Department and Institute for Nanoscience and Engineering, University of Arkansas, USA — [3]Jiangsu Key Laboratory of Thin Films, School of Physical Science and Technology, Soochow University, China — [4]Fonds de la Recherche Scientifique (FNRS), Bruxelles, Belgium

We carry out density functional theory (DFT) calculations to explore the antiferromagnetic (AFM) spin spiral in multiferroic $BiFeO_3$. We calculate the spin spiral energy dispersion $E(\mathbf{q})$ along the high symmetry directions of the pseudo-cubic unit cell, for four different structural phases: *cubic*, $R\bar{3}c$, $R3m$ and $R3c$. In all cases, we find a large exchange frustration. The comparison provides detailed insight into how polarization and octahedral anti-phase tilting affect the different magnetic interactions and the magnetic ground state in $BiFeO_3$. For the $R3c$ structural ground state, we find an AFM spin spiral ground state with a periodicity of ∼80 nm in good agreement with experiments and previous findings. This spin spiral is driven by a Dzyaloshinskii-Moriya (DM) interaction stemming from the Fe–Bi ferroelectric displacement. The spiral appears to be stable because the anisotropy energy in $R3c$ $BiFeO_3$ is too small to enforce the collinear order. For all the four phases, we discuss the magnetic ground state and identify its stabilization mechanisms [Xu, B., *et al.*, Phys. Rev. B **103**, 214423 (2021)].

MA 15.33 Thu 13:30 P

Progress in Additive Manufacturing of (Pr,Nd)-Fe-Cu-B Permanent Magnets — •Jianing Liu[1], Lukas Schäfer[1], Konstantin Skokov[1], Holger Merschroth[2], Jana Harbig[2], Ying Yang[3], Matthias Weigold[2], Stefan Barcikowski[3], and Oliver Gutfleisch[1] — [1]Functional Materials, Technical University of Darmstadt, Germany — [2]Institute of Production Management, Technology and Machine Tools, Technical University of Darmstadt, Germany — [3]Technical Chemistry I, University of Duisburg-Essen, Germany

Additive Manufacturing (AM) of permanent magnets is an upcoming and challenging task in material science and engineering. The direct use of binder-free AM technique like Laser Powder Bed Fusion (L-PBF) does not easily allow obtaining a microstructure necessary for high coercivity. In order to achieve the desired microstructure and hard magnetic properties after printing, we propose here Pr-Fe-Cu-B based alloy as a useful alloy system and compare this with its Nd-based counterpart. Our studies describe the Pr-Fe-Cu-B alloys and their annealing optimization for L-PBF. In order to achieve an improved flowability and refined microstructure, the grain boundary engineering with nanoparticles shows a great potential. The nanoparticle functionalized Pr-Fe-Cu-B powder was being validate as precursor for AM. During L-PBF, the hypothesis of heterogeneous nucleation induced by NP inoculums during resolidification is explored with the goal of suppressing grain coarsening and realizing more uniaxial growth.

We acknowledge the support of the Collaborative Research Centre/Transregio 270 HoMMage.

MA 15.34 Thu 13:30 P

Qualification of rapidly quenched permanent magnet powders applied in additive manufacturing — •Tobias Braun[1], Lukas Schäfer[1], Stefan Riegg[1], Iliya Radulov[1], Imants Dirba[1], Esmaeil Adabifiroozjaei[2], Konstantin P. Skokov[1], Leopoldo Molina-Luna[2], and Oliver Gutfleisch[1] — [1]Funktionale Materialien, Material- und Geowissenschaften, Technische Universität Darmstadt, Germany — [2]Advanced Electron Microscopy, Material- und Geowissenschaften, Technische Universität Darmstadt, Germany

Additive manufacturing (AM) of permanent magnets has been an important research field in recent years due to its potential for near net shape processing of complex geometries with tailored stray field distribution and therefore better use of mostly resource-critical materials. One of the most applied materials in production of fully dense metallic magnets by LPBF is the rare-earth lean Nd-Fe-B based, atomized commercial material MQP-S by Magnequench. The powder qualifies due to spherical shape and size for the use in LPBF. The exchange-coupling mechanism induced by the two-phase nanostructure results in significant coercive fields and enhanced remanences, both however can be strongly reduced during the LPBF process.

The influence of the AM process on the magnetic properties is studied in detail by advanced magnetic and transmission electron microscopic characterization methods supported by temperature dependent x-ray diffraction and differential thermal analysis. Based on this, we review reported results on printed materials allowing a critical view on the powder material choice in AM.

MA 15.35 Thu 13:30 P

Effect of chemical disorder on the magnetic exchange couplings in $L1_0$ FeNi (tetrataenite) — •Ankit Izardar and Claude Ederer — Materials Theory, ETH Zurich, Wolfgang-Pauli-Strasse 27, 8093 Zurich, Switzerland

$L1_0$ $Fe_{50}Ni_{50}$ (tetrataenite) is a promising candidate for permanent magnets with relatively high energy product containing only cheap and abundant elements. Unfortunately, the laboratory synthesis of the ordered phase is extremely challenging and several attempts have been made to achieve a high degree of chemical order in this alloy. Therefore, it is important to know how deviations from perfect chemical order affect magnetic properties.

Using first-principles-based density-functional theory calculations, we provide insights into the impact of the chemical disorder on the magnetic exchange interactions in tetrataenite. Our calculations show very strong variations in the magnetic exchange couplings (by more than 80%). Furthermore, by employing a model study, we estimate the effect of these strong variations in, e.g., the nearest neighbour couplings, compared to simply using averaged coupling constants. Our results indicate that using averaged coupling constants can lead to an overestimation of the Curie temperature of around 5%.

MA 15.36 Thu 13:30 P

Transport properties of systematically disordered Cr_2AlC films — •Joao S. Cabaco[1], Ulrich Kentsch[1], Jurgen Lindner[1], Jurgen Fassbender[1], Christoph Leyens[2,3], Rantej Bali[1], and Richard Boucher[2] — [1]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Institute for Materials Science, Technische Universität Dresden, Dresden, Germany — [3]Fraunhofer Institute for Material and Beam Technology IWS Dresden, Dresden, Germany

Nano-lamellar composite materials, known as MAX-phases, can possess a combination of ceramic and metallic properties. A prototype compound is Cr_2AlC, formed from a unit cell of Cr_2C sandwiched between atomic planes of Al. Here we observe the modifications to the structural, transport and magnetic behavior of 500 nm thick Cr_2AlC after irradiation with Co^+ ions, and Ar^+ noble gas ions as control. X-ray shows that ion-irradiation induces a suppression of the 0002 reflection, indicating a deterioration of the crystal structure. Increasing the ion fluence leads to an increase of the saturation magnetization at 1.5 K, whereby both Ar^+ and Co^+ cause an increased magnetization, respectively to 150 $kA.m^{-1}$ and 190 $kA.m^{-1}$, for the highest fluences used. At Co^+ fluences of 5×10^{13} $ions.cm^{-2}$ the magnetoresistance (MR) shows a 2 orders of magnitude increase, up to 3% (10 T) at 100 K. A similar effect also occurs for 5×10^{12} $ions.cm^{-2}$ Ar^+ irradiated films, however, with a smaller MR-increase. The disordering of MAX phase films may reveal interesting spin-related transport phenomena.

MA 15.37 Thu 13:30 P

Local structure in FeRh thin films after ion irradiation — •Johanna Lill[1], Benedikt Eggert[1], Katharina Ollefs[1], Sakura Pascarelli[2], Alexander Schmeink[3,4], Kay Potzger[3], Jürgen Lindner[3], Jürgen Fassbender[3,4], William Griggs[5], Thomas Thomson[5], Rantej Bali[3], and Heiko Wende[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen, Germany — [2]ESRF, Grenoble, France — [3]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [4]Dresden University of Technology, Germany — [5]The University of Manchester, United Kingdom

Equiatomic B2 FeRh exhibits antiferromagnetic ordering at room temperature and undergoes a meta-magnetic phase transition to ferromagnetic ordering at 370K. Ferromagnetic ordering can also be induced by structural disorder caused by moderate ion irradiation [1]. Larger irradiation fluence results in a paramagnetic state. In this work we investigate FeRh thin films for different irradiation fluences of 110 keV Ne^+ by Fe K edge extended X-ray absorption fine structure spectrosopy at low temperatures. For low irradiation fluences, we find an increase of the lattice parameter and a decrease of the Debye-Waller-factor, while for higher fluences a change from the bcc to the fcc phase occurs. XRD as well as magnetometry results confirm the phase transitions, and are consistent with the EXAFS findings. From magnetometry, we see an increase of the magnetisation and a shift of the phase transition to lower temperatures with rising irradiation fluence. Financial support by DFG (WE 2623/14-2 and BA 5656/1-2) is acknowledged.

[1] W. Griggs et al. APL Mater. 8, 121103 (2020)

MA 15.38 Thu 13:30 P

Magnetic ordering/disordering in MnS and the effects of pressure on its structural landscape — •Artem Chmeruk[1] and Maribel Núñez-Valdez[1,2] — [1]Deutsches GeoForschungsZentrum GFZ, Telegrafenberg, 14473, Potsdam — [2]Goethe-Universität Frankfurt am Main, Altenhoeferallee 1 D-60438, Frankfurt a.M., Germany

We investigate magnetic ordering/disordering in MnS polymorphs and their pressure stability fields by applying density functional theory (DFT) in combination with special quasi-random structures (SQS) and occupational matrix control (OMC) algorithms to deal with the correlated Mn *d*-electrons. Departing from the experimentally known low temperature antiferromagnetic (AFM) ordering in different MnS polymorphs, we evaluate their energy stability and compare to experimental observations. Then to simulate their paramagnetic (PM) state above Néel temperature, we construct their SQS supercells of randomly distributed *up* $\uparrow$ and *down* $\downarrow$ local Mn magnetic moments. Our calculated enthalpy landscape indicates that, the RS polymorph remains the most stable phase at 0 GPa, but as pressure increases, it undergoes a structural transformation to an orthorhombic MnP-type structure at about 21 GPa. The identification of this pressure-induced phase transition sheds light onto the nature of an unknown phase previously reported at $\sim$26 GPa from high-pressure diamond-anvil-cell experiments. In general, we show that our methodology provides accurate magnitudes of structural parameters, energy band gaps, and local magnetic moments and it could be extended to the study of other transition metal sulphides.

MA 15.39 Thu 13:30 P

Magnetostructural phase transition in $Fe_{60}V_{40}$ alloy thin films — •Md. Shadab Anwar[1,3], H. cansever[1], B. Boehm[2], R. A. Gallardo[5], R. Hübner[1], S. Zhou[1], U. Kentsch[1], B. Eggert[4], H. Wende[4], K. Potzger[1], J. Fassbender[1], K. Lenz[1], J. Lindner[1], O. Hellwig[1,2], and R. Bali[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Germany — [2]TU Chemnitz, Germany — [3]TU Dresden, Germany — [4]University of Duisburg-Essen, Germany — [5]Universidad Técnica Federico Santa María, Chile

Ferromagnetism can be induced in non-ferromagnetic precursors such as B2 $Fe_{60}Al_{40}$[1] and B2 $Fe_{50}Rh_{50}$[2] through lattice disordering. Here we study a magnetostructural transition in $Fe_{60}V_{40}$ thin films using ion-irradiation. We show that the as-grown films possess an M_s of 17 kA/m and irradiation with 25 keV Ne^+-ions at a fluence of $\sim$ 5 x $10^{15}ions/cm^2$ leads to an increase of M_s to $\sim$ 750 kA/m. A structural short-range order in the as-grown films can be observed, that transforms to A2 phase (bcc) via ion-irradiation. The A2 region appears to nucleate at the film surface, and with increasing Ne^+-fluence, it propagates deeper into the film. Mössbauer spectroscopy and ferromagnetic resonance have been applied to track the variation of local magnetic ordering and dynamic behaviour respectively.

Financial support by DFG grants BA 5656/1-2 and WE 2623/14-2 is acknowledged.

[1]Ehrler, J.*et al., New J. Phys.*,22,073004(2020)
[2]Eggert, B.*et al., RSC Adv.*,10,14386(2020)

MA 15.40 Thu 13:30 P

Manipulation of multiferroic properties in h-$YMnO_3$ upon substitution at the Mn-site with non-magnetic impurities — •M. Giraldo[1], M. Lilienblum[1], E. Gradauskaite[1], H. Sim[2], J.-G. Park[2], Th. Lottermoser[1], and M. Fiebig[1] — [1]ETH Zurich — [2]Seoul National University

Chemical substitution is an effective way to tailor the properties of complex oxides. For example, pronounced effects in domain wall conductivity or mixing of magnetic groundstates in h-$R$$MnO_3$ have been explored by chemical substitution at the Mn-site. Here, we investigate the enhancement and suppression of electric and magnetic long-range order in h-$YMnO_3$ upon substituting Mn by Al and Ga. By combining second-harmonic spectroscopy and piezoresponse force microscopy, a complete suppression of ferroelectric order upon 20% Al substitution was found. In contrast, substitution with Ga upon 50% leads to an enhancement of the ferroelectric (FE) response. This is due to the chemical pressure induced by the distinct ionic sizes of Al, Ga & Mn. On the level of the FE domains, the suppression of the FE order manifests in a progressive size decrease upon increased Al concentration while there is no size variation upon Ga substitution. On the magnetic level, we find a progressive decrease of the ordering temperatures. This is due to the direct perturbation of the magnetic sublattices formed by the Mn^{3+} moments and the progressive dilution of the magnetic long-range order. By tracing changes in the inherent properties of these systems, we aim to broaden the understanding for new routes in the manipulation of ferroic properties in these compounds.

