Programme for

the 1st Symposium on

"Research Network on Spintronic Materials and Devices for the Sustainable Society (SpinMaD)"

27-28 November 2025

Seminar Rooms 1&2 at Max Planck Institute for Chemical Physics of Solids

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Thursday, 27 November

08:30 Registration

09:00-09:10 Opening remark (Claudia Felser)

09:10-11:10 Session 1: Spintronics × topology

Chair: Atsufumi Hirohata (*Tohoku Univ.*)

3 invited talks (30 min.) + 2 contributed talks (15 min.)

09:10-09:40 Claudia Felser (*Max Planck Inst. for Chem. Phys. of Solids*)
"Chirality and topology"

09:40-10:10 Le Duc Anh (*Univ. of Tokyo*)
"Epitaxial growth and topological transport properties of Sn-based quantum heterostructures"

10:10-10:25 Rikako Yamamoto (*Max Planck Inst. for Chem. Phys. of Solids*)
"Spectromicroscopic insights into bulk altermagnetism in α-MnTe"

10:25-10:40 Masayuki Ishida (*Univ. of Tokyo*)
"Highly efficient spin-charge conversion in ferromagnetic metal Fe / topological Dirac semimetal α-Sn heterostructures"

10:40-11:10 Bryan Hickey (*Univ. of Leeds*)
"Giant Rashba effect in topological surfaces states with metal overlayers"

11:10-11:30 Coffee/Tea

11:30-12:45 Session 2: Spintronics × Characterisation & Fabrication

Chair: Bryan Hickey (*Univ. of Leeds*)

2 invited talk (30 min.) + 1 contributed talk (15 min.)

11:30-12:00 Rudi Schäfer (*IFW Dresden*)
"Magneto-optics, revisited"

12:00-12:30 Atsufumi Hirohata (*Tohoku Univ.*)
"Control of a compensation temperature in a ferrimagnetic Heusler alloy"

12:30-12:45 Olha Bezsmertna (*Helmholtz-Zentrum Dresden-Rossendorf*)
"Transfer of magnetic nanomembranes: from fundamental curvilinear nanomagnetism to flexible electronic applications"

12:50-13:00 Symposium photo (main entrance of the Institute)

13:00-14:00 Lunch (canteen)

14:00-15:30 Session 3: Spin × Energy

Chair: Hiroki Koizumi (*Tohoku Univ.*)

2 invited talks (30 min.) + 2 contributed talks (15 min.)

14:00-14:30 Julius Hohlfeld (*Inst. Jean Lamour*)

"Spin and heat accumulation induced magnetization reversal (SAAHIR)"

14:30-14:45 Shutaro Karube (*Kyoto Univ.*)

"Observation of anisotropic orbital Hall effect"

14:45-15:00 Heda Zhang (*Max Planck Inst. for Chem. Phys. of Solids*)

"Magnetoelectric coupling effect in a non-centrosymmetric superconductor"

15:00-15:30 Masaki Mizuguchi (*Nagoya Univ.*)

"Spin caloritronic materials and devices"

15:30-17:00 Poster Session (foyer)

01 Cheng Xu (*Max Planck Inst. for Chem. Phys. of Solids*), "Chiral superconductivity from spin polarized Chern band in twisted $MoTe_2$"

02 Yuki Higuchi (*Univ. of Osaka*), "Determination of the actual valence band of a topological insulator Bi_2Se_3"

03 Erjian Cheng (*Max Planck Inst. for Chem. Phys. of Solids*), "Interwoven magnetic kagome metal overcoming geometric frustration"

04 Gen Zu (*Max Planck Inst. for Chem. Phys. of Solids*), "Interpretation of crystal energy landscapes with Kolmogorov–Arnold networks"

05 Yuchen Zhao (*Max Planck Inst. for Chem. Phys. of Solids*), "Scanning magnetometry of van der Waals magnets under *in-situ* controlled strain"

06 Zaizhou Jin (*Tohoku Univ.*), "Low Gilbert damping of the frustrated kagome semimetal Fe_3Sn_2"

07 Esita Pandey (*Max Planck Inst. for Chem. Phys. of Solids*), "Realization of broadly tunable compensation in ferrimagnetic MnFeVAl Heusler alloy"

08 Shogo Yamashita (*Max Planck Inst. for Chem. Phys. of Solids*), "Magnetic and transport properties of compensated ferrimagnetic Heusler alloys at finite-temperatures: *ab initio* spin fluctuation theory"

09 Hiroki Koizumi (*Tohoku Univ.*), "*d*-wave altermagnetism in epitaxial $NiCo_2O_4$ thin films via easy-cone magnetic anisotropy"

10 Paulina Justyna Prusik (*Helmholtz-Zentrum Dresden-Rossendorf*), "Domain walls in a magnetoelectric Cr_2O_3"

11 Nikolai Peschcherenko (*Max Planck Inst. for Chem. Phys. of Solids*), "Transport sensing of spin fluctuations: non-saturating resistance and giant negative magnetoresistance"

12 Hayato Nakayama (*Keio Univ.*), "Evaluation of spin-current generation in Si-Al nanoalloy films"

13 Shingen Miura (*Univ. of Tokyo*), “Epitaxial growth and characterization of superconducting Sn/InSb heterostructure on GaAs substrates”

14 Lin Guo (*Helmholtz-Zentrum Dresden-Rossendorf*), “Eco-sustainable printed magnetoresistive sensors”

15 Guannan Mu (*Helmholtz-Zentrum Dresden-Rossendorf*), “Flexible and printed spintronic magnetic field sensors”

17:00-21:00 Visit to the Christmas Market (optional)

Friday, 28 November

09:15-11:00 Session 5: Spintronic Devices

Chair: Masaki Mizuguchi (*Nagoya Univ.*)

3 invited talks (30 min.) + 1 contributed talks (15 min.)

09:15-09:45 Christopher Marrows (*Univ. of Leeds*)

"Temperature gradient-driven motion of magnetic domains in a magnetic metal multilayer by entropic forces"

09:45-10:15 Giovanni Finocchio (*Univ. of Messina*)

"Unconventional computing with spintronic devices"

10:15-10:30 Edouard Lesne (*Max Planck Inst. for Chem. Phys. of Solids*)

"Spin-to-charge conversion in epitaxial $Mn_3Sn(0001)$ noncollinear antiferromagnetic films"

10:30-11:00 Benjamin Uhlig (*Fraunhofer Inst. for Photon. Microsys.*)

"From novel concepts to reliable devices, research on spintronics in a modern CMOS cleanroom"

11:00-11:20 Coffee/Tea

11:20-12:50 Session 6: Spintronic Materials

Chair: Giovanni Finocchio (*Univ. of Messina*)

3 invited talks (30 min.)

11:20-11:50 Stuart Parkin (*Max Planck Inst. for Microstr.*)

"2D and 3D racetrack memory"

11:50-12:20 Thomas Thomson (*Univ. of Manchester*)

"Spin transport and spin-charge interconversion in graphene and TMDs"

12:20-12:50 Libor Šmejkal (*Max Planck Inst. for Phys. of Complex Sys.*)

"Altermagnetic spintronics and multiferroics"

13:00-14:00 Lunch (canteen)

13:40-14:00 Laboratory Tour upon request (contact Edouard Lesne)

14:00-14:45 Session 7: Spintronics × Dimensions

Chair: Tom Thomson (Univ. of Manchester)

1 invited talk (30 min.) + 1 contributed talk (15 min.)

14:00-14:30 Kazuyuki Sakamoto (*Univ. of Osaka*)

"Spin-polarized bands of atomic layer superconductors"

14:30-14:45 Ning Mao (*Max Planck Inst. for Chem. Phys. of Solids*)

"Spin diffusion probe of magnetization frustration"

14:45-15:05 Coffee/Tea

15:05-16:20 Session 8: Magnonics

Chair: Kazuyuki Sakamoto (*Univ. of Osaka*)

2 invited talks (30 min.) + 1 contributed talk (15 min.)

15:05-15:35 Mathias Weiler (*Rheinland-Pfälzische Tech. Univ. Kaiserslautern-Landau*)

"Magnetoacoustics and magnon-polarons in surface acoustic wave devices"

15:35-15:50 Kazuto Yamanoi (*Keio Univ.*)

"Magnon-phonon coupling using the multi-overtones surface acoustic wave device"

15:50-16:20 Helmut Schultheiss (*Helmholtz-Zentrum Dresden-Rossendorf*)

"How a nano-core shatters the collective of an entire vortex"

16:20-16:30 Closing remark

18:00-20:30 Symposium dinner

Restaurant Anna im Schloss (Taschenberg 2, 01067 Dresden)

https://www.anna-dresden.de/en

1-1

Chirality and Topology

Claudia Felser

Chirality—the property of an object being distinguishable from its mirror image—emerges as a unifying principle across physics, chemistry, and materials science. In quantum materials, chirality couples real-space geometry with electronic topology, enabling control over charge, spin, and orbital degrees of freedom. Our research explores how chiral crystal structures and topological band crossings intertwine to produce exotic transport and magnetic phenomena. Berry curvature acts as a bridge between structural and electronic chirality, linking lattice symmetries to spin and orbital textures, while chiral phonons and magnetic order enable the transfer of handedness across multiple quasiparticle sectors. These effects open pathways for manipulating currents and reaction selectivity through symmetry engineering. Recently, chiral topological semimetals such as PdGa have demonstrated how quantum geometry can separate charge carriers by chirality, giving rise to non-linear Hall effects and current-induced orbital magnetization even without external magnetic fields. Extending this concept to non-collinear antiferromagnets like Mn_3Sn and Mn_3Ge, where spin chirality replaces structural handedness, connects chirality to the core of spintronic functionality. In these systems, the interplay of Berry curvature, chiral spin textures, and topological band structure enables dissipationless spin transport and field-tunable spin–charge conversion. Together, these findings establish chirality—not only as a geometric property but as an active quantum degree of freedom—for designing next-generation topological and spintronic materials.

Epitaxial growth and topological transport properties of Sn-based quantum heterostructures

Le Duc Anh[1,2,*], Masaaki Tanaka[1,2]
[1]*Dept. of Electrical Engineering and Information Systems, The University of Tokyo, Japan*
[2]*Center for Spintronics Research Network (CSRN), The University of Tokyo, Japan.*
*anh@cryst.t.u-tokyo.ac.jp

Among many topological materials, α-Sn stands out as a unique and promising candidate: It is the only elemental material that shows multiple topological phases, such as topological Dirac semimetal (TDS) and topological insulator (TI), which can be controlled by various means such as strain, thickness, or applying electric field (Fig. 1a) [1]. Furthermore, α-Sn is known to undergo a phase transition to a superconducting β-Sn phase upon heating. In this work, we utilize this ability to fabricate and study the topological transport of Sn-based quantum structures. We grow single-crystalline α-Sn thin films on InSb (001) substrates (Fig. 1b) using molecular beam epitaxy (MBE). Then, we directly draw nanoscale superconducting patterns into the plane of a TDS α-Sn thin film using a focused ion beam (FIB), which induces a phase transition of the irradiated α-Sn to a superconducting β-Sn (Fig. 1c). In β-Sn nanowires embedded in a TDS α-Sn thin film, we observe giant nonreciprocal superconducting transport, where the critical current changes by ±35% upon reversing the current direction under a parallel magnetic field [3]. Angular dependence of the superconducting diode effect on the magnetic field direction is similar to that of the chiral anomaly effect in TDS α-Sn, suggesting that the nonreciprocal superconducting transport might occur along the β-Sn/α-Sn interfaces. These Sn-based quantum planar structures thus are promising as a universal platform for investigating topological superconducting circuits of any shape.

This work was partly supported by Grants-in-Aid for Scientific Research, CREST and PRESTO programs of JST, UTEC-FSI, Murata Science Foundation, and Spin-RNJ.

References: [1]. D. Zhang et al., *Phys. Rev. B* **97**, 195139 (2018). [2]. L. D. Anh, K. Takase et al., *Adv. Mater.* **33**, 2104645 (2021). [3] L. D. Anh, K. Ishihara et al., *Nature Commun.***15**, 8014 (2024).

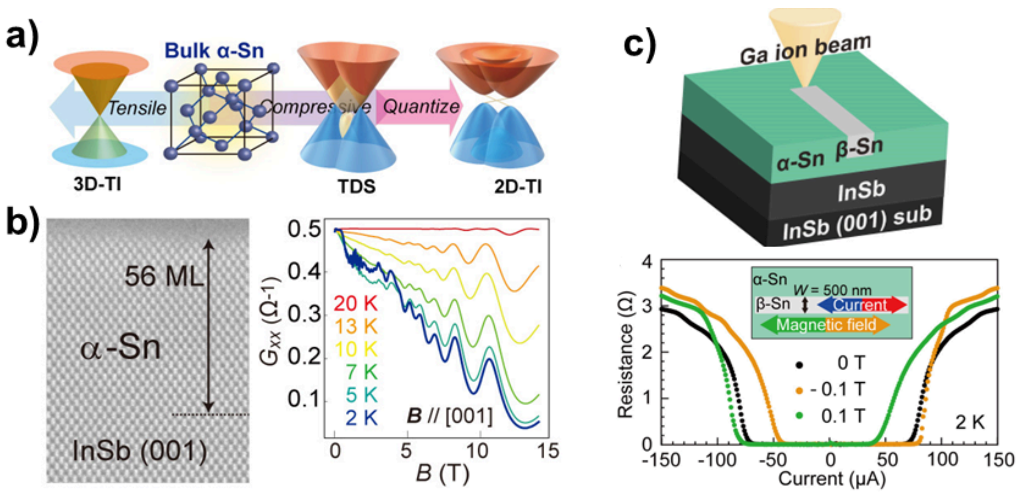


Fig. 1. a) Rich topological phase diagram of -Sn. b) -Sn is epitaxially grown with the highest quality thus far (left). The very high quantum mobilities in these samples result in strong SdH oscillations (right). c) α-Sn/β-Sn planar structures formed by FIB (top) and the superconducting diode effect observed in β-Sn nanowires (bottom) upon applying a parallel magnetic field.

