MA 11: Functional Antiferromagnetism

Time: Monday 15:00–18:45 Location: EB 202

MA 11.1 Mon 15:00 EB 202

Anisotropic magneto-transport properties in a short period helical magnet — •Ryota Nakano[1], Rinsuke Yamada[1], Sebastian Esser[1], Masaki Gen[2], Akiko Kikkawa[2], Yasujiro Taguchi[2], Maurice Colling[3], Jan Masell[2,3], Masashi Tokunaga[2,4], Hajime Sagayama[5], Hiroyuki Ohsumi[6], Yoshikazu Tanaka[6], Takahisa Arima[2,7], Yoshinori Tokura[1,2,8], and Max Hirschberger[1,2] — [1]Dep. of Applied Physics, University of Tokyo, Japan — [2]RIKEN CEMS, Japan — [3]Inst. of Theoretical Solid State Physics, Karlsruhe Institute of Technology, Germany — [4]ISSP, University of Tokyo, Japan — [5]Inst. of Materials Structure Science, KEK, Japan — [6]RIKEN SPring8, Japan — [7]Dep. of Advanced Materials Science, University of Tokyo, Japan — [8]Tokyo College, University of Tokyo, Japan

Antiferromagnetic materials have recently attracted considerable attention due to their potential in future spintronic applications thanks to numerous characteristic features: they are robust against external magnetic field, produce no stray field, and display ultrafast dynamics. Anisotropic magnetoresistance (AMR) effect is one way to electrically read out spin textures of antiferromagnets. However, AMR has been so far studied mainly on collinear magnets and its amplitude tends to be small. In this presentation, we will show that partial Fermi surface gapping through Ruderman-Kittel-Kasuya-Yosida (RKKY) interactions can enlarge AMR in a short period helical magnet and show some experimental results of a rare-earth-based target material.

MA 11.2 Mon 15:15 EB 202

Exchange spin-orbit coupling and unconventional p-wave magnetism — •Anna Birk Hellenes[1], Tomáš Jungwirth[2,3], Jairo Sinova[1,2], and Libor Šmejkal[1,2] — [1]JGU Mainz — [2]FZU Prague — [3]University of Nottingham

Relativistic spin-orbit coupling is a cornerstone in fundamental and applied research, governing phenomena such as spin Hall effects and topological insulators. The mechanism arises from the Dirac equation in non-centrosymmetric crystals and is typically confined to meV scales unless introducing heavy elements. In this work, we unveil a previously overlooked mechanism based on a magnetic analog of p-wave He-3 superfluidity that does not require heavy elements. Our mechanism shares the characteristic signature of spin-orbit coupling with the Dirac approach – namely, antisymmetric, p-wave, time-reversal-invariant spin polarization in the band structure. Unlike the relativistic Dirac equation, our spin-orbit coupling emerges from the magnetic exchange interaction in non-centrosymmetric crystals exhibiting a non-collinear spin order. We predict giant spin splitting magnitudes on the order of hundreds of meV in a realistic material candidate, namely antiperovskite Ce_3InN. Our findings open avenues for giant exchange spin-orbit coupling phenomena in materials comprising abundant light elements, with implications ranging from spintronics and nanoelectronics to topological matter [1].

[1]: Hellenes, Jungwirth, Sinova, and Šmejkal, arXiv:2309.01607.

MA 11.3 Mon 15:30 EB 202

Non-Volatile Spin-Orbit Torque Driven Antiferromagnetic Memristor — •Joao Godinho[1], Pradeep Rout[1], Ruslan Salikhov[2], Olav Hellwig[2,3], Zbynek Soban[4], Ruben Otxoa[5], Kamil Olejnik[4], Tomas Jungwirth[4,6], and Joerg Wunderlich[1,4] — [1]University of Regensburg, Regensburg, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [3]Institute of Physics, Chemnitz University of Technology, Chemnitz, Germany — [4]Institute of Physics, ASCR, Prague, Czech Republic — [5]Hitachi Cambridge Labyoratory, Cambridge, United Kingdom — [6]School of Physics and Astronomy, University of Nottingham, United Kingdom

Magnetic data storage is based on the switching and detection of energetically degenerate ferromagnetic ground states with reversed magnetization separated by a sufficiently high energy barrier to maintain the long-term non-volatility of the stored data. Therefore, exploiting the many advantages of zero net moment antiferromagnets (AFM) for fast and energy-efficient magnetic storage will also rely on the realization of switching and detecting stable AFM states with reversed magnetic order. Here we show switching between non-volatile states with opposite Néel vector detections in a compensated out-of-plane synthetic AFM. The manipulation of the AFM order is achieved by generating relativistic effective spin-orbit fields and its detection via higher-order magneto-transport responses. Furthermore, besides the storing of binary "0" or "1" corresponding to two fully polarized magnetic states with reversed Néel vectors, we also show that partial switching enables the realization of non-volatile memristor type of devices.

