# The 2020 Around-the-Clock Around-the-Globe Magnetics Conference

IEEE MAGNETICS

27th of August 2020

## *Program Booklet*

*Brought to you by the IEEE Magnetics Society*

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# Program Overview

## General Conference Information

Welcome to the 2020 Around-the-Clock Around-the-Globe (AtC-AtG) Magnetics Conference, sponsored by the IEEE Magnetics Society! This brand new conference is a global virtual event that runs for **24 consecutive hours**. It allows scholars worldwide to present research during their local daytime (*or morning, or evening for some!*) by progressing through global time zones. The technical program includes 9 invited talks or tutorials from senior scientists in the international magnetics community and 70 contributed oral presentations from graduate students and post-doc researchers worldwide. This conference is organized by the newest generation of magnetics professionals (featuring graduate students and post docs from around the globe), aiming to provide an opportunity for worldwide participants to meet and discuss the development in some areas of magnetism research during this challenging time of the COVID-19 global pandemic.

The AtC-AtG conference is divided into three consecutive virtual sessions based on the geographic locations and time zones; they are 1) Asia-Pacific, 2) Europe-Middle East-Africa, and 3) Americas. These sessions will be hosted on the Zoom virtual conferencing platform by subcommittees located in different regions of the world. To register and for more information please go to ieeemagnetics-atc-atg

**The AtC-AtG conference is sponsored by:**

IEEE MAGNETICS

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## Conference Policies

Attendees should not record the talks given during this conference.

## Best presentation award

The best oral presentation competition, sponsored by the IEEE Magnetics Society recognizes and encourages excellence in research in fields of magnetism. All participants accepted for contributed talks are automatically enrolled in the competition. There will be a total of 9 Best Presentation winners (among the 70 contributed talks), 3 from each region (Asia - Pacific, Europe - Middle East - Africa, and the Americas), each of whom will be awarded a cash prize of $500 (USD). Winners will be selected by the program committee and will be announced at the end of each conference channel. If willing, the winners will get an opportunity to share their recorded presentations online after the live conference.

## Upcoming Conferences

"The Online Spintronics Seminar Series (OSSS) helps scientists working in the field of spintronics to present their research to colleagues and the general public. The series was created when many universities and research institutions were locked down and conferences canceled due to the COVID-19 pandemic. We hope the OSSS helps scientists to continue sharing new results and gives students from around the world an opportunity to learn from the experts."
To register and for more information please go to www.spintalks.org

MMM2020
Palm Beach, Florida
Nov 2 - 6, 2020

"The 2020 Magnetism and Magnetic Materials Conference (November 2-6, 2020) includes all aspects of fundamental and applied magnetism, with sessions reviewing the latest advances in magnetic materials, emerging applications, new phenomena, spin electronics, energy and power applications, biomagnetism and much more."
For registration and more information please go to https://magnetism.org

# AtC-AtG Conference Program Agenda

## Region 1: Asian/Pacific Area

**09:00 to 18:00 – Tokyo time (GMT +9)**

| | |
|---|---|
| 08:50 - 09:00 | **Opening remarks** Advisory Board Member |
| 09:00 – 10:30 | Session 1-1 |
| 10:30 - 11:30 | **Invited talk** Prof. Yoshichika Otani (UoT, Japan) |
| 11:30 - 13:00 | Session 1-2 |
| 13:00 - 14:00 | **Invited talk** Prof. Hyunsoo Yang (NUS, Singapore) |
| 14:00 - 15:30 | Session 1-3 |
| 15:30 - 16:30 | **Invited talk** Prof. Anjan Barman (SNBNCBS, India) |
| 16:30 - 17:45 | Session 1-4 |
| 17:45 - 18:00 | **Closing remarks** Advisory Board Member |

## Region 2: Europe/Middle East/Africa

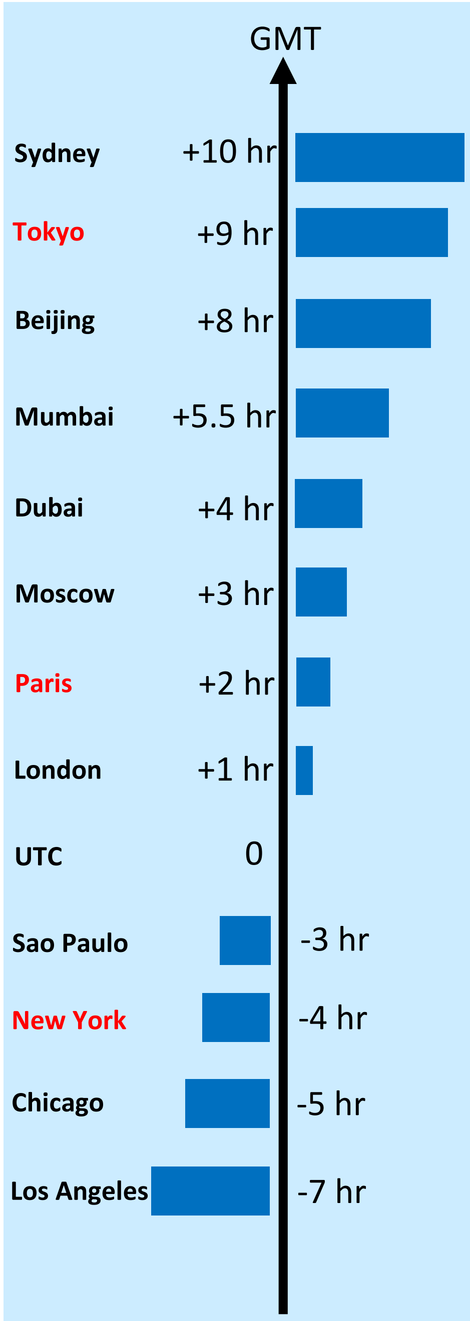
**10:00 to 19:00 – Paris time (GMT +2)**

| | |
|---|---|
| 09:50 - 10:00 | **Opening remarks** Advisory Board Member |
| 10:00 - 11:30 | Session 2-1 |
| 11:30 - 12:30 | **Invited talk** Dr. José Maria Porro (BCMaterilas, Spain) |
| 12:30 - 14:00 | Session 2-2 |
| 14:00 - 15:00 | **Invited talk** Prof. Mathias Kläui (JGU, Germany) |
| 15:00 - 16:30 | Session 2-3 |
| 16:30 - 17:30 | **Invited talk** Dr. Anna Semisalova (UDE, Germany) |
| 17:30 - 18:45 | Session 2-4 |
| 18:45 - 19:00 | **Closing remarks** Advisory Board Member |

## Region 3: North/South America

**11:50 to 21:15 – New York time (GMT -4)**

| | |
|---|---|
| 11:50 - 12:00 | **Opening remarks** Advisory Board Member |
| 12:00 - 13:30 | Session 3-1 |
| 13:30 - 14:30 | **Invited talk** Dr. Mark Stiles (NIST, USA) |
| 14:30 - 16:00 | Session 3-2 |
| 16:00 - 17:00 | **Invited talk** Prof. Amal El-Ghazaly (Cornell, USA) |
| 17:00 - 18:30 | Session 3-3 |
| 18:30 - 19:30 | **Invited talk** Dr. Guohan Hu (IBM, USA) |
| 19:30 – 21:00 | Session 3-4 |
| 21:00 – 21:15 | **Closing remarks** Advisory Board Member |



# Invited speakers

1. **Prof. Yoshichika Otani**, University of Tokyo (Japan): "Novel functions observed in a topological antiferromagnet" **10:30 Tokyo Time**
2. **Prof. Hyunsoo Yang**, National University of Singapore (Singapore): "Magnetization switching based on topological spin textures and magnons" **13:00 Tokyo Time**
3. **Prof. Anjan Barman**, S.N Bose Center for Basic Sciences (India): "Spin-orbit effects on spin dynamics" **15:30 Tokyo Time**
4. **Dr. José Maria Porro**, BC Materials (Spain): "Neutron and synchrotron radiation as probes to study magnetic materials" **11:30 Paris Time**
5. **Prof. Mathias Kläui**, Johannes Gutenberg University of Mainz (Germany): "Skyrmion dynamics - from individual ultrafast motion to diffusion and collective crystallization of 2D lattices" **14:00 Paris Time**
6. **Dr. Anna Semisalova**, University of Duisburg-Essen (Germany): "Laterally patterned magnetic landscape in FeAl" **16:30 Paris Time**
7. **Dr. Mark Stiles**, NIST (USA): "Spintronics for neuromorphic computing" **13:30 New York Time**
8. **Prof. Amal El-Ghazaly**, Cornell University (USA): "Tunable magnetoelectric components and devices" **16:00 New York Time**
9. **Dr. Guohan Hu**, IBM (USA): "Materials for STT-MRAM applications" **18:30 New York Time**

# The 2020 Around-the-Clock Around-the-Globe Magnetics Conference

Conference Date: 27th August 2020

## Invited speakers

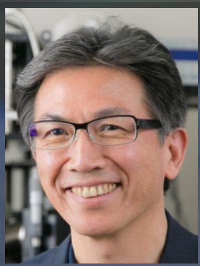
### Asia and Pacific

**Anjan Barman**

S.N. Bose National Centre for Basic Sciences,

India

"Spin-orbit effects on spin dynamics"



**Yoshichika Otani**

The University of Tokyo,

Japan

"Novel functions observed in a topological antiferromagnet"

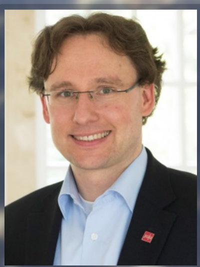
**Hyunsoo Yang**

National University of Singapore,

Singapore

"Magnetization switching based on topological spin textures and magnons"

### Europe, Middle East and Africa

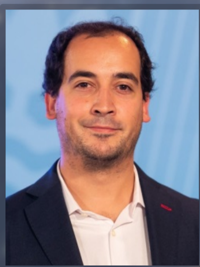


**Mathias Kläui**

Johannes Gutenberg University Mainz,

Germany

"Skyrmion dynamics - from individual ultrafast motion to diffusion and collective crystallization of 2D lattices"



**José Maria Porro**

BCMaterials,

Spain

"Neutron and synchrotron radiation as probes to study magnetic materials"

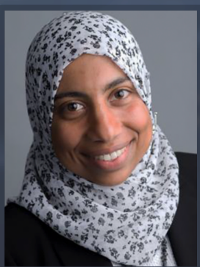
**Anna Semisalova**

University of Duisburg-Essen,

Germany

"Laterally patterned magnetic landscapes in FeAl"

### Americas



**Amal El-Ghazaly**

Cornell University,

USA

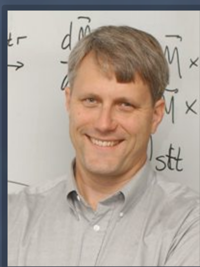
"Tunable magnetoelectric components and devices"

**Guohan Hu**

IBM,

USA

"Materials for STT-MRAM applications"



**Mark Stiles**

National Institute of Standards and Technology (NIST),

USA

"Spintronics for neuromorphic computing"

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# Novel Functions Observed in a Topological Antiferromagnet

27 Aug
10:30
GMT+9

Yoshichika Otani
The University of Tokyo, Japan

Recently a chiral antiferromagnet $Mn_3Sn$ has been demonstrated to exhibit a large anomalous Hall effect (AHE) at room temperature, the magnitude of which reaches almost the same order of magnitude as in ferromagnetic metals irrespective of a tiny spontaneous magnetization of about 1 mT [1]. The first principle calculation revealed that this large AHE originates from a significantly enhanced Berry curvature associated with the formation of Weyl points near Fermi energy [2,3]. Even more, recently detailed comparison between angle-resolved photoemission spectroscopy (ARPES) measurements and density functional theory (DFT) calculations revealed significant bandwidth renormalization and damping effects due to the strong correlation among Mn 3d electrons. Magnetotransport measurements provide strong evidence for the chiral anomaly of Weyl fermions, i.e., the emergence of positive magnetoconductance only in the presence of parallel electric and magnetic fields. In this way, all the characteristic electronic properties of $Mn_3Sn$ imply that the spin Hall effect (SHE) could also take place in the $Mn_3Sn$ [4]. In this study, we set up our device that consists of ferromagnetic NiFe (blue squares) and nonmagnetic Cu electrodes formed on the top surface of a micro-fabricated single crystal of $Mn_3Sn$. We found that antiferromagnets have richer spin Hall properties than nonmagnetic materials, that is, in the noncollinear antiferromagnet $Mn_3Sn$, the SHE has an anomalous sign change when it's triangularly ordered moments switch orientation. Our observations demonstrate that a novel type of contribution to the SHE (magnetic SHE, MSHE) and the inverse SHE (MISHE) that is absent in nonmagnetic materials can be dominant in some magnetic materials, including antiferromagnets. We attribute the dominance of this magnetic mechanism in $Mn_3Sn$ to the momentum-dependent spin splitting produced by the noncollinear magnetic order. This discovery further expands the horizons of antiferromagnet spintronics and motivates a universal outlook on spin-charge coupling mechanisms in spintronics [5]. In this talk, we show experimental results of two complementary experiments, such as detection of spin accumulation induced by the direct SHE and spin pumping induced inverse SHE in $Mn_3Sn$. Our experimental results demonstrate that we could observe the spin accumulation associated with the direct DHE and also the signals due to the inverse SHE. Furthermore, we will discuss antiferromagnetic domain wall dynamics experimentally observed in these novel antiferromagnets [6].