1-3

Spectromicroscopic Insights into Bulk Altermagnetism in α-MnTe

R. Yamamoto[1,2*], L. A. Turnbull[1,2], M. Schmidt[1], J. C. Corsaletti Filho[1], H. J. Binger[1], M. Di Pietro Martínez[1,2], M. Weigand[3], S. Finizio[3,4], Y. Prots[1], G. M. Ferguson[1], U. Vool[1], S. Wintz[3], and C. Donnelly[1,2]

[1] *Max Planck Institute for Chemical Physics of Solids*

[2] *International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM[2]), Hiroshima University*

[3] *Institute for Nanospectroscopy, Helmholtz-Zentrum Berlin*

[4] *Swiss Light Source, Paul Scherrer Institute*

* Rikako.Yamamoto@cpfs.mpg.de

Antiferromagnets have been extensively studied because of their robustness against external magnetic fields and potential for ultrafast operation [1,2]. Altermagnets possess antiferromagnetic spin configurations while breaking time-reversal symmetry, enabling spin-polarized phenomena without net magnetization. This unique combination makes them attractive candidates for next generation spintronic applications [3]. Among known altermagnets, α-MnTe, comprising two antiferromagnetic sublattices related by a mirror symmetry, stands out as a promising material. Key altermagnetic signatures, including the anomalous Hall effect [1], momentum-space spin splitting [5,6], and circular dichroism [7,8] have been experimentally demonstrated. However, most earlier studies focused on molecular-beam-epitaxy-grown thin films and relied on surface-sensitive probes such as angle-resolved photoemission spectroscopy and photoemission electron microscopy.

To establish altermagnetism in the bulk, we performed x-ray magnetic circular dichroism (XMCD) imaging in transmission on a 200-nm-thick lamella extracted from a single α-MnTe crystal [9]. We successfully observed XMCD contrast that is not expected for a conventional antiferromagnet, consistent with previous thin-film measurements [7,8]. In addition, we resolved magnetic domains and spin textures, including domain walls and vortex-like configurations. By acquiring XMCD images at multiple photon energies, we extracted a XMCD spectrum across the Mn $L_{2,3}$ edges from a single domain. The spectrum exhibits an oscillatory structure, in agreement with spectra calculated using a local density approximation and dynamical mean-field theory for the altermagnetic state [7], indicating sensitivity to the full sample volume rather than only the surface. These results demonstrate that transmission XMCD spectroscopic imaging is a robust and quantitative technique for probing altermagnetic order in bulk systems, enabling direct visualization of individual altermagnetic domains and nanoscale spin textures within complex magnetic configurations.

References: [1] R. Cheng, D. Xiao, and A. Brataas, *Phys. Rev. Lett*. **116**, 207603 (2016). [2] H. Qiu *et al.*, *Adv. Science* **10**, 2300512 (2023). [3] L. Šmejkal, J. Sinova, and T. Jungwirth. *Phys. Rev. X* **12**, 031042 (2022). [4] L. Šmejkal *et al.*, *Sci. Adv*. **6**, eaaz8809 (2020). [5] J. Krempaský *et al.*, *Nature* **626**, 517 (2024). [6] S. Lee *et al.*, *Phys. Rev. Lett*. **132**, 036702 (2024). [7] A. Hariki *et al.*, *Phys. Rev. Lett*., **132**, 176701 (2024). [8] O. J. Amin *et al.*, *Nature* **636**, 348 (2024). [9] R. Yamamoto *et al.*, *Phys. Rev. Applied* **24**, 034037 (2025).

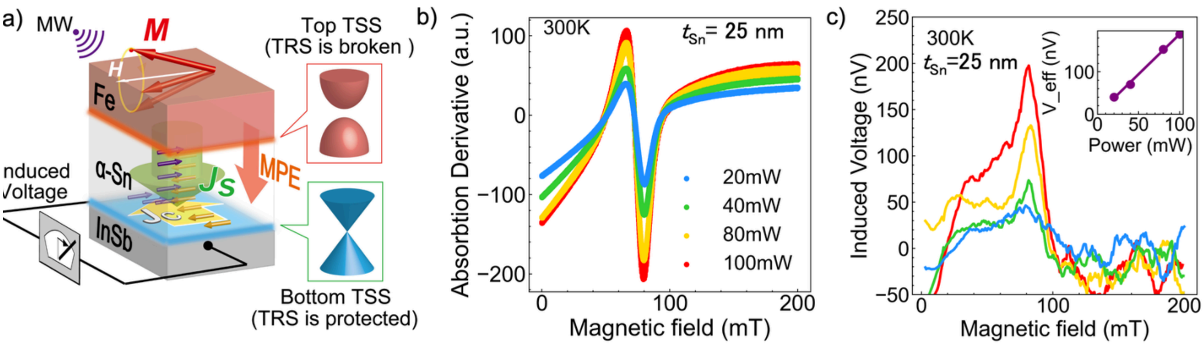
Highly efficient spin-charge conversion in ferromagnetic metal Fe / topological Dirac semimetal α-Sn heterostructures

Masayuki Ishida[1*], Soichiro Fukuoka[1], Takahiro Chiba[3,4], Yohei Kota[5], Masaaki Tanaka[1,2,6], and Le Duc Anh[1,2],
[1]Dept. of Electrical Engineering and Information Systems, The University of Tokyo, Japan
[2]Center for Spintronics Research Network (CSRN), The University of Tokyo, Japan
[3] Department of Information Science and Technology, Graduate School of Science and Engineering, Yamagata University, Japan
[4]Department of Applied Physics, Graduate School of Engineering, Tohoku University, Japan
[5]National Institute of Technology, Fukushima College, Japan
[6]Institute for Nano Quantum Information Electronics (NanoQuine), The University of Tokyo, Japan
*E-mail: masayuki-ishida1118@g.ecc.u-tokyo.ac.jp

Topological surface states (TSS) of topological materials are promising for effective spin-charge interconversion. However, when interfacing a topological material to a ferromagnetic layer, the TSS is destroyed by time reversal symmetry breaking and inserting a conductive spacer layer is usually required to preserve TSS [1]. However, this method could cause current shunting and increase the probability of spin scattering at the interface. In this work, we demonstrate that highly efficient spin-charge conversion (SCC) is possible when directly interfacing topological Dirac semimetal (TDS) α-Sn [2] with ferromagnetic Fe.

Spin-pumping experiment was carried out at room temperature on ferromagnetic Fe / TDS α-Sn heterostructures with varying the α-Sn thickness. We observed clear SCC, indicated by the simultaneous observation of ferromagnetic resonance (FMR) and a voltage peak that is proportionate to the applied microwave power at FMR conditions in the samples with Sn thickness above 25 nm. The inverse Edelstein length is estimated to be ~3.14 nm, which is comparable to the largest value reported thus far at room temperature [3]. Combined with DFT calculations, our results indicate that the SCC occurs at the TSS of TDS on the substrate side, suggesting the long spin-diffusion length of TDS α-Sn.

[1] Rojas-Sánchez, J.C. *et al. Phys. Rev. Lett.* **116**, 096602 (2016).
[2] L. D. Anh *et al*., *Adv. Mater.* **33**, 2104645 (2021).
[3] Longo, E. *et al. Adv. Funct. Mater.* **34**, 2407968 (2024).



a) Concept illustration of this work. b) FMR spectrum and c) spin-pumping-induced voltage of Fe (4 nm)/-Sn (25 nm)/InSb heterostructure. Inset in figure c shows the rf power dependency of the peak voltage.

1-5

Giant Rashba Effect in Topological Surface States with Metal Overlayers.

A Yagmur,[1] I Gelen,[1] J Burton,[1] M Rogers,[1] P M Shepley,[1] M Ali,[1] C S Knox,[2] J R Freeman,[2] S Sasaki,[1] and B J Hickey*[1]

[1]School of Physics and Astronomy, University of Leeds, LS2 9JT, Leeds, UK.

[2]School of Electrical and Electronic Engineering, University of Leeds, LS2 9JT. UK

* B.J.Hickey@leeds.ac.uk

We have discovered a giant Rashba effect in high mobility, large grain, thin films of Bi_2Se_3 induced by an overlayer of Se with a Rashba parameter of $\alpha_R = 2.0 \pm 0.6$ eVÅ. Through breaking the inversion symmetry of the structure, the Se overlayer has created an additional spin-orbit effect via the Rashba field adding to the intrinsic spin-orbit interaction of the Bi_2Se_3 . The intrinsic spin-orbit lifetime (τ_{so}) is of the order of 60 fs, found by fitting the magnetoresistance including corrections for Dirac fermions. We determined the electron-electron interaction time, τ_{ee}, over temperatures from 1 K to 20 K, and showed that the behaviour is consistent with confined electrons. Using dielectric constants to estimate the screening and the interaction times, we explained that the frequently observed increase in the low temperature zero-field resistivity is due to electron-electron interactions. We demonstrated the presence of spin-momentum locked states by showing that the spin-diffusion length is of the same order of magnitude as the elastic mean free path. Together these findings offer new insight into transport in topologically protected states.

We gratefully acknowledge financial support from the UK funding council EPSRC (NAME EP/V001914/1, CAMIE EP/X027074/1 and Royce Institute EP/P022464/1).

Magneto-optics, revisited

Rudolf Schäfer

Leibniz Institute for Solid State and Materials Research (IFW) Dresden, Germany

r.schaefer@ifw-dresden.de

2-1

Two aspects of magneto-optics are reviewed that have hardly be considered in the past: (i) For MOKE magnetometry it will be shown that the obtained hysteresis loops need to be interpreted very carefully as they are measured locally, determined by the internal (not applied) field and local magnetization processes [1]. Such local loops may be seen as *hysterons* according to the classical Preisach hysteresis model (Fig. 1). (ii) For wide-field MOKE microscopy numerous magneto-optical effects will be discussed that lead to intensity-based domain contrast in the absence of analyser and compensator [2]. They are summarized in Fig. 2 together with the „conventional“ effects. These effects may require linearly or circularly polarised polarized light for illumination. They can either be applied directly as alternative to the conventional effects (like the transverse Kerr effect for domain imaging in ferromagnetic materials or the linear birefringence effect for imaging domains in altermagnets) or there existence should at least be realised as they can lead to superimposed contrasts and misleading interpretations in magneto-optical microscopy.

Acknowledgements: Thanks to Ivan Soldatov (IFW) for contributing to the experiments

References: [1] I. Soldatov et al., IEEE Magn. Lett. **11**, 2405805 (2020); [2] R. Schäfer, et al., Appl. Phys. Rev. **8**, 031402 (2021)

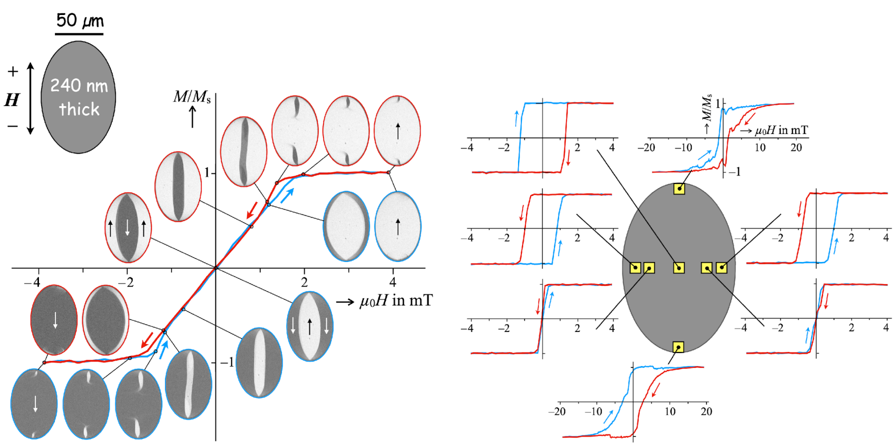


Fig. 1 Global MOKE magnetization curve together with domain images (left) and local loops (right), measured at the indicated positions on a permalloy film element