MA 11.4 Mon 15:45 EB 202

Impact of growth conditions on magnetic anisotropy and magnon Hanle effect in α-Fe_2O_3 — •Monika Scheufele[1,2], Janine Gückelhorn[1,2], Matthias Opel[1], Akashdeep Kamra[3], Hans Huebl[1,2,4], Rudolf Gross[1,2,4], Stephan Geprägs[1], and Matthias Althammer[1,2] — [1]Walther-Meißner-Institut, BAdW, Garching, Germany — [2]TUM School of Natural Sciences, Physics Department, TUM, Garching, Germany — [3]IFIMAC and Departamento de Física Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Madrid, Spain — [4]Munich Center for Quantum Science and Technology, Munich, Germany

The antiferromagnetic insulator α-Fe_2O_3 exhibits a spin-reorientation transition (Morin transition) at $T_M = 263\,K$ – a feature often absent in thin films. To tune T_M, we investigate the impact of different growth conditions on the magnetic anisotropy in α-Fe_2O_3 films [1]. Unlike for films deposited in a molecular oxygen atmosphere, we observe a finite T_M for those grown in atomic oxygen even down to a thickness of 19 nm. Furthermore, we observe a clear impact of the growth conditions on the magnon Hanle effect, i.e. the precession of magnon pseudospin around its equilibrium pseudofield in easy-plane antiferromagnets. The maximum magnon Hanle signal is significantly enhanced and the peak position shifted to lower magnetic field values for films grown in atomic oxygen, suggesting changes in the magnetic anisotropy. This shows that the growth conditions allow to fine-tune the magnetic anisotropy in α-Fe_2O_3 and thereby to engineer the magnon Hanle effect.

[1] M. Scheufele *et al.*, APL Mater. **11**, 091115 (2023).

MA 11.5 Mon 16:00 EB 202

Hexagonal MnTe with Antiferromagnetic Spin Splitting and Hidden Rashba-Dresselhaus Interaction for Antiferromagnetic Spintronics — Suman Rooj, Jayita Chakraborty, Abhijeet Kumar, and •Nirmal Ganguli — Department of Physics, Indian Institute of Science Education and Research Bhopal, Bhauri, Bhopal 462066, India

Hexagonal MnTe emerges as a critical component in designing magnetic quantum heterostructures, calling for a detailed study. After finding a suitable combination of exchange-correlation functional and corrections, our study within *ab initio* density functional theory uncovers an insulating state with a preferred antiferromagnetic order. We compute the exchange interaction strengths to estimate the antiferromagnetic ordering temperature via Monte Carlo calculations. Our calculations and symmetry analysis reveal a large spin splitting in the system due to the antiferromagnetic order without considering spin-orbit interaction, except in the k_x-k_y plane. Critically examining the band dispersion and spin textures obtained from our calculations and comparing them with an insightful symmetry analysis and analytical model, we confirm a combined Rashba-Dresselhaus interaction in the k_x-k_y plane, around the K point of the system. Our results and insights would help design heterostructures of MnTe for technological applications.

https://doi.org/10.1002/apxr.202300050

MA 11.6 Mon 16:15 EB 202

Magnetization Dynamics in α-Fe_2O_3/NiFe Thin Film Bilayers — •Hassan Al-Hamdo[1], Tobias Wagner[2], Philipp Schwenke[1], Gutenberg Kendzo[1], Misbah Yaqoob[1], Maximilian Dausend[1], Laura Scheuer[1], Tamara Azevedo[1], Vitaliy I. Vasyuchka[1], Philipp Pirro[1], Olena Gomonay[2], and Mathias Weiler[1] — [1]Fachbereich Physik and Landesforschungszentrum OPTIMAS, RPTU Kaiserslautern-Landau, 67663 Kaiserslautern, Germany — [2]Institute of Physics, JGU Mainz, 55099 Mainz, Germany

We experimentally investigate the magnetization dynamics in exchange-coupled bilayers of α-Fe_2O_3/$Ni_{80}Fe_{20}$ (Py). α-Fe_2O_3 is a canted antiferromagnet with small magnetic moment along the c-axis above the Morin temperature $T_M \approx 260$ K. Below T_M, α-Fe_2O_3 is a collinear antiferromagnet with Néel vector along the c-axis [1-3]. We deposit polycrystalline 10-nm Py thin films on α-Fe_2O_3 crystals and measure the bilayer magnetization dynamics as a function of temperature using broadband ferromagnetic resonance. We observe that the coupling of dynamic α-Fe_2O_3 and Py moments depends on both: temperature and crystalline orientation of α-Fe_2O_3, resulting in qualitatively different dynamics than previously observed by us in Mn_2Au/Py [4].