## References

[1] S. Nakatsuji et al., “Large anomalous Hall effect in a non-collinear antiferromagnet at room temperature” Nature, vol. 527, pp. 212–215, 2015.
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[3] H. Yang, et al., "Topological Weyl semimetals in the chiral antiferromagnetic materials Mn3Ge and Mn3Sn", New J. Phys. Vol. 19, pp. 015008, 2017.
[4] K. Kuroda et al., .Evidence for magnetic Weyl fermions in a correlated metal", Nat Mater., vol. 16, pp. 1090, 2017.

[5] M. Kimata et al., “Magnetic and magnetic inverse spin Hall effects in a non-collinear antiferromagnet”, Nature, vol. 565, pp. 627-630, 2019.
[6] S. Sugimoto et al., .Electrical nucleation, displacement, and detection of antiferromagnetic domain walls in the chiral antiferromagnet Mn3Sn",
Communications Physics vol. 3, pp. 111, 2020.

**Biography**

Yoshichika Otani received the B.S., M.S., and Ph.D. degrees from Keio University, Japan, in 1984, 1986, and 1989. He was a research fellow at the Physics Department of Trinity College Dublin, the University of Dublin, Ireland (1989–1991), and a researcher at the Laboratoire Louis Néel, CNRS, France (1991–1992). He was an assistant professor at the Department of Physics, Keio University (1992–1995), and an associate professor at the Department of Materials Science, Tohoku University (1995–2002). From 2001 to 2004, he led the Quantum Nano-Scale Magnetics Research Team at the RIKEN Frontier Research System (FRS) as a team leader. In 2004 he became a professor at the Institute for Solid State Physics (ISSP), the University of Tokyo. Since 2004 he has additionally been the leader of the Quantum Nano-Scale Magnetism Research Team at the RIKEN Center for Emergent Matter Science (CEMS). Prof. Otani has published over 250 technical articles in peer-reviewed journals, including book chapters and review articles, and has given more than 100 invited and plenary presentations at international conferences. He has been coordinating the Nano Spin Conversion Science project, supported by the Japanese Ministry of Education, Culture, Sports, Science, and Technology since 2014 to elucidate the interconversion mechanisms among phonons, photons, magnons, and electrons. He has been a committee member of the Commission on Magnetism (C9) of the International Union of Pure and Applied Physics since 2011 and will become vice chair in 2018.

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# Magnetization Switching based on Topological Spin Textures and Magnons

27 Aug
13:00
GMT+9

Hyunsoo Yang

National University of Singapore, Singapore

Layered topological materials such as topological insulators (TIs) and Weyl semimetals are a new class of quantum matters with large spin-orbit coupling. We reveal spin textures of such materials using the bilinear magneto-electric resistance (BMR), which depends on the relative orientation of the current with respect to crystallographic axes [1,2]. We also visualize current-induced spin accumulation in topological insulators using photocurrent mapping [3]. Topological surface states (TSS) dominated spin orbit torques are identified in $Bi_2Se_3$ [4], and magnetization switching at room temperature using $Bi_2Se_3$ as a spin current source is demonstrated [5]. In order to tackle current shunting issues in TI, we propose two approaches. Weyl semimetals have a larger conductivity compared to TIs and they can generate a strong spin current from their bulk states. We show the current-driven magnetization switching in $WTe_2$/NiFe with a low power [6]. The current shunting issue can be also overcome by the magnon-mediated spin torque, in which the angular momentum is carried by precessing spins rather than moving electrons. Magnon-torque-driven magnetization switching is demonstrated in the $Bi_2Se_3$/NiO/Py devices at room temperature [7]. By injecting the electric current to an adjacent $Bi_2Se_3$ layer, spin currents were converted to magnon torques through an antiferromagnetic insulator NiO. The presence of magnon torque is evident for larger values of the NiO-thickness where magnons are the only spin-angular-momentum carriers. The demonstration reveals that the magnon torque is sufficient to control the magnetization [5]. Looking towards the future, we hope that these studies will spark more works on harnessing spin currents from topological materials and revealing interesting spin textures at topological material/magnet interfaces. All magnon-driven magnetization switching without involving electrical parts could be achieved in the future. The results will invigorate magnon-based memory and logic devices, which is relevant to the energy-efficient control of spin devices.

**References**

[1] P. He et al., “Bilinear magnetoelectric resistance as a probe of three-dimensional spin texture in topological surface states” Nat. Phys. 14, 495 (2018)
[2] P. He et al., “Nonlinear magnetotransport shaped by Fermi surface topology and convexity” Nat. Comm. 10, 1290 (2019)
[3] Y. Liu et al., “Direct visualization of current-induced spin accumulation in topological insulators” Nat. Comm. 9, 2492 (2018)
[4] Y. Wang et al., “Topological Surface States Originated Spin-Orbit Torques in Bi2Se3” Phys. Rev. Lett. 114, 257202 (2015)
[5] Y. Wang et al., “Room temperature magnetization switching in topological insulator-ferromagnet heterostructures by spin-orbit torques” Nat. Comm. 8, 1364 (2017)
[6] S. Shi et al., “All-electric magnetization switching and Dzyaloshinskii–Moriya interaction in WTe2/ferromagnet heterostructures” Nat. Nano. 14, 945 (2019)

[7] Y. Wang et al., “Magnetization switching by magnon-mediated spin torque through an antiferromagnetic insulator” Science 366, 1125 (2019)

**Biography**

Hyunsoo Yang is a Globalfoundries Chaired Professor in the Department of Electrical and Computer Engineering, National University of Singapore (NUS), working on various magnetic materials and devices for spintronics applications. He worked at CS technology, LG Electronics in San Jose, and Intelligent Fiber Optic Systems, California. He received his Doctorate from Stanford University. From 2004-2007, he was at IBM-Stanford Spintronic Science and Applications Center. He has authored 200 journal articles, given 180 invited presentations, and holds 15 patents. He was a recipient of the Outstanding Dissertation Award for 2006 from the American Physical Society (GMAG) and IEEE Magnetics Society Distinguished Lecturers for 2019.

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# Spin-Orbit Effects in Spin Dynamics

27 Aug
15:30
GMT+9

Anjan Barman

S. N. Bose National Centre for Basic Sciences, Salt Lake, Kolkata 700106, India

Ferromagnetic/nonmagnetic (FM/NM) thin film heterostructures show a range of quantum properties, namely, perpendicular magnetic anisotropy (PMA), spin-orbit torque, spin Hall effect (SHE), Rashba effect, spin pumping, and interfacial Dzyaloshinskii - Moriya interaction. The above properties are generally controlled by the spin-orbit coupling and interface plays an essential role in controlling these properties. Besides, they have huge potential applications in new generation spintronic and magnonic devices. Here, we present the investigation of time- and wave-vector-resolved ultrafast spin dynamics in FM/NM thin film heterostructures induced by optical, thermal and spin-orbit-torque excitation using time-resolved magneto-optical Kerr microscope and Brillouin light scattering spectroscopy. We present a unified approach towards investigation and control of spin dynamics occurring between femtosecond and nanosecond timescales in Co/Pd multilayers with PMA [1]. We demonstrate a novel all-optical method to investigate SHE and spin Hall angle (SHA) in FM/NM bilayer [2] and show a giant SHA in -W [3]. Further we exhibit an all-optical detection of interface spin-mixing conductance and spin transparency in Ta(W)/CoFeB heterostructures based on spin pumping [4]. We next investigate the interfacial Dzyaloshinskii-Moriya interaction (iDMI) from asymmetric spin-wave dispersion using Brillouin light scattering and show pure iDMI in NM(Ta, graphene)/FM(CoFeB, NiFe)/TaOx, Ta) heterostructures [5-6]. The effects of variation of thicknesses of FM and NM layers and defects at the interface are discussed. Finally, we demonstrate the development of an on-demand magnonic nanostructures based on voltage controlled magnetic anisotropy. Application of spatially periodic electric fields across CoFeB/MgO interface leads to periodic modulation of magnetic anisotropy leading towards selective propagation of spin waves through different nanochannels and opening of magnonic bandgap. The author gratefully acknowledges financial assistance from Department of Science and Technology, Department of Information Technology and S. N. Bose National Centre for Basic Sciences.

## References

[1] S. Pan, O. Hellwig, and A. Barman, Phys. Rev. B, vol. 98, pp. 214436, 2018.
[2] A. Ganguly et al., Appl. Phys. Lett., vol. 105, pp. 112409, 2014.
[3] S. Mondal at al., Phys. Rev. B, vol. 96, pp. 054414, 2017.
[4] S. N. Panda et al., Sci. Adv., vol. 5, pp. eaav7200, 2019.
[5] A. K. Chaurasiya et al., Phys. Rev. Applied, vol. 9, pp. 014008, 2018.
[6] A. K. Chaurasiya et al., Phys. Rev. B, vol. 99, pp. 035402, 2019.

## Biography

Prof. Anjan Barman obtained his Ph.D. from the Indian Association for the Cultivation of Science (Jadavpur University), Kolkata, India in 1999. He worked as Postdoctoral Fellow in Technion, Israel, University of Exeter and University of Leeds, UK and University of California Santa Cruz, USA. Subsequently, he worked as Assistant

Professor in University of South Carolina Columbia, USA and Indian Institute of Technology Delhi between 2006 and 2009 before joining the S. N. Bose National Centre for Basic Sciences, Kolkata, India in 2009, where he is a Senior Professor now. Prof. Barman leads the Spintronics and Spin Dynamics Research Group here with world class laboratories with indigenously built experimental setups namely time-resolved MOKE microscope, broadband and spin-torque ferromagnetic resonance, conventional and microfocused Brillouin light scattering, THz time-domain spectrometer, to name a few. He has guided/graduated 25 PhD students and more than 50 Masters/Bachelor students. He has published nearly 200 research papers in international journals and books and a monograph titled 'Spin Dynamics and Damping in Ferromagnetic Thin Films and Nanostructures' from Springer. He is an Editorial Board Member of Scientific Reports and Reviewer of more than 30 international journals. He also reviews research grant proposals from various countries in the world. He is a recipient of Material Research Society of India Medal and an elected Fellow of Indian Academy of Sciences Bangalore.