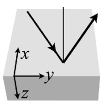
	Polarization analysis (analyser & compensator)	Intensity analysis (no analyser, no comp.)
Linear in *M*	Magnetic Circular Birefringence (& dichroism) (P-MOKE, L-MOKE) (Linear light)  $\begin{pmatrix} 1 & -iQ_V m_z & iQ_V m_y \\ iQ_V m_z & 1 & -iQ_V m_x \\ -iQ_V m_y & iQ_V m_x & 1 \end{pmatrix}$	T-MOKE (Linear & circular light) $\begin{pmatrix} 1 & -iQ_V m_z & iQ_V m_y \\ iQ_V m_z & 1 & -iQ_V m_x \\ -iQ_V m_y & iQ_V m_x & 1 \end{pmatrix}$ Magnetic Circular Dichroism (L-MCD, P-MCD) (Circular light)
Quadratic in *M*	Magnetic Linear Birefringence (Linear light) $\begin{pmatrix} B_1 m_x^2 & B_2 m_x m_y \\ B_2 m_x m_y & B_1 m_y^2 \end{pmatrix}$	Magnetic Linear Dichroism (Linear light) $\begin{pmatrix} B_1 m_x^2 & B_2 m_x m_y \\ B_2 m_x m_y & B_1 m_y^2 \end{pmatrix}$
Linear in grad *M*	Birefringent Gradient Effect (Linear light) $\begin{pmatrix} -\frac{\partial m_x}{\partial y} - \frac{\partial m_y}{\partial x} & \frac{\partial m_x}{\partial x} - \frac{\partial m_y}{\partial y} \\ \frac{\partial m_x}{\partial x} - \frac{\partial m_y}{\partial y} & \frac{\partial m_x}{\partial y} + \frac{\partial m_y}{\partial x} \end{pmatrix}$	Dichroic Gradient Effect (Linear light) $\begin{pmatrix} -\frac{\partial m_x}{\partial y} - \frac{\partial m_y}{\partial x} & \frac{\partial m_x}{\partial x} - \frac{\partial m_y}{\partial y} \\ \frac{\partial m_x}{\partial x} - \frac{\partial m_y}{\partial y} & \frac{\partial m_x}{\partial y} + \frac{\partial m_y}{\partial x} \end{pmatrix}$

Fig. 2 Summary of magneto-optical effects at visible light, also showing their relevant elements in the

2-2

2D and 3D Racetrack Memory

Stuart S.P. Parkin
Max Planck Institute of Microstructure Physics, Halle (Saale), Germany
stuart.parkin@mpi-halle.mpg.de

Spintronics allows for advanced memory and storage technologies that go beyond today's charge-based devices. Of especial interest is Magnetic Racetrack Memory (RTM) that is a unique memory-storage device that relies on the current driven motion of multiple domain walls along magnetic conduits. Racetrack Memory has evolved in several distinct stages that we have dubbed versions 1.0-4.0 [1]. In version 4.0 we showed that chiral domain walls can be driven at speeds exceeding 1 km/s in synthetic antiferromagnetic racetracks by spin currents generated via the spin Hall effect in proximal metallic layers [2]. We discuss recent developments in both 2D and 3D Racetrack Memory. In particular, we show that Racetrack Memory can be scaled to dimensions that are technologically relevant. Using integrated anomalous Hall read sensors, we demonstrate that domain walls can be positioned by nanosecond long current pulses along racetracks just 50-80 nm wide with a spatial resolution of ~10 nm [3]. We discuss recent advances in materials for Racetrack Memory including highly efficient current induced domain wall motion in 2D ferromagnets[4], and high entropy alloys as efficient spin-orbit torque sources [5]. Finally we present several schemes for building prototype 3D racetracks. In one case freestanding membranes composed of atomically engineered thin film heterostructures that form the racetrack are formed on a sacrificial water-soluble sacrificial release layer. The freestanding membranes are transferred onto protrusions that have been pre-patterned on sapphire wafers to create 3D racetracks [6,7]. In a second approach we fabricate 3D chiral magnetic racetracks via a novel state-of-the-art multi-photon super-resolution lithography system. We show how the interplay between the geometrical chirality and the spin chirality of the individual domain walls allows for domain wall diode devices [8].

1 Parkin, S. S. P. & Yang, S.-H. Memory on the Racetrack. *Nat. Nanotechnol.* **10**, 195-198 (2015).
2 Yang, S.-H., Ryu, K.-S. & Parkin, S. S. P. Domain-wall velocities of up to 750 ms^{-1} driven by exchange-coupling torque in synthetic antiferromagnets. *Nat. Nanotechnol.* **10**, 221-226 (2015).
3 Jeon, J.-C., Migliorini, A., Yoon, J., Jeong, J. & Parkin, S. S. P. Multi-core memristor from electrically readable nanoscopic racetracks. *Science* **386**, 315-322 (2024).
4 Guan, Y. *et al.* Highly efficient current-induced domain wall motion in a room temperature van der Waals magnet. *Nat. Commun.* (2025).
5 Wang, P. *et al.* High Entropy Alloy Thin Films as Efficient Spin-Orbit Torque Sources for Spintronic Memories. *Adv. Mater.*, 2416820 (2025).
6 Gu, K. *et al.* 3D racetrack memory devices designed from freestanding magnetic heterostructures. *Nat. Nanotechnol.* **17**, 1065-1071 (2022).
7 Gu, K. *et al.* Atomically-Thin Freestanding Racetrack Memory Devices. *Adv. Mater.* 2505707 (2025).
8 Farinha, A. M. A., Yang, S.-H., Yoon, J., Pal, B. & Parkin, S. S. P. Interplay of geometrical and spin chiralities in 3D twisted magnetic ribbons. *Nature* **639**, 67–72 (2025).

Transfer of magnetic nanomembranes: from fundamental curvilinear nanomagnetism to flexible electronic applications

Olha Bezsmertna[1,*], Oleksandr Pylypovskyi[1], Rui Xu[1], Eduardo Sergio Oliveros Mata[1], Andrea Sorrentino[2], Mykola Vinnichenko[3], Peter Fischer[4,5] and Denys Makarov[1]

[1] *Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany*

[2] *Alba Light Source, MISTRAL beamline, Cerdanyola del Vallès 08290, Spain*

[3] *Fraunhofer Institute for Ceramic Technologies and Systems IKTS, 01277 Dresden, Germany*

[4] *Department of Physics, University of California, Santa Cruz, California 95064, United States*

[5] *Lawrence Berkeley National Laboratory, Berkeley, California 94720, United States*

* o.bezsmertna@hzdr.de

Magnetic nanomembranes provide a versatile platform whose functionality can be extended through controlled transfer processes and geometric design. We show that ultrathin flat magnetic field sensors can be reliably transferred onto flexible substrates, preserving their structural integrity and magnetic performance, thus enabling mechanically compliant devices for applications where low weight, conformability, and durability are essential [1]. At the same time, beyond flat architectures, functionality of magnetic nanomembranes can be extended through tailoring their geometry and topology. Curved and three-dimensional magnetic nanomembranes induce new forms of geometry-driven magnetic interactions, enabling stabilization of complex non-trivial magnetic configurations and offering a platform to study complex curvature-driven magnetic phenomena [2].

Fig. 1 Optical image of transferred large-scale magnetoresistive Co/Cu membrane

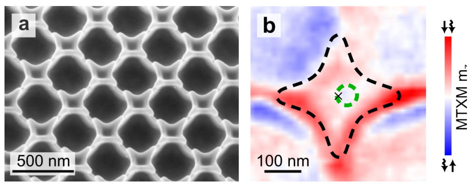


Fig. 2: SEM image of curvilinear hierarchical magnetic Permalloy nanomembrane of the nanoflower shape (a), which reveals stabilization of non-cantered vortex (b) due to the magnetostatics-driven symmetry break

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Spin and heat accumulation induced magnetization reversal (SAAHIR)

Julius Hohlfeld [1]

[1] *Inst. Jean Lamour*

3-1

Observation of anisotropic orbital Hall effect

Shutaro Karube[1,2,3,*]

1 Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan
2 Center for Spintronics Research Network, Institute for Chemical Research, Kyoto University, Uji, Kyoto 611-0011, Japan
3 PRESTO, Japan Science and Technology Agency, Kawaguchi-shi, Saitama 332-0012, Japan
* karube.shutaro.8s@kyoto-u.ac.jp

In recent years, theoretical studies have proposed that orbital angular momentum can be transported within solids [1], followed by a number of experimental demonstrations [2,3]. The transport of orbital angular momentum is referred to as an “orbital current,” while the mechanism responsible for generating it is known as the “orbital Hall effect.” In contrast to the spin Hall effect, the conversion from charge current to orbital current is a non-relativistic process that does not rely on spin–orbit interaction. Consistent with this, finite orbital Hall angles have been observed even in materials with weak spin–orbit coupling, such as 3d transition metals [2–4]. Nevertheless, most experimental works have focused on polycrystalline samples, leaving the influence of band structure and crystal orientation in epitaxial films largely unexplored.

In this study, we investigated the orbital Hall effect using epitaxial Ti thin films with controlled crystal orientations, taking advantage of Ti’s minimal spin–orbit interaction to isolate the orbital contribution. Ti(1-100) epitaxial films were grown on sapphire M-plane substrates, followed by the deposition of polycrystalline Ni for orbital torque detection. Harmonic Hall measurements were carried out at room temperature. When an electric field was applied along the [0001] and [11-20] directions in the Ti(1-100) plane, damping-like torque efficiencies of different magnitudes were obtained. These observations qualitatively agree with theoretical predictions of orbital Hall conductivity anisotropy, reflecting the influence of the underlying band structure. Building on this anisotropy, we further examined magnetization reversal driven by orbital torque and successfully identified variations in the required reversal current density. The orbital Hall-related behaviors observed in epitaxial Ti are discussed in detail.

Acknowledgements:
This work was supported by the JSPS KAKENHI (JP24H00030) and the JST PRESTO (JPMJPR22B4).

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Magnetoelectric coupling effect in a non-centrosymmetric superconductor

Heda Zhang[1,*]

[1] *Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany*

* Heda.Zhang@cpfs.mpg.de

3-3

The magnetoelectric coupling effect in non-centrosymmetric superconductors introduces interactions between spin and charge. Through spin–orbit coupling, the supercurrents in these systems can acquire spin polarization, giving rise to novel effects such as electronic magnetochiral anisotropy (eMChA) and finite-momentum pairing. I will present our angle-dependent measurements on 4Hb-TaS_2, which reveal secondary superconducting domes in the presence of an external magnetic field. Interestingly, these secondary domes only appear for when the field vector and the current vector is primarily parallel, which indicates their magnetoelectric coupling origin. In addition, a conceptual idea for an EMC SQUID device will be discussed, along with updates on its development.

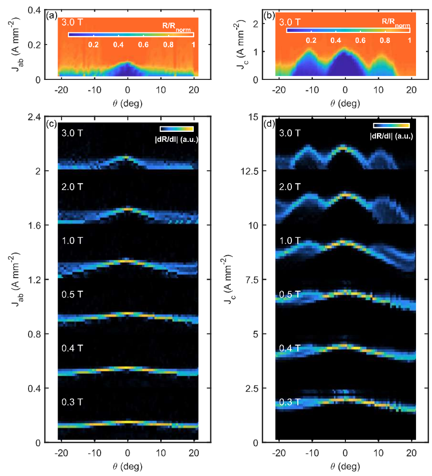

Fig. 1 Secondary superconducting domes in 4hb-TaS_2.

3-4

Spin caloritronic materials and devices

Masaki Mizuguchi,[1,2,3]*

[1] *Institute of Materials and Systems for Sustainability, Nagoya University, Japan*

[2] *Graduate School of Engineering, Nagoya University, Japan*

[3] *Institute for Advanced Study, Nagoya University, Japan*

* mizuguchi.masaki@material.nagoya-u.ac.jp

The correlation between spin and charge in electronic transports has been energetically studied in a scheme of spintronics research. Recently, the coupling between heat current, spin current and charge current is also attracting much attention, and this newly established filed is called “spin caloritronics”. The Nernst effect is a common thermomagnetic effect, which has been known for a long time. When a temperature gradient is applied on a material with spontaneous magnetization, an electric field is induced in the perpendicular direction to both the temperature gradient and the magnetization, which is called the anomalous Nernst effect (ANE). We have reported ANE measurements of an $L1_0$-ordered epitaxial FePt thin film, which is a well-known material with a large magnetic anisotropy, for studying thermomagnetic effects in ordered alloys [1]. We also studied the material dependence of ANE regarding the spin-orbit interaction in several perpendicularly magnetized ordered-alloy thin films [2]. The ANE has some advantages against the Seebeck effect, which is widely used as a thermoelectric power generation element, does not have. Therefore, it is expected that the ANE can be applied to high-performance thermoelectric energy conversion elements by strategical designing [3]. Obtaining materials with a large ANE is indispensable to realize a practical application of ANE-based energy conversion. From this point of view, this talk describes our study on the ANE in various nanostructured magnetic materials. The enhancement of ANE for thin films with porous structures and development of energy-conversion device by electromagnetic waves using spin-currents will be discussed [4-9].

Acknowledgements: This research was supported by JST-CREST (JPMJCR1524) and Grant-in-Aid for Scientific Research (S) (21H05016) from Japan Society for the Promotion of Science.