[1] D. Schroeer *et al*, Phys. Rev. Lett. **19**, 632 (1967).
[2] G. Haigh *et al*, Philos. Mag. **2**, 877-890 (1957).
[3] G. Rollmann *et al*, Phys. Rev. **B 69**, 165107 (2004).
[4] H. Al-Hamdo *et al*, Phys. Rev. Lett. **131**, 046701 (2023).

MA 11.7 Mon 16:30 EB 202

Revealing the higher-order spin nature of the Hall effect in non-collinear antiferromagnet Mn3Ni0.35Cu0.65N — •Adithya Rajan[1], Tom G. Saunderson[1], Fabian R. Lux[1], Dongwook Go[2], Hasan M. Abdullah[3], Arnab Bose[1], Udo Schingenschögl[3], Aurélien Manchon[4], Yuriy Mokrousov[1,2], and Mathias Kläui[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany — [2]Peter Grünberg Institut and Institute for Advanced Simulation, Forschungszentrum Jülich, 52424 Jülich, Germany — [3]King Abdullah University of Science and Technology (KAUST), Thuwal 23955-6900, Saudi Arabia — [4]CINaM, Aix-Marseille Université, CNRS, Marseille, France

We reveal [1] the complex origin of the anomalous Hall effect arising in noncollinear antiferromagnets by performing Hall measurements with fields applied in selected crystalline directions. Our coplanar magnetic field geometry goes beyond the conventional perpendicular field geometry used for ferromagnets and allows us to suppress any magnetic dipole contribution. We map the in-plane anomalous Hall contribution and demonstrate a 120 ° symmetry governed by the octupole moment at high fields. At low fields we subsequently discover a surprising topological Hall-like signature, and, from a combination of theoretical techniques, we show that the spins can be recast into dipole, emergent octupole and noncoplanar effective magnetic moments. These coexisting orders enable magnetization dynamics unachievable in either ferromagnetic or conventional collinear antiferromagnetic materials.

[1] A. Rajan, et al., arXiv:2304:10747 (2023)

15 min. break

MA 11.8 Mon 17:00 EB 202

Electronic structure of epitaxial $CuFeS_2$ thin films — •Anders Christian Mathisen, Richard Justin Schenk, Stefanie Suzanne Brinkman, Xin Liang Tan, Matthias Hartl, Christoph Brüne, and Hendrik Bentmann — Center for Quantum Spintronics, Department of Physics, NTNU Trondheim, Norway

Chalcopyrite, $CuFeS_2$, has over the years seen interest in many areas, often due to its thermoelectric properties, and as a source of copper. More recently, the material has gained attention as an antiferromagnetic semiconductor with a high Néel temperature (T_N = 823 K). $CuFeS_2$ is a collinear antiferromagnet with alternating spin-polarized planes along the *c*-direction of the body-centered tetragonal unit cell (space group $I\bar{4}2d$, No. 122). This is especially useful in the field of ultra-fast electronics, where the high-frequency spin dynamics and robustness against external magnetic fields plays an essential role. We present epitaxial growth of $CuFeS_2$ thin films on Si(001) substrates using molecular beam epitaxy (MBE). We probed the electronic structure of these films using laboratory-based photoelectron momentum microscopy and soft X-ray angle-resolved photoemission spectroscopy (ARPES). We compare the experimental findings to the results of *ab initio* calculations based on density functional theory. Our results promote $CuFeS_2$ thin films as a candidate for device concepts in antiferromagnetic spintronics.