MA 15.41 Thu 13:30 P

Antiferromagnetic spin cycloids imaged with a Scanning Nitrogen-Vacancy Magnetometer — •Hai Zhong[1], Johanna Fischer[2], Aurore Finco[3], Vincent Jacques[3], and Vincent Garcia[2] — [1]Qnami AG, Switzerland — [2]Unité Mixte de Physique, CNRS, Thales, Université Paris Saclay, France — [3]Laboratoire Charles Coulomb, CNRS, Université de Montpellier, France

Multiferroics, such as $BiFeO_3$, in which antiferromagnetism and ferroelectricity coexist at room temperature, appear as a unique platform for spintronic and magnonic devices. The nanoscale structure of its ferroelectric domains has been widely investigated with piezoresponse force microscopy (PFM). However, the $BiFeO_3$ nanoscale magnetic textures and their potential for spin-based technology remain concealed. We present two different antiferromagnetic spin textures in $BiFeO_3$ thin films with different epitaxial strains, using a commercial scanning Nitrogen-Vacancy magnetometer (SNVM) based on a single NV defect in diamond. Two $BiFeO_3$ samples were grown on $DyScO_3$ (110) and $SmScO_3$ (110) substrates. The striped ferroelectric domains in both samples are first observed by the in-plane PFM, and SNVM confirms the existence of the spin cycloid texture. At the local scale, the combination of PFM and SNVM allows to identify the relative orientation of the ferroelectric polarization and cycloid propagation directions on both sides of a domain wall. Our results show the potential for reconfigurable nanoscale spin textures on multiferroic systems by strain engineering.

MA 15.42 Thu 13:30 P

Coupling of magnetic and electric order in hybrid improper ferroelectric $Ca_3Mn_{1.9}Ti_{0.1}O_7$ — •Yannik Zemp[1], Mads C. Weber[1], Thomas Lottermoser[1], Morgan Trassin[1], Bin Gao[2], Sang-Wook Cheong[2], and Manfred Fiebig[1] — [1]Department of Materials, ETH Zurich — [2]Rutgers University, New Jersey

Multiferroic hybrid improper ferroelectrics such as $Ca_3Mn_{1.9}Ti_{0.1}O_7$ (CMTO) provide a novel mechanism to couple ferroelectricity and ferromagnetism. Both ferroic orders are induced by the same structural distortions. Theoretically, these structural distortions allow an electrical control of the magnetic order. Experimental evidence of such a coupling is lacking, however, because high leakage currents prevent contact-based electrical measurements. Here we use two complementary non-contact methods, namely SQUID magnetometry and optical second harmonic generation (SHG) to scrutinize the magnetic and polar orders and their coupling in CMTO. We find clear evidence for a ferromagnetic moment below $T_N = 115$ K. Furthermore, we detect a massive increase in the SHG signal below the magnetic ordering temperature. Using SHG spectroscopy and domain analysis, we unveil the origin of this increase as a direct influence of the magnetic order on the ferroelectric state. This work shows that the magnetic and polar orders in multiferroic hybrid improper ferroelectrics can indeed be strongly coupled.

MA 15.43 Thu 13:30 P

Voltage control of perpendicular exchange bias — •Jonas Zehner[1,2], Daniel Wolf[2], Mantao Huang[3], Usama M. Hasan[3], David Bono[3], Kornelius Nielsch[2], Karin Leistner[1], and Geoffrey S. D. Beach[3] — [1]TU Chemnitz — [2]IFW Dresden — [3]MIT Cambridge

Ferromagnetic layers adjacent to an antiferromagnetic layer give rise to the exchange bias effect which is the basis for a variety of magnetic field sensors or magnetophoretic devices. Controlling exchange bias systems by voltage rather than by electrical current is highly desired for low power magnetic devices. So far, voltage control of exchange bias was mainly reported for systems with an in-plane unidirectional anisotropy below room temperatures. In this abstract, we present the voltage control of a NiO/Pd/Co system exhibiting perpendicular exchange bias system at room temperature. We show that the presence of a Pd interlayer (0.2 nm) is crucial for achieving perpendicular magnetic anisotropy (PMA), and thus also perpendicular exchange bias, in our system. We apply a hydrogen gating mechanism to reversibly switch between PMA and in-plane magnetic anisotropy, and thus to switch on and off perpendicular exchange bias. The observed correlation between an increased coercivity and a decreased exchange bias in the first cycle is explained with a crystallization process of the initially amorphous ferromagnetic layer. The hydrogen gating effect is further transferred to an exchange biased ferrimagnetic (GdCo) system in which we achieve a sign change of the exchange bias due to a hydrogen induced shift of the Curié temperature.

MA 15.44 Thu 13:30 P

Fast non-volatile electrical switching of the magnetoelectric domain states in the cubic spinel Co_3O_4 — •Maximilian Winkler, Somnath Ghara, Korbinian Geirhos, Lilian Prodan, Vladimir Tsurkan, Stephan Krohns, and Istvan Kezsmarki — Experimentalphysik V, Universität Augsburg, Germany

Here, we investigate the magnetoelectric effect of Co_3O_4 at temperatures below the Neel-temperature of T_N = 30K. A large magnetoelectric coefficient of up to 14ps/m is achieved if the system is cooled through T_N while magnetic and/or electric fields are applied. According to these poling procedures we provide a systematic analysis of how the magnetoelectric domain state can be controlled and even in situ switched by reversing the direction of either the electric or the magnetic field. The complete switching of the antiferromagnetic state is found to be faster than microseconds. Altogether, the control of the magnetoelectric domains and the fast switching dynamics makes the linear magnetoelectric coupling of Co_3O_4 highly interesting for spintronics.

MA 15.45 Thu 13:30 P

Domain Walls in a Row-Wise Antiferromagnetic Monolayer — Jonas Spethmann, Martin Grünebohm, Roland Wiesendanger, Kirsten von Bergmann, and •André Kubetzka — Department of Physics, University of Hamburg

We investigate magnetic domain walls in a row-wise antiferromagnetic (AFM) system, the fcc-stacked manganese monolayer on Re(0001) [1], employing 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 a transient 2Q state [3], a non-collinear spin texture with characteristic 90° angles in the wall center. 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, magnetic atom manipulation is used to image the domain wall structure with atomic spin-resolution and to modify wall positions, opening new possibilities to investigate AFM systems and prepare AFM spin configurations.

[1] J. Spethmann, *et al.*, Phys. Rev. Lett. **124**, 227203 (2020).
[2] J. Spethmann, *et al.*, Nature Commun. **12**, 3488 (2021).
[3] P. Kurz, PhD thesis, Aachen, Germany (2000).

MA 15.46 Thu 13:30 P

Surface spin flop mediated vertical magnetic textures — •Benny Boehm[1], Lorenzo Fallarino[2], and Olav Hellwig[1,2,3] — [1]Insitute of physics, Chemnitz University of Technology, D-09107 Chemnitz, Germany — [2]Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, D-01328 Dresden, Germany — [3]Center for Materials, Architectures and Integration of Nanomembranes (MAIN), Chemnitz University of Technology, D-09107 Chemnitz, Germany

Antiferromagnets (AFs), and in particular synthetic antiferromagnets (SAFs), are gaining increasing interest due to their wide variety of useful properties at the micro and nanoscale. Despite of their macroscopically vanishing remanent magnetic moment and therefore high stability with respect to external magnetic field, AFs and SAFs may also provide other unique static magnetic states as well as promising characteristics for dynamic applications, such as high domain wall velocities and excitation frequencies reaching into the THz regime.

Although the static magnetic properties of atomic AFs are intrinsically predefined by their crystal structure, SAFs allow for much more freedom, due to their much larger degree of tunability. Furthermore, SAFs grant easy access to magnetic textures and even allow to manipulate them, for example via the surface spin flop (SSF), towards the desired behavior. We will report on the control of SSF mediated vertical AF domain walls, which may prove to be a promising platform for magnetization dynamics and thus are an interesting candidate for future applications, such as re-programmable spin wave guides.

MA 15.47 Thu 13:30 P

Control of stripe domain-wall magnetization in multilayers with perpendicular magnetic anisotropy — •Ruslan Salikhov[1], Fabian Samad[1], Aladin Ullrich[2], Manfred Albrecht[2], Nikolai Kiselev[3], and Olav Hellwig[1,4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]University of Augsburg, Augsburg, Germany — [3]Forschungszentrum Jülich, Jülich, Germany — [4]Chemnitz University of Technology, Chemnitz, Germany

We report on the controlled switching of domain wall (DW) magnetization 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 originates from the polarization of the Bloch-type DWs. 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. Our findings are relevant for DW-based magnonics and bubble skyrmion applications in magnetic multilayers.

MA 16: General Assembly of the Division of Magnetism

Time: Thursday 17:30–18:30 Location: MVMA

All members of the Division of Magnetism are invited to participate!

MA 17: Skyrmions II (joint session MA/KFM)

Time: Friday 10:00–13:15 Location: H5

Invited Talk MA 17.1 Fri 10:00 H5

Emergent electromagnetic response of nanometer-sized spin textures — •Max Hirschberger[1,2], Takashi Kurumaji[2], and Leonie Spitz[2] — [1]Quantum-Phase Electronics Center, The University of Tokyo, Bunkyo-ku 113-8656, Tokyo, Japan — [2]RIKEN Center for Emergent Matter Science (CEMS), Wako 351-0198, Saitama, Japan

Recently, we have worked to reduce the size of topological spin textures in bulk magnets towards the scale of several nanometers, exploiting new material platforms which are centrosymmetric and thus fundamentally different from previously explored non-centrosymmetric (chiral or polar) systems. Nanometer-sized skyrmions reported here are not stabilized by the Dzyaloshinskii-Moriya interaction, but rather by frustrated exchange or Ruderman-Kittel-Kasuya-Yosida (RKKY) interactions. A wide array of experimental techniques in condensed matter was incorporated to establish the presence of skyrmion lattices in the new materials Gd_2PdSi_3 and $Gd_3Ru_4Al_{12}$, with Heisenberg Gd^{3+} magnetic moments.

When a conduction electron moves through such a topological spin texture, it acquires a quantum mechanical phase (Berry phase), sometimes modeled by a (virtual) emergent magnetic field B_{em} acting on the electron. Nanometric skyrmions give rise to B_{em} of order 500 Tesla, and we have recently found quantitative evidence for this giant B_{em} using electrical Hall measurements and thermoelectric properties such as the topological Nernst effect. Ongoing work is focused on the control of magnetic interactions and electromagnetic responses via chemical composition tuning.

MA 17.2 Fri 10:30 H5

Current-induced H-shaped-skyrmion creation and their dynamics in the helical phase — •Ross Knapman[1], Davi R Rodrigues[2], Jan Masell[3], and Karin Everschor-Sitte[2,4] — [1]Institute of Physics, Johannes Gutenberg University Mainz, 55128 Mainz, Germany — [2]Faculty of Physics, University of Duisburg-Essen, 47057 Duisburg, Germany — [3]RIKEN Center for Emergent Matter Science (CEMS), Wako 351-0198, Japan — [4]Center for Nanointegration Duisburg-Essen, University of Duisburg-Essen, 47057 Duisburg, Germany

A promising application of magnetic skyrmions is in racetrack memory devices. [1] While efforts focussing on this have often been concentrated on the use of ferromagnetic racetracks, previous work has suggested that the use of helimagnets could be more effective. [2] Here, the helices provide a means to naturally confine the skyrmions to quasi-1D channels, mitigating the skyrmion Hall effect. They additionally allow for high-speed skyrmion motion. Inspired by previous works in which it is suggested that skyrmions can be created through the interplay of spin-polarized currents and magnetic impurities, [3] we propose a method of creating skyrmions in a helical background. [4]

[1] Fert, A et. al., Nat. Nanotechnol. 8(3), 152-156 (2013).
[2] Müller, J. et.al., Phys. Rev. Lett. 119(13), 137201 (2017).
[3] Everschor-Sitte, K. et. al., New J. Phys. 19(9), 092001 (2017).
[4] Knapman, R. et. al., J. Phys. D: Appl. Phys. 54(40). 404003 (2021).