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# Neutron and Synchrotron Radiation as Probes to Study Magnetic Materials

27 Aug
11:30
GMT+2

José Maria Porro

(1) BCMaterials, Basque Center for Materials, Applications and Nanostructures, Spain
(2) Ikerbasque, the Basque Foundation for Science, Spain

One of the key aspects for the development of new materials relies on the ability to profoundly study their fundamental properties. The usage of neutron and synchrotron radiation sources provides scientists with unique tools to probe matter in a wide range of length and timescales, accessing to both the structure and time-resolved dynamics of the materials issue of study. In this talk, an introduction to different neutron and synchrotron radiation scattering techniques will be presented, together with some specific science cases related to magnetism and magnetic materials studied with these techniques. More concretely, the following techniques and science cases will be presented: 1. X-Ray Photon Correlation Spectroscopy to study the magnetization dynamics of artificial spin ices. 2. Transmission X-Ray Microscopy to study the propagation of magnetic charges in artificial spin ices. 3. Powder Neutron Diffraction to study the origin of magnetism in Heusler-type Magnetic Shape Memory Alloys. 4. A combination of Single Crystal Neutron Diffraction and X-Ray Magnetic Circular Dichroism to study the magnetism in high temperature Magnetic Shape Memory Alloys. A brief introduction to the field of artificial spin ices and to Heusler-type magnetic shape memory alloys will also be presented.

**References**

[1] S. A. Morley, D. A. Venero, J. M. Porro, A. Stein, M. C. Rosamond, S. T. Riley, P. Steadman, S. Langridge, C.H. Marrows, "Vogel-Fulcher-Tammann freezing of a thermally fluctuating artificial spin-ice probed by x-ray photon correlation spectroscopy", Phys. Rev. B 95 104422, 2017
[2] S. A. Morley, J. M. Porro, A. Hrabec, M. C. Rosamond, G. Burnell, M. Y. Im, P. J. Fischer, S. Langridge, C. H. Marrows, "Field-driven mobility of emergent magnetic charges in square artificial spin-ice", Sci. Rep. 9, 15989, 2019
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**Biography**

José Maria Porro has a Physics PhD in Materials Science, from the University of the Basque Country (2014), under the supervision of the Ikerbasque Research Professor Paolo Vavassori, nanomagnetism group co-leader at CIC nanoGUNE in Donostia-San Sebastián, Basque Country, Spain. He has post-doctoral experience as a research associate for 3.5 years at the Large Scale Structures group of the ISIS neutron and muon source of the Rutherford Appleton Laboratory, Science and Technology Facilities Council, of the United Kingdom. He was also a visitor scientist for three years at the I10 beamline of the Diamond Light Source, the synchrotron facility of the United Kingdom. In 2017 he secured a Marie Sklodowska-Curie Individual Fellow at the BCMaterials, the Basque Centre for Materials, Applications and Nanostructures of the Basque Country. Currently he holds an Ikerbasque Research Fellow position at BCMaterials. His expertise is focalized in nanomagnetism and, more recently, in the field of Heusler-type magnetic shape memory alloys. He has demonstrated hands-on experience in the design and fabrication of micro and nano-patterned structures, as well as in their characterization by means of standard lab-based techniques, combined with a strong experience in the usage of large scale structures such as neutron and synchrotron sources to complement the characterization of the studied materials.

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# Skyrmion Dynamics - from Individual Ultrafast Motion to Diffusion and Collective Crystallization of 2D Lattices

27 Aug
14:00
GMT+2

Mathias Kläui

Johannes Gutenberg University Mainz, Germany and NTNU Trondheim, Norway

In our information-everywhere society IT is a major player for energy consumption. Novel spintronic devices can play a role in the quest for GreenIT if they are stable and can transport and manipulate spin with low power. Devices have been proposed, where switching by energy-efficient approaches, such as spin-polarized currents is used [1], for which we develop new highly spin-polarized materials and characterize the spin transport using THz spectroscopy [2]. Firstly, to obtain ultimate stability of states, topological spin structures that emerge due to the Dzyaloshinskii-Moriya interaction (DMI) at structurally asymmetric interfaces, such as chiral domain walls and skyrmions with enhanced topological protection can be used [3-5]. Here we will introduce these spin structures ad we have investigated in detail their dynamics and find that it is governed by the topology of the spin structure [3]. By designing the materials, we can even obtain a skyrmion lattice phase as the ground state [4]. Beyond 2D structures, we recently developed also systems with chiral interlayer exchange interactions that lend themselves to the formation of chiral 3D structures [6]. Secondly, for ultimately efficient spin manipulation, we use spin-orbit torques, that can transfer more than 1 per electron by transferring not only spin but also orbital angular momentum. We combine ultimately stable skyrmions with spin orbit torques into a skyrmion racetrack device [4], where the real time imaging of the trajectories allows us to quantify the novel skyrmion Hall effect [5]. Recently, we determined the possible mechanisms that lead to a dependence of the skyrmion Hall effect on skyrmion velocity [7]. We furthermore use spin-orbit torque induced skyrmion dynamics for non-conventional stochastic computing applications, where we have developed a skyrmion reshuffler device [8] based on skyrmion diffusion [8]. Such diffusion can furthermore be controlled by symmetry – breaking in-plane magnetic fields [9]. Finally, we take the next step beyond studying the properties of skyrmions and use them as model systems to study phases and phase transitions in two dimensions. We determine the transition of skyrmions from a disordered "liquid" phase to a "hexatic" phase, which is a particular phase that only exists in 2D [10]. This demonstrates that skyrmion lattices are perfectly 2D systems, opening up an avenue to using skyrmions as model systems to study statistical mechanics, phases and phase transitions [10].

**References**

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**Biography**

Mathias Kläui is professor of physics at Johannes Gutenberg-University Mainz and Director of the Center for Dynamics and Topology. He studied at RWTH Aachen University and received his PhD at the University of Cambridge, after which he joined the IBM Research Labs in Zürich. He was a junior group leader at the University of Konstanz and then became associate professor in a joint appointment between the EPFL and the PSI in Switzerland before moving to Mainz. Since 2017 he has been Adjunct Professor in the Center for Quantum Spintronics at the Norwegian University of Science and Technology. His work focuses on nanomagnetism and spin dynamics on the nanoscale in new materials. His research covers from blue sky fundamental science to applied projects with major industrial partners. He has published more than 290 articles and given more than 220 invited talks. He is a Senior member of the IEEE and has been elected to the technical and administrative committees of the magnetics society. He is also a Fellow of the IOP and the European Academy of Sciences and has been awarded a number of prizes and scholarships as well as three grants of the European Research Council. Contact details and more information at www.klaeui-lab.de, klaeui@uni-mainz.de

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# Laterally Patterned Magnetic Landscapes in $Fe_{60}Al_{40}$

27 Aug
16:30
GMT+2

Anna Semisalova

University of Duisburg-Essen, Faculty of Physics & CENIDE, AG Farle, Germany

Correlation between the ordered/disordered chemical structure and magnetism in several B2 alloys (e.g., $Fe_{60}Al_{40}$ and equiatomic FeRh) has stimulated significant efforts of researchers working in nanomagnetism, spintronics and materials science [1, 2, 3, 4]. These binary transition metal alloys allow a delicate tuning of magnetic properties in magnetic bilayers and laterally patterned nanostructures using structural disordering via ion bombardment. The magnetization of $Fe_{60}Al_{40}$ (FeAl) is highly sensitive to the transition from the B2-ordered structure to the A2 (bcc, or disordered) one [4,5,6]. The paramagnetic (PM) FeAl alloy can be turned at room temperature into a ferromagnet (FM) with a saturation magnetization of up to 800 $kA/m$ when the structural disorder is introduced by ion irradiation with Ne ions [1]. Disordering of the structure is accompanied by a lattice expansion. Ion beam irradiation through lithographically produced masks allows for magnetic patterning of periodical disorder-induced nanostructures embedded in non-ferromagnetic structurally ordered FeAl surrounding, in other words the design of magnetic landscapes. Similarly, this technique can be used to produce individual embedded nanomagnets [7] in a paramagnetic surrounding. In this talk, recent examples of ferromagnetic nanostructures and magnetic landscapes in FeAl will be given. Magnetization dynamics and ferromagnetic resonance in periodical ferromagnetic nanostructures with vertical interfaces between patterned FM and PM regions will be discussed with the focus on vertical and lateral spin-pumping effects in thin films.

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**Biography**

Anna Semisalova is a lecturer at the Faculty of Physics, University of Duisburg-Essen (UDE) since March 2019. She obtained her PhD in Physics from Lomonosov Moscow State University (MSU) in 2012 in the topic of dilute magnetic semiconductors. After a postdoc and a following assistant professorship (since 2013) at Lomonosov MSU in nanomagnetism and smart magnetic materials, she spent 4 years as a postdoctoral research fellow at the Institute of Ion Beam Physics and Materials Research, Helmholtz-Zentrum Dresden – Rossendorf (2015-2019) where she joined a team working on research of the disorder-induced ferromagnetism in B2 materials ($Fe_{60}Al_{40}$, $Fe_{50}Rh_{50}$). Current scientific activities in UDE are focused on magnetization dynamics in thin films and nanostructures, including laterally patterned magnetic landscapes produced by ion irradiation. She co-authored 2 patents and a book chapter (Springer Series in Materials Science). Contact: anna.semisalova@uni-due.de

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# Spintronics for Neuromorphic Computing

27 Aug
13:30
GMT-4

Mark Stiles
National Institute of Standards and Technology, USA

Human brains can solve many problems with orders of magnitude more energy efficiency than traditional computers. As the importance of such problems, like image, voice, and video recognition increases, so does the drive to develop computers that approach the energy efficiency of the brain to solve them. Magnetic devices have several properties that make them attractive for such applications. I give a brief overview of the variety of devices and approaches that are under consideration [1,2] and then focus on magnetic tunnel junctions. Based on the ability to read the magnetic state of a tunnel junction through the tunneling magnetoresistance and the ability to electrically control it through spin-transfer and spin-orbit torques, magnetic tunnel junctions are actively being developed for integration into CMOS integrated circuits to provide non-volatile memory. This development makes it feasible to consider other geometries that have different properties. I describe computing schemes based on two such alternative configurations, spin-torque nano-oscillators, which can be excited into an oscillatory state and used in analogy with oscillatory processes in the brain and superparamagnetic tunnel junctions, which thermally fluctuate between states and can be used in analogy to the stochastic process in the brain. Finally, I focus on representative projects for each of these structures from work by collaborators. The first [3] uses spin-torque nano-oscillators in a reservoir computing scheme and the second [4] uses superparamagnetic tunnel junction for stochastic computing.

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**Biography**

Mark Stiles is a NIST Fellow in the Advanced Computing Group in the Physical Measurement Laboratory. He received a M.S./B.S. in Physics from Yale University, and M.S. and Ph.D. degrees in Physics from Cornell University. Following post-doctoral research at ATT Bell Laboratories, he joined the research staff at NIST. Mark's research has focused on the development of a variety of theoretical methods for predicting the properties of magnetic nanostructures and has recently shifted to neuromorphic computing. He has helped organize numerous conferences and has served the American Physical Society on the Executive Committee of the Division of Condensed Matter Physics and as Chair and on the Executive Committee of the Topical Group on Magnetism. He has also served as a Divisional Associate Editor for Physical Review Letters, served on the Editorial Board of Physical Review Applied, and is an Associate Editor for Reviews of Modern physics. Mark is a Fellow of the American Physical Society and has been awarded the Silver Medal from the Department of Commerce.