MA 11.9 Mon 17:15 EB 202

The impact of local exchange coupling on spin-Hall effects measurements in non-collinear antiferromagnets — •Rouven Dreyer[1], James M. Taylor[1], Piet Urban[1], Binoy K. Hazra[2], Stuart S. P. Parkin[2], and Georg Woltersdorf[1,2] — [1]Institute of Physics, Martin Luther University Halle-Wittenberg, 06120 Halle, Germany — [2]Max Planck Institute for Microstructure Physics, 06120 Halle, Germany

Non-collinear antiferromagnets (AFs) have been found to serve as an efficient source of intrinsic spin Hall effect (SHE) relevant for spintronic devices. However, the role of their chiral domain structure, and the transmission of the resulting spin current across interfaces with ferromagnets (FMs), remain open questions. Using a combination of electrically-detected spin-torque ferromagnetic resonance (ST-FMR) and optically-detected super-Nyquist-sampling magneto-optical Kerr effect (SNS-MOKE) measurements, we investigate the SHE generated by the non-collinear spin texture of Mn_3Ir in heterostructures with $Ni_{80}Fe_{20}F$. The enhanced damping due to interfacial exchange coupling between the AF and FM complicates extraction of the spin Hall angle (SHA) using ST-FMR. In contrast, SNS-MOKE studies allow for a local detection of the SHA, and reveal modifications of the coupling-induced anisotropy upon exposure to a combination of DC and RF currents. These findings open a path to quantify the SHE generated by an AF more accurately. Moreover, we demonstrate an efficient control mechanism for setting the exchange bias by exposing the AF to a combination of small bias fields and current induced heating.

MA 11.10 Mon 17:30 EB 202

Cubic Mn_3Ge thin films stabilized through epitaxial growth as a candidate noncollinear antiferromagnet — •James M Taylor[1], Anastasios Markou[2], Jacob Gayles[2], Yan Sun[2], Dominik Kriegner[2], Walter Schnelle[2], Peter Werner[1], Claudia Felser[2], and Stuart S P Parkin[1] — [1]Max Planck Institute of Microstructure Physics, Halle — [2]Max Planck Institute for Chemical Physics of Solids, Dresden

Metallic antiferromagnets with chiral spin textures induce Berry-curvature-driven anomalous and spin Hall effects that arise from topological bandstructure features. Here we use epitaxial engineering to stabilize thin films of Mn_3Ge with a cubic phase. This cubic phase is distinct from tetragonal ferrimagnetic and hexagonal noncollinear antiferromagnetic structures with the same chemical composition. First-principle calculations indicate that cubic Mn_3Ge will preferentially form an all-in/all-out triangular spin texture. We present evidence for this noncollinear antiferromagnetism through magnetization and magnetotransport measurements, finding a Néel temperature of 490 K. Simulation of the resulting bandstructure suggests the presence of Berry-curvature-generating features. These highlight cubic Mn_3Ge as a candidate material for topological antiferromagnetic spintronics.

MA 11.11 Mon 17:45 EB 202

Anisotropic magnetotransport enabled by low symmetry doped Hematite. — •Edgar Galindez-Ruales[1], Libor Šmejkal[1,2], Jairo Sinova[1,2], Gerhard Jakob[1], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg University Mainz, Staudingerweg 7, 55128 Mainz, Germany. — [2]Institute of Physics, Academy of Sciences of the Czech Republic, Czech Republic.

This study investigates the origin of anisotropic magnetotransport in doped hematite. Experimental evidence demonstrates hematite's unconventional nature, challenging traditional magnetic paradigms and revealing distinct transport behaviors linked to altermagnetism. Doped hematite exhibits transverse voltage phenomena, coinciding with the spin-flop transition and featuring both odd and even components with strong crystal orientation dependencies. Advanced transport measurements reveal robust Hall conductivity contributions, deviating from expected symmetries in conventional antiferromagnets, suggesting the presence of altermagnetism [1]. Notably, a significant sign inversion in the Hall effect at a 45-degree orientation contradicts anticipated symmetries, highlighting the role of altermagnetic properties [2]. These findings elucidate the link between altermagnetism and crystal-direction-dependent transport, holding promising implications for spintronics. This study presents conclusive evidence supporting altermagnetic symmetries as a contributing mechanism shaping crystal-dependent magnetotransport in hematite. [1] L. Šmejkal et al., PRX 12, 040501 (2022). [2] E. Galindez-Ruales et al., ArXiv:2310.16907 (2023).