MA 17.3 Fri 10:45 H5

Magnetic skyrmions probed by SP-STM: topology imprinted on the charge current and spin transfer torque — •Krisztian Palotas[1,2], Levente Rozsa[3], and Laszlo Szunyogh[2] — [1]Wigner Research Center for Physics, Budapest, Hungary — [2]Budapest University of Technology and Economics, Hungary — [3]University of Konstanz, Germany

The controlled creation/annihilation of individual magnetic skyrmions have been demonstrated by using spin-polarized scanning tunneling microscopy (SP-STM) [Science 341, 636], where the spin-polarized current exerts a torque on the spin moments of the sample. However, the detailed microscopic mechanism of this process is presently unknown. Our work contributes to this understanding by a theoretical investigation of the tunneling electron charge and spin transport probing magnetic skyrmions. The spin-polarized charge current (I) and tunneling spin transport vector quantities, the longitudinal spin current and the spin transfer torque (STT), are consistently calculated within a simple electron transport theory [PRB 94, 064434]. The electron tunneling model is extended to SP-STM in high spatial resolution, and applied to magnetic skyrmions [PRB 97, 174402; PRB 98, 094409]. Besides the vector spin transport characteristics, the relationships among conventional charge current SP-STM images [PRB 96, 024410], the magnitudes of the spin transport quantities [PRB 97, 174402], and the topology of various skyrmionic objects are analyzed [J. Magn. Magn. Mater. 519, 167440]. It is also shown that at specific SP-STM tip positions the STT efficiency (STT/I) can reach very large values ~h/e.

MA 17.4 Fri 11:00 H5

Alternative to Dzyaloshinskii-Moriya interaction for monolayer Fe_3GeTe_2 and other two-dimensional ferromagnets with trigonal prismatic symmetry — •Ivan Ado[1,2], Gulnaz Rakhmanova[3], Dmitry Zezyulin[3], Ivan Iorsh[3], and Misha Titov[1] — [1]Radboud University, Institute for Molecules and Materials, 6525 AJ Nijmegen, The Netherlands — [2]Institute for Theoretical Physics, Utrecht University, 3584 CC Utrecht, The Netherlands — [3]ITMO University, Faculty of Physics, Saint-Petersburg, Russia

Our work reveals a new potential source of noncollinear magnetic textures in a certain class of two-dimensional ferromagnets. Namely, in those that are described by the trigonal prismatic symmetry (point group D_{3h}): monolayer Fe_3GeTe_2, some transition metal dichalcogenides, and others. It is known that the Dzyaloshinskii-Moriya interaction does not contribute to the free energy density in such systems. We find that there exists a single (!) fourth order "chiral" contribution beyond the Dzyaloshinskii-Moriya interaction compatible with D_{3h} (if boundary effects are neglected). We study whether it is consistent with recent experiments on Fe_3GeTe_2. We also find that this contribution might stabilize bimerons – the in-plane analog of skyrmions. Surprisingly, we were even able to estimate the radius of such bimerons analytically.

[1] I. A. Ado, Gulnaz Rakhmanova, Dmitry A. Zezyulin, Ivan Iorsh, and M. Titov, arXiv:2105.14495

MA 17.5 Fri 11:15 H5

Skyrmions as quasiparticles: Free energy and entropy — •Daniel Schick, Markus Weissenhofer, Levente Rózsa, and Ulrich Nowak — Fachbereich Physik, Universität Konstanz, DE-78457 Konstanz, Germany

Magnetic skyrmions are quasiparticles primarily investigated due to their exceptional stability enabling data storage [1] and magnetic logic applications[2]. While at low temperatures they are robust against thermal fluctuations, they are rapidly created and annihilated at high temperatures[3]. In our paper[4], we calculated the free energy and entropy of magnetic skyrmions for a (Pt0.95Ir0.05)/Fe bilayer on Pd(111), using atomistic spin simulations at different temperatures. At low temperatures, skyrmions possess a higher entropy than the topologically trivial state, reducing the free-energy difference between skyrmions and collinear states with increasing temperature. At elevated temperatures we find the free energy of skyrmions to be lower than that of topologically trivial states, meaning that they are energetically preferred due to entropic stabilization. While this result is qualitatively in line with linear spin-wave theory, going beyond this approximation reveals deviations and even sign changes in both the energy difference and the entropy difference at increased temperatures.

[1] G. Yu et al., Nano Lett. 17, 1, 261-268, 2017
[2] S. Luo et al., Nano Lett. 18, 2, 1180-1184, 2018
[3] S. von Malottki et al., Phys. Rev. B 99, 060409(R), 2019
[4] D. Schick et al., Phys. Rev. B 103, 214417, 2021

MA 17.6 Fri 11:30 H5

Non-linear Magnetic Response of Topological Spin Textures in Helimagnetic FeGe — •Mariia Stepanova[1,2], Jan Masell[3], Erik Lysne[1,2], Peggy Schoenherr[4], Laura Köhler[5], Michael Paulsen[6], Alireza Qaiumzadeh[2], Naoya Kanazawa[7], Achim Rosch[8], Yoshinori Tokura[3,7], Arne Brataas[2], Markus Garst[5], and Dennis Meier[1,2] — [1]NTNU, Trondheim, Norway — [2]Center for Quantum Spintronics, NTNU, Trondheim, Norway — [3]RIKEN, Wako, Japan — [4]UNSW, Sydney, Australia — [5]KIT, Karlsruhe, Germany — [6]PTB, Berlin, Germany — [7]University of Tokyo, Tokyo, Japan — [8]Universität zu Köln, Köln, Germany

Chiral magnets possess a periodic layered structure which is similar to cholesteric liquid crystals, forming a wide variety of non-trivial topological defects. Using magnetic force microscopy (MFM), we resolve 1D and 2D topological defects in the near-room temperature helimagnet FeGe, including disclinations and dislocations with nonzero topological winding number, as well as three fundamental types of helimagnetic domain walls. Interestingly, in addition to their non-trivial structure, all topological defects in FeGe exhibit a pronounced non-linear magnetic response in MFM, which is not observed in regions with perfect lamellar-like order. This magnetic signature is reminiscent of the "lines of flare" that arise in cholesteric liquid crystals, suggesting local variations in magnetic susceptibility. By combining MFM and micromagnetic simulations, we investigate the origin of the magnetic signature of the topological defects and discuss possibilities to utilize the anomalous local response as read-out signal in spintronics devices.

MA 17.7 Fri 11:45 H5

Lifetimes of skyrmions and antiskyrmions in exchange frustrated films — •Moritz A. Goerzen[1], Stephan von Malottki[1,2], Sebastian Meyer[1,4], Pavel F. Bessarab[2,3], and Stefan Heinze[1] — [1]Institute of Theoretical Physics and Astrophysics, University of Kiel — [2]University of Iceland, Reykjavík, Iceland — [3]ITMO University, St. Petersburg, Russia — [4]Université de Liège, Sart Tilman, Belgium

Recently, it has been shown that isolated skyrmions can be stabilized in zero magnetic field in a Rh/Co bilayer on the Ir(111) surface due to frustration of exchange interactions [1]. Here, we predict that antiskyrmions are also metastable at zero field in this film system and can co-exist with skyrmions. Based on an atomistic spin model parametrized from density functional theory [1], we calculate the lifetime of these co-existing topological states using the geodesic nudged elastic band method as well as transition state theory in harmonic approximation [2,3]. We find significant differences between the lifetimes of skyrmions and antiskyrmions due to the effect of the Dzyaloshinskii-Moriya interaction.

[1] Meyer, Perini *et al.*, Nature Comm. **10**, 3823 (2019)
[2] Bessarab *et al.*, Sci. Rep. **8**, 3433 (2018)
[3] von Malottki *et al.*, Phys. Rev. B **99**, 060409 (2019)

MA 17.8 Fri 12:00 H5

Identification of skyrmion transition mechanisms by sub-10 nm maps of the transition rate — •Stephan von Malottki[1,2], Florian Muckel[3], Christian Holl[3], Benjamin Pestka[3], Marco Pratzer[3], Pavel F. Bessarab[1,4], Stefan Heinze[2], and Markus Morgenstern[3] — [1]Science Institute, University of Iceland — [2]ITAP, University of Kiel — [3]Institute of Physics B and JARA-FIT, RWTH Aachen University — [4]ITMO University, St. Petersburg

In addition to the conventional radial symmetric collapse of magnetic skyrmions, recent studies predicted the occurrence of skyrmion annihilation processes via the chimera skyrmion state [1-3]. Here, we demonstrate the realization of both the radial symmetric and the chimera transition mechanism in the ultra-thin film system fcc-Pd/Fe/Ir(111) [4]. Scanning tunneling microscopy is used to create transition rate maps of magnetic switching events induced by single electron events. In combination with energy density maps of the transition states obtained by atomistic spin simulations parametrized from first principles, they allow for the identification of both annihilation mechanisms. It is further shown, that a transition between both mechanisms can be achieved by the application of external in- and out-of-plane magnetic fields, yielding a sound agreement between experiment and theory.

[1] Meyer et al., Nat. Commun. **10**, 3823 (2019)
[2] Heil et al., Phys. Rev. B **100**, 134424 (2019)
[3] Desplat et al., Phys. Rev. B **99**, 174409 (2019)
[4] Muckel et al., Nat. Phys. **17**, 395-402 (2021)

MA 17.9 Fri 12:15 H5

Kinetic small-angle neutron scattering of skyrmion lattice order in chiral magnets — •Denis Mettus[1], Alfonso Chacon[1], Andreas Bauer[1], Sebastian Mühlbauer[2], Alla Bezvershenko[3], Lukas Heinen[3], Achim Rosch[3], and Christian Pfleiderer[1] — [1]Physik-Department, Technische Universität München, D-85748 Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Garching, Germany — [3]Institute for Theoretical Physics, Universität zu Köln, D-50937 Köln, Germany

Skyrmions are topologically non-trivial spin textures that attract great interest, offering a possible avenue towards novel spintronics applications, e.g. in skyrmion-based racetrack memory. A key feature that motivates this interest is related to the exceptionally efficient coupling of skyrmion lattice order to spin currents, notably spin-polarized charge currents and magnon currents as observed in MnSi, FeGe, and Cu_2OSeO_3. This raises the question of the microscopic mechanisms that control the pinning and the elasticity modulus of the skyrmion lattice, and how they depend on the topology, electronic structure, and disorder. In the following contribution, we report kinetic studies of skyrmion lattice order by means of Time-resolved Small Angle Neutron Scattering (TISANE). We compare the unpinning processes in different systems, such as $Mn_{1-x}Fe_xSi$ where spin-transfer torques are dominated by spin-polarized charge currents and insulating material Cu_2OSeO_3 with the spin transfer torques being due to magnon currents.

MA 17.10 Fri 12:30 H5

Decoding of complex magnetic structures from Hall-effect measurements — •Juba Bouaziz[1], Hiroshi Ishida[2], Samir Lounis[1,3], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany — [2]College of Humanities and Sciences, Nihon University, Sakura-josui, Tokyo 156-8550, Japan — [3]Faculty of Physics, University of Duisburg-Essen, 47053 Duisburg, Germany

It is generally accepted that the Hall response of complex spin-textures is given in terms of the linear superposition of the ordinary (OHE), the anomalous (AHE) and the topological Hall effect (THE). This addition is not questioned and is experimentally used to relate Hall responses to magnetic textures. Here, using a simple and transparent multiple scattering approach, we show that this relation is incomplete [1]. We introduce a missing contribution, the non-collinear Hall effect (NHE). The angular form of this term depends on the underlying crystal structure. The presence of the NHE may results in a substantial Hall response in non-collinear magnets without invoking the presence of non-coplanar spin textures or magnetic skyrmions and enables the decoding of exotic non-collinear magnetic textures that have been observed in itinerant magnets. [1] J. Bouaziz et al. PRL 126, 147203 (2021).

This work was supported by DFG through SPP 2137 "Skyrmionics" (Project BL444/16-1), SFB 1238 (project C01) and SFB/TRR 173 (project MO 1731/5-1), DARPA TEE program, through grant MIPR# HR0011831554 from DOI, and ERC- consolidator grant 681405-DYNASORE.

MA 17.11 Fri 12:45 H5

Spin-orbit enabled all-electrical readout of chiral spin-textures — •Imara Lima Fernandes[1], Stefan Blügel[1], and Samir Lounis[1,2] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich & JARA, D-52425 Jülich, Germany — [2]Faculty of Physics, University of Duisburg-Essen and CENIDE, 47053 Duisburg, Germany

Non-collinear magnetic states are promising candidates for future information technology. However, their implementation in conventional memories is hindered by the inability of the electrical readout of their chiral nature based on current perpendicular to-plane (CPP) geometries [1,2,3]. In this work, we investigate the emergence of a rich family of new spin-mixing magnetoresistances enabling highly efficient all-electrical readout of the chirality and helicity of spin-swirling textures. Such transport effects are systematised at various non-collinear magnetic states and compared with the revealed spin-orbit-independent multi-site magnetoresistances. Owing to their simple implementation in readily available reading devices, the proposed magnetoresistances offer exciting and decisive ingredients to explore with all-electrical means the rich physics of topological and chiral magnetic objects.

– Funding is provided by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (ERC-consolidator grant 681405 – DYNASORE and grant 856538 – 3D MAGiC). [1] Crum et al., Nat. Commun. 6, 8541 (2015); [2] Hanneken et al., Nat. Nano. 10, 1039 (2015); [3] Fernandes et al., Nat. Commun. 11, 1602 (2020).

MA 17.12 Fri 13:00 H5

Skyrmion Dynamics at Finite Temperatures: Beyond Thiele's Equation — •Markus Weissenhofer, Levente Rózsa, and Ulrich Nowak — Fachbereich Physik, Universität Konstanz, Universitätsstraße 10, DE-78457 Konstanz, Germany

Magnetic textures are often treated as quasiparticles following Thiele's equation of motion [1]. We use atomistic spin simulations based on the stochastic Landau-Lifshitz-Gilbert equation to simulate the Brownian and current-driven motion of ferromagnetic skyrmions in a (Pt0.95Ir0.05)/Fe-bilayer on a Pd(111) surface.