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# Tunable Magnetoelectric Components and Devices

27 Aug
16:00
GMT-4

Amal El-Ghazaly
Cornell University, USA

This seminar presents research that delves into the challenge of engineering devices that are highly versatile and tunable to meet the ever-broadening application demands of the future.

The talk will focus on two ways in which magnetic and piezoelectric materials can be used to make extremely versatile devices with applications in communications, sensing, and haptic interfaces. First, the various types of magnetic materials will be compared in terms of their frequency ranges, advantages, and limitations with respect to applications in communications and sensing [1]. Next, some tricks will be discussed for how reliable high frequency magnetic materials can be produced. To address versatility, magnetoelectric (magnetic and piezoelectric) heterostructures will be presented to provide tunable composite properties [2]. Finally, completely new applications of magnetoelectric composites for haptic interfaces will be discussed. Material composites containing both magnetic and piezoelectric particles will be controlled magnetically such that they actuate into 3D tactile displays and, additionally, will be sensed electrically to detect tactile pressure on the interface. These concepts, together, demonstrate the importance of materials to the design of broadly versatile devices for future electronics.

**References**

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**Biography**

Amal El-Ghazaly is an assistant professor in the department of electrical and computer engineering at Cornell University. Her work combines magnetism, ferroelectricity, and optics to create tunable, versatile electronic systems for telecommunications, sensing and actuation. Prior to joining Cornell in 2019, she was a postdoctoral research fellow at the University of California Berkeley, where she was awarded the University of California President's Postdoctoral Fellowship in 2017. Her postdoctoral research explored new possibilities for ultrafast all-electrical switching of magnetic nanodots for faster and more energy-efficient computer memories. She earned a Ph.D. in electrical engineering from Stanford University, where she was funded by both NSF and NDSEG graduate research fellowships as well as the Stanford DARE fellowship until her graduation in 2016. Her Ph.D. research focused on radio frequency devices using magnetic and magnetoelectric thin-film composites for tunable wireless communications. She received her B.S. and M.S. degrees in electrical and computer engineering from Carnegie Mellon University in 2011.

# Materials for STT-MRAM Applications

27 Aug
18:30
GMT-4

Guohan Hu
IBM TJ Watson Research Center, USA

Spin Transfer Torque Magnetic Random Access Memory (STT-MRAM) is a type of emerging memory which holds the promise of high speed, high endurance, non-volatility, and good scalability. Since the theoretical prediction of the STT switching mechanism in 1996, significant progress has been made in the field, largely through materials innovations. This talk will review the key materials discoveries that enabled the advancement of STT-MRAM technology, including the theoretical prediction and experimental realization of large tunneling magneto-resistance (TMR) with MgO tunnel barrier and the discovery of CoFeB based materials with interfacial perpendicular magnetic anisotropy (iPMA). We will also discuss our recent results at IBM on demonstration of reliable 2 ns switching of STT-MRAM devices [1], and methods to lower the device switching current [2], using optimized magnetic materials.

**References**

[1] G. Hu et al., “Spin-transfer torque MRAM with reliable 2 ns writing for last level cache applications”, IEDM Tech. Dig., 38-41 (2019).
[2] G. Hu et al., “STT-MRAM with double magnetic tunnel junctions”, IEDM Tech. Dig., 668-671 (2015).

**Biography**

Guohan Hu is a Principal Research Staff Member and Manager of the MRAM Materials and Devices group at the IBM T. J. Watson Research Center. Guohan received a B. S. degree in Materials Science  Engineering and a B. S. degree in Economics from Tsinghua University in 1997. Guohan received her Ph.D. degree in Materials Science and Engineering from Cornell University in 2002. Her research has been on MRAM materials and devices, magnetic oxide thin films, and patterned media.

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# Contributed talks from Asia-Pacific

**All contributed talks in this session will follow Tokyo Time (GMT +9). The session will start at 08:50 and end at 18:00.**

# PROGRAM SCHEDULE

## Region 1: Asia-Pacific

**09:00 to 18:00 - Tokyo Time (GMT +9)**

08:50 - 09: 00 Opening Remarks

| Session 1-1 | Session 1-3 |
|---|---|
| **09:00 - 09:15**<br>Ryohei Nemoto, CHIBA-U (Japan) | **13:00 - 14:00**<br>Prof. Hyunsoo Yang NUS, Singapore |
| **09:15 - 09:30**<br>Hariom Jani, NUS (Singapore) | **14:00 - 14:15**<br>Kacho Imtiyaz Ali Khan, IITD (India) |
| **09:30 - 09:45**<br>Yao Guang, IOP-CAS (China) | **14:15 - 14:30**<br>Zilu Wang, BUAA (China) |
| **09:45 - 10:00**<br>May Inn Sim, NUS (Singapore) | **14:30 - 14:45**<br>Yuta Sasaki, NIMS (Japan) |
| **10:00 - 10:15**<br>Edwin Chue, NUS (Singapore) | **14:45 - 15:00**<br>Ajit Kumar Sahoo, IITH (India) |
| **10:15 - 10:30**<br>Rui-Hao Li, CWRU (USA) | **15:00 - 15:15**<br>Soundararaj Annamalai, IITH (India) |
| **Session 1-2** | **15:15 - 15:30**<br>Papori Seal, NITN (India) |
| **10:30 - 11:30**<br>Prof. Yoshichika Otani, U-TOKYO, Japan | **Session 1-4** |
| **11:30 - 11:45**<br>Mahmoud Rasly, NIMS (Japan) | **15:30 - 16:30**<br>Prof. Anjan Barman, BOSE NCBS India |
| **11:45 - 12:00**<br>Joynarayan Mukherjee, TIFRH (India) | **16:30 - 16:45**<br>Himanshu Bangar, IITD (India) |
| **12:00 - 12:15**<br>Dolly Taparia, IITG (India) | **16:45 - 17:00**<br>Pankaj Pathak, IITD (India) |
| **12:15 - 12:30**<br>Bibekananda Paikaray, IITH (India) | **17:00 - 17:15**<br>Namrata Bansal, IITD (India) |
| **12:30 - 12:45**<br>Anna Chlenova, URFU (Russia) | **17:15 - 17:30**<br>Israa Medlej, LU (Lebanon) |
| **12:45 - 13:00**<br>Fida Mohmed, NITSRI (India) | **17:30 - 17:45**<br>Brahmaranjan Panigrahi, IITH (India) |

**17:45 - 18:00** Closing Remarks

# Instability of skyrmion due to external magnetic field: milli-kelvin STM study of Co islands on Ru(0001)

27 Aug
09:00
(GMT+9)
1-1-1

Ryohei Nemoto[1], Loic Mougel[2], Wulf Wulfhekel[2], and Toyo Kazu Yamada[1]
[1]Chiba University, Japan; [2]Karlsruhe Institute of Technology, Japan

The skyrmion is energetically stabilized by chiral Dzyaloshinskii–Moriya interaction (DMI) because structural inversion symmetry is broken and spin–orbit coupling is present[1]. This skyrmion is expected to be applied as a new information carrier [2,3]. A compression of the skyrmion is caused by the Zeeman energy due to an external magnetic field. When an external magnetic field larger than the skyrmion collapse field ($B_c$) is applied, to the magnetic moment of the skyrmion center atom is reversed. Then, surrounding atom moments align ferromagnetically. Namely, the skyrmion is collapsed.In this research, the BC of isolated skyrmions of cobalt (Co) islands grown on Ru(0001) was studied by means of ultra-high vacuum (UHV) scanning tunneling microscopy (STM) setup combined with a dilution refrigerator (30 mK). Co monolayer islands on Ru(0001) have known to have a spin spiral structure with a periodicity of 37 nm [4]. Also, the spin spiral structure changes to the skyrmion by applying an external magnetic field of Be $\approx$ 230 mT. Once the skyrmion is formed, the skyrmion remains below Be. However, we found that a diameter of the skyrmion depends on an external magnetic field when the field increased from 0 mT to 750 mT [5]. Magnetic moment distribution on the sample surface was monitored by detecting tunneling anisotropic magneto-resistance (TAMR) signal using a non-magnetic W tip. TAMR mapping showed a skyrmion diameter of $\approx$11 nm at 300 mT and $\approx$4 nm at 700 mT [5].

**References**

[1] A. Fert et al., Phys. Rev. Lett. 44, 1538 (1980).
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# Topological Half-skyrmions and Bimerons in an antiferromagnetic insulator at room temperature

27 Aug
09:15
(GMT+9)
1-1-2

Hariom Jani[1], Jack Harrison[2], J-C. L. Jiahao Chen[2], Francesco Maccherozzi [3], J. S. Chang-Beom Eom[4], Saurav Prakash[1], Ariando[1], T. Venkatesan[1] and Paolo G. Radaelli[2]

[1]National University of Singapore, Singapore; [2]University of Oxford, United Kingdom;[3]Diamond Light Source, United Kingdom[4]University of Wisconsin-Madison, United States

In the quest for post-CMOS technologies, ferromagnetic skyrmions and their anti-particles have shown great promise as topologically protected solitonic information carriers in memory-in-logic or neuromorphic devices. However, the presence of dipolar fields in ferromagnets, restricting the formation of ultra-small topological textures, and the deleterious skyrmion Hall effect when driven by spin torques have thus far inhibited their practical implementations. Antiferromagnetic analogues, which are predicted to demonstrate relativistic dynamics, fast deflection-free motion and size scaling have recently come into intense focus, but their experimental realizations in natural antiferromagnetic systems are yet to emerge. Here, we demonstrate a family of topological antiferromagnetic spin-textures in $\alpha-Fe_2O_3$ an earth-abundant oxide insulator – capped with a Pt over-layer. By exploiting a first-order analogue of the Kibble-Zurek mechanism, we stabilize exotic merons-antimerons (half-skyrmions), and bimerons, which can be erased by magnetic fields and re-generated by temperature cycling. These structures have characteristic sizes in the range ≈100 nm that can be chemically controlled via precise tuning of the exchange and anisotropy, with pathway to further scaling. Driven by current-based spin torques from the heavy-metal over-layer, some of these AFM textures could emerge as prime candidates for low-energy antiferromagnetic spintronics at room temperature.

**References**

[1] Link: https://arxiv.org/abs/2006.12699

# Creating zero-field skyrmions in exchange-biased multilayers with X-ray illumination

27 Aug
09:30
(GMT+9)
1-1-3

Yao Guang[1], Guoqiang Yu[1], Luliia Bykova[2], Yizhou Liu[1], Markus Weigand[2], Se Kwon Kim[3], Junwei Zhang[4], Yaroslav Tserkovnyak[3], Xiufeng Han[1], and Gisela Schütz[2]

[1]Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China; [2]Max Planck Institute for Intelligent Systems, Heisenbergstraße, 70569 Stuttgart, German; [3]Department of Physics and Astronomy, University of California, Los Angeles, CA 90095, USA; [4]Key Laboratory for Magnetism and Magnetic Materials of Ministry of Education

Magnetic skyrmions hold promises for high-density and energy-efficient information storage devices owing to their small size, low driving-current density and topological non-volatility. Precise creation of a single nanoscale skyrmion is a prerequisite to further understand the skyrmion physics and tailor skyrmion-based applications. Utilizing the technique of scanning X-ray microscopy [1,2], we demonstrate the creation of individual skyrmions at zero external field in an exchange-biased magnetic multilayer with exposure to soft X-rays [3]. In particular, a single skyrmion with 100-nm size can be created at the desired position using a focused X-ray spot of sub-50-nm size. This single skyrmion creation is driven by the X-ray-induced modification of the antiferromagnetic order and the corresponding exchange bias. Furthermore, artificial skyrmion lattices with various arrangements can be patterned using X-ray [3]. These results confirm the potential of accurate optical control of single skyrmion at sub-100 nm scale. We envision that X-ray could serve as a versatile tool for local manipulation of magnetic orders

## References

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[3] Y. Guang *et al.*, Nature Commun. 11, 949 (2020).

