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, Forschungszen-

trum 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], Adrià 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.

This work is funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - TRR 270, B06 and Russian Science Foundation (RSF) No. 17-72-20022.

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 $5{\times}10^{13}$ 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 $5{\times}10^{12}$ 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* ↑ and *down* ↓ 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 ∼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 ~ 5 x 10^{15}ions/cm^2 leads to an increase of M_s to ~ 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.

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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.

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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.

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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 $T_N = 30$K. 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.

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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.

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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 $[\text{Co (0.44 nm)/Pt (0.7 nm)}]_X$ (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.