Our results reveal that the existing theory based on Thiele's equation is insufficient to describe the dynamics of skyrmions at finite temperatures. We propose an extended equation of motion that goes beyond Thiele's equation by taking into account the coupling of the skyrmion to the magnonic heat bath leading to an additional dissipative term that is linear in temperature. Our results indicate that this so-far-neglected magnon-induced friction even dominates for elevated temperatures and lower Gilbert damping values, typical for thin films and multilayers [2].

[1] A. A. Thiele, Phys. Rev. Lett. 30, 230, (1973)
[2] Weißenhofer et al. , Phys. Rev. Lett., (in press 2021)

MA 18: Posters Magnetism V

Topics: Magnetic Particles / Clusters (18.1-18.8), Magnetic Instrumentation and Characterization (18.9-18.18), Magnetic Imaging Techniques (18.19-18.21), Computational Magnetism (18.22-18.27), Electron Theory of Magnetism and Correlations (18.28-18.31), Bio- and Molecular Magnetism, Biomedical Applications (18.32-18.38), Magnetic Information Technology, Recording, Sensing (18.39-18.42)

Time: Friday 10:00–13:00 Location: P

MA 18.1 Fri 10:00 P

Influence of surface water on adhesive forces in chondritic material — •Cynthia Pillich[1], Tabea Bogdan[2], Joachim Landers[1], Gerhard Wurm[2], and Heiko Wende[1] — [1]University of Duisburg-Essen and Center for Nanointegration Duisburg-Essen (CENIDE), Faculty of Physics, Lotharstr. 1, 47057 Duisburg, Germany — [2]University of Duisburg-Essen, Faculty of Physics, Lotharstr. 1, 47057 Duisburg, Germany

The growth of planetesimals at the so called "bouncing barrier" is still not fully understood. Evaporation of surface water on protoplanetary dust grains induced by high temperatures in the vicinity of the young star might explain improved sticking at the mm-range. As meteorites contain primordial phases representing the material in our young solar system, they offer an insight into the mechanics of planetary formation. A fragment of the iron-rich meteorite "Sayh al Uhaymir" was ground and subsequently heated in vacuum at temperatures up to 1400 K and adhesive forces were determined by Brazilian tests after cooling down to room temperature. We compare changes in adhesive forces upon exposure to high temperatures of meteoritic matter holding surface water and dried material. Compositional and concomitant structural transformations induced by tempering were investigated by ^{57}Fe-Mössbauer spectroscopy, probing the abundance of iron bearing phases.

Funding by the DFG (projects WE 2623/19-1 and WU 321/18-1) is gratefully acknowledged.

MA 18.2 Fri 10:00 P

Exploring the dynamical behaviour of spherical exchange-biased Janus particles as a new tool for microfluidic biointeraction screening — •Rico Huhnstock, Claudia Jauregui Caballero, Meike Reginka, Michael Vogel, and Arno Ehresmann — Institute of Physics and Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, Heinrich-Plett-Str. 40, D-34132 Kassel

Janus particles (JPs) with engineered magnetic properties show significant potential for controlled motion in fluids by external dynamic magnetic fields [1]. In this work, we introduce an exchange bias (EB) thin film system on spherical non-magnetic particles as functionalized JPs and investigate their motion behaviour when being manipulated by dynamically varying artificial magnetic field landscapes above a topographically flat substrate. Due to the EB an Onion magnetization texture is stabilized within the magnetic cap of the JP [2], which is usually not accessible for micron-sized particles and allows for comparably high transport velocities. Probing the dynamics of the JPs in a microfluidic environment resulted in a superposition of controlled translational and rotational movements, emphasizing their potential use for biomolecular interaction analysis. This holds true not only for one-dimensional, but also two-dimensional translational motion. In addition, we highlight experimental possibilities to address and seperate each motion domain (translation and rotation) individually.

[1] Baraban *et al.* (2012), ACS Nano, 6(4):3383-3389.
[2] Tomita *et al.* (2021), J. Appl. Phys., 129:015305.

MA 18.3 Fri 10:00 P

Study of nanoparticle dynamics in binary solutions across phase transitions — •Juri Kopp[1], Joachim Landers[1], Samira Webers[1], Soma Salamon[1], Julian Seifert[2], Karin Koch[2], Annette M. Schmidt[2], and Heiko Wende[1] — [1]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen — [2]Institute for Physical Chemistry, University of Cologne

In previous magnetorheological measurements of cobalt ferrite nanoparticles in aqueous polymer solutions, Webers et al. [1] studied the thermomagnetic behavior across phase transitions showing a distinct change in magnetization. To prepare pre-aligned hybrid materials, it is important to know their stability and magnetic behavior under the influence of phase transitions such as crystallization. Here, we study the dynamics of hematite nanospindles and cobalt ferrite nanoparticles in sucrose solutions of different concentration via temperature dependent Mössbauer spectroscopy and AC-susceptometry (ACS). These methods enable us to analyze the particle mobility and particle orientation across phase transitions. ACS data obtained upon decreasing temperature reveal a supercooled state and spontaneous crystallization whereas during the heating process a mixed-fluid phase is observed, which has also been shown in the Mössbauer spectroscopy results of the sample with the smallest amount of sucrose. This work is supported by the DFG, priority programme SPP1681 (WE 2623/7-3). [1] S. Webers et al., ACS Appl. Polym. Mater. 2020, 2, 7, 2676-2685

MA 18.4 Fri 10:00 P

High throughput analysis of surface-functionalized superparamagnetic particles in dynamic magnetic field landscapes — •Yahya Shubbak[1,2], Rico Huhnstock[1,2], Kristina Dingel[2,3], Katharina Getfert[1,2], Bernhard Sick[2,3], Arno Ehresmann[1,2], and Michael Vogel[1,2] — [1]Institute of Physics & Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), University of Kassel, D-Kassel — [2]AIM-ED - Joint Lab Helmholtzzentrum für Materialien & Energie, D-Berlin — [3]Intelligent Embedded Systems, University of Kassel, D-Kassel

The precise manipulation of micro- and nano-particles in microfluidic environments opens new avenues for investigations of biomolecular analyte detection and interactions.[1] Motion control schemes based on a combination of static magnetic field landscapes superposed with external magnetic field pulses enable translatory motion control of magnetic particles at the nanoscale over macroscopic distances.[3] Here we demonstrate a novel method harnessing AI-enhanced fully-automated optical recognition algorithms [4] to analyze changes in the motion behavior of such particles due to liquid mediated surface to surface (particle to substrate) interaction.

[1] Lim, B. et al. J. Phys. D: Appl. Phys. 50, 33002 (2017) [2]*Lin, G. et al. Lab on a chip 17, 1884*1912 (2017) [3]*Issadore, D. et al. Lab on a chip 14, 2385*2397 (2014) [4] Dingel, K .et al. Computer Physics Communications, 262, 107859 (2021)

MA 18.5 Fri 10:00 P

Structure and magnetism of Fe/Fe3C/Carbon nanocomposites: Influence of the pyrolysis conditions — •Elisavet Papadopoulou[1], Nikolaos Tetos[1], Aram Manukyan[2], Harutyun Gyulasaryan[2], Gayane Chilingaryan[2], Michael Farle[1], and Marina Spasova[1] — [1]Faculty of Physics and Center of Nanointegration (CENIDE), University of Duisburg-Essen, Duisburg, 47057 Germany — [2]Institute for Physical Research of National Academy of Sciences (IPR-NAS), Ashtarak, 0203 Armenia

Carbon-encapsulated iron-cementite (Fe/Fe3C) magnetic nanoparticles were synthesized by an up-scalable solid-state pyrolysis method using iron phthalocyanine as metal precursor. The dependence of the magnetic, structural and morphological parameters on the pyrolysis conditions are presented. The nanocomposites contain α-Fe, cementite (Fe3C) and pure carbon with an average particle size of 12.5 * 2 nm. The saturation magnetization of Fe M=102 Am2/kg measured at room temperature increases by 30 % for higher synthesis temperature (973 K $<$ T $<$ 1173 K), indicating an increase in Fe content. This is in good agreement with the increasing volume fraction of iron from 0.5% to 8.6% in the same synthesis temperature range from the XRD. The effective magnetic anisotropy constant obtained from an analysis of approach to saturation magnetization (LAS) is 4.9 * 0.72 x 104 J/m3 at room temperature.

This work was supported by the EC project H2020-EU.4.b. - Twinning of research institutions no. 857502 (MaNaCa).

MA 18.6 Fri 10:00 P

Magnetic structure of Fe chains on Rh(111) substrate — •Balázs Nagyfalusi[1], László Udvardi[1,2], and László Szunyogh[1,2] — [1]Budapest University of Technology and Economics, Budapest Hungary — [2]MTA-BME Condensed Matter Research Group, Budapest, Hungary

As the size of the functional elements of spintronics devices approaches the scale of a few hundreds of atoms, the role of first principles simulations designed to model the magnetic properties of such systems becomes more pronounced. We present a method developed in the framework of the embedded cluster Green's function method aimed at minimizing the overall torque on the magnetic moments. In order to find the local minima of the energy landscape we use the gradient descent method combined with Newton-Raphson iterations where the torque and the Hessian matrix are calculated directly from first principles instead of relying on an effective spin Hamiltonian.

This procedure is applied to Fe chains deposited on Rh(111) substrate in different stacking positions. The stability of the ground state spin configurations is tested against a small vertical relaxation of the layers. The symmetry of the magnetic configurations is explained in terms of exchange interactions appearing in a suitable spin model. The comparison of the magnetic ground states obtained from ab initio and spin model calculations indicates the limits of spin models.

MA 18.7 Fri 10:00 P

Element-specific characterization of catalytic ferrite nanoparticles via Mössbauer spectroscopy — •Soma Salamon[1], Joachim Landers[1], Georg Bendt[2], Sascha Saddeler[2], Anna Rabe[2], Swen Zerebecki[3], Malte Behrens[2], Stephan Schulz[3], Stephan Barcikowski[3], and Heiko Wende[1] — [1]Faculty of Physics and CENIDE, University of Duisburg-Essen — [2]Institute of Inorganic Chemistry and CENIDE, University of Duisburg-Essen — [3]Institute of Technical Chemistry I and CENIDE, University of Duisburg-Essen

Mössbauer spectroscopy is utilized as an element-specific, nondestructive measurement method to probe hyperfine interactions in ferrite materials, which are promising candidates for electrocatalysis applications. Evaluation of low temperature spectra recorded at high magnetic fields allows us to determine the degree of inversion in spinel systems, providing important clues on the distribution of Fe-ions on different crystallographic sites, while the isomer shift makes it possible to draw conclusions on the valency states. This enables us to correlate changes in ion distribution in the lattice with improvements in catalytic activity, which can be achieved by a number of methods. Several examples of nanoparticulate systems will be shown: The modification of particle composition during and after synthesis, as well as laser treatment of nanoparticles. In all cases, our measurement method offers valuable insights into which parameters are modified by the respective sample treatment, facilitating a more effective search for the best method to increase catalytic efficiency. Funding by the DFG via the CRC/TRR 247 (ID 388390466, Project B2) is acknowledged.

MA 18.8 Fri 10:00 P

Electronic and magnetic properties of building blocks of Mn and Fe atomic chains on Nb(110) — •András Lászlóffy[1], Krisztián Palotás[1], Levente Rózsa[2], and László Szunyogh[3] — [1]Wigner RCP, ELKH, Budapest, Hungary — [2]Department of Physics, University of Konstanz — [3]Budapest University of Technology and Economics, Budapest, Hungary

We present results for the electronic and magnetic structure of Mn and Fe clusters on Nb(110) surface, focusing on building blocks of atomic chains as possible realizations of topological superconductivity. The magnetic ground states of the atomic dimers and most of the monatomic chains are determined by the nearest-neighbor isotropic interaction. To gain physical insight, the dependence on the crystallographic direction as well as on the atomic coordination number is analyzed via an orbital decomposition of this isotropic interaction based on the spin-cluster expansion and the difference in the local density of states between ferromagnetic and antiferromagnetic configurations. A spin-spiral ground state is obtained for Fe chains along the $[1\bar{1}0]$ direction as a consequence of the frustration of the isotropic interactions. Here, a flat spin-spiral dispersion relation is identified, which can stabilize spin spirals with various wave vectors together with the magnetic anisotropy. This may lead to the observation of spin spirals of different wave vectors and chiralities in longer chains instead of a unique ground state.

MA 18.9 Fri 10:00 P

Magnetic field dependent power loss of surface acoustic waves in thin nickel layers — •Jan Philipp Kress, Sebastian Kölsch, Alfons Schuck, and Michael Huth — Physikalisches Institut, Goethe Universität, Frankfurt am Main, Germany

Though mostly applied in mobile communication devices for high-frequency filtering in the GHz regime, surface acoustic wave (SAW) technology is also a promising approach in magnonics by employing the coupling of spin degrees of freedom with time-dependent elastic deformations. We present a simple setup for ferromagnetic resonance excitation by a surface acoustic wave with a rotatable electromagnet operating at room temperature. We tested our setup with an interdigital-transducer structure made from Cr/Au by UV lithography on YZ-cut $LiNbO_3$ and excited a Rayleigh-type SAW at a fundamental frequency of 290 MHz and measured its attenuation for various higher harmonics after passing a polycrystalline Ni thin film. By varying the magnetic field direction within the Ni thin film plane we measured the angle-dependent attenuation which can be related to the magnetoelastic coupling coefficient of Ni.