# Interplay of Skyrmion-Skyrmion Interactions with Current-driven Dynamics in Multilayer Nanowires

27 Aug
09:45
(GMT+9)
1-1-4

May Inn Sim[1,2], Dickson Thian[2], Anthony K.C. Tan[3], Pin Ho[2], Hang Khume Tan[2], Nelson Lim Chee Beng[2], Sherry Lee Koon Yap[2], and Anjan Soumyanarayanan[1,2]

[1]Department of Physics, National University of Singapore; [2]Institute of Materials Research and Engineering, Agency for Science, Technology & Research (A⋆STAR); [3]Data Storage Institute, Agency for Science, Technology & Research (A⋆STAR)

Magnetic skyrmions are topologically protected two-dimensional spin structures stabilized by interfacial Dzyaloshinskii-Moriya interactions in ferromagnetic thin film multilayers [1]. Their stability in nanowire devices coupled with ease of electrical manipulation and detection suggests a range of applications, especially for memory and novel computing architectures. Planar charge currents in multilayer nanowires exert a spin-orbit torque, which can be used to move skyrmions longitudinally, i.e. along the current direction. Meanwhile, skyrmions also experience a Magnus force which results in a transverse deflection known as the Skyrmion Hall effect (SkHE). Notably, the size of a skyrmion is expected to play a key role in determining its velocity, SkHE deflection, and interaction with disorder [2]. These facets have been examined extensively within simulations, and recently in experimental works [3]. In this work, we investigate the converse effect – wherein skyrmion dynamics affects their size. To this end, we examine the dynamics of skyrmions in configurations with density $\approx 10$ $\mu m^2$ in Pt/Co/MgO multilayer nanowires with an in situ external magnetic field. A series of unidirectional current pulses (J $\approx$ 4–5 $\times$ $10^11$ $A/m^2$) were applied through the nanowire. This was followed by imaging of intermediate skyrmion positions on the nanowires by magnetic force microscopy (MFM) and image analysis to track skyrmion trajectories.While skyrmion motion was initially consistent with the flow regime with size-independent velocity, they were found to gradually aggregate at the nanowire edge due to the SkHe. Intriguingly, clustering of skyrmions appear to have a steric effect, affecting skyrmion sizes. Within the cluster, skyrmions are quantifiably smaller ($> 20\,\%$) than the skyrmions on the periphery. Interactions between pinned and moving skyrmions in relation to their spatial positions in the cluster were also studied.This work suggests that skyrmion-skyrmion interactions may play a key role in influencing their dynamics in dense device configurations. Furthermore, it highlights possibilities for the dynamic engineering of current induced skyrmion behaviour along a nanowire with strategic size manipulation.

## References

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[2] K.Litzius *et al.*, Nat. Phys. 13, (2017).
[3] K. Zeissler *et al.*, Nat. Commun. 11, 1–11 (2020).

# Temperature evolution of skyrmion stability and formation mechanism in chiral multilayers

27 Aug
10:00
(GMT+9)
1-1-5

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Magnetic skyrmions - nanoscale topological spin structures stabilised by chiral interactions - are promising candidates for next-generation computing and memory devices. Recently, sub-100nm skyrmions have been stabilised at room temperature in asymmetrically structured Co/Pt-based multilayer films that boast large values of DMI, which serves as a vital step towards such devices [1]. As such devices may operate at room temperature and beyond, it is critical to the role of temperature in influencing the behaviour of skyrmion in multilayer films. Skyrmions can be formed via two possible pathways - nucleation from uniform magnetisation when the magnetic field is swept from saturation to zero field, or evolution from magnetic stripes when the field is swept from zero to saturation. The latter can be further divided into two distinct mechanisms – the reversible shrinking of a stripe into a skyrmion or the irreversible fission of a stripe into multiple skyrmions. Notably, it has been recently established that the preferred mechanism can be identified by utilising a technique known as first-order reversal curve (FORC) magnetometry. FORC magnetometry is sensitive to irreversible magnetic processes, which manifest as observable features on a derived FORC diagram [2]. For skyrmionic multilayers, a large peak separation between relevant features is indicative of stripe-to-skyrmion fission being the preferred mechanism.In this work, FORC magnetometry was performed, in conjunction with Lorentz transmission electron microscopy (LTEM), on Ir/Fe/Co/Pt multilayers over temperatures of 100 - 450K. Contrary to expectations, upon increasing temperature we observed an increase in peak separation from FORC, indicative of a marked enhancement in skyrmion stability and an increased tendency towards the fission formation mechanism of skyrmions. This result is consistent with findings from LTEM measurements, where we observe an increase in skyrmion formation with temperature. With theoretical modelling from geodesic nudged elastic band (GNEB) simulations, we frame these results in the context of the interplay between the key magnetic interactions involved in skyrmion formation. These findings establish temperature as an important tuning parameter and provide insights into skyrmion formation and stability, which is crucial to the realisation of skyrmionic devices.

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# Chiral-Anomaly-Induced Nonlinear Hall Effect in Weyl Semimetals

27 Aug
10:15
(GMT+9)
1-1-6

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Weyl semimetals (WSMs) are a newly discovered class of quantum materials which can host a number of massless quasiparticles called Weyl fermions with a well-defined chirality near the band-crossing points (Weyl nodes). One of the most unique features of WSMs is the chiral anomaly – a pair of Weyl nodes of opposite chirality acts as source and drain of electrons in the presence of non-perpendicular electric and magnetic fields. To date, the most remarkable phenomenon induced by chiral anomaly is the longitudinal negative magnetoresistance, which is a linear response effect to an external electric field. In this work, we theoretically investigate the transport properties of WSMs in the nonlinear regime and predict a novel nonlinear Hall effect in tilted Weyl semimetals with broken inversion symmetry. Intuitively, a steady-state density difference between a pair of Weyl nodes is established when the chiral pumping and internode relaxation reach a balance, which conspires with the anomalous velocity to give rise to this nonlinear Hall effect. Taking the semiclassical Boltzmann approach, we find that the chiral-anomaly-induced nonlinear Hall (CNH) conductivity scales linearly with both the electric and magnetic fields, and depends critically on the tilting of the Weyl cones in both type-I and type-II WSMs. Moreover, for the CNH effect to be nonvanishing, the whole Fermi surface for the Weyl nodes must be asymmetric. We also show that this effect does not rely on a finite Berry curvature dipole, in contrast to the intrinsic quantum nonlinear Hall effect that was proposed to occur in time-reversal invariant materials [1].

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# Tunneling magnetoresistance devices with amorphous CoFeBTa-based free layers for the low-magnetic field sensing applications

27 Aug
11:30
(GMT+9)
1-2-1

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Tunneling magnetoresistance (TMR) devices based on CoFeB/MgO/CoFeB magnetic tunnel junctions (MTJs) sensors have exhibited potential for low magnetic-field sensing applications [1]. To improve the field-sensitivty of the TMR sensors, a soft magnetic layers; e.g. NiFe, is often stacked with CoFeB free layer (FL) [2]. However, the lamination of NiFe above/below CoFeB tends to degrade the TMR ratio because the 111 texture of NiFe propagates to the CoFeB layer. Alternatively, amorphous soft magnets exhibit no influence on the texturing of CoFeB, thus TMR ratio can be maintained high.In this study, we investigated TMR sensors devices with amorphous CoFeBTa (CFBT) soft magnetic layers for the FL of CoFeB/MgO/CoFeB-magnetic tunnel junctions in the aspects of magnetic, TMR and low-frequency noise properties. The TMR films were prepared by magnetron sputtering with a stacking structure of SiO2 sub./Ta (2)/Ru (10)/Ta (2)/Ru (10)/Ta (5)/CFBT (tCFBT = 20-80)/Ta (0.3)/CoFeB (3)/MgO (2)/CoFeB (2.5)/CFBT (0.6)/CoFe (0.5)/Ru (0.8)/CoFe (3)/IrMn (8)/Ru (8) (thickness in nm). The CFBT/Ta/CoFeB trilayer works as a FL, where the 0.3 nm-thick Ta interlayer was inserted to promote the crystallization of CoFeB during annealing. Investigating the layer structures by scanning transmission electron microscopy revealed that CFBT layer remained amorphous even after annealing at 350 C, while the CoFeB layers in contact with the MgO tunnel barrier crystallized to 001-textured CoFe. TMR ratio $\approx$160 % was obtained for the MTJ with tCFBT = 20 nm. The interface roughness between CoFeB reference layer and MgO tunnel barrier increased with increasing tCFBT in FL, by which TMR ratio decreased as tCFBT increased. We applied two-step annealing technique to linearize the R-H curve [1, 2]. First annealing was conducted along the easy axis (EA) of FL at temperature 350°C and the second annealing performed at orthogonal direction to EA of FL at 200°C. Crossed-magnetization configuration between free and reference layers was realized, which results in linear R-H curves. 1/f noise dominated the sensor noise in frequency below 10 kHz and its voltage density was higher in the intermediate magnetization state with a Hooge's noise parameter of $4 \times 10^{-8} \mu m^2$, increased in proportion to bias voltage and decreased in proportion to the square root of device area. The sensor showed detectivity of 2.2 nT/Hz0.5 at 10 Hz, which is smaller than that reported (12.8 nT/Hz0.5) for TMR sensors based NiFe FL [3].

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# Observation of Weyl fermion in a strongly correlated noncollinear antiferromagnetic thin film

27 Aug
11:45
(GMT+9)
1-2-2

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The interplay of symmetry and topology has revealed many exotic states of matter among which topological Weyl semimetal is one of the youngest candidates. Most of the studies on topological Weyl systems are limited to the weakly interacting materials1. Here, we report the observation of Weyl nodes in a strongly correlated noncollinear antiferromagnetic (NCAFM) system using magnetotransport measurements and density functional theory calculation.In the presence of parallel electric and magnetic fields, conservation of opposite chiral Weyl fermions violates which is known as Chiral anomaly, a distinctive feature of Weyl semimetals (WSMs)2. We have grown NCAFM Mn3Pt thin films on STO (100) substrate using co d.c. sputtering technique. High resolution X-ray diffraction measurements confirm the growth of phase pure and epitaxial Mn3Pt thin films. The residual resistivity ratio (RRR) of 25 nm Mn3Pt thin film was found to be 25.7 indicating a good crystalline quality of the film. A large (33 %), non-saturating, positive magnetoresistance (MR) has been observed at low temperature (2 K) while the magnetic field is applied perpendicular to the electric field. The MR becomes negative when both electric and magnetic fields are parallel to each other confirming the presence of chiral anomaly. This negative longitudinal MR is very sensitive to the angle between electric and magnetic fields and vanishes when the angle deviates more than 5 degree. Furthermore, density functional theory calculations suggested the evidence of linearly dispersive band crossing in the electronic band structure of Mn3Pt. Our results pave the possibilities to explore new Weyl semimetals in thin films which can be useful for topological device applications.