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Poster Session (foyer)

P-1

Chiral superconductivity from spin polarized Chern band in twisted $MoTe_2$

Cheng Xu[1,2], Nianlong Zou[1], Nikolai Peshcherenko[3], Ammar Jahin[4], Tingxin Li[5], Shi-Zeng Lin[4,6], and Yang Zhang[1,7,*]

[1] *Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*

[2] *Department of Physics, Tsinghua University, Beijing 100084, China*

[3] *Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany*

[4] *Theoretical Division, T-4, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

[5] *School of Physics and Astronomy, Shanghai Jiao Tong University, Shanghai, China*

[6] *Center for Integrated Nanotechnologies (CINT), Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA*

[7] *Min H. Kao Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, Tennessee 37996, USA*

Superconductivity has been observed in twisted $MoTe_2$ within the anomalous Hall metal parent state. Key signatures—including a fully spin/valley polarized normal state, anomalous Hall resistivity hysteresis, superconducting phase adjacent to the fractional Chern insulating state, and a narrow superconducting dome at zero gating field—collectively indicate chiral superconductivity driven by intravalley pairing of electrons. Within the Kohn–Luttinger mechanism, we compute the superconducting phase diagram via random phase approximation, incorporating Coulomb repulsion in a realistic continuum model. Our results identify a dominant intravalley pairing with a narrow superconducting dome of p + ip type at zero gate field. This chiral phase contrasts sharply with the much weaker time-reversal-symmetric intervalley pairing at finite gating field. Our work highlights the role of band topology in achieving robust topological superconductivity and supports the chiral and topological nature of the superconductivity observed in twisted $MoTe_2$.

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Poster Session (foyer)

Determination of the actual valence band of a topological insulator Bi_2Se_3

Yuki Higuchi[1,*], Ryota Itaya[1], Harutaka Saito[2], Yuichiro Toichi[1], Takahiro Kobayashi[1], Mito Tomita[1], Shigemi Terakawa[1], Katsuhiro Suzuki[3], Kenta Kuroda[4], Takako Kotani[5], Fumihiko Matsui[6], Shigemasa Suga[7], Hitoshi Sato[8], Kazunori Sato[2], and Kazuyuki Sakamoto[1]

[1] *Department of Applied Physics, The University of Osaka, Japan*
[2] *Department of Materials and Manufacturing Science, The University of Osaka, Japan*
[3] *Department of Mechanical Engineering, National Institute of Technology, Niihama College, Japan*
[4] *Department of Physical Science, Hiroshima University, Japan*
[5] *Advanced Mechanical and Electronic System Research Center, Tottori University, Japan*
[6] *UVSOR Synchrotron Facility, Institute for Molecular Science, Japan*
[7] *SANKEN, The University of Osaka, Japan*
[8] *Hiroshima Synchrotron Radiation Center, Hiroshima University, Japan*
* yhiguchi@ap.eng.osaka-u.ac.jp

P-2

Topological insulators (TIs) are promising candidates for next-generation spintronics devices. To actualize the spintronics devices, an accurate understanding of the binding energy (E_B) of the bulk valence band maximum (BVBM) is essential, together with tuning the Fermi level above and below the Dirac point (DP) [1-3]. However, even in the case of Bi_2Se_3, a typical n-type TI, different results on the E_B of the BVBM have been reported. BVBM with E_Bs lower than that of the DP were reported in Refs. [4,5], which means that it is not possible to make a p-type Bi_2Se_3, and with E_Bs higher in Refs. [6,7]. In this talk, I will present detailed experimental and theoretical studies on the location of BVBM of Bi_2Se_3. Trace of the location of BVBM was observed at E_B higher than that of DP in the photon energy-dependent angle-resolved photoemission spectroscopy (ARPES) measurements that covers several Brillouin zones. The theoretical calculations performed using a quasiparticle self-consistent *GW* (QSGW)-DFT, which can provide a qualitative and quantitative assessment of the bulk band structure, support our experimental results. The obtained results indicate that Bi_2Se_3 is a good material candidate for next generation spintronics devices.

Acknowledgments: The authors thank the financial support provided by the JSPS KAKENHI Grants (No. JP24K23032, JP22H01957, JP22H01943, JP22AG002, JP22BU007, JP22K04909, JP20H05621, and JP20K03863) and the Spintronics Research Network of Japan.

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Poster Session (foyer)

Interwoven magnetic kagome metal overcoming geometric frustration

Erjian Cheng [1]

[1] *Max Planck Inst. for Chem. Phys. of Solids, Germany*

P-3

Interpretation of Crystal Energy Landscapes with Kolmogorov–Arnold Networks

Gen Zu,[1] Ning Mao,[1] Claudia Felser,[1] and Yang Zhang[2,3]

[1] *Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany*
[2] *Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*
[3] *Min H. Kao Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, Tennessee 37996, USA*

Characterizing the energy landscape of crystalline materials is central to predicting their thermodynamic stability, electronic structure, and functional behavior. While machine learning (ML) has enabled rapid property prediction across chemical compound space, most existing models offer limited interpretability due to complicated network architecture, hindering their utility in scientific discovery. In this work, we introduce Kolmogorov–Arnold Networks (KANs) as a framework for interpretable materials property prediction based solely on chemical composition. KANs replace traditional fixed activation functions with learnable univariate functions parameterized via B-splines, allowing post hoc inspection of task-specific nonlinearities. We develop a composition-based model—ElementWeightedKAN—to predict formation energy, band gap, and work function across large materials datasets. The model achieves state-of-the-art accuracy on the order of hundreds of meV, while also learning physically meaningful latent representations. Through embedding analysis, correlation studies, and principal component analysis (PCA), we show that KANs uncover interpretable chemical trends aligned with periodic groupings and quantum mechanical properties—without explicit supervision. These results demonstrate that KANs provide both predictive performance and scientific insight, offering a promising direction for interpretable, composition-based materials informatics.

P-4

Scanning Magnetometry of van der Waals magnets under in-situ controlled strain

Yuchen Zhao[1], Jose C. Corsaletti Filho[1], Yejin Lee[1], Chenhui Zhang[4], Hyunsoo Yang[4], Elena Gati[1,3], Claire Donnelly[1,2], and Uri Vool[1]

[1]Max Plank Institute for Chemical Physics of Solids, Dresden
[2]International Institute for Sustainability with Knotted Chiral Meta Matter (WPI-SKCM2), Hiroshima University, Hiroshima, Japan
[3]Institute of Solid State and Materials Physics, Technical University of Dresden, 01187 Dresden, Germany
[4]Department of Electrical and Computer Engineering, National University of Singapore, Singapore 117576, Singapore

In recent years, van der Waals magnets have emerged as one of the promising research directions in the field of condensed matter physics. The discovery of this class of material opens up a new chapter in exploring exotic quantum phenomena down to the monolayer limit and sheds light on spintronics applications[1]. Due to their thin nature, van der Waals magnets are mechanically more flexible than their bulk counterparts, allowing them to withstand greater strain. Strain tuning offers a promising approach to control the magnetic properties by distorting lattice structures, changing magnetic energy landscapes, and possibly inducing new magnetic states. However, imaging the magnetic properties of van der Waals magnets under large (over 1%), in-situ controlled strain remains a technical challenge to tackle, with so far only small strain achieved under microscopic techniques[2]. Here, we report a technique that enables large in-situ strain engineering of vdW magnets under scanning probe microscopy at room temperature. We demonstrate the use of a piezoelectric actuator-based uniaxial strain cell[3] and show results on Fe3GaTe2 flakes as a proof-of-principle example of our method. By incorporating this setup into Magnetic Force Microscopy (MFM), we can locally probe the influence of strain on magnetic textures, revealing strain modulation of the magnetic configuration. In the future, this setup will open the study of strain-induced magnetic effects in a broad class of van der Waals systems.

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Poster Session (foyer)

Low Gilbert damping of frustrated Kagome magnet Fe_3Sn_2

○ Zaizhou Jin [1,2], Edouard Lesne [3], Kouki Nukui [1,2], Soma Miki [2], Claudia Felser [3], Atsufumi Hirohata [3,4], Shigemi Mizukami [2,4]
Graduate School of Engineering, Tohoku Univ.[1], WPI-AIMR, Tohoku Univ.[2], MPI-CPfS, Germany.[3], CSIS, Tohoku Univ.[4]

E-mail: jin.zaizhou.t4@dc.tohoku.ac.jp

P-6

Kagome magnetic materials host a wide range of intriguing phenomena, including magnetic frustration, spin-liquid behavior, skyrmions, and topologically nontrivial electronic states such as Weyl nodes, Dirac cones, and flat bands. These features give rise to emergent transport and optical responses—most notably the anomalous Hall effect, anomalous Nernst effect, and chiral anomaly [1–3]. A distinctive characteristic of kagome systems is that their band structure is inherently tied to both lattice geometry and magnetic order. Thus, tuning the magnetic state offers an effective pathway for manipulating topological properties, motivating growing interest in the spin dynamics of magnetic kagome materials [4,5]. In this study, we investigate a representative frustrated kagome magnet, Fe_3Sn_2, grown by magnetron sputtering on (111) $SrTiO_3$ substrates. Using time-resolved magneto-optical Kerr effect (TR-MOKE) measurements, we focus on quantifying the Gilbert damping in Fe_3Sn_2. Figure 1 illustrates the experimental configuration, where the out-of-plane component of the kagome magnetic moments is detected via polar-MOKE geometry using a probe pulse. A typical TR-MOKE signal is shown in Fig. 2, where the magnetic response is isolated by subtracting traces measured under ±2 T fields to suppress extrinsic contributions. We find that the effective damping parameter in crystalline Fe_3Sn_2 epitaxial films is approximately 0.01—substantially lower than the values previously reported [4,5]. These results underscore the promise of topological kagome magnets as potential low-dissipation platforms for future spintronic applications. These findings highlight the potential of topological kagome magnets for spintronic applications. This work is partially supported by JSPS KAKENHI (21H05000, 24K21234), MEXT X-NICS (JPJ011438), and JST ASPIRE (JPMJAP2409). S.M. thanks to Spin-RNJ and Z.J. thanks to JST SPRING and GP-Spin at Tohoku Univ.

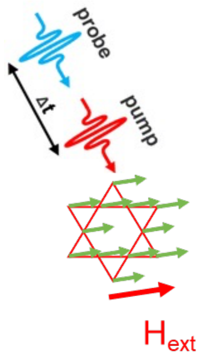

Figure 1: Schematic illustration of measurement configuration.

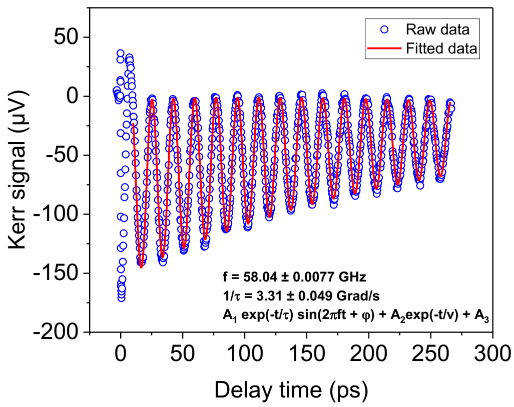

Figure 2: Typical TRMOKE signal obtained for the Fe_3Sn_2 film.

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P-7

Poster Session (foyer)

Realization of Broadly Tunable Compensation in Ferrimagnetic MnFeVAl Heusler Alloy

Esita Pandey,[1,*] Shogo Yamashita,[1] Edouard Lesne,[1] Gerhard Fecher,[1] Claudia Felser,[1] and Atsufumi Hirohata [1,2]

[1] *Max-Planck-Institute for Chemical Physics of Solids, Dresden, Germany*

[2] *Tohoku University, Sendai, Japan*

*Esita.Pandey@cpfs.mpg.de

Half-metallic ferromagnets, with their 100% spin polarization, are attractive for spintronic applications; however, their large dipole fields limit device performance. Zero-moment spintronic systems are highly desirable, as they minimize stray fields while maintaining stability against external magnetic perturbations. Although antiferromagnets suppress stray fields, their band structure precludes spin-polarized bulk carriers [1-2]. Compensated ferrimagnets offer an ideal solution, combining a net-zero magnetic moment with spin-polarized conduction [3]. Achieving a compensated state over a broad temperature range is critical for practical device applications. In this study, we demonstrate the realization of a near-zero-moment state in $Mn_{1.44}V_{0.5}Fe_{1.08}Al_{0.98}$ Heusler alloy thin films with a wide tunable compensation range. Films of varying thickness were fabricated on thermally oxidized Si substrates with a W buffer layer using simultaneous triple-target sputtering in an ultra-high-vacuum system. Structural analysis via X-ray diffraction shows that the W underlayer is stabilized in the body-centered cubic (bcc) α-phase with (110) orientation, while the Heusler films exhibit pronounced [110] texture and a lattice parameter close to bulk values. Magnetometry measurements reveal that the samples are magnetically isotropic and exhibit an exceptionally low saturation magnetization (~2 emu/cc) at RT. Furthermore, the magnetization remains nearly constant, varying only from 2.5 to ~2.0 emu/cc over 250–350 K (Fig. 1), confirming a stable low-moment state. These results position MnFeVAl films as promising candidates for thermally stable, stray-field-free spintronic devices with robust spin-polarized transport.