MA 18.10 Fri 10:00 P

Analysis of the magnetization profile of 3D printed shape programmable magnetic elastomer actuators — •Kilian Schäfer, Martin Lehmann, Iliya Radulov, and Oliver Gutfleisch — Institute of Materials Science, Technical University Darmstadt, Germany

Magnetically responsive materials can be used as sensors and actuators. The advantages of magnetic actuation mechanisms are fast response, wireless operation and the possibility to operate in enclosed confined spaces. Mechanically soft sensors and actuators are beneficial when compliant and safe interaction with the human body is needed. In addition to that, they can easily adapt to changing environments and can have a simpler design, which potentially results in greater durability and lower cost.

One example of magneto responsive soft materials are composites of polymers and hard magnetic particles, like NdFeB. Recently it was shown that the shape of these composites can be controlled with a magnetic field if the material was magnetized in a specific way beforehand. The material has to be folded in the same way as the desired deformation. Here we realized a programmable magnetic elastomer actuator based on polyurethane and NdFeB particles and present a method to characterize the imprinted magnetization profile in these composites with a custom build 3D Hall Mapper. The device measures all components of the stray field with a spatial resolution of 150 μm. The detailed information will help to improve the design and magnetization strategies of magneto-active composites. Based on this, we evaluate the actuation performance of a 3D printed composite.

MA 18.11 Fri 10:00 P

Kompaktes membranbasiertes Faraday-Magnetometer für tiefe Temperaturen — •Lukas Worch, Markus Kleinhans, Marc A. Wilde und Christian Pfleiderer — Technische Universität München, Garching, Deutschland

Auf Basis von metallisierten SiN-Membranen wurde ein kompaktes, kapazitiv ausgelesenes Faradaymagnetometer konstruiert, welches in einem ^{3}He-Einsatz und einem supraleitenden 15 T Magneten betrieben wird. Mithilfe einer unabhängigen supraleitenden Gradientenspule können die Kraft- und Drehmomentbeiträge zur Kapazitätsänderung voneinander getrennt werden. Eine elektrostatische Kalibrationsroutine erlaubt die quantitative Bestimmung der Magnetisierung. Die kommerziell verfügbaren Membranen erlauben ein einfaches und schnelles Tauschen der Probe. Durch eine drehbare Probenbühne können zudem winkelabhängige Messungen durchgeführt werden. Erste Messergebnisse an Gadolinium Gallium Granat zeigen Signaturen des komplexen Phasendiagramms in der Magnetisierung.

MA 18.12 Fri 10:00 P

Quadratic and third-order magneto-optic Kerr effect in Ni(111) thin films with and without twinning — •Maik Gaerner[1], Robin Silber[2], Tobias Peters[1], Jaroslav Hamrle[3], and Timo Kuschel[1] — [1]Bielefeld University, Germany — [2]IT4Innovations, VŠB - Technical University of Ostrava, Czech Republic — [3]Charles University, Prague, Czech Republic

To separate and study the dependencies of the linear magneto-optic Kerr effect (MOKE) and quadratic MOKE on the crystallographic direction, the so-called eight-directional method can be used [1]. So far, this method or similar ones have been utilized to characterize (001)- and (011)-oriented thin films of cubic crystal structure [2,3]. Here, we apply the eight-directional method to Ni(111) thin films and report on a strong three-fold anisotropy in longitudinal MOKE (LMOKE). This anisotropy can be explained by theory as an optical interplay of elements in the permittivity tensors of first and second order in M, effectively creating cubic MOKE contributions, i.e., MOKE of third order in M. Furthermore, we observe that in a Ni(111) thin film with twinning (two structural (111) phases with 60 deg. in-plane rotation), those oscillations are substantially reduced compared to a thin film with almost no twinning. This indicates that the LMOKE anisotropy truly is of crystallographic origin in the ferromagnetic layer and is not due to other, e.g., interface effects.

[1] K. Postava et al., J. Appl. Phys. 91, 7293 (2002)
[2] R. Silber et al., Phys. Rev. B 100, 064403 (2019)
[3] J. H. Liang et al., Appl. Phys. Lett. 108, 082404 (2016)

MA 18.13 Fri 10:00 P

Exploring the phase diagram of GdTe3 using thermal expansion and magnetostriction — •Thom Ottenbros[1], Claudius Müller[1], Shiming Lei[2], Ratnadwip Shingha[2], Leslie Schoop[2], Nigel Hussey[1,3], and Steffen Wiedmann[1] — [1]HFML-EMFL, Nijmegen, Netherlands — [2]Princeton University, USA — [3]University of Bristol, UK

Thermal expansion and magnetostriction are powerful tools to explore phase transitions and ultimately determine the phase diagram of correlated electron systems.

We present the mapping of the phase diagram of GdTe3, a van der Waals layered antiferromagnetic metal with high carrier mobility [1]. At zero magnetic field, we find three magnetic transitions in the thermal expansion: a Néel transition at 12.0 K, and two others at 7.0 and 10.0 K. In magnetostriction experiments up to 30 T and at 1.3 K, another transition occurs around 20 T before the onset of quantum oscillations.

Furthermore, we give an overview of capacitive dilatometry at the HFML-EMFL in Nijmegen and discuss new high field experiments using a uniaxial stress dilatometer [2].

[1] S. Lei et al., Science Advances 6, eaay6407 (2020). [2] R. Kuechler et al., Rev. Sci. Inst. 87, 073903 (2016).

MA 18.14 Fri 10:00 P

Single-crystal growth and magnetic characterization of rare-earth-doped yttrium orthosilicate — •Tim Hofmann, Andreas Bauer, Fabian Kessler, and Christian Pfleiderer — Chair for the Topology of Correlated Systems, Department of Physics, Technical University of Munich, Germany

The monoclinic Yttrium orthosilicate Y2SiO5 doped with several ten ppm of rare-earth atoms, such as Er^{3+}, Yb^{3+}, or Nd^{3+}, is a candidate material for optical applications in quantum information technology. The amount of dopants decisively influences key properties, such as the linewidth or the coherence time, and in turn precise control on the doping levels is essential. Here, we report the preparation of polycrystalline material using a sol–gel process, followed by single-crystal growth by means of the optical floating zone technique. The quantitative determination of doping on ppm level is challenging when using conventional characterization techniques. Instead, we infer information from magnetization measurements at low temperature for magnetic fields up to 14 T applied along the optical axes b, $D1$, and $D2$. We find paramagnetic contributions characteristic of rare-earth ions. Distinct anisotropy hints towards the importance of crystal electric field effects for both the fundamental characterization and potential applications in quantum information technology.

MA 18.15 Fri 10:00 P

2.6 Tesla Cryogen Free Mu3e System — •Dr. Roger Mitchell — Cryogenic Ltd, London, UK

Cryogenic Ltd has manufactured a large bore cryogen-free magnet system to enable investigations of the lepton-flavour violating decay of muons into an electron and two positrons. The magnet is installed at the Paul Scherrer Institute in Villigen, Switzerland. The cryostat has a 1 metre room temperature bore and houses a 2.6T magnet with a base homogeneity of <0.12% over a 1.3m central region. The NbTi magnet comprises four separately powered windings. Varying the current in the windings permits subtle changes to the field profile as well as establishing a shallow gradient field along the bore. The magnetic stray field is limited to 5mT at 1m by encasing the cryostat in a 27 tonne passive shield with overall dimensions of 2.1m diameter x 3.4m long. Access to 1m bore tube is via semicircular swing doors each weighing 0.5 tonnes. The magnet cold mass is 1.5 tonnes and is cooled to 3.5K using four 1.5W Gifford McMahon two-stage cryocoolers. The magnet operated to full field without training. To ensure safety in operation the magnet is magnetically balanced within the iron shield using a series of load cells to monitor relative displacements between the cryostat and the shield. The overall system footprint was subject to severe spatial restrictions imposed by the beamline architecture. Careful optimisation was necessary to achieve the critical specifications within the dimensional constraints. The room temperature bore will house a purpose-built detector developed at PSI which is inserted via a rail system attached to the bore wall.

MA 18.16 Fri 10:00 P

Measurement of de Haas-van Alphen effect by means of temperature modulation — •Michelle Hollricher, Marc A. Wilde, and Christian Pfleiderer — Department of Physics, Technical University of Munich, D-85748 Garching, Germany

Measurements of the quantum oscillations of the magnetization M as a function of magnetic field B, i.e. the de Haas-van Alphen effect, are a powerful tool for mapping the Fermi surfaces of metals. The most established methods for measuring $M(B)$ or other quantities utilize either the magnetic torque or inductively pick up the response to a large-amplitude modulation of B. Here we report the development and characterization of a temperature modulation technique (TMT) for measuring quantum oscillations in M, combining a thermally linked sample-heater-thermometer arrangement with an inductive pick-up. Advantages of the method are the absence of dissipation due to a modulated field and the ability to separate signals arising from orbits with different effective masses. It was found that TMT may prove to be especially advantageous for detecting oscillations related to orbits with heavy effective masses. The TMT was employed on Bi single crystals at temperatures down to 1.9 K and in magnetic fields up to 9 T. Pronounced quantum oscillations well into the quantum limit of the electron pockets were observed.

MA 18.17 Fri 10:00 P

Meissner flux repulsion and trapped flux in sub-millimeter size superconductors observed with enhanced neutron depolarization — •Jorba Pau[1], Schulz Michael[2], Seifert Marc[1,2], Tsurkan Vladimir[3,4], Böni Peter[1], and Pfleiderer Christian[1] — [1]Physik-Department, Technische Universität München, Garching, Germany — [2]Heinz-Maier-Leibnitz Zentrum (MLZ), Technische Universität München, Garching, Germany — [3]Experimental Physics V, Center for Electronic Correlations and Magnetism, University of Augsburg, Augsburg, Germany — [4]Institute of Applied Physics, Chisinau, Republic of Moldova

Neutron depolarization is a unique probe which can quantify the level of magnetic inhomogeneity at a mesoscopic scale in the bulk of a sample. We report the construction of a focusing neutron guide module increasing the neutron flux at the focal spot by a factor of 20. This module was used to enhance ND measurements, demonstrating an increase of an order of magnitude in the signal to noise ratio while maintaining the exposure time. The construction and utilization details are addressed. Additionally, a proof of principle experiment on superconducting niobium and lead was conducted. We demonstrate that, with the enhanced ND technique, the Meissner flux repulsion and trapped magnetic flux of very small superconducting samples can be observed. This opens the possibility of using ND to investigate superconductors, ferromagnets, or even spin glasses under very high pressures.

MA 18.18 Fri 10:00 P

MIASANS at the longitudinal neutron resonant spin echo spectrometer RESEDA — •Jonathan Leiner[1,2], Christian Franz[1,2,3], Johanna Jochum[1,2], and Christian Pfleiderer[1,2] — [1]Technical University of Munich, Garching, Germany — [2]Heinz Maier-Leibnitz Zentrum (MLZ), Garching, Germany — [3]JCNS at MLZ, FZ Jülich GmbH, Garching, Germany

The RESEDA (Resonant Spin-Echo for Diverse Applications) instrument has been optimized for neutron scattering measurements of quasielastic and inelastic processes over a wide parameter range. One spectrometer arm of RESEDA is configured for the MIEZE (Modulation of Intensity with Zero Effort) technique where the measured signal is an oscillation in neutron intensity over time, which is prepared by two precisely tuned radio-frequency (RF) flippers. With MIEZE, all of the spin-manipulations are performed before the beam reaches the sample, and thus the signal from sample scattering is not disrupted by any depolarizing conditions there (i.e. magnetic materials). The MIEZE spectrometer is being further optimized for the requirements of small-angle neutron scattering (MIASANS), a versatile combination of the spatial and dynamical resolving power of both techniques. We present the progress on (i) installing new superconducting solenoids as part of the RF flippers to significantly extend the dynamic range (ii) design and installation of modular options for both reflecting guides and evacuated flight paths with absorbing walls for background reduction (iii) installation of a new detector on a translation stage within a vacuum vessel for flexibility with angular coverage and resolution.