MA 11.12 Mon 18:00 EB 202

Surface-symmetry-driven phenomena in magnetoelectric Cr_2O_3 — •Oleksandr V. Pylypovskyi[1,2], Sophie F. Weber[3], Pavlo Makushko[1], Igor Veremchuk[1], Nicola A. Spaldin[3], and Denys Makarov[1] — [1]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany — [2]Kyiv Academic University, 03142 Kyiv, Ukraine — [3]Materials Theory, ETH Zürich, Wolfgang-Pauli-Strasse 27, 8093 Zürich, Switzerland

Antiferromagnetic (AFM) Cr_2O_3 is a unique collinear magnetoelectric material at room temperature. The bulk properties stemming from its magnetic symmetry render chromia of high interest for fundamentals and applications [1]. Features of the chromia surface remain much less explored. Here, we consider nominally compensated surfaces (m and a planes) of Cr_2O_3 [2]. We show that they provide a sizeable Dzyaloshinskii–Moriya interaction (DMI) determined by the surface magnetic symmetry point group and quantify it to be about $1\,\mathrm{mJ/m^2}$ by means of *ab initio* and micromagnetic approaches. The DMI leads to the development of nonzero surface magnetization $\vec{M}$ whose sign is uniquely determined by the AFM state. The m and a planes of Cr_2O_3 behave as the canted ferrimagnet and canted 4-sublattice antiferromagnet, respectively. The coupling of $\vec{M}$ to the direction of the Néel vector is shown by magnetotransport measurements.

[1] P. Makushko et al., Nat. Comm. 13, 6745 (2022). [2] O.V. Pylypovskyi, S. F. Weber et al., ArXiv:2310.13438 (2023).

MA 11.13 Mon 18:15 EB 202

Bi-directional current-induced switching of insulating antiferromagnetic thin films — •Christin Schmitt[1], Adithya Rajan[1], Grischa Beneke[1], Aditya Kumar[1], Tobias Sparmann[1], Hendrik Meer[1], Beatrice Bednarz[1], Rafael Ramos[2], Miguel Angel Niño[3], Michael Foerster[3], Eiji Saitoh[2], and Mathias Kläui[1] — [1]Institute of Physics, Johannes Gutenberg-University Mainz, Germany — [2]Department of Applied Physics, The University of Tokyo, Japan — [3]ALBA Synchrotron Light Facility, Spain

Antiferromagnets (AFMs) have gained interest as active elements in spintronic devices due to intrinsic dynamics in the THz range and the absence of stray fields. Efficient electrical writing and reading is necessary in terms of applications but challenging to realize. For insulating AFMs different switching mechanisms based on spin-orbit torques (SOTs) or thermomagnetoelastic effects have been put forward [1,2]. Here, we focus on ultrathin CoO/Pt films, where SOTs should be particularly pronounced. We observe that electrical pulses along the same path can lead to an increase or decrease of the electrical readout-signal, depending on the current density of the pulse. By photoemission electron microscopy (PEEM) employing the x-ray magnetic linear dichroism (XMLD) effect we shed light on this observation and determine for which situations this is a sign of two competing switching mechanisms or a result of the way the electrical measurement is conducted [3]. [1] T. Moriyama, et al., Sci. Rep. 8, 14167 (2018). [2] P. Zhang, et al., Phys. Rev. Lett. 123, 247206 (2019). [3] C.Schmitt, et al., arXiv:2303.13308.

MA 11.14 Mon 18:30 EB 202

Mechanisms of current driven Néel vector reorientation in $\mathbf{Mn_2Au}$ — •Guzmán Orero Gámez[1], Sonka Reimers[1], Lukas Odenbreit[1], Yuran Niu[2], Evangelos Golias[2], Mathias Kläui[1], and Martin Jourdan[1] — [1]Institut für Physik, Johannes Gutenberg-Universität, Staudinger Weg 7, 55128, Mainz, Germany — [2]MAX IV Laboratory, Lund, Sweden

Current pulse driven Néel vector reorientation in metallic antiferromagnets (AFM) is one of the most promising concepts in antiferromagnetic spintronics. We have shown that such reorientation can be achieved in the metallic antiferromagnet Mn_2Au through two distinct mechanisms [Rei2023]. The first mechanism is the bulk Neél spin orbit torque, which originates from the unusual crystal structure of Mn_2Au in conjunction with strong spin-orbit coupling. The second mechanism originates from magnetoelastic coupling associated with current driven heating effects. In order to separate these two mechanisms experimentally, we use different geometries to alter the current path, thus changing the strain pattern. Additionally, we modify the pulse duration to reduce the heating. We show that both effects are present with the thermomagnetoelastic being dominant for longer pulse lengths. We use XMLD-PEEM with in-situ current pulsing together with AMR measurements to probe the reorientation of the Néel vector.

[Rei2023] *Reimers, S., et al. Current-driven writing process in antiferromagnetic Mn_2Au for memory applications. Nat. Commun.* ***14****, 1861 (2023).*