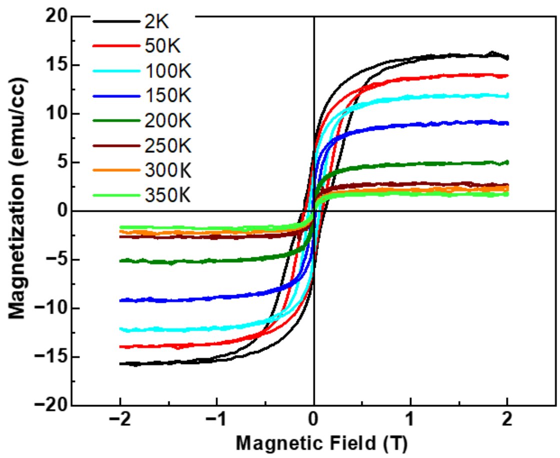

Fig. 1 M-H loops measured at various temperature using an MPMS3 SQUID-VSM magnetometer.

Acknowledgements: This research was supported by the ERC Advanced Grant "SAHAJ" and the JST Aspire Program "SpinMaD."

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Poster Session (foyer)

P-8

Magnetic and transport properties of compensated ferrimagnetic Heusler alloys at finite-temperatures: ab initio spin fluctuation theory

Shogo Yamashita,[1] Esita Pandey[1], Gerhard H. Fecher[1], Claudia Felser[1], Atsufumi Hirohata[1,2,3]

[1] Max-Planck-Institute for Chemical Physics of Solids, D-01187 Dresden, Germany

[2] Center for Science and Innovation in Spintronics, Tohoku University, Sendai, Japan

[3] Research Institute of Electrical Communication, Tohoku University, Sendai, Japan

* Shogo.yamashita@cpfs.mpg.de

Fully compensated ferrimagnets are promising materials for spintronics applications from the viewpoints of suppressing stray magnetic fields and high-density integration for memory applications due to net zero magnetization. In particular, Heusler alloys with 24 valence electrons per unit cell have been attracting attention because they can simultaneously achieve a half-metallic electronic structure with nearly 100% spin polarization at the Fermi level and fully compensated ferrimagnetism at a finite temperature.

For practical use in spintronics devices, it is important to exhibit such excellent magnetic properties at room temperature or above. However, ever discovered fully compensated Heusler alloys $\mathrm{Mn_{1.5}V_{0.5}FeAl}$ has lower Curie temperature than room-temperature[1] and this faces difficulty for devises applications. Therefore, alternative candidates have been strongly desired to design.

In this study, we focused on novel fully compensated Heusler alloys $\mathrm{Mn_2Co_{0.5}V_{0.5}Z}$ $(\mathrm{Z = Al, Ga})$.

To investigate finite-temperature properties of this alloy, we developed an *ab initio* spin fluctuation theory at finite-temperatures based on the coherent potential approximation and disordered local moment[2,3].

We applied this theory to $\mathrm{Mn_2Co_{0.5}V_{0.5}Al(Ga)}$ and investigated the temperature dependence of the electronic structure, magnetic properties, and electrical conductivity (spin conductivities) of $\mathrm{Mn_2Co_{0.5}V_{0.5}Z}$ $(\mathrm{Z = Al, Ga})$. We have found that it has high Curie temperature higher than room-temperature and robust spin transport properties originated from half metallic electronic structure even at room-temperature or above.

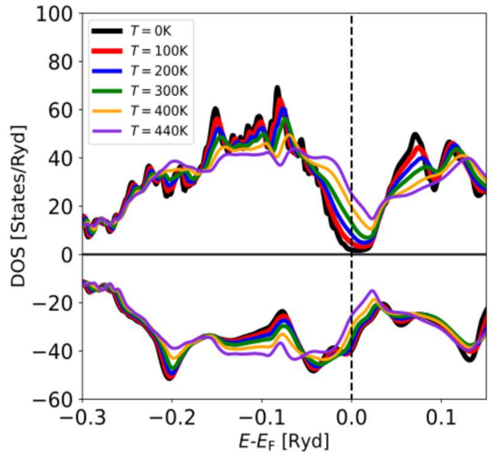

Fig. 1 Temperature dependence of density of states of $\mathrm{Mn_2Co_{0.5}V_{0.5}Al}$

In this presentation, we will report these results and discuss future prospects.

Acknowledgements: This research has been financially supported by the European Commission (EC) European Research Council (ERC) Advanced Grant "Strain-Free All Heusler Alloy Junctions—SAHAJ" (No. 101097475).

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P-9

d-wave altermagnetism in epitaxial $NiCo_2O_4$ thin films via easy-cone magnetic anisotropy

Hiroki Koizumi[1], Yamasaki Yuichi[2], Atsufumi Hirohata[1]

1 Tohoku University, Sendai, Japan, 2 NIMS, Tsukuba, Japan

$NiCo_2O_4$ (NCO) is a conductive inverse spinel oxide which shows ferrimagnetism with a Néel temperature as high as 400 K [1]. Recently, the spin reorientation in NCO(001) films has been reported in which the magnetic anisotropy changes from perpendicular magnetic anisotropy (PMA) to easy-cone magnetic anisotropy at low temperature [2]. Then, the magnetic easy direction is tilted from perpendicular to the film plane, which is a conical shape. Since the conical shape has a degree of freedom to the in-plane direction, NCO could have a non-colinear spin texture. In this study, we investigate whether NCO has a non-colinear spin texture, by carefully measuring the Hall effect.

Firstly, we performed Hall measurements in the easy-cone state. An unconventional response was observed, implying the presence of a nontrivial spin texture induced by easy-cone magnetic anisotropy. Next, we investigated the dependence of the unconventional Hall effect on the direction of the applied current (I). As shown in Fig. 1(a), the extracted unconventional Hall signal is reversed by a 90° rotation, whereas it disappears when I is parallel to NCO||⟨110⟩. In general, the anomalous Hall effect (AHE) originating from magnetic dipoles and magnetic octupoles should be independent of the current direction. Therefore, the unconventional Hall effect observed in NCO must be attributed to another type of nontrivial spin texture. A symmetry analysis based on cluster magnetic multipole theory [3] indicates that the anisotropic AHE originates from the cluster magnetic toroidal quadrupole (cMTQ). Furthermore, we found that when the cMTQ structure is realized in a spinel lattice, it possesses the characteristics of a *d*-wave altermagnet. Tight-binding calculations revealed that the characteristic band dispersion of a *d*-wave altermagnet appeared [5].

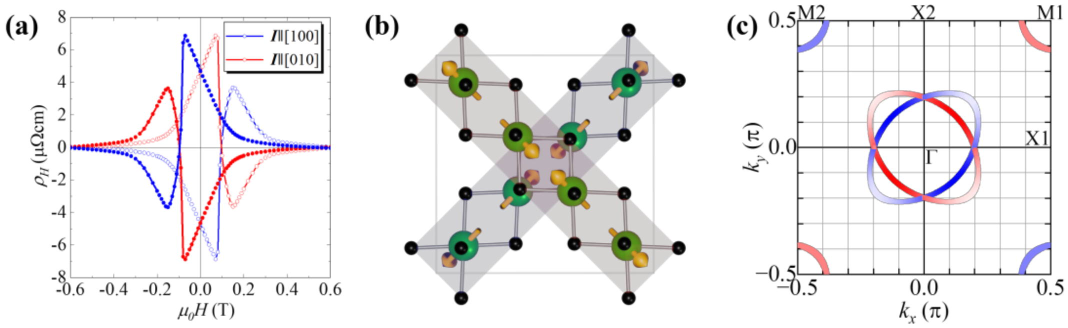

Figure 1: **(a)** Current-direction dependence of the unconventional anomalous Hall effect. **(b)** Spin texture and the associated lattice deformation. **(c)** Fermi surface exhibited by the cMTQ spin texture in a spinel lattice.

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P-10

Domain walls in magnetoelectric Cr_2O_3

Paulina J. Prusik[1,2], I. Veremchuk[1], P. Rickhaus[3], F. Radu[4], G. Seniutinas[3], A.N. Anisimov[1], G.V. Astakhov[1], V. Borras[3], P. Makushko[1], P. Lehmann[5], K. Wagner[5], S.F. Weber[6], L. Žaper[3], R. Hübner[1], F. Ganss[1], T. Kosub[1], N.A. Spaldin[4], K.D. Belashchenko[5], D.D. Sheka[8], J.Fassbender[1], P. Maletinsky[5], O.V. Pylypovskyi[1,6], and D. Makarov[1]

[1]Helmholtz-Zentrum Dresden-Rossendorf e.V., Institute of Ion Beam Physics and Materials Research, 01328 Dresden, Germany
[2]Faculty of Physics, Dresden University of Technology, 01062 Dresden, Germany
[3]Qnami AG, Qnami AG, Hofackerstrasse 40 B, CH-4132 Muttenz, Switzerland
[4]Helmholtz-Zentrum Berlin für Materialien und Energie, 14109 Berlin, Germany
[5]Department of Physics, University of Basel, Klingelbergstrasse 82, Basel CH-4056, Switzerland
[6]Materials Theory, ETH Zürich, 8093 Zürich, Switzerland
[7]University of Nebraska-Lincoln, Lincoln, NE 68588, USA
[8]Taras Shevchenko National University of Kyiv, 01601 Kyiv, Ukraine
[8]Kyiv Academic University, Kyiv 03142, Ukraine

A magnetoelectric, room-temperature collinear antiferromagnet Cr_2O_3 (chromia) is a promising material for spintronic applications [1] and fundamental research [2,3,4].

A theoretical study of domain wall properties in chromia is presented and compared with experimental observations. Structural defects, such as grain boundaries commonly present in thin films, act as pinning sites for domain walls. In granular thin films of chromia, two distinct types of domain walls are identified [5]. We show that the energy landscape formed by small grain boundaries determines the critical size of a Cr_2O_3 bit, below which it predominantly remains in a single-domain magnetic state, even when prepared using zero-field cooling [6].

A micromagnetic σ-model for Cr_2O_3 is derived, revealing a symmetry-breaking term that influences non-collinear magnetic textures. This term couples the gradients of the magnetic texture with the external magnetic field, leading to certain magnetic textures in chromia producing a finite magnetization. These theoretical predictions are confirmed by scanning nitrogen-vacancy magnetometry.

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Poster Session (foyer)

P-11

Transport sensing of spin fluctuations: non-saturating resistance and giant negative magnetoresistance

Nikolai Peshcherenko[1], Jeroen van der Brink[2,3,4], Shu Zhang[2,5] and Yang Zhang[6,7]

[1]Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany
[2]Institute for Theoretical Solid State Physics, IFW Dresden, 01069 Dresden, Germany
[3]Würzburg-Dresden Cluster of Excellence ct.qmat, 01069 Dresden, Germany
[4]Institute of Theoretical Physics, Technische Universität Dresden, 01062 Dresden, Germany
[5]Okinawa Institute of Science and Technology, Okinawa, Japan
[6]Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA
[7]Min H. Kao Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, Tennessee 37996, USA

Fluctuations in magnets play an important role for the emergence of exotic magnetic excitations. However, absence of charge degrees of freedom often prevents these fluctuations from mediating electronic transport. Based on recent experiments, we suggest a possible probe of spin fluctuations induced transport. Namely, we consider a conducting metal/insulating magnet heterostructure, so that the itinerant electrons from the metal could interact with localized magnetic moments in the magnet. Our results for magnetoresistivity provide a good agreement with the experimental data (both for quantum and classical magnetic moments fluctuations observed in $Dy_2Ti_2O_7$ [1] and $Yb_2Ti_2O_7$ [2] correspondingly). Our study opens up new possibilities for exploring exotic magnetic states via transport measurements.

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Evaluation of spin-current generation in Si-Al nanoalloy films

H. Nakayama[1], K. Yamanoi[1], Y. Nozaki[1,2]
([1]Dept. of Phys., Keio Univ., [2]CSRN, Keio Univ.)

Introduction

Heavy metals with strong spin-orbit interaction (SOI) such as Pt have been employed for spin current generation. However, in recent years, a phenomenon has been reported in which spin currents are generated without relying on SOI, utilizing local vorticity produced by non-uniform charge currents (electric current vorticity) [1], based on spin-vorticity coupling [2], i.e., the coupling between local rotation (vorticity) and electron spin. Previous study on spin current generation via electric current vorticity has demonstrated that the certain materials consisting of Si and Al which are known as weak SOI materials can achieve spin current generation efficiency comparable to that of Pt. This finding indicates that even weak SOI materials can realize high spin current generation functionality equivalent to strong SOI materials by designing film structure, which is of great significance for the development of sustainable spintronic devices that avoid dependence on strong SOI materials. In this study, we evaluated spin-torque efficiency of Si-Al nanoalloy films fabricated with systematically varied compositional ratios using two deposition methods.