MA 18.19 Fri 10:00 P

Microfocused optical spin-wave spectroscopy with vector magnetic fields — •Yannik Kunz, Michael Schneider, Björn Heinz, Lars Niklas Hess, Philipp Pirro, Vitaliy Vasyuchka, and Mathias Weiler — Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

The field of magnonics aims to exploit spin waves for information processing purposes. Experimental techniques that allow accurate spin-wave spectroscopy in magnonic microstructures are needed to tailor magnonic devices. The micro-focused frequency-resolved magneto-optic Kerr effect (FR-MOKE) can be used for spatially resolved spin-wave measurements in the frequency-domain with phase resolution, empowered by vector network analysis [1]. Here we present a FR-MOKE setup that provides 3D vector magnetic fields to study linear and non-linear spin-wave dynamics in micropatterned magnonic conduits in all field geometries. The setup allows simultaneous integration of micro-focused Brillouin Light Scattering and time-resolved MOKE to access both coherent and incoherent spin-wave dynamics as a function of frequency and/or time. We characterize the setup performance through optical spin-wave spectroscopy measurements of metallic and insulating magnonic devices. [1] L. Liensberger et al. IEEE Magn. Lett. 10, 5503905 (2019)

MA 18.20 Fri 10:00 P

Time-Resolved Imaging of Ferromagnetic Resonances in the Oldenburg Ultrafast Transmission Electron Microscope (UTEM) — •Jonathan Weber, Nikita Porwal, Michael Winkelhofer, and Sascha Schäfer — Carl-von-Ossietzky Universität Oldenburg, Deutschland

Recent progress in the development of laser driven, high-brightness photocathodes offers a path to investigate magnetization dynamics with unparalleled resolution by employing a Lorentz imaging scheme in an ultrafast transmission electron microscope [1,2].

Aiming to extend the accessible frequency range, we develop a setup for Lorentz-imaging detected ferromagnetic resonances. Beyond the nanometer spatial resolution, inherent to transmission electron microscopy, a setup for fs-temporal resolution is presented, employing nano-localized photoemission from a Schottky-field emitter in the Oldenburg UTEM. The laser system which is used for the generation of ultrashort electron pulses is also utilized as a master clock for the synthetization of phase-locked microwave signals [3]. Making use of a custom-made sample holder we pass these signals to a microresonator which excites precessions of the magnetic moments in nanostructured Py films at GHz frequencies. With this advanced excitation scheme we aim to further establish ultrafast Lorentz microscopy as a powerful tool to characterize magnetic dynamics on the nanoscale.

[1] T. Eggebrecht et al. Phys. Rev. Lett. 118, 097203 (2017)
[2] N. R. da Silva et al. Phys. Rev. X 8, 031052 (2018)
[3] M.R. Otto et al. Struct. Dyn. 4, 051101 (2017)

MA 18.21 Fri 10:00 P

Force-detected magnetic resonance of nanometer thin films: measuring copper nuclear spins with a nanoladder sensor — •Gesa Welker[1], Martin Héritier[2], Martin de Wit[1], Tim Fuchs[1], Jaimy Plugge[1], Freek Hoekstra[1], Alexander Eichler[2], Christian Degen[2], and Tjerk Oosterkamp[1] — [1]Leiden Institute of Physics, Leiden University, The Netherlands — [2]ETH Zurich, Switzerland

Magnetic Resonance Force Microscopy (MRFM) is a non-invasive 3D imaging technique that can be used to characterize biological and solid-state samples on the nanoscale. Small ensembles of spins are detected by measuring the attonewton forces they exert on an ultrasoft cantilever. State of the art for biological samples is the imaging of a single tobacco mosaic virus with nanometer resolution (Degen, 2009), based on the detection of nuclear 1H (proton) spins. An important goal in the field is improving measurement sensitivity in order to achieve higher image resolution, the ultimate goal being single-nuclear-spin resolution. In this poster we present a new type of force sensor for MRFM, designed for increased sensitivity and operation at millikelvin temperatures to reduce thermal noise. The sensor combines a nanoladder cantilever (spring constant 16 μN/m) with a micromagnet of 1.1 μm radius. Using the new sensor, we unambiguously identified a copper nuclear resonance signal.

MA 18.22 Fri 10:00 P

Finite-element dynamic-matrix approach to calculate spin-wave dispersions in waveguides with arbitrary cross section — •Lukas Körber[1,2], Gwen Quasebarth[1,2], Andreas Otto[2], and Attila Kákay[1] — [1]Helmholtz-Zentrum Dresden - Rossendorf, Dresden Germany — [2]Technische Universität Dresden

One of the key objectives in curvilinear magnetism is the determination of the spin-wave dispersion and mode profiles in magnetic waveguides with surface curvature. Due to the geometrical complexity, dynamic micromagnetic simulations are often used to obtain quantitive predictions where only approximate analytical approaches are available. However, especially in geometries which require an accurate modeling of the sample surface, these dynamic micromagnetic simulations become computionally exhausting. To address this challenge, we present a finite-element dynamic-matrix approach to efficiently calculate the dispersion and spatial mode profiles of spin waves propagating in waveguides with arbitrary cross section where the equilibrium magnetization is invariant along the propagation direction. This is achieved by solving a linearized version of the equation of motion of the magnetization numerically only in a single cross section of the waveguide at hand. To take account of the dipolar interaction we present an extension of the well-known Fredkin-Koehler method to plane waves. As an application of our method, we present the first results on the spin-wave dispersion in nanotubes with thick shell which exhibits higher-order standing modes along the radial direction as well as an extremely strong dispersion asymmetry compared to thin-shell nanotubes.

MA 18.23 Fri 10:00 P

Automated spin-dynamics simulations with AiiDA-Spirit — •Philipp Rüssmann[1], Jordi Ribas Sobreviela[1,2], Moritz Sallermann[1], and Stefan Blügel[1] — [1]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, Jülich, Germany — [2]RWTH Aachen University, Aachen, Germany

The Spirit framework (spirit-code.github.io) allows to perform spin-dynamics simulations of magnetic materials based on the solution of the Landau-Lifshitz-Gilbert equation. These calculations can be used, for example, to find the magnetic ground state based on exchange coupling parameters, to calculate the Curie Temperature with a Monte Carlo method or perform geodesic nudged elastic band calculations for the minimal energy transition path between two magnetic states. We present the AiiDA-Spirit plugin (aiida-spirit.readthedocs.io) that connects the Spirit code to the AiiDA framework. AiiDA allows to perform automated calculations while keeping track of the data provenance between calculations. The AiiDA-Spirit plugin is able to use exchange coupling parameters calculated based on first-principles calculations within the AiiDA-KKR package (aiida-kkr.readthedocs.io). This facilitates multi-scale modelling, bridging the gap from the atomic scale of quantum mechanical simulations to the micrometer scale of magnetic structures and devices. — We acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG) under Germany's Excellence Strategy – Cluster of Excellence Matter and Light for Quantum Computing (ML4Q) EXC 2004/1 – 390534769.

MA 18.24 Fri 10:00 P

Energy-efficient control of magnetization reversal in bistable nanowires — •Mohammad Badarneh[1], Grzegorz Kwiatkowski[1], and Pavel Bessarab[1,2] — [1]University of Iceland, Reykjavík, Iceland — [2]ITMO University, St. Petersburg, Russia

We explore theoretical limits for the energy-efficient control of switching phenomena in bistable magnetic nanowires. We calculate optimal control paths (OCPs) for the magnetization switching as functions of the switching time, damping and various parameters of the nanowires. Following an OCP involves concerted rotation of the magnetic moments in such a way that the system's internal modes are effectively used to aid magnetization switching. OCP calculations demonstrate that short nanowires reverse their magnetization via coherent rotation which can be induced by applying uniform external magnetic field with frequency defined by a collective in-phase precession of the magnetization [1]. If the length of the wire exceeds a certain critical length, standing spin wave emerges during magnetization switching [2]. Such spin wave assisted magnetization switching has recently attracted much attention as a promising technique to reduce the switching field for magnetic recording. Our results demonstrate that optimal switching mechanisms and corresponding control stimuli can be predicted from first principles, contributing to the development of low-power technologies.

[1] G.J. Kwiatkowski et al., Phys. Rev. Lett. 126, 177206 (2021)

[2] M.H.A. Badarneh et al., Nanosyst. Phys. Chem. Math. 11(3), 294 (2020)

MA 18.25 Fri 10:00 P

Exchange interactions in hematite from first principles — •András Deák[1], Tobias Dannegger[2], Martin Evers[2], László Szunyogh[1,3], and Ulrich Nowak[2] — [1]Department of Theoretical Physics, Budapest University of Technology and Economics, Hungary — [2]Fachbereich Physik, Universität Konstanz, Germany — [3]MTA-BME Condensed Matter Research Group, Budapest University of Technology and Economics, Hungary

Antiferromagnets have lately appeared in the forefront of spintronics research, with exciting novel magnonic spin transport applications for collinear insulating antiferromagnets. We will detail our investigations of hematite (α-Fe_2O_3), a well-known collinear insulating antiferromagnet showing weak ferromagnetism.

We assess magnetic ordering in the material using the Screened Korringa–Kohn–Rostoker (SKKR) multiple scattering theory. We use a multiscale description by deriving spin model parameters from first principles and investigating the ground state spin configuration and its stability using this model. With this approach we can tackle the nature of the weak ferromagnetic distortion in this antiferromagnet, and provide spin model parameters that can be used in large-scale simulations of magnon dynamics effects.

MA 18.26 Fri 10:00 P

Quantum effects in thermally activated domain wall switching in ferromagnets — •Grzegorz J. Kwiatkowski[1] and Pavel F. Bessarab[1,2] — [1]Science Institute of the University of Iceland, Reykjavík, Iceland — [2]ITMO University, St. Petersburg, Russia

Most widely used data storage technologies are based on nanoscale magnetic structures [1]. In order to improve both memory retention and energy efficient writability one needs to increase stability of magnetic samples without a change in energy barrier which directly affects the costs or rewritning the memory. Due to this fact it is vital to optimise the preexponential factor in Arrhenius law, which requires one to properly study the effect of internal degrees of freedom on thermal switching pocesses [2,3]. We present analytic estimation of rate of escape for domain wall switching in 3D samples with focus on how results scale with internal parameters and sample size. Since for spin waves minimum excitation energy is larger then average thermal fluctuation for high frequency modes we employ Bose-Einstein statistics, which leads to nontrivial temperature dependencies of the preexponential factor opening up new possibilities for enhancing stability of magnetic structures. This work was funded by the Russian Science Foundation (Grant No. 19-72-10138) and the Icelandic Reseach Fund (Grant No. 184949-052).

[1] W. A. Challener et al. Nature Photonics volume 3, pages 220-224 (2009) [2] P. F. Bessarab, V. M. Uzdin and H. Jónsson Physical Review Letters 110.2, 020604 (2013) [3] G. Fiedler et al. Journal of Applied Physics 111, 093917 (2012)

MA 18.27 Fri 10:00 P

Energy-efficient control of magnetic states — Mohammad Badarneh[1], Grzegorz Kwiatkowski[1], Sergei Vlasov[2], Igor Lobanov[2], Valery Uzdin[2], and •Pavel Bessarab[1,2] — [1]University of Iceland, Reykjavik — [2]ITMO University, St. Petersburg, Russia

Control of magnetization switching is critical for the development of novel technologies based on magnetic materials. Transitions between magnetic states can follow various pathways which are not equivalent in terms of energy consumption and duration. In this study, we propose a general theoretical approach based on the optimal control theory to design external stimuli for efficient switching between target magnetic states. The approach involves calculation of optimal control paths (OCPs) for the desired magnetic transition. Following an OCP involves rotation of magnetic moments in such a way that the strength of the external stimulus is minimized, but the system's internal dynamics is effectively used to aid the switching. All properties of the switching pulses including temporal and spatial shape can be derived from OCPs in a systematic way. Various applications of OCP calculations are presented, including energy-efficient switching of a nanomagnet by means of external magnetic field [1] or electric current, and spin-wave assisted magnetization reversal in nanowires [2].

This work was funded by the Russian Science Foundation (Grant No. 19-72-10138), the Icelandic Reseach Fund (Grant No. 184949-052).

[1] G.J. Kwiatkowski *et al.*, Phys. Rev. Lett. **126**, 177206 (2021).

[2] M.H.A. Badarneh *et al.*, Nanosyst. Phys. Chem. Math. **11**, 294 (2020).

MA 18.28 Fri 10:00 P

Magnon topology in chiral crystals: Multifold crossings and nodal planes — •Niclas Heinsdorf, Xianxin Wu, and Andreas Schnyder — Max Planck institute for condensed matter physics

We investigate the topology of magnon excitations in magnets with chiral space groups. The presence of (magnetic) screw rotations lead to symmetry enforced Weyl points and nodal planes in the magnon band structure. In addition, there are multifold crossings pinned at high-symmetry points. We systematically analyze the band topology of these crossings and calculate their topological charges. In particular, we find that the magnon nodal planes carry a quantized topological charge similar to magnon Weyl points. Analogous to the protected spin currents on the surface of topological insulators, the topologically nontrivial magnon crossings result in protected surface modes of heat quanta. We propose several candidate materials and calculate their magnon band structures, topological invariants, and topologically protected surface modes.

MA 18.29 Fri 10:00 P

Magnetic interactions in correlated systems from first principles — •Vladislav Borisov[1], Yaroslav O. Kvashnin[1], Nikolaos Ntallis[1], Qichen Xu[2], Rebecca Clulow[1], Peter Svedlindh[1], Danny Thonig[3], Patrik Thunström[1], Manuel Pereiro[1], Anders Bergman[1], Erik Sjöqvist[1], Anna Delin[2], Lars Nordström[1], and Olle Eriksson[1,3] — [1]Uppsala University, SE-75120 Uppsala, Sweden — [2]KTH Royal Institute of Technology, SE-10691 Stockholm, Sweden — [3]Örebro University, SE-70182, Örebro, Sweden

The formation of non-trivial magnetic textures, such as skyrmions, depends on the interplay between the Heisenberg and Dzyaloshinskii-Moriya (DM) interactions. In this work, we discuss a general theoretical framework based on density functional (DFT) and dynamical mean-field theories which allows to calculate these interactions accurately from first principles including electronic correlations.