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# Tunable sensing characteristics of fully epitaxial CIP-GMR magnetic sensors using bcc Cu and Rh spacers

27 Aug
12:00
(GMT+9)
1-2-3

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Development of giant magnetoresistance (GMR) based magnetic sensors has received enormous interest owing to their potential applications in the field of hard disk drives, automotive industry, biomedical sensors, etc [1]. For advances in sensor technology, linear and reversible magnetoresistance (MR) to the applied field is crucial. In this context, Nakano et al. [2] demonstrated linear tunnel magnetoresistance (TMR) in a magnetic tunnel junction (MTJ) with a synthetic antiferromagnetic (AFM) reference layer. Although they achieved high sensitivity of 0.062 %/mT, the device had complex layer structure. An alternative method to obtain the linear MR is to utilize the GMR structure with nonorthogonal magnetization between ferromagnetic (FM) layers using the Rh spacer [3]. Recently, Fathoni et al. [4] demonstrated a dramatic enhancement in the MR ratio upto 40.5 % in a current-in-plane (CIP)-GMR device by exploiting the metastable body-centered-cubic (bcc) Cu spacer. Hence, it is cogitated that combining both CIP-GMR with Cu spacer and GMR structure with perpendicular magnetization using Rh spacer should help in obtaining large linear MR with high sensitivity.Accordingly, we have fabricated CIP-GMR film stack of MgO(001)/Co0.5Fe0.5(3 nm)/Rh(0.84 nm)/Co0.5Fe0.5(x)/Cu(1.6 nm)/Co0.5Fe0.5(y nm)/MgO(2 nm) with x = 1-2 and y = 0-4 nm. Microstructural analysis confirmed the growth of (001)-oriented CoFe, Rh, and Cu films with bcc structure. Numerical simulation for CoFe/Rh/CoFe films revealed that perpendicular magnetic anisotropy (PMA) is not induced in the top CoFe layer. However, biquadratic coupling with 90 orientation of magnetizations is developed between two CoFe layers. As a result, the R-H curve showed a nearly linear variation of MR to the applied field with a maximum MR of 1.25 %. The observations of 90 coupling and the absence of expected PMA are mainly due to the growth of bcc type Rh. To enhance the linear MR, we added another CoFe(y) layer via the Cu spacer to form AFM coupling between middle and top CoFe layers [4]. This process enhanced the MR ratio rapidly to >20 % with the highest sensitivity of 0.047 %/mT and a reduced nonlinearity of 0.98 %FS in a sensing field range of 220 mT for the film stack with x = 1.5 and y = 3 nm, which is comparable to the result of MTJ [2]. The tunability of sensitivity and nonlinearity with respect to the FM layer's thickness in CIP-GMR devices make them promising candidates for applications in new generation sensors.

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# Electrical detection of spin current in different combinations of Py and Ta bi-layer/tri-layer thin films.

27 Aug
12:15
(GMT+9)
1-2-4

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The prospect of using spin currents in information processing devices is a subject of great interest because of its low power consumption and zero stray fields. Spin pumping can generate spin currents in non-magnetic metals avoiding the problem of impedance mismatch. Thus efficient spin pumping mechanism at the interface between ferromagnetic/non-magnetic materials is vital for potential pure spin current based devices applications. Generation of spin currents via spin pumping and its detection by inverse spin Hall effect (ISHE) [1] is a fundamental technique to understand and the various functionalities of the spintronic devices consist of ferromagnetic (FM)/heavy metal(HM) bi-layer [2,3]. Recently, a large spin current injection which is characterized by a parameter called spin mixing conductance (g $\uparrow\downarrow$) is observed in Py/Ta systems using the mixed crystalline phase of Ta [4].In this work, we represent a comparative ISHE measurement of Ta/Py, Py/Ta, and Ta/Py/Ta combinations. In-plane angular ($\theta$) ISHE measurement shows the dominance of the ISHE voltage component over all other rectification effects. The Vsym to Vasym ratio is found to be 76.28 in our sample at 180° rotation. The sign of the voltage signals in SiO2/Ta (10 nm)/Py (4 nm) and SiO2/Py (4 nm)/Ta (10 nm) shows the opposite behavior due to the opposite spin current direction from Py to Ta. The lowest value of g$\uparrow\downarrow$ and $\alpha$ in $SiO_2$/Ta (10 nm)/Py (4 nm) sample can be attributed to the oxidation of the Py top layer due to the absence of any capping layer. On the other hand, $SiO_2$/Py (4 nm)/Ta (10 nm) sample has larger g and $\alpha$ as spin pumping takes place from the whole Py layer which is protected from oxidation by the same HM layer. In the case of $SiO_2$/Ta (10nm)/Py (4nm)/Ta (2 nm) sample, the g and $\alpha$ values are low due to two opposite spin current direction. However, the values are slightly higher as compared to $SiO_2$/Ta (10 nm)/Py (4 nm) sample. Our study reveals that spin current generated via spin pumping can be controlled by various FM/NM layer combinations, its interchange, and the addition of the capping layer.

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# Asymmetric magnetoimpedance sensitive elements

27 Aug
12:30
(GMT+9)
1-2-5

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Investigation of magneto impedance (MI) effect in thin films was stimulated by their potential applications for small magnetic field sensors [1] including biosensors [2]. This effect consists in the change in electrical impedance of a ferromagnetic conductor under application of an external magnetic field. Classic MI film structures consist of top and bottom ferromagnetic layers or multilayered structures [2, 3] of equal thickness separated by a conductive lead. From theoretical point of view symmetric MI film provide the highest sensitivity with respect to uniform external magnetic field. At the same time, in biosensing with magnetic labels non-uniform magnetic fields should be detected. Variation of the geometry of MI structure can be an effective method for improving sensor characteristics. The idea to test the efficiency of asymmetric sensitive elements for biosensing was introduced some time ago and certain aspects were discussed [4,5]. In this work, we describe our experience in design, fabrication and characterization of FeNi/Ti based MI sensitive elements with symmetry features.Following rf-sputtered structures were studied: [Ti (6 nm) / FeNi (100 nm)]$_5$ Ti(6nm)/Cu(500 nm)/Ti(6 nm)/[Ti (6 nm)/FeNi(100 nm)]$_x$, where $x = 0 - 5$. Magneticmeasurements of the hysteresis loops were carried out by magnetooptical Kerr-microscope (MOKE) from both sides (film and substrate surfaces) of themultilayered structure. Total impedance, its real and imaginary parts were measured in microstripe line [4]. Comparative analysis showed that a large asymmetry of the structure does notlead to an equally large reduction in MI sensitivity to the external magnetic field. Symmetric structure (x=5) have higher MI ratio of total impedance, but even lowersensitivity 20 %/Oe relative to the asymmetric structure (x=4) with 24 %/Oe. Furthermore, the smaller working field value was observed for x=4 sample. We explained difference due to magnetostatics interaction and effective anisotropy axisdeviations. MOKE visualization of magnetization process from both sides ofstructures was also useful for magnetic properties understanding. This work was funded by the RSF grant number 18-19-00090.

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# The Investigation of spin Seebeck effect in Ce doped Yttrium Iron Garnet thin films using Rhodium as a spin current detector

27 Aug
12:45
(GMT+9)
1-2-6

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The aim of the work was to explore Rhodium (Rh) for the detection of pure spin current generated in Cerium doped ferromagnetic insulator Yttrium Iron Garnet (CeYIG) via inverse spin Hall effect (ISHE) for application in spin caloritronics. Rh is a 4d metal, showing large spin orbit coupling strength, spin Hall conductivity and negligible magnetic susceptibility, indicating the absence of magnetic proximity effect (MPE). With spin caloritronics demanding the growth of nanometer thick films with very low magnetic damping, such quality CeYIG nano films have been synthesized via pulsed laser deposition technique (PLD), optimum for the investigation of pure spin current generation via ISHE.Here in we deposited highly crystalline smooth surfaced CeYIG thin films with extremely low magnetic damping, optimum for the investigation of spin Seebeck effect (SSE), through pulsed laser deposition technique. The optimization of the growth conditions, investigation of the magnetic properties and damping behavior of thin films has been extensively carried out for Ce YIG. The highly crystalline smooth surfaced CeYIG thin films with extremely low magnetic damping, were used for the investigation of SSE. A Hall bar patterned thin film of Rh metal was sputtered on these CeYIG films to obtain Rh/CeYIG hybrid structure. We were successfully able to achieve a room temperature thermal voltage Vth (SSE voltage) in our Rh/CeYIG hybrid system, under an applied temperature gradient of 13 K. Furthermore, our magneto-transport and magnetoresistance measurements clearly revealed that the observed spin current generation and its subsequent detection is free from any parasitic effects. The work can open a new window in the exploration of pure and uncontaminated spin currents generated in a ferromagnetic insulator CeYIG, using Rh as spin current detector.

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# Observation of spin backflow in IrMn based trilayer structures

27 Aug
14:00
(GMT+9)
1-3-1

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Spin pumping [1] in a ferromagnet (FM)/ non-magnetic (NM) thin films plays an important role in spin to charge conversion and defining various applications in microwave and THz spintronic devices [2]. In a FM/NM bilayer structure, the spin pumping enhances the phenomenological Gilbert damping coefficient () of the FM layer [3]. On the other hand, a NM/FM/NM trilayer heterostructure offers two FM/NM interfaces, which results in a larger spin pumping as compared to the bilayer counterpart. In this work, we have studied the spin pumping in NiFe (10 nm)/Pt (tPt), Pt (tPt)/NiFe (10 nm)/Pt (2 nm) and IrMn (tIrMn)/NiFe (10 nm)/Pt (2 nm) heterostructures by systematically varying the thickness of the underlayer and top-layer. Here, the trilayer heterostructures were grown using DC magnetron sputtering at ultra-high vacuum conditions. Ferromagnetic resonance (FMR) spectroscopy [4] was performed for a frequency range of 3-8 GHz to study the dependence of the NM layer thickness on effective Gilbert damping constant ($\alpha$eff). In NiFe/Pt bilayer system, maximum spin pumping/enhancement in Gilbert damping is observed when the thickness of the Pt layer is greater than diffusion length (tPt $> \lambda$) as shown in Fig.1 (a). However, even larger eff is observed for Pt on both sides of NiFe. Hence, both underlayer and top layer Pt thin films contribute equally to enhance the spin pumping from the NiFe layer. In the case of IrMn/NiFe/Pt, up to a thickness of 1 nm of the IrMn layer, we observe a decrease in eff shown in Fig.1 (c). This decrease in eff arises due to spin backflow from IrMn, which may be caused by either due to underlayer microstructures or Néel ordering at the NiFe/IrMn interface. We also found that for IrMn thickness larger than 1.8 nm, an enhancement of damping constant is observed indicating a contribution of spin pumping for thicker IrMn. This study shows a potential method of using different underlayer in NM/FM/NM trilayer structures to obtain a tunable Gilbert damping.