Experimental method

We prepared three groups of Si-Al nanoalloy films on Si substrate by using magnetron sputtering: (1) multilayered samples deposited in chamber E, (2) multilayered samples deposited in chamber U, and (3) co-sputtered samples deposited in chamber U. The film structures of each group are as follows: (1) Sub./Si(10)/[Al(t_{Al})/Si(t_{Si})]$_{10}$/Al(0.5)/$Ni_{95}Cu_5$(10) (thickness in nm), where t_{Si} and t_{Al} ratios were set to (0.25, 0.75), (0.5, 0.5), (0.6, 0.4), (0.75, 0.25), and (0.87, 0.13). (2) Sub./[Si(0.5)/Al(t_{Al})]$_n$/Si(0.5)/Al(0.5)/$Ni_{95}Cu_5$(10), where t_{Al} was varied from 0 to 7.1 nm in 0.1 nm increments, and the number of stacked Al layers n was varied from 5 to 15 in steps of 5. (3) Sub./Si(4.8)/$Si_{1-x}Al_x$(10)/$Ni_{95}Cu_5$(10), where x values are 0.2, 0.4, 0.6, and 0.8. Note that we aim to promote atomic intermixing using high-energy sputtered particles in multilayered samples. We performed the spin-torque ferromagnetic resonance (ST-FMR) measurement [3] to evaluate the spin current generation efficiency in the Si/Al nanoalloy films.

Results

Figure 1 shows representative STFMR spectra of the samples belonging to each group: (a) a sample from group (1) with (t_{Si}, t_{Al}) = (0.6, 0.4), (b) a sample from group (2) with t_{Al} = 0.5 nm and n = 10, and (c) a sample from group (3) with x = 0.4. Spectra with different shapes were obtained depending on the deposition conditions, and notably, the spectra of group (1) exhibited an enhanced symmetric component. This result suggests that while alternating sputtering is effective for efficient spin current generation, its effect may not appear under certain deposition conditions.

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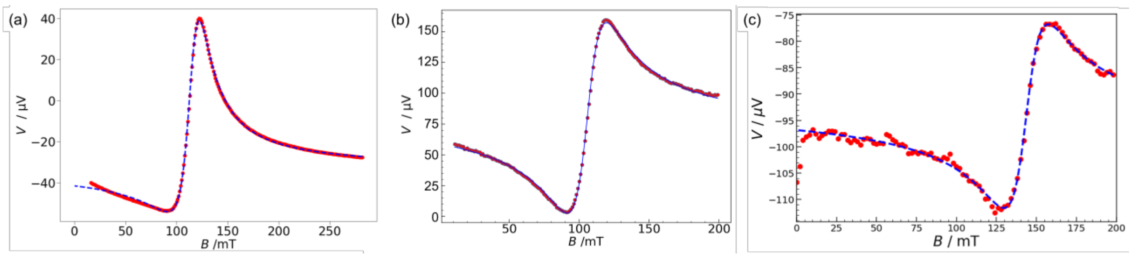

Fig. 1. The representative ST-FMR spectra for (a) group (1), (b) group (2), and (c) group (3).

P-13

Epitaxial growth and characterization of a superconducting Sn/InSb heterostructure on GaAs substrates

Shingen Miura[1,*], Hirotaka Hara[1], Tomoki Hotta[1], Hideki Maki[1], Masaaki Tanaka[1,2] and Le Duc Anh[1,2]
[1]*Department of Electrical Engineering and Information Systems, The University of Tokyo*
[2]*Center for Spintronics Research Network (CSRN), The University of Tokyo*
*E-mail: shingen-miura0516@g.ecc.u-tokyo.ac.jp

Topological superconductivity has drawn great interest as a foundation for fault-tolerant quantum computation due to the potential emergence of Majorana fermions that are protected from external disturbance [1]. To explore such superconductivity, we investigated Sn/InSb heterostructures grown on semi-insulating GaAs (001) substrates by molecular beam epitaxy (MBE). Using InSb buffer layers effectively reduced the lattice mismatch, enabling coherent epitaxial growth of α-Sn, as confirmed by reflection high-energy electron diffraction (RHEED) and X-ray diffraction (XRD) measurements. The XRD spectrum shows clear diffraction peaks from both α-Sn and β-Sn, indicating the coexistence of the two phases (Fig.1 (a)).

Electrical transport measurements revealed a superconducting transition at $T_C \approx 3.7$ K, consistent with β-Sn. Notably, the in-plane critical magnetic field exhibited twofold angular symmetry independent of the current direction; this is an unconventional feature that cannot be explained by conventional isotropic β-Sn superconductivity alone (Fig.1 (b)). This anisotropy can be attributed to proximity-induced superconductivity in α-Sn from neighboring β-Sn regions (Fig. 1 (c)). Since the α-Sn is a topological Dirac semimetal, such proximity-induced superconductivity may lead to the realization of a topological superconducting state with an anisotropic energy gap [2, 3].

These findings demonstrate the successful epitaxial growth of α-Sn/β-Sn mixed films on insulating GaAs substrates and highlight their potential as a promising platform for realizing unconventional superconductivity.

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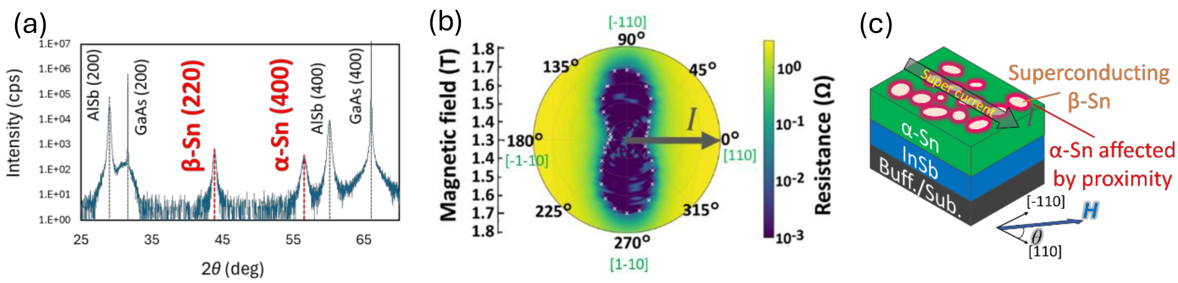

Fig.1 (a) XRD pattern of the sample used in the experiment, showing peaks corresponding to β-Sn and α-Sn phases. (b) Polar plot of the electrical resistance as a function of the in-plane magnetic field angle θ (on a logarithmic scale). The resistance shows maxima at $\theta = 90°$ and $\theta = 270°$, indicating in-plane anisotropic superconductivity with two-fold symmetry in the Sn film. (c) Schematic illustration of the Sn/InSb heterostructure. Supercurrent I flows along the $[110]$ direction, while the magnetic field H is applied in-plane and rotated at an angle θ from the I direction. Island-like β-Sn induces superconductivity throughout the α-Sn layer via the proximity effect.

Eco-Sustainable Printed Magnetoresistive Sensors

Lin Guo[1], Xiaotao Wang[1], Proloy Taran Das[1], Yevhen Zabila[1], Tetiana Voitsekhivska[1], Eduardo Sergio Oliveros-Mata[1], Oleksandr Pylypovskyi[1], Rico Illing[1], Conrad Schubert[1], Ihor Veremchuk[1], Denys. Makarov[1]

[1] Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden- Rossendorf e.V. (HZDR), 01328 Dresden, Germany

Magnetoresistive sensors, capable of non-contact detection of magnetic fields and consequently relative motion, have been extensively used across a broad spectrum of applications, ranging from environmental monitoring and industrial automation to biomedical diagnostics and the Internet of Things (IoT). Owing to their functional versatility, over 100 billion magnetoresistive sensor units were deployed globally in 2022, with market projections estimating that this number could exceed 1 trillion units by 2030. Meanwhile, the massive deployment of magnetoresistive sensor arise the sustainability concerns from two aspects: 1. Carbon footprint in fabrication. 2. Electronics waste (E-waste) issue at the end of their lifetime. Here, we propose the printed eco-sustainable magnetoresistance sensors. First, the printed processing offer low-cost, energy-efficiency and scalable production, significantly reduce the carbon footprint during the fabrication[1,2]. Second, we explored the printed recyclable giant magnetoresistance (GMR) and anisotropic magnetoresistance (AMR) sensors by GMR micro-flakes and AMR micro-particles fillers with polyepichlorohydrin (PECH) binder[3]. The printed MR sensors exhibited reliable MR performance and achieved completely recycling by acetone solvent and permanent magnets. Further, we developed a fully green printed magnetoresistance with Fe@Fe_3O_4 core-shell particles as functional filler, carboxymethyl cellulose as matrix binder, and water as solvents. Given that the skill-fully engineered magnetic structure and spin dependent transport, the printed sensors exhibit the remarkable low field magnetoresistance and sensitivity. Take merits of the low carbon footprint and scalable fabrication, fully green raw materials and recyclability of the printed MR sensors, we developed an effective approach to design eco-sustainable MR sensors, and demonstrated a promising pathway for the future eco-sustainable electronics.

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P-15

Flexible and printed spintronic magnetic field sensors

Content

Work with spintronic functional elements for flexible magnetic field sensors, we were interested in improving their performance, relying on new materials and metrological approaches. We employ novel fabrication technics as an alternating magnetic field activation of self-healing of percolation network [1]. It allows to fabricate printable magnetoresistive sensors revealing an enhancement in sensitivity of more than one and two orders of magnitude, relative to previous reports. Printed electronics are attractive due to their low-cost and large-area processing features, which have been successfully extended to magnetoresistive sensors and devices [2]. This technology was enabled initially, by thin films magnetic field sensors, embedded in a soft and flexible format to constitute magntosensitive electronic skin (e-skins). But now we demonstrate what interactive electronics, based on flexible spin valve switches [3] or printed and stretchable Giant Magnetoresistive Sensors, could act also as a logic elements, namely momentary and permanent (latching) switches. All this printing technology aspects are yet to be developed to comply with requirements to mechanical conformability of on-skin appliances. Due to the fact that the metallic layer is subjected to unsteady mechanical stresses, deposition of the magnetic sensor onto few microns thick non-rigid substrate creates numerous problems, and the strain sensitivity is the first effect which have to be discussed. The thermoelectric effect is the second effect that also have to be considered in order to minimize thermal errors. These aspects will be discussed more detailed in this contribution.

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Author: Mu, Guannan (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany)
Co-authors: Dr ZABILA, Y. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Prof. ALBRECHT, M. (University of Augsburg, Augsburg, Germany); Prof. BARUCCA, G. (Università Politecnica delle Marche, Ancona, Italy); Dr CAÑÓN BERMÚDEZ, S. (HZDR); Dr FAGIANI, F. (Politecnico di Milano, Milano, Italy); Prof. FASSBENDER, J. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Dr HA, M. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Dr HASSAN, M. (Università Politecnica delle Marche, Ancona, Italy); Dr ILLING, R. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Prof. IONOV, L. (University of Bayreuth, Bayreuth, Germany); Dr KOSUB, T. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); LAURETI, S. (Consiglio Nazionale delle Ricerche, Roma, Italy); Dr MAKAROV, D. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Mr MAKUSHKO, P. (HZDR); Mr MILKIN, P. (University of Bayreuth, Bayreuth, Germany); Dr MÖNCH, I. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Dr OLIVEROS MATA, S. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Dr PYLYPOVSKYI, O. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Prof. RINALDI, C. (Politecnico di Milano, Milano, Italy); Dr SCHMIDT, N. (University of Augsburg, Augsburg, Germany); Dr VARVARO, G. (Consiglio Nazionale delle Ricerche, Roma, Italy); Prof. VLADYMYRSKYI, I. (Paton Institute of material Science and Electric Welding, Kyiv, Ukraine); Dr VOLKOV, O. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); WANG, Y. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany); Dr XU, R. (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany)

Presenter: Mu, Guannan (Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany)

TEMPERATURE GRADIENT-DRIVEN MOTION OF MAGNETIC DOMAINS IN A MAGNETIC METAL MULTILAYER BY ENTROPIC FORCES

LIN HUANG[1,2], JOSEPH BARKER[1], LEKSHMI KAILAS[1], SOUMYARUP HAIT[1], SIMON D. CONNELL[1], GAVIN BURNELL[1], & CHRISTOPHER H. MARROWS[1]*

[1]School of Physics and Astronomy, University of Leeds, Leeds, United Kingdom
[2]School of Material Science, University of Sheffield, Sheffield, United Kingdom
**email: c.h.marrows@leeds.ac.uk*

We studied the displacement of magnetic domains under temperature gradients in perpendicularly magnetized Ta/[Pt/$Co_{68}B_{32}$/Ir]×10/Pt multilayer tracks with microfabricated Pt heaters/thermometers by magnetic force microscopy (MFM). Subtracting out the effects of the Oersted field from the heating current reveals the pure temperature gradient-driven motion, which is always towards the heater. An example is shown in Figure 1. The larger the thermal gradient along the track (owing to proximity to the heater or larger heater currents), the larger the observed displacements of the domains, up to a velocity of around 1 nm/s in a temperature gradient of 20 K/μm. Quantitative estimates of the strength of different driving mechanisms shows that entropic forces [1] dominate over spin Seebeck (magnon) [2] and spin-dependent Seebeck (electron) [3] effects.