First, we demonstrate that dynamical correlations can lead to non-monotonic variations of magnetic exchange, for example, in skyrmionic B20 compounds MnSi and FeGe and low-dimensional system of Co/Pt(111) bilayer [1].

Secondly, we use the proposed theoretical approach to study the doped B20 compounds $Fe_{0.75}TM_{0.25}Si$ (TM = Co, Rh, Ir) and $Co_{0.75}TM_{0.25}Si$ (TM = Fe, Ru, Os) and predict that skyrmions can be stabilized in all these compounds and the DM interaction is enhanced in the 4*d*- and 5*d*-doped systems. We also report successful synthesis for (Fe,Ir)Si and (Co,Ru)Si and measurements for the later.

1. PRB 103, 174422 (2021).

MA 18.30 Fri 10:00 P

Local spin Hamiltonians from model electronic structure theory — Simon Streib[1], Vladislav Borisov[1], Manuel Pereiro[1], Anders Bergman[1], Erik Sjöqvist[1], Anna Delin[2,3], Mikhail Katsnelson[4], Olle Eriksson[1,5], and •Danny Thonig[5] — [1]Department of Physics and Astronomy, Uppsala University, Sweden — [2]Department of Applied Physics, KTH Royal Institute of Technology, Sweden — [3]Swedish e-Science Research Center (SeRC), KTH Royal Institute of Technology, Sweden — [4]Institute for Molecules and Materials, Radboud University, The Netherlands — [5]School of Science and Technology, Örebro University, Sweden

The derivation of spin Hamiltonians from ab initio calculations is an important tool for modeling effective precession fields in the dynamics of magnetic materials since a full electronic description of the dynamics is computationally very demanding. In this work, we contrast two different – "local" and "global" – approaches. The global approach aims at describing arbitrary spin configurations, whereas the local approach is only valid for small magnetic fluctuations locally around a given spin configuration. We argue that global symmetry requirements, such as time-reversal symmetry, do not necessarily restrict local spin Hamiltonians if the dependence of the effective exchange parameters on the magnetic state is taken into account. We present a general formalism to map model electronic structure theory to a local spin Hamiltonian and we check our formalism by means of numerical calculations for low-dimensional structures, like dimers and chains [1].

[1] S. Streib et al., Phys. Rev. B 103, 224413 (2021)

MA 18.31 Fri 10:00 P

An automated tool for generation of optimal Voronoi tessellation of crystal structures by the inclusion of void sites — •Roman Kováčik and Stefan Blügel — Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich and JARA, 52425 Jülich, Germany

The performance of the electronic structure calculation within the Korringa-Kohn-Rostoker Green function method strongly relies on a good convergence with respect to the angular momentum expansion. This in turn depends on an as close-packed as possible definition of the atomic structure, due to the Voronoi tessellation used to partition the space. Hence, for the crystal structures with low packing density, an appropriate set of void sites has to be defined, which we address in our newly developed python tool.

The lower and upper bound of the number of void sites is estimated from the packing density, using simple geometrical arguments or assuming atomic radii of the present species. Within these bounds, a number of all distinct sets of Wyckoff positions is generated, corresponding to the space group of the input structure and yet unoccupied by present atoms. In case of a free coordinate in a particular Wyckoff position, a user defined number of random initial positions are tried. The fitness of the resulting Voronoi tessellation is examined as a function of the radius of void sites from the minimum ratio of inscribed and circumscribed sphere and the maximum ratio of circumscribed sphere and nearest neighbor distance over the Voronoi cells. Solutions are presented for several trivial and non-trivial crystal structures.

MA 18.32 Fri 10:00 P

Light-, temperature-, and x-ray-induced spin-crossover transition of molecules adsorbed on a graphite surface — •Jorge Torres[1], Lalminthang Kipgen[1], Sascha Ossinger[2], Sangeeta Thakur[1], Clara W.A. Trommer[2], Ivar Kumberg[1], Rahil Hosseinifar[1], Evangelos Golias[1], Sebastien Hadjadj[1], Jendrik Gördes[1], Chen Luo[3], Kai Chen[3], Florin Radu[3], Felix Tuczek[2], and Wolfgang Kuch[1] — [1]Freie Universität Berlin, Institut für Experimentalphysik, Berlin, Germany — [2]Christian-Albrechts-Universität zu Kiel, Institut für Anorganische Chemie, Kiel, Germany — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

When iron spin-crossover molecules (SCM) are irradiated by light, their spin configuration can be excited from the ground state S_0 to an exited state S_1 and from there even to a metastable state of different multiplicity. For Fe(II) complexes this corresponds to a transition from low-spin (LS) to high-spin (HS) states. When the temperature is changed, this transition takes place in terms of thermodynamic effects. In this work we deposited different sub-, mono- and multilayer coverages of $[Fe\{(pzpy)pz\}_2]$ on highly oriented pyrolytic graphite and measured them by X-ray absorption spectroscopy. Analysis of the HS and LS fraction showed that for almost all samples the light-induced excited spin-state trapping (LIESST) effect resulted in twice the HS fraction than the thermally induced spin-state transition. The transition temperature $T_{1/2}$ (50% HS and 50% LS) is located at 300 K, opening a window for potential applications at room temperature.

MA 18.33 Fri 10:00 P

Hyperthermia setup for efficient nanoparticle heating — •Daniel Kuckla, Amirarsalan Asharion, Julia-Sarita Brand, Vinzenz Jüttner, and Cornelia Monzel — Heinrich-Heine-Universität Düsseldorf

All biological systems are temperature dependent. Of special interest is the influence of elevated temperatures on malignant tissue and how this can be exploited for medical treatments. One approach called "magnetic hyperthermia" uses bio-functionalized magnetic nanoparticles (MNPs) which heat in an alternating magnetic field. By targeting MNPs to the malignant cells, a spatially selective heating of tissue is realized. Here, we present a hyperthermia setup, which allows to image the behaviour of cells marked with MNPs on a microscope while being subjected to an alternating magnetic field. We provide a comprehensive characterization of the setup components and magnetic fields generated, as well as strategies to limit off-target power dissipation. We further quantify the heat generated by MNPs in well-defined in vitro and biomimetic environments. The efficient generation of high-frequency magnetic fields and direct observation of MNP responses will provide valuable information on the heat generation mechanism in different environments.

MA 18.34 Fri 10:00 P

Spectroscopic studies of a Fe(II) spin-crossover complex in the room temperature regime — •Lea Spieker[1], Stephan Sleziona[1], Gérald Kämmerer[1], Carolin Schmitz-Antoniak[2], Torsten Kachel[3], Soma Salamon[1], Damian Günzing[1], Tobias Lojewski[1], Nico Rothenbach[1], Andrea Eschenlohr[1], Katharina Ollefs[1], Senthil Kumar Kuppusamy[4], Mario Ruben[4,5], Uwe Bovensiepen[1], Peter Kratzer[1], Marika Schleberger[1], and Heiko Wende[1] — [1]Faculty of Physics and Center for Nanointegration Duisburg-Essen (CENIDE), University of Duisburg-Essen — [2]Jülich Research Center — [3]Helmholtz Center Berlin — [4]Karlsruhe Institute of Technology — [5]CNRS-University of Strasbourg

Spin-crossover complexes with a bi-stable spin-state switching in the room temperature regime, influenced by external stimuli such as light, pressure, temperature, or X-rays, are desirable for applications. With different spectroscopic methods, like Raman- and X-ray absorption spectroscopy, we investigated a Fe(II) complex showing a phase transition from a diamagnetic low-spin (S=0) to a paramagnetic high-spin (S=2) state in the room temperature regime ($T_{1/2\uparrow} = 330\,\mathrm{K}$) with a broad thermal hysteresis of $\Delta T = 50\,\mathrm{K}$. Unique changes of the molecular bondings during a temperature-induced phase transition are confirmed by Raman spectroscopy measurements combined with density functional theory calculations. In addition, X-ray absorption spectroscopy measurements reveal a thermally reversible soft X-ray induced excited spin-state trapping effect in the room temperature regime. Financially supported by CRC 1242 Project A05 (Project-ID 278162697).

MA 18.35 Fri 10:00 P

High-frequency Electron Paramagnetic Resonance studies on a pentagonal-bipyramidal V(III) complex — •Lena Spillecke, Changhyn Koo, and Rüdiger Klingeler — Kirchhoff-Institute for Physics, Heidelberg University, Germany

We present detailed high-frequency/high-field electron paramagnetic resonance (HF-EPR) studies as well as magnetic susceptibility measurements down to 400 mK on the first pentagonal-bipyramidal Vanadium(III) complex with a Schiff-base N_3O_2 pentadentate ligand. [1] By detailed measurements on loose and fixed powder samples we rationalized precisely the crystal field parameters and g-value information of this complex and also quantified small but finite intermolecular dimer-like antiferromagnetic magnetic coupling of $J = -1.1\ \mathrm{cm}^{-1}$. Especially the observation of intermolecular coupling is somehow surprising considering the isolated character and large distance between the V(III) centers. However, theoretical analysis reveals that the interaction between distant V(III) centers is mediated via π-stacking contacts between the ligands of neighboring complexes. In conclusion this work gives a deep insight into the magnetic properties of a V(III) complex and demonstrates how HF-EPR spectroscopy can act as powerful tool for the investigation of magnetic properties.

[1] *Bazhenova et al., Dalton Trans. 49, 15287-15298 (2020)*

MA 18.36 Fri 10:00 P

High-frequency EPR study on the exchange couplings in 3d-4f heterometallic complexes with diverse structures — •Changhyun Koo[1], Lena Spillecke[1], Silvia Menghi[1], Sebastian Schmidt[2], Yan Peng[2], Naushad Ahmed[3], Maheswaran Shanmugam[3], Annie K. Powell[2], and Rüdiger Klingeler[1] — [1]Kirchhoff Institute for Physics, Heidelberg University, Heidelberg, Germany — [2]Institute of Inorganic Chemistry, Karlsruhe Institute of Technology, Karlsruhe, Germany. — [3]Department of Chemistry, Indian Institute of Technology, Mumbai, India.

3d-4f heterometallic complexes are suggested to enhance the magnetic anisotropy barrier in single molecular magnets (SMM) candidate metal organic complexes as combining benefits of 3d and 4f magnetic ions. Though the exchange coupling between 3d and 4f ions, J_{3d-4f}, is essential, its quantitative determination is still challenging. In this presentation, the precise J_{3d-4f} values in several 3d-4f heterometallic complexes with various molecular structures, i.e. Cu_2Ln with linear bonding, Fe_4Ln_2 with ring-like structure, and Fe_2Ln_2 butterfly-like structure (Ln = Tb, Dy, Ho, Yb, and Gd) are determined by means of the high-frequency electron paramagnetic resonance (HF-EPR) technique. Based on the current studies, the effect of the exchange interaction on the magnetic properties of the complexes is discussed.

MA 18.37 Fri 10:00 P

Thermal- and Light-Induced Spin-Crossover Characteristics of a Functional Iron(II) Complex at Submonolayer Coverage on HOPG — •Sangeeta Thakur[1], Evangelos Golias[1], Ivar Kumberg[1], Kuppusamy S. Kumar[2], Rahil Hosseinifar[1], Jorge Torres[1], Lalminthang Kipgen[1], Christian Lotze[1], Lucas M. Arruda[1], Florin Radu[3], Mario Ruben[2], and Wolfgang Kuch[1] — [1]Freie Universität Berlin, Institut für Experimentalphysik, Berlin, Germany — [2]Institute of Nanotechnology, Karlsruhe Institute of Technology (KIT), Eggenstein-Leopoldshafen, Germany — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany

The role of molecule-substrate interactions on the thermal- and light-induced spin-state switching characteristics of 0.4 monolayer of a functional spin-crossover(SCO)-complex $[Fe(H_2B(pz)_2)_2COOC_{12}H_{25}$-bipy] on a highly oriented pyrolytic graphite (HOPG) substrate was studied using x-ray absorption spectroscopy [1]. A spin-state coexistence of 42% low-spin (LS) and 58% high-spin (HS) is observed for the complex at 40 K, in contrast to the complete spin-state switching observed in the bulk and in SiOx-bound 10 nm thick films [2], highlighting the role of molecule-substrate interactions. The 100% HS state obtained after light irradiation at 10 K indicates the occurrence of efficient on-surface light-induced spin switching, encouraging the development of light-addressable molecular devices based on SCO complexes.

[1] S. Thakur et al. J. Phys. Chem. C 125, 25, (2021).
[2] K. S. Kumar et al., Adv. Mater. 30, 1705416, (2018).