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# Modulation of field-like spin orbit torque in heavy metal / ferromagnet heterostructure

27 Aug
14:15
(GMT+9)
1-3-2

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Spin orbit torque (SOT) has drawn widespread attention in the emerging field of magnetic memory devices, such as magnetic random access memory (MRAM). To promote the performance of SOT-MRAM, most efforts have been devoted to enhance the SOT switching efficiency by improving the damping-like torque.[1-6] Recently, some studies noticed that the field-like torque also plays a crucial role in the nanosecond-timescale SOT dynamics.[7-9] However, there is not yet an effective way to tune its relative amplitude. Here, we experimentally modulate the field-like SOT in W/CoFeB/MgO trilayers through tuning the interfacial spin accumulation. We find that the CoFeB with enhanced spin dephasing, either generated from larger layer thickness or from proper annealing, can distinctly boost the spin absorption and enhance the effective interfacial spin mixing conductance $G_r$, as indicated by spin Hall magnetoresistance measurement. While the damping-like torque efficiency increases with $G_r$, the field-like torque efficiency turns out to decrease with it. The results suggest that the interfacial spin accumulation, which largely contributes to a field-like torque, is reduced by higher interfacial spin transparency. Our work shows a new path to further improve the performance of SOT-based ultrafast magnetic devices. [10]

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# Terahertz emission in epitaxially grown $Co_2MnSi$/Pt bilayer thin films

27 Aug
14:30
(GMT+9)
1-3-3

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Metallic spintronic thin films with ferromagnetic metal (FM) / heavy metal (HM) bilayer thin films can be utilized as an ultra-broadband single-cycle terahertz(THz) emitter ranging from 1 to 20 THz.[1] Peak intensity of THz pulses was comparable with the conventional non-linear optic materials such as a ZnTe crystal. The proposed model of THz emission in FM/HM bilayer thin film is as follows; the transient spin current flows from the FM layer into the HM layer after the laser pulse irradiation, and the spin current is converted into a transverse pulsed charge current via the inverse spin Hall effect(ISHE) in the HM layer, then it emits the single-cycle THz pulses. Since the source of spin current is the FM layer, the choice of the FM layer is a key factor to enlarge the THz emission intensity.[2, 3] The half-metallic Heusler alloys, such as a Co2MnSi (CMS), are promising material candidates for the FM layer because of their potentially high spin polarization around the Fermi level. In this study, we investigated the THz emission from CMS/Pt bilayer thin films. Films were deposited on a MgO(001) substrates by using an ultra-high vacuum magnetron sputtering system and the stacking structures of films were MgO(20) / [CMS, CoFe(5)] / Pt(2). The CMS layers were in-situ annealed at 300, 400, 500 and 600 degree centigrade for 1 h. The pulse laser-induced THz emission was measured by means of the pump-probe method and electro-optic sampling. The pulse laser source was Yb:KGW, with a wavelength, pulse width, and pulse repetition rate of 1028 nm, 230 fs, and 10 kHz, respectively. The emitted THz wave was detected by the probe laser pulse, which through an optical delay line, and 800 $\mu$m-thick-CdTe(110) crystal. A magnetic field of 100 mT was applied by using a permanent magnet. The sign change of the detected THz waveforms under the positive and negative magnetic fields was clearly confirmed, which indicates the THz emission was due to ISHE. Besides, the THz emission intensity was increased after the annealing process, which is due to the enhancement of the chemical ordering of CMS. The THz emission intensity exhibits a maximum at an annealing temperature of 400 degree centigrade. THz emission intensity for the CMS film was 2 times larger than that for the CoFe film. This work was partially supported by JSPS KAKENHI Grant Number H1803787.

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# Disorder domains in GdTb-FeCo system

27 Aug
14:45
(GMT+9)
1-3-4

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Perpendicular magnetic anisotropy (PMA) in thin films have the potential for applications in high-density storage media and various spintronics devices [1]. In this study, we have considered the GdTb-FeCo based quaternary system of variable thicknesses which exhibits strong PMA at optimized thickness. The structural, magnetic, and microscopic properties of these films are investigated. At higher thickness, a spin re-orientation behavior is observed where magnetization goes from in-plane to out-of-plane. Magnetic parameters of 150nm film do not follow the trend of rest of the thickness range (30-300nm), which could be attributed to a lesser extent of pinning sites impeded to domain wall motions. A variety of microscopic domains can be referred to as disorder domains, have been observed. Gd-like and Tb-like contributing domains are observed at different film thicknesses. A critical thickness is observed at 150 nm, where most of the Tb sub-lattices are dominated over the Gd sub-lattices. Our experimental findings were complemented by finite-difference 3D micromagnetic simulations.

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# Enhancement of Magnetic and Surface Properties in Magneto-electrodeposited of FePd alloy thin films

27 Aug
15:00
(GMT+9)
1-3-5

Soundararaj Annamalai and J. Mohanty

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Superimposition of external constant magnetic field (CMF($\|$, $\perp$)) during electrodeposition process influencing magnetic, morphological and microstructural properties in electrodeposited thin films. Existence of Magneto hydrodynamic effect (MHD) and Lorentz force (fL) in electrolyte medium, in presence of magnetic field is inducing such effects is the reason for various effects in these films [1]. The relationship between plating current density (j) and magnetic field (B) direction causing convective force maxima or minima plays an important role in these films [2]. Tunable properties of FePd alloy thin films (Fe50Pd50 : higher PMA, Fe70Pd30 : FSMA) creates interest to study these films under CMF (0.8 T) by tunable electrodeposition technique at (-1.0 V, -1.05 V and -1.1 V) reduction potentials. FePd alloy thin films are prepared under CMF (0.8T $\|$, $\perp$) up to 100 seconds using pulsed electrodeposition technique. A clear investigation of magnetic, morphological and microstructural properties are carried out to understand the CMF effects. GI-XRD results show a variation in crystalline structure as FCC at (-1.0 V and -1.05 V) and BCC structure at (-1.1 V), which is due to the variation in alloy composition by anomalous co-deposition behavior of FePd alloy electrodeposition system [3]. Further structural analysis prove formed nano-crystallites (-1.05 V (7.95 nm) no CMF) are improving in (4.16 nm CMF ($\|$)), and degrading in (8.42 nm CMF ($\perp$)). M-H loop measurements shows all the deposits are clear in-plane magnetized, with increasing saturation magnetization (Ms) as Fe (at %) goes high. Interestingly, highest saturation magnetization found (1157 emu / cc: -1.1 V CMF ($\|$)) proves that external magnetic field causes an increase in magnetic anisotropy and quality of films. AFM images reveal high quality thin films with low roughness (Ra = 2.8 nm (-1.05V) CMF ($\|$)), whereas perpendicular to field leads to higher roughness. Realized patch like domain pattern in MFM investigation (-1.05 V) indicate parallel CMF helping easy formation of domains in electrodeposited films. However, films grow at higher deposition potential even in presence of parallel CMF found lesser effect in deposited films. Counter play between external magnetic field and deposition potentials is the reason for lower effect in higher deposition potentials.

## References

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# Comparative Study of Magnetic Hyperthermia Response of $Fe_3O_4$ And $MnFe_2O_4$ Nanoparticles

27 Aug
15:15
(GMT+9)
1-3-6

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Magnetic hyperthermia is a method of treating cancer by the elevated temperature of magnetic nanoparticle (MNP), under the application of alternating magnetic field. This technique is based on the observation that tumor cells get destroyed at a temperature range of 41°C to 46°C, while normal cells remain unaffected[1,2]. For decades, numerous researches have been going on to improvise hyperthermic efficacy using various kinds of materials. Among them, Fe3O4 and $\gamma$-Fe2O3 MNPs were extensively studied for hyperthermia application due to their selective heating capability and low toxicity. However, there is a growing body of literature that recognizes MnFe2O4 MNPs to have greater biocompatibility[3]. In this work, we have focused on comparative study of structural and magnetic properties along with Induction heating responses for probable use in Magnetic hyperthermia. We have synthesized Fe3O4 (FN) and MnFe2O4 (MN) nanoparticles using simple Solvothermal method described elsewhere[4]. Respective X -Ray Diffractogram confirms their crystallization, with crystallite size of 4.3nm and 27.2nm for FN and MN respectively. High resolution Transmission electron microscopy image depicts spherical shape nanoparticle for both FN and MN, with an average particle size of 5 ± 1nm and 30 ± 2nm for FN and Mn. Magnetic characterization of nanoparticles shows wide difference in values of Saturation magnetization(Ms) and Crystalline anisotropy(Kc). For FN and MN respectively, Ms is 12.5 emu/g and 52.1 emu/g, Kc is 0.35 × 105 J/m3 and 1.3 × 105 J/m3. MNPs under application of alternating magnetic field generates heat due to relaxation loss and hysteresis loss. Nanoparticle of 2mg/mL DI water was treated under the application of alternating magnetic field of certain frequency of 336 kHz and amplitudes of 18.04 kAm-1 for a period of 900 seconds (Easy Heat AMBRELL 8310, UK). To quantify heat generation ability of the nanoparticles Specific Absorption Rate (SAR) has been calculated for three different applied field amplitude. SAR is found to increase concomitantly with magnetic parameter. FN yields an SAR of 68.4W/g while MN yields 21.6W/g. Obtained SAR portrays FN and MN as promising Hyperthermic agent to be used in future.

The authors acknowledge UGC-DAE-CSR Mumbai for supporting a collaborative project (No. UDCSR/MUM/CD/CSR-M-239-2017 1005) during 2017–19.

**References**

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# Spin-orbit coupling dependent spin pumping in TMDs/$Ni_{80}Fe_{20}$ bilayer

27 Aug
16:30
(GMT+9)
1-4-1

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Two-dimensional (2D) transition metal dichalcogenides (TMDs) have received considerable attention in recent years due to their unique properties and tremendous potential for device applications [1]. TMDs possess a direct bandgap [2] and a large spin-orbit coupling (SOC) strength [3] in the monolayer form, which makes them promising for spintronics. In the ferromagnetic resonance (FMR) condition, a ferromagnet (FM) acts as a source of spin angular momentum, and it leads to the pumping of pure spin current from FM to the non-magnetic layer (NM). In this work, we probe the efficiency of spin pumping from Ni80Fe20 (Py) into various monolayer TMDs (MoS2, MoSe2, WS2, WSe2) used as a spin sink. Py of different thickness was deposited using UHV magnetron sputtering on the commercially purchased monolayer TMD samples on the c-cut sapphire substrate. Spin pumping is studied using FMR setup for excitation frequency of 2-10 GHz. The FMR measurements clearly show enhanced damping in the case of tungsten (W) based TMD/Py samples. We calculated the spin mixing conductance g (↑↓) and found it to be approximately four times in the case of WS2 / Py (7.28 $\times$ $10^{18}$ $m^{-2}$) as compared to $MoS_2$ / Py (1,86$\times$ $10^{18}m^{-2}$) samples. The interfacial magnetic anisotropy energy density ($K_S$) is plotted with g(↑↓), and it can be observed that the $K_S$ has a crucial role in the increased spin pumping. We attribute this to the d-d hybridization at the interface, which enhances interfacial SOC [4]. We have shown in this work that the spin pumping is much more significant in the case of W based TMD/Py samples because of their larger SOC strength. This work establishes a way to regulate spin pumping with the SOC strength, which can lead to advances in spintronics based devices.

## References

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# Voltage Controlled Magnetization Switching of FeGaB Elliptical Nanomagnets on PMN-PT Substrate

27 Aug
16:45
(GMT+9)
1-4-2

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Magnetization switching is the core of nanomagnetic memory and logic devices. Phenomenon such as the spin-transfer torque (STT), spin-orbit torque (SOT), and current-driven switching had been investigated extensively for controlled magnetization switching. However, these phenomena fall short to perceive the required magnetic switching and inevitably accompanied by thermal issues, leading to inefficient functionality. To address these issues related to magnetization reversal efficiently, the concept of straintronics is explored extensively recently. Straintronics devices are comprised of a heterostructure of ferromagnetic and piezoelectric materials, in which an applied electric field across the piezoelectric induces a strain at the interface of heterostructure causing the magnetization switching. In this work, we uncover the magnetization switching of elliptical disk-shaped FeGaB nanomagnets of different sizes on top of the piezoelectric PMN-PT substrate using micromagnetic finite element method (FEM). Aspect Ratio (major axis: minor axis) of the elliptical disk nanomagnet is varied while keeping the thickness constant. At the first pre-stress equilibrium state (ground state) for different nanomagnets due to free precession and damping mechanism is formed, which is followed by the application of external voltage pulse. For larger aspect ratio nanomagnets, intermediate strain-induced incoherent states are observed which is attributed to the larger damping in the magnetization distribution as a function of time. Also, when the magnitude of the external voltage pulse is made zero, the magnetization switched back to the ground state. This shows the volatile memory nature of the larger aspect ratio nanomagnets. On the contrary, intermediate coherent states are observed for lower aspect ratio nanomagnets. When the magnitude of the external voltage pulse is made zero for lower aspect ratio nanomagnets they tried to remain in the immediate previous state. This also shows the non-volatile memory nature of the low aspect ratio nanomagnets. Quantitative analysis of the interplay between the stress anisotropy, exchange, and demagnetization energy is used to understand the magnetization switching. While incoherent magnetization switching in straintronic devices is not preferable, the proposed work can have deeper implications for the design of the such devices which can be potentially useful in future voltage induced nanomagnetic memory and logic devices.