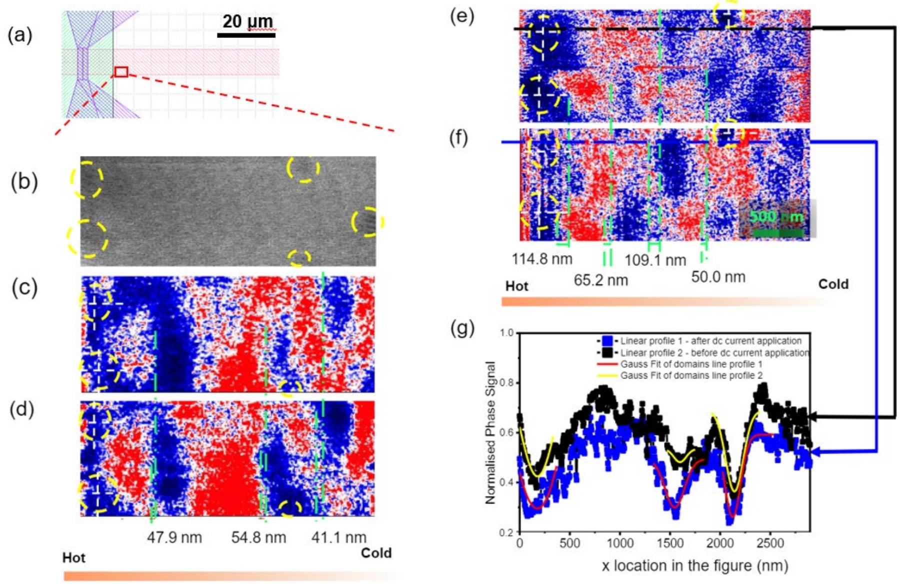

Fig 1: MFM imaging of thermally-induced domain motion. (a) Schemetic of magnetic track (red) spanned by electrically isolated (green) Pt heater/thermometer (purple). (b) MFM image when the track is fully saturated in +700 Oe. The dark regions in the dashed yellow circles are defects on the track surface. (c) and (d) are the MFM images in +30 Oe before and after a +30 mA current was applied to the heater, respectively. Dashed green lines indicate position of the leading edge of the reverse domains. (e) and (f) MFM images in +30 Oe before and after a -30 mA current was applied to the heater, respectively. Dashed blue and black lines indicate the positions of the line profiles that are shown in (g).

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Unconventional computing with spintronic devices

Giovanni Finocchio,[1]*

[1] *University of Messina, Italy*

* gfinocchio@unime.it

Ising machines (IMs) represent a promising hardware-friendly unconventional computing paradigm for solving combinatorial optimization problems (COPs)[1-2]. These machines operate by searching the ground state of an Ising Hamiltonian. In this talk, I will focus on probabilistic computing, a computational paradigm using probabilistic units (p-bits, or p-dits)[3] in the middle between traditional electronics and quantum technology. I will show how to map hard combinatorial optimization problems (Max-Sat, Max-Cut, etc) into Ising machine and how to implement those in spintronic technology.[4]

The hardware implementation of a PIM with spintronics introduces variability between devices. We study the effect of this non-ideal behavior on the success probability of solving several COPs and we compare the three well-known energy minimization algorithms: simulated annealing (SA), parallel tempering (PT) and simulated quantum annealing (SQA). The results demonstrate that SQA consistently outperforms both SA and PT, showing remarkable robustness to device variability.[5]

Another popular paradigm in the physical implementation of IMs is oscillator-based Ising machines (OIMs), where the computational units are frequency-locked oscillators. We investigate MTJs working as spin-torque nano-oscillators, which serve as the building blocks for this paradigm. Furthermore, we propose an adaptive IM, an approach that integrates the advantages of both PIMs and OIMs into a unified dynamic system. Specifically, single MTJ-based hardware can be leveraged to implement both paradigms, thereby reducing the area footprint by half and eliminating the bottleneck associated with state transitions between the two paradigms.

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Spin-to-charge conversion in epitaxial Mn3Sn(0001) noncollinear antiferromagnetic films

Surya N. Panda[1], Ning Mao[1], Nikolai Peshcherenko[1], Xiaolong Feng[1], Yang Zhang[2,3], Anastasios Markou[4], Claudia Felser[1], and Edouard Lesne[1,*]
[1]Max Planck Institute for Chemical Physics of Solids, 01187 Dresden, Germany
[2]Department of Physics and Astronomy, University of Tennessee, Knoxville, Tennessee 37996, USA
[3]Min H. Kao Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, Tennessee 37996, USA
[4]Physics Department, University of Ioannina, 45110 Ioannina, Greece
* edouard.lesne@cpfs.mpg.de

The generation and control of spin currents are crucial for advancing next-generation spintronic technologies. These technologies depend on materials capable of efficiently sourcing and interconverting spin and charge currents, while overcoming some limitations associated with conventional ferromagnets and heavy metals. Kagome topological antiferromagnetic Weyl semimetals, such as Mn_3Sn, present unique advantages owing to their distinct magnetic order and significant Berry curvature-driven charge and spin transport phenomena [1-3].

In this study [4], we systematically investigate spin current generation via ferromagnetic resonance spin pumping and spin-to-charge conversion phenomena in epitaxial (0001)-oriented Mn_3Sn thin films. Our findings reveal a moderate spin Hall angle of 0.9% and a nearly isotropic in-plane spin Hall conductivity of 44.4 ($\hbar$/e) $\Omega^{-1}.cm^{-1}$ at room temperature. The lack of anisotropy of the inverse spin Hall effect (ISHE) across two inequivalent crystallographic directions of hexagonal Mn_3Sn suggests a competitive interplay between the intrinsic ISHE of topological origin driven by spin Berry curvature, and various extrinsic mechanisms. Nonetheless, in $Mn_3Sn(0001)/Ni_{81}Fe_{19}$ heterostructures, we observe a high spin-mixing conductance of 28.52 nm^{-2} and an interfacial spin-transparency of approximately 72%. Notably, we also find that the spin diffusion length in $Mn_3Sn(0001)$ epitaxial films exceeds 15 nm at room temperature. Our results highlight the potential and limitations of the topological Weyl noncollinear antiferromagnet Mn_3Sn as an efficient material for spin transport and conversion in prospective spintronic applications.

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From novel concepts to reliable devices, research on Spintronics in a modern CMOS cleanroom.

Benjamin Lilienthal-Uhlig*, Meike Hindenberg, Christoph Durner, Maximilian Sohr, Tatiana Gurieva

Fraunhofer IPMS, An-der-Bartlake 5, 01099 Dresden, Germany

* Benjamin.Lilienthal-Uhlig@ipms.fraunhofer.de

5-4

Spintronics, the study of spin-dependent electronic phenomena, holds tremendous promise for revolutionizing next-generation computing technologies. This presentation explores the different challenges and opportunities regarding the transfer from fundamental research to practical device implementation within a state-of-the-art CMOS cleanroom environment (Figure 1).

Fig. 1: 300mm wafer-level PVD tool for MTJ stack deposition.

Within an exemplary framework, we will showcase a range of projects undertaken by our research group. Starting from the development of tailored stack configurations for Tunnel Magnetoresistance (TMR) sensors and Spin-Transfer Torque Magnetoresistive Random Access Memory (STT MRAM), as well as Racetrack Memory, we will additionally delve into advanced array-level device measurements specifically designed for automotive MRAM applications [1], addressing the growing demand for reliable and high-performance memory solutions. Apart from this, also novel concepts such as cryogenic spintronic memory devices or applications in the field of neuromorphic computing [2] will be discussed, underscoring their potential in future computing architectures.

Overall, this talk will emphasize the importance of bridging the gap between fundamental academic research and practical industrial applications. By leveraging the capabilities of a CMOS cleanroom, we can facilitate the transition from theoretical concepts to robust, scalable devices, ultimately paving the way for the integration of spintronic technologies into mainstream applications.

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Control of a Compensation Temperature in a Ferrimagnetic Heusler alloy

Esita Pandey,[1] Shogo Yamashita,[1] Edouard Lesne,[1] Gerhard Fecher,[1] Hiroki Koizumi,[2] A Young Lee,[2] Claudia Felser[1] and Atsufumi Hirohata[1,2,*]

[1] *Max Planck Inst. Chem. Phys. Solids, Germany*

[2] *Tohoku University, Japan*

* atsufumi.hirohata.d1@tohoku.ac.jp

In spintronic devices, an antiferromagnet and ferrimagnet has been attracting intensive attention due to their a small intrinsic magnetisation and THz oscillation [1]. Heusler alloys have a potential to exhibits these magnetism with maintaining their half-metallicity [2]. For the ferrimagnetic device applications, it is necessary to expand the compensation temperature range by controlling the spin density of states in a Heusler alloy.

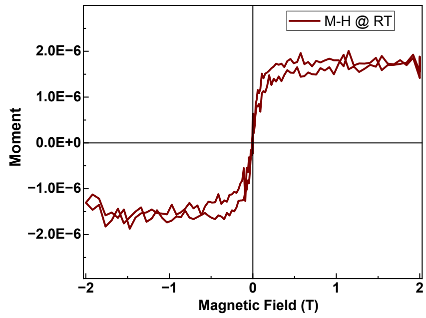

Fig. 1 Magnetisation curve of a MnFeVAl film.

In this study, we predicted a series of fully-compensated ferrimagnetic Heusler alloys using first-principles calculations and grew them on a thermally-oxidised Si substrate with a Ta and W seed layer using combinatorial sputtering in an ultrahigh vacuum. The films were then annealed at a temperature between 400 and 600 ºC for 1-2 hours, followed by structural and magnetic characterisation by X-ray diffraction, energy dispersive X-ray spectroscopy and physical property measurement system. Figure 1 shows a representative magnetisation curve of Ta (10)/W (7.5)/MnFeVAl (60)/Ta (7) (thickness in nm) measured at room temperature. The film was found to be crystallised in the *B*2 phase with the saturation magnetisation of ~2 emu/cm^3, almost agreeing with the calculation on $Mn_{1.5}FeV_{0.5}Al$ [3]. We will discuss further development on the optimisation of the fully-compensated ferrimagnets.

Acknowledgements: This study has been financially supported by ERC Advanced Grant “SAHAJ” and JST Aspire Program “SpinMaD”.

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Spin transport and spin-charge interconversion in graphene and TMDs

T. Thomson[1, *], D. Burrow[1], H. DeLibero[1], O. Deveci[1], R. Dragomir[1], E. Chalmers[2], N. Natera-Cordero[2], A. Strudwick[2] and Ivan vera Marun[1]

[1] *University of Manchester, UK*

[2] *GEIC, Manchester, UK*

* thomas.thomson@manchester.ac.uk

6-2

Since graphene was first isolated its potential as a material for spintronics has been explored [1]. The low spin-orbit coupling of graphene makes it a natural candidate as a spin transport channel [2]. However, spintronic functionality also requires layers capable of generating, manipulating and detecting spin through spin-charge interconversion, typically using spin Hall effects (SHE) and spin orbit torques (SOT). In this presentation, our recent results in creating ballistic, spin-coherent transport in hBN/Gr/hBN devices, fig.1, with 1D magnetic contacts will be described. Transverse magnetic focusing in a graphene device, allows coupling of the spin and orbital degrees of freedom through charge transfer doping and proximity exchange at the ferromagnetic contacts. This coupling provides a gate-tuneable modulation of both the amplitude and polarity of the spin signal, reminiscent of the functionality of a Datta-Das spin field-effect transistor. These results demonstrate a new operational principle for spintronic devices based on spin-dependent electron optics in low spin-orbit coupling materials.

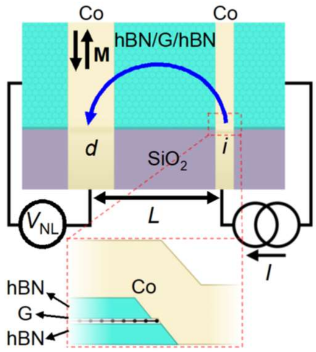

Fig. 1 Schematic of a device set up in the non-local measurement configuration.

In addition to spin transport, this presentation will also describe work to understand spin-charge interconversion in 2D materials where research is at an earlier stage of development. We focus on transition metal dichalcogenides (TMD) grown by CVD as these provide a clear route to creating wafer-scale devices [3]. In our investigation we measure spin pumping effects using ferromagnetic resonance spectroscopy (FMR) in TMD/Ferromagnetic (FM) heterostructures specifically, $MoS_2/Ni_{0.8}Fe_{0.2}$ bilayers with varying $Ni_{0.8}Fe_{0.2}$ thicknesses. Our results show a lower contribution to the phenomenological damping parameter (α) from surface effects than control films deposited on SiO_2. A reduction in surface damping is often attributed to a drop in spin pumping, so here the implication is that other interfacial effects such as spin-memory loss must also be considered in determining the physical origin of the measured damping parameter.

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6-3

Altermagnetic spintronics and multiferroics

Libor Šmejkal[1]*

[1] *Max Plank Institute for the Physics of Complex Systems, 01187 Dresden, Germany*

* lsmejkal@uni-mainz.de

In the first part of the talk, we introduce the theoretical framework of spin symmetries [1–2] and the unconventional magnetic classes delimited by spin symmetries known as altermagnets—characterized by d-, g-, or i-wave spin-polarized order [1–3]—as well as antialtermagnets, which host p-, f-, or h-wave spin order [4-5]. We also discuss the recent direct experimental observation of altermagnetism in photoemission spectra [6-7], guided by our theoretical predictions [1].