MA 18.38 Fri 10:00 P

Modeling spin-phonon relaxation in organic semi-conductors from first-principles — •Uday Chopra, Erik R. McNellis, and Jairo Sinova — Johannes Gutenberg University, Staudingerweg 7, Mainz 55128

Spin-orbit coupling (SOC) is one of the major causes of spin-relaxation in organic semiconductors. It generally works in conjunction with other factors, for example a hopping driven spin-flip mechanism [1,2]. In this work, we explore spin-relaxation caused due to molecular vibrations. We present a model to estimate the spin-phonon couplings using finite-differences within harmonic approximation from a first-principles approach. Using these couplings we are able to derive the spin-relaxation times (T1) between the Zeeman energy levels for Raman-like processes using the Fermi's Golden rule. Our model assumes a relaxation mediated via two phonons via an intermediate state. This enables us to evaluate and predict the temperature dependence of T1 and analyse the contribution of relevant phonon-modes that dominate the relaxation. We present our findings using organic-semiconductors and single-molecule magnets to demonstrate transferability across different systems. [1] Chopra et al. Phys. Rev. B 100, 134410 (2019) [2] Chopra et al. J. Phys. Chem. C 123, 19112, (2019)

MA 18.39 Fri 10:00 P

Optical control of 4f orbital state in rare-earth metals — N. Thielemann-Kühn[1], •T. Amrhein[1], W. Bronsch[1], S. Jana[2], N. Pontius[2], R. Engel[3], P. Miedema[3], D. Legut[4], K. Carva[5], U. Atxitia[1], B. Van Kuiken[6], M. Teichmann[6], R. Carley[6], L. Mercadier[6], A. Yaroslavtsev[6,7], G. Mercurio[6], L. Le Guyader[6], N. Agarwal[6], R. Gort[6], A. Scherz[6], M. Beye[3], P. Oppeneer[7], M. Weinelt[1], and C. Schüssler-Langeheine[2] — [1]Freie Universität Berlin — [2]HZB — [3]DESY — [4]IT4Innovations — [5]Charles University — [6]European XFEL — [7]Uppsala University

High density magnetic storage devices base on materials with large magneto crystalline anisotropy (MCA) that needs to be overcome by laser heating above the Curie temperature to enable bit writing [1]. In a time-resolved X-ray absorption experiment at the European XFEL we found that the MCA itself can be manipulated on fs time scales by an optical stimulus [2]. In 4f rare-earth metals the magnetic moment and high MCA stems from the 4f system that is not directly accessible with optical wavelengths. We show, however, that the direct excitation of 5d electrons drives 4f-5d inelastic electron scattering and 4f-5d electron transfer, initiating orbital excitations in the 4f shell that change the MCA tremendously. Besides the technological relevance of such handle on MCA, 4f electronic excitations directly alter exchange and electron-phonon coupling and thus contribute to a more fundamental understanding of non-equilibrium dynamics.

[1] W. Challener et al. Nature Photon 3, 220-224 (2009).
[2] arXiv:2106.09999

MA 18.40 Fri 10:00 P

Characterization of superconducting niobium lumped-element-resonators for strong magnon-photon coupling to yttrium-iron-garnet (YIG) structures — •Philipp Geyer[1], Karl Heimrich[1], Philip Trempler[1], Frank Heyroth[2], Sandra Gottwals[1], and Georg Schmidt[1,2] — [1]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Von-Danckelmann-Platz 3, 06120 Halle (Saale), Germany — [2]Interdisziplinäres Zentrum für Materialwissenschaften, Martin-Luther-Universität Halle-Wittenberg, Nanotechnikum Weinberg, 06120 Halle (Saale), Germany

In the past years the field of hybrid quantum magnonics appears a promising candidate for quantum information processing. Here, magnons can be an important mediator for coupling between different quantum states [1]. We investigate superconducting Nb lumped-element-resonators grown on annealed sapphire (0001) substrates. The resonators are fabricated by optical lithography, Nb sputtering and lift-off. The deposition of niobium was done by argon ion sputtering at room-temperature and the niobium was not covered by a protecting layer. Nevertheless, we observe for 50 nm thin films superconducting transition temperatures above 7 K and sufficiently high critical B-fields. Our work is focused on resonators which excite preferably high localized magnetic fields. YIG particles will be transferred from high quality free standing YIG microstructures to achieve strong coupling between microwave photons and magnons [3]. [1] D. Lachange-Quirion et.Al. Science, Vol. 367, Issue 6476, pp. 425-428 (2020) [2] P. Trempler et. Al. Appl. Phys. Lett. 117, 232401 (2020)

MA 18.41 Fri 10:00 P

Mapping the Stray Fields of a Micromagnet Using Spin Centers in SiC — •Mauricio Bejarano[1,2], Francisco Jose Trindade Goncalves[1], Michael Hollenbach[1,2], Toni Hache[1,3], Tobias Hula[1,3], Yonder Berencén[1], Jürgen Fassbender[1], Manfred Helm[1], Georgy V. Astakhov[1], and Helmut Schultheiss[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Technische Universität Dresden, 01062 Dresden, Germany — [3]Technische Universität Chemnitz, 09107 Chemnitz, Germany

We report on utilizing an ensemble of V_{Si} centers as a room-temperature sensor of static stray fields generated by magnetic microstructures patterned on top of a SiC substrate. We use optically-detected magnetic resonance (ODMR) to measure the impact of the stray fields on the intrinsic V_{Si} resonance frequencies. The spin resonance at the spin centers is driven by a micrometer-sized microwave antenna patterned next to the magnetic element. The antenna pattern is made to ensure that the driving microwave fields are delivered locally and more efficiently compared to conventional millimeter-sized circuits. We observe a spatially dependent frequency shift of the V_{Si} resonances which enables us to determine the field contribution from the magnetic element in its close vicinity. Our results are a first step toward developing magnon-quantum applications by deploying local microwave fields and stray fields at the micrometer length scale. This work was supported in part by the German Research Foundation under Grants SCHU 2922/4-1 and AS 310/5-1.

MA 18.42 Fri 10:00 P

Optical read-out of the Néel vector in metallic antiferromagnet Mn_2Au — •V. Grigorev[1], M. Filianina[1], S. Yu. Bodnar[1], S. Sobolev[1], N. Bhattacharjee[1], S. Bommanaboyena[1], Y. Lytvynenko[1], Y. Skourski[2], D. Fuchs[3], M. Klaeui[1], M. Jourdan[1], and J. Demsar[1] — [1]Institute of Physics, Uni Mainz, 55128 Mainz, Germany — [2]HLD-EMFL, HZDR, 01328 Dresden, Germany — [3]IQMT, KIT, 76344 Eggenstein-Leopoldshafen, Germany

Metallic antiferromagnets with broken inversion symmetry on the two sublattices, strong spin-orbit coupling and high Néel temperatures offer new opportunities for applications in spintronics. Especially Mn_2Au, with high Néel temperature and conductivity, is particularly interesting for real-world applications. The read-out of the staggered magnetization, *i.e.* the Néel vector is limited to studies of anisotropic magnetoresistance or X-ray magnetic linear dichroism. Here, we report on the in-plane reflectivity anisotropy of Mn_2Au (001) films, which were Néel vector aligned in pulsed magnetic field. In the near-infrared, the anisotropy is $\approx 0.6\%$, with higher reflectivity for the light polarized along the Néel vector. The observed magnetic linear dichroism is about four times larger than the anisotropic magnetoresistance, suggesting the dichroism in Mn_2Au is a result of the strong spin-orbit interactions giving rise to anisotropy of interband optical transitions, in-line with recent studies of electronic band-structure. The considerable magnetic linear dichroism in the near-infrared could be used for ultrafast optical read-out of the Néel vector in Mn_2Au.

MA 19: PhD Focus Session: Symposium on "Magnetism - A Potential Platform for Big Data?" (joint session MA/O/AKjDPG)

As pointed out in a recent Nature editorial article titled "Big data needs a hardware revolution", new technologies and hardware architectures are necessary in order to cope with the ever increasing amount of information. Google's AlphaGo's success apprised of the potential of parallel computing, yet energy efficiency remained as a major challenge. Hardware developers came up with mimicking the human brain as the most efficient processor, leading to the field of neuromorphic computing. An immense amount of research is deployed in different fields to screen for fast, low energy consuming and scalable solutions. In this focus session we elucidate on the potential role of magnetism in the development of non-Von Neumann hardware platforms to fulfill the current needs of AI and Big Data. An introduction to neuromorphic computing is followed by implementations of magnetic devices for processing and data storage in the information age. We finalise with a panel conversation with the speakers, where we aim to discuss the potential of magnetic-based devices in helping solve current challenges in the field of brain-inspired computing.

Organizers: Mauricio Bejarano and Tobias Hula (Helmholtz-Zentrum Dresden Rossendorf), Luis Flacke (Walther-Meissner Institute and TU Munich)

Time: Friday 13:30–16:30 Location: H5

Invited Talk MA 19.1 Fri 13:30 H5

"Neuromorphic Computing": A Productive Contradiction in Terms — •Herbert Jaeger — Rijksuniversiteit Groningen (NL) Faculty of Science and Engineering - CogniGron

The term "computing" has a specific, firm, powerful, traditional meaning – condensed in the paradigm of Turing computability (TC). A core aspect of TC is the perfectly reliable composition of perfectly identifiable symbolic tokens into complex, hierarchical symbolic structures. But all which is novel and promising and original in "neuromorphic" information processing leads away from such perfect symbolic compositionality. Apparently new formal conceptions of "computing" would be most welcome (and a new term for it, too). In my talk I will carve out a number of concrete aspects that separate neuromorphic information processing from symbolic computing - some of them being classical topics in the philosophy of AI, others having more recently emerged from technological progress in non-digital hardware.

Invited Talk MA 19.2 Fri 14:00 H5

Neuromorphic computing with radiofrequency spintronic devices — •Alice Mizrahi[1], Nathan Leroux[1], Danijela Markovic[1], Dedalo Sanz Hernandez[1], Juan Trastoy[1], Paolo Bortolotti[1], Leandro Martins[2], Alex Jenkins[2], Ricardo Ferreira[2], and Julie Grollier[1] — [1]Unité Mixte de Physique CNRS, Thales, Université Paris-Saclay, 91767 Palaiseau, France — [2]International Iberian Nanotechnology Laboratory (INL), 4715-31 Braga, Portugal

The need for energy efficient artificial intelligence has motivated research on the implementation of neural networks in hardware, using emerging technology. In particular, spintronic nano-oscillators have emerged as promising candidates to emulate neurons due to their non-linear behavior. However, in order to scale such systems to deep neural network capable of performing state of the art artificial intelligence tasks, it is necessary to have physical synapses – which weights can be tuned –connecting the neurons. Here we propose a scalable architecture for neural networks using spintronic RF oscillators as neurons and spintronic RF resonators as synapses. First, we show how individual spintronic resonators, and in particular magnetic tunnel junctions, can multiply RF signals by a tunable weight, thus emulating synapses. Then, we show how to assemble these devices into chains performing the multiply and accumulate function, which is at the core of neural network. Finally, we show how to assemble a full neural network and perform classification tasks. These results open the path for compact and energy efficient deep neural networks.

10 min. break.

Invited Talk MA 19.3 Fri 14:40 H5
Data Storage and Processing in the Cognitive Era — •Giovanni Cherubini — IBM Research - Zurich

In this talk, I will present the emerging vision of cognitive data systems. A data system comprises physical devices that provide means to acquire, store and modify data for analytics and communications tasks, with the goal of obtaining high-value information. With the need to deal with exponentially growing amounts of data, however, the system size and complexity present major challenges for data storage and processing. In addition, with the approaching end of Moore's law, there is a dire need to significantly improve the energy efficiency of data systems. To address these challenges, cognitive data systems will require novel learning algorithms and computing paradigms. The talk will be divided into two parts, focusing on data storage and processing aspects. First, I will present advanced technologies for big data storage systems, with focus on magnetic tape drives of future generations, targeting areal densities of several hundred gigabits per square inch on a flexible medium. Next, I will introduce novel in-memory computing techniques and devices that are based on non-von Neumann architectures and aim at achieving the efficiency of the human brain.

Invited Talk MA 19.4 Fri 15:10 H5
Brain-inspired approaches and ultrafast magnetism for Green ICT — •Theo Rasing — Radboud University, Institute for Molecules and Materials, Heijendaalseweg 135, 6525AJ Nijmegen, the Netherlands

The explosive growth of digital data use and storage has led to an enormous rise in global energy consumption of Information and Communication Technology (ICT), which already stands at 7% of the world electricity consumption. New ICT technologies, such as Artificial Intelligence push this exponentially increasing energy requirement even more, though the underlying hardware paradigm is utterly inefficient: tasks like pattern recognition can be performed by the human brain with only 20W, while conventional (super)computers require 10 MW. Therefore, the development of radically new physical principles that combine energy-efficiency with high speeds and high densities is crucial for a sustainable future. One of those is the use of non-thermodynamic routes that promises orders of magnitude faster and more energy efficient manipulation of bits. Another one is neuromorphic computing, that is inspired by the notion that our brain uses a million times less energy than a supercomputer while, at least for some tasks, it even outperforms the latter. In this talk, I will discuss the state of the art in ultrafast manipulation of magnetic bits and present some first results to implement brain-inspired computing concepts in magnetic materials that operate close to these ultimate limits.

10 min. break.

Discussion MA 19.5 Fri 15:50 H5
Panel discussion PhD Focus Session — •Tobias Hula[1], Mauricio Bejarano[1], and Luis Flacke[2] — [1]Helmholtz-Zentrum Dresden Rossendorf — [2]Walther-Meissner Institute and TU Munich

Panel discussion for PhD Focus Session:"Magnetism - A Potential Platform for Big Data?"