In the second part, we highlight emerging research directions in spintronics and multiferroics driven by spin-symmetry concepts based on unconventional sustainable magnetic materials [8]. Topics will include topological quasiparticles in antiferromagnets and altermagnets and their role in enhancing the spin Hall effect [2,9]; giant and tunneling magnetoresistance[10] and nonlinear-current-induced spin polarization in altermagnets [11]; and the altermagnetoelectric effect, see Fig. 1, in altermagnetic multiferroics [3].

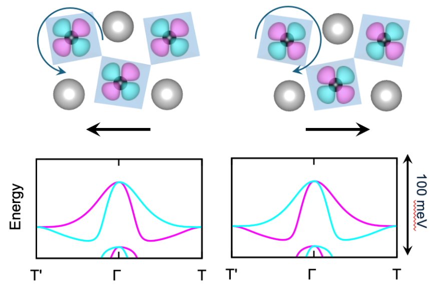

Fig. 1 Altermagnetoelectric effect: reversing applied electric field (black arrows in top panels) controls the altermagnetic d-wave order (top panels) and spin polarisation (bottom panels) in the electronic band structure.

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Spin-Polarized Bands of Atomic Layer Superconductors

Yuichiro Toichi,[1] Tatsuya Shishidou,[2] Yuki Higuchi,[1] Sven Schemmelmann,[3] Fabian Schöttke,[3] Shunsuke Tsuda,[4] Koichiro Yaji,[4] Jun Fujii,[5] Jacek Osiecki,[6] Mats Leandersson,[6] Craig Polley,[6] Michael Weinert,[2] Markus Donath[3] and Kazuyuki Sakamoto[1,7,*]

[1] *Department of Applied Physics, The University of Osaka, Japan*
[2] *Department of Physics, University of Wisconsin-Milwaukee, USA*
[3] *Physikalisches Institut, Universität Münster, Germany*
[4] *Center for Basic Research on Materials, National Institute for Materials Science, Japan*
[5] *Istituto Officina dei Materiali, Consiglio Nazionale delle Ricerche (CNR-IOM), Italy*
[6] *MAX IV Laboratory, Lund University, Sweden*
[7] *Spintronics Research Network Division, OTRI, The University of Osaka, Japan*
* kazuyuki_sakamoto@ap.eng.osaka-u.ac.jp

The combination of spin-polarized bands with superconductivity may lead to the formation of novel superconducting states [1], which are indispensable for creating superconducting spintronics devices, and it is therefore interesting to investigate the electronic states of superconductors composed of heavy elements with strong spin-orbit coupling (SOC). Thallium (Tl) and Indium (In) are such heavy elements, known to exhibit superconductivity below critical temperatures of approximately 2.4 K [2] and 3.4 K [3] in their bulk phase and approximately 0.9 K [4,5] and 3 K [6] in bilayer films formed on solid surfaces. Furthermore, bulk Tl has been reported to possess an ideal electronic state that harbors the chiral Majorana mode [7]. In this talk, I will present the spin-polarized electronic states of the Tl and In bilayer superconductors and discuss their origins, especially the origins of the spin-polarized states that cannot be explained by the ordinary so-called Rashba effect and Zeeman effect. The effects of organic molecule adsorption to the Tc of one of these superconducting ALMs, the In bilayer, and the role of the spin-orbit coupling on the superconducting state will also be presented.

7-1

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Spin diffusion probe of magnetization frustration

Ning Mao[1], Shu Zhang[2,3], Claudia Felser[1] and Yang Zhang[4,5]

[1] *Max Planck Institute for Chemical Physics of Solids, 01187, Dresden, Germany*

[2] *Collective Dynamics and Quantum Transport Unit, Okinawa Institute of Science and Technology Graduate University, Japan*

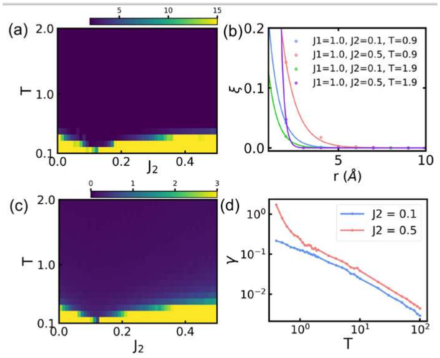
[3] *Max-Planck-Institute for Physical Complex System, 01187 Dresden, Germany*

[4] *Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996, USA*

[5] Min H. Kao Department of Electrical Engineering and Computer Science, University of Tennessee, Knoxville, Tennessee 37996, USA

* Presenter's email address: Ning.Mao@cpfs.mpg.de

We develop a diffusive framework to describe finite-temperature dynamics in J1-J2 Heisenberg model, and propose that spin diffusion constant can serve as a probe of the frustration. Using a SLN approach, we derive an analytic form of the dynamical correlation function that depends solely on the spin diffusion constant. Comparison with large-scale spin-dynamics simulations on the order of 10^4 spins demonstrates



excellent agreement across all timescales and momentum scales. The phase diagram of γ is further consistent with that obtained from the spin correlation length, indicating that our model captures the full finite-temperature behavior. To test its universality, we compute the spin conductivity σs and susceptibility χ via the Kubo formula and find that σs/χ coincides with γ, even without assuming diffusive transport. These results establish the spin diffusion constant as a quantitative measure of frustration in magnetic systems.

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7-2

Magnetoacoustics and magnon-polarons in surface acoustic wave devices

Mathias Weiler*

RPTU Kaiserslautern-Landau, Kaiserslautern, Germany

* mweiler@rptu.de

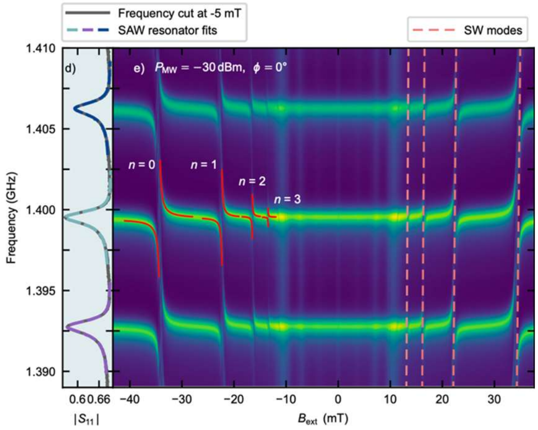

Fig. 1: Avoided crossing of SAW and SW modes in a magnetoacoustic resonator [6].

Spin waves form the basis for the field of magnonics, where they are used for information transport and processing [1]. Acoustic waves, in particular surface acoustic waves (SAWs), are widely employed as frequency filters in mobile communication technology. Spin waves and SAWs have comparable group velocities and wavelengths and are typically operated at microwave frequencies. In magnetic media, spin waves can interact with SAWs which defines the field of magnetoacoustics. Magnetoacoustic devices can be used to excite and detect magnetization dynamics acoustically and control SAW propagation magnetically [2-4].

8-1

Magnons and phonons can hybridize in surface magnetoacoustic wave resonators [5,6]. To explore this hybridization in low-loss materials, we use a hybrid structure consisting of yttrium iron garnet (YIG) magnetic films and ZnO – based SAW resonators. In our heterostructures, a magnon-polaron forms due to the strong coupling of SAWs and spin waves (SW) with degenerate dissipation rates below 1.5 MHz as evidenced by the avoided crossing of acoustic and magnonic dispersions (see Fig. 1) and Rabi-like oscillations of the magnon-phonon quasiparticle in the time-domain [6]. The hybridization is well described by a phenomenological model that accounts for the spatial profiles of both magnon and phonon modes.

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Magnon-phono coupling using the multi-overtones surface acoustic wave device

KAZUTO YAMANOI[1]*, YUKIO NOZAKI[1, 2]

[1*]Department of Physics, Keio University, Yokohama 223-8522, Japan
[2]Center for Spintronics Research Network, Keio University, Yokohama 223-8522, Japan
*k.yamanoi@keio.jp

The coupling between spin waves and surface acoustic waves (SAWs), known as magnon-phonon coupling, plays a pivotal role in the development fo magnon-based logic devices. This coupling is strongest where the dispersion relations of spin waves and SAWs intersect. Recently, acoustic cavity structures have attracted significant attention as a means to achieve magnon–phonon strong coupling, enabling hybrid states that could advance coherent information processing, quantum technologies, and novel spintronic functionalities.

In this study, we developed a high-Q acoustic resonator based on a metamaterial design to enhancement magnon-phonon coupling. As shown in Fig. 1(a), interdigital transducers (IDTs) with a multilayer Ti (2 nm)/ Al (50 nm)/ Ti (2 nm) structure were fabricated on a $LiNbO_3$ substrate using the lift-off method. Acoustic reflectors were added on both sides of the IDTs to confine the SAWs and form a resonant cavity efficiently.

Figure 1(b) shows the transmission signal measured with a vector network analyser (VNA). The fundamental SAW mode around 0.21 GHz matches well with the theoretical prediction for an IDT period of 16 μm. Notably, we observed higher harmonics up to ~6.6 GHz, confirming the potential of high overtone SAW resonators. We also discuss Q-factor enhancement achieved through metamaterial structuring and its implications for creating magnon-phonon strong coupling.

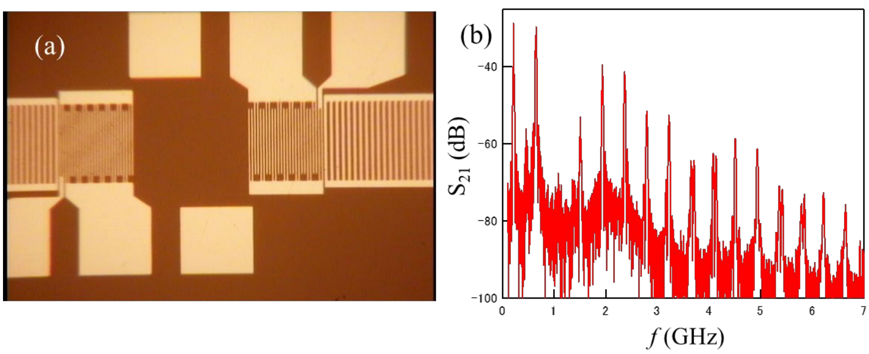


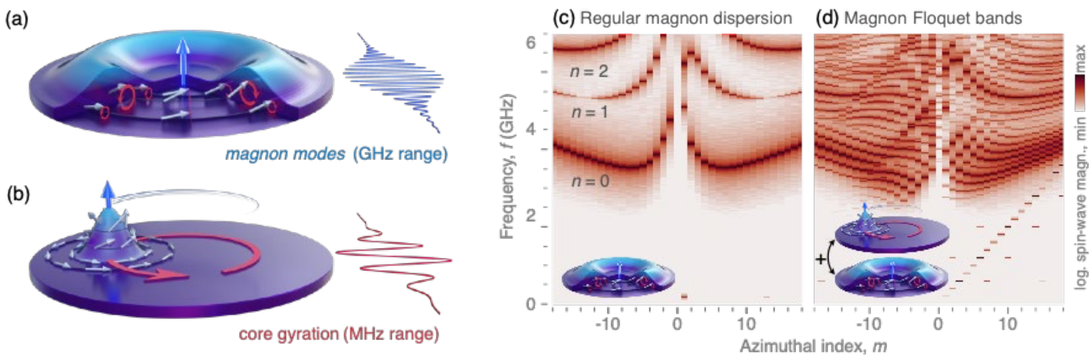
Fig. 1(a) Optical micrograph of Fabry–Pérot type acoustic resonator. (b) Frequency dependence of the transmission signal of the multiple overtones surface acoustic wave device.

8-3

How a nano-core shatters the collective of an entire vortex

Christopher Heins[1], Lukas Körber[3], Joo-Von Kim[4], Thibaut Devolder[4], Johan H. Mentink[3], Attila Kákay[1], Jürgen Fassbender[1,2], Katrin Schultheiss[1]*, Helmut Schultheiss[1,2]*
[1]Helmholtz-Zentrum Dresden–Rossendorf
Institut für Ionenstrahlphysik und Materialforschung, Dresden, Germany
[2]Fakultät Physik, Technische Universität Dresden, Germany
[3]Radboud University, Institute of Molecules and Materials,
Nijmegen, The Netherlands
[4]Centre de Nanosciences et de Nanotechnologies,
CNRS,Université Paris-Saclay France
*k.schultheiss@hzdr.de, * h.schultheiss@hzdr.de

Magnetic vortices are prominent examples for topology in magnetism with a rich set of dynamic properties. They exhibit an intricate magnon spectrum and show a special eigen-resonance of the vortex texture itself, the gyroscopic motion of the vortex core. While there has been studies about magnon assisted reversal of the vortex core polarity, the impact of the vortex core motion on the magnon spectrum wasn't addressed so far. Both excitation types are clearly separated by one order of magnitude in their resonance frequencies, where magnons are in the lower GHz range and the vortex typically gyrates at a few hundred MHz. This clear separation allows for experiments studying the temporal evolution of the magnon spectrum when the motion of the vortex core is driven by an external stimulus. We present experimental and numerical studies on how the magnon eigenstates are transformed into Floquet bands, when the vortex ground state is periodically modulated intime by the gyroscopic motion of the vortex core. The existence of the Floquet bands is evidenced by the appearance of magnon frequency combs, where the comb spacing is determined by the frequency of the gyroscopic motion.



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