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# Bragg MOKE as a technique for measuring interfacial Dzyaloshinskii-Moriya interaction

27 Aug
17:00
(GMT+9)
1-4-3

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[2]Centre for Applied Research in Electronics (CARE) department, Indian Institute of Technology Delhi, New Delhi, Delhi,India

The Dzyaloshinskii-Moriya interaction (DMI) plays a crucial role in the stabilization of chiral spin textures [1]. Interfacial DMI (iDMI) induced by a lack of inversion symmetry and strong spin orbit coupling at the interface of Ferromagnet/Heavy Metal (FM/HM) heterostructures provides various opportunities for future spintronic devices. Recently, iDMI in a thin film of NiFe/Graphene (NiFe/Gr) heterostructures has been detected using Brillouin light scattering [2] and using spin-polarized electron microscopy [3]. In this study, we propose a simple method of measuring DMI by using the Bragg magneto-optical Kerr effect (MOKE). We observe an asymmetric shift in the hysteresis loop, which is proportional to the strength of iDMI [4]. Here, we utilize Bragg-MOKE in longitudinal mode to which occurs when a broad polarized beam is incident on a periodic array of the magnetic features with size comparable to the wavelength of laser. We have investigated the hysteresis loop shift for 1 and 2 order of diffraction in off-specular geometry for both patterned graphene (Gr/NiFe(10nm)/Ta) and reference (NiFe(10nm)/Ta). We used triangular pattern as proposed in Ref [4]. We found a shift in hysteresis loop for the Gr/NiFe/Ta sample, which likely due to the presence of iDMI that was previously measured using BLS [2]. Hence, the Bragg-MOKE technique can be a potential technique for rapid quantification of iDMI in magnetic heterostructures. Moreover, the magnetic force microscopy (MFM) measurements and micromagnetic simulations con firm the presence of iDMI.

## References

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# Skyrmion based Random Bit Generator

27 Aug
17:15
(GMT+9)
1-4-4

Israa Medlej[1, 2], Riccardo Tomasello[1], Abbass Hamadeh[2], Fouad El Haj Hassan[2], and Giovanni Finocchio[1]

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Magnetic skyrmion are topologically protected [1],[2] non-uniform configuration of the magnetization which can behave as particles [3]. They can be easily manipulated (nucleated, shifted and detected) by spin-polarized current, and for this reason they offer a wide range of applicability fields [2]. In this work, we study the skyrmion dynamics driven by the spin-Hall effect in a synthetic antiferromagnet within a micromagnetic framework. We show that, in presence of thermal fluctuations at room temperature, the skyrmion motion is not deterministic [4]. In other words, this motion follows stochastic law of motion (casual sequence of 0 and1), and therefore it is natural to think skyrmions as building blocks of random bit generators if combined witha device designed for this scope. The parameters used in our study are the same as in [5]. We have shown, via a full micromagnetic simulations, the possibility to move skyrmions randomly in presence of spin-Hall effect and thermal fluctuations in a synthetic antiferromagnets, where the skyrmion hall effect is absent [5]. We have observed that, under the steady action of the current, skyrmions stochastically divided in the two output branches of our device starting from a continuous nucleation in the input branches. Our results are also robust to the presence of defects in the form of randomly distributed grains of the perpendicular anisotropy. Our achievements open the path for the design of random bit generators based on skyrmions.

**References**

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# Effect of Tantalum capping layer on damping parameter in $Co_{50}Fe_{50}$ thin films.

27 Aug 17:30 (GMT+9) 1-4-5

B. Panigrahi[1], S. K. Sahoo[1], H. Basumatary[2], M. M. Raja[2], and A. Haldar[1]

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The use of a nonmagnetic (NM) capping layer on top of a ferromagnetic (FM) layer can efficiently increase the Gilbert damping parameter when the choice of the NM layer is a heavy metal. Due to the spin pumping phenomena, spin current is generated in the NM layer due to the magnetic oscillations in the FM layer resulting an increase in the damping of the FM layer[1],[2]. Heavy metals such as Pt, Ta etc. show high spin orbit coupling, possess short diffusion lengths (few nm) and are found to be excellent for spin hall effect[3]. Interestingly, in case of the thickness of the NM layer becomes smaller or comparable to its spin diffusion length[4], non-equilibrium spin accumulation occurs at the interface due to the Rashba spin orbit interaction[5] which acts opposite to the damping. Therefore, a proper combination of FM/NM layer with appropriate thickness offers avenues for optimization of damping parameters and exploration spin pumping phenomena. We have considered Co50Fe50 (CoFe) and Ta as FM and NM layer, respectively. Note that Co50Fe50 based alloy thin films offer high saturation magnetization at the room temperature and better thermal stability[6],[7]. A series of bilayer thin films were fabricated using sputtering method by varying the thickness of Ta (tTa = 2nm, 5nm, 10nm, 20nm, 30nm) for a fixed thickness of CoFe (tCoFe=20nm) layer. Magnetic hysteresis measurements were carried out by using magneto-optical Kerr effect (MOKE) technique. We have used co-planner waveguide with lock-in amplifier based ferromagnetic resonance (FMR) technique to study the magnetization dynamics by varying the field from -300 mT to +300 mT and frequency from 2-18GHz. From MOKE measurement the coercive field (Hc) was found to be 18.9 mT and 24.4 mT, respectively. FMR spectra reveal that CoFe(20nm)/Ta(2nm) has lower damping value (0.041) as compared to the damping value (0.068) of bare CoFe(20nm).As The spin diffusion length of Ta is 2.7 nm[3], therefore Rashba spin orbit interaction is expected to be significant at interface. The damping parameter was further increased and got saturated at higher thicknesses of Ta. The linewidth ($\Delta$H) was found to be 115.5 mT and 142.9 mT for CoFe(20nm)/Ta(2nm), bare CoFe(20nm) sample, respectively. The resonance field (Hres) was obtained as 123.2 mT and 122.8 mT, respectively. Saturation magnetization ($4\pi M_s$) was extracted from the Kittel fitting as 1.86 T. Spin mixing conductance was found to be $38.7 \times 10^{-18} m^{-2}$ for CoFe(20nm)/Ta(2nm).

**References**

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# Contributed talks from Europe, Middle-East and Africa

**All contributed talks in this session will follow Paris Time (GMT +2). The session will start at 9:50 and end at 19:00.**

# PROGRAM SCHEDULE

## Region 2: Europe

**10:00 to 19:00 – Paris time (GMT+2)**

**09:50 - 10:00** Opening Remarks

| Session 2-1 | Session 2-3 |
|---|---|
| **10:00 - 10:15**<br>Thomas Feggeler, UDE (Germany) | **14:00 - 15:00**<br>Prof. Mathias Kläui, JGU (Germany) |
| **10:15 - 10:30**<br>Dongwook Go, FZJ (Germany) | **15:00 - 15:15**<br>Kaushalya Jhuira, IJL (France) |
| **10:30 - 10:45**<br>Corrado Carlo Maria Capriata, KTH (Sweden) | **15:15 - 15:30**<br>Juan M. Gomez-Perez, CIC nanoGUNE (Spain) |
| **10:45 - 11:00**<br>Moritz Geilen, TUK (Germany) | **15:30 - 15:45**<br>Dmitrii Khokhriakov, CUT (Sweden) |
| **11:00 - 11:15**<br>Md Anamul Hoque, CUT (Sweden) | **15:45 - 16:00**<br>Vladislav Borisov, UU (Sweden) |
| **11:15 - 11:30**<br>Rahul Gupta, UU (Sweden) | **16:00 - 16:15**<br>Venkata Krishna Bharadwaj, JGU (Germany) |
| **Session 2-2** | **16:15 - 16:30**<br>Kevin Hofhuis, ETH Zurich/PSI (Switzerland) |
| **11:30 - 12:30**<br>Dr. José Maria Porro, BC Materials (Spain) | **Session 2-4** |
| **12:30 - 12:45**<br>Héctor Corte-León, NPL (UK) | **16:30 - 17:30**<br>Dr. Anna Semisalova, UDE (Germany) |
| **12:45 - 13:00**<br>Sandra Ruiz-Gómez, ALBA sync. (Spain) | **17:30 - 17:45**<br>Álvaro Díaz-García, UoS (Spain) |
| **13:00 - 13:15**<br>Paula Corte-León, UPV/EHU (Spain) | **17:45 - 18:00**<br>Luigi Solimene, Pol. di Torino (Italy) |
| **13:15 - 13:30**<br>José A. Fernandez Roldan, UoO (Spain) | **18:00 - 18:15**<br>Thanh Binh Nguyen, UoY (UK) |
| **13:30 - 13:45**<br>Giulia Serrano, UoF (Italy) | **18:15 - 18:30**<br>Felix Schreiber, JGU (Germany) |
| **13:45 - 14:00**<br>María Salvador, UoO (Spain) | **18:30 - 18:45**<br>Markus Gößler, TUG (Austria) |

**18:45 - 19:00** Closing Remarks

# Element-specific and spatially resolved detection of GHz magnetization dynamics in a single $Fe_3O_4$ nanoparticle chain

27 Aug
10:00
GMT+2
2-1-1

T. Feggeler[1], R. Meckenstock[1], D. Spoddig[1], B. Zingsem[1,2], H. Ohldag[1,3,4], H. Wende[1], M. Farle[1,5], M. Winklhofer[6] and K. Ollefs[1]

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Magnetic nanoparticles have been suggested for soliton based [1] and biomagnonic logic devices [2]. For biomagnonics it is possible to create binary logic devices by manipulating the magnon dispersion of nanoparticle chains in magnetotactic bacteria by changing the DNA controlled arrangement of the nanoparticles [2]. Here we present spatially resolved FMR measurements on a single $Fe_3O_4$ nanoparticle chain (19 particles in two segments, single particle size 40 nm to 50 nm) situated in a bacterium Magnetospirillum Magnetotacticum, using Scanning Transmission X-ray Microscopy detected Ferromagnetic Resonance (STXM-FMR) [3]. The employed instrument allows to probe the element-specific and spatially-resolved ($<$50 nm) magnetization dynamics up to 10 GHz with ps sampling [3]. Our measurements at 6.748 GHz show a resonant response of nanoparticle chain segments yielding a uniform phase and non-uniform amplitude distribution. Micromagnetic simulations confirm the experimental observations. Financial support: FWF Project I-3050, ORD-49, DFG Project 321560838.

**References**

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# Theory of spin-orbital coupled dynamics for understanding spin-orbit torque

27 Aug
10:15
GMT+2
2-1-2

D. Go [1,2,3], F. Freimuth[1], J-P. Hanke[1], F. Xue[4,5] O. Gomonay[2], K-J. Lee[6], S. Blügel[1], P. M. Haney[4], H-W. Lee[3] and Y. Mokrousov[1,2]

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Spin-orbit torque, which allows for electrical manipulation of the magnetization, is one of the most important phenomena in spintronics. Although several microscopic mechanisms have been proposed such as spin Hall effect and interfacial spin-orbit coupling, it is challenging to disentangle various competing contributions both theoretically and experimentally. In this talk, we examine the fundamental physical nature of spin-orbit torque in the view of angular momentum exchange between different degrees of freedom in solid – angular momentum carried by spin and orbital of the conduction electron, mechanical angular momentum of the lattice, and spin angular momentum carried by local magnetic moment. We show that analyzing angular momentum transfers between these channels reveals fundamental nature of the microscopic mechanism. As a proof of principle, we compare Fe/W(110) and Ni/W(110) based on our first-principles implementation of the formalism and show that spin-orbit torques in these systems are dominated by spin torque and orbital torque mechanisms, respectively. Since orbital and spin Hall effects in W have opposite signs, it leads to opposite signs of the effective spin Hall angles for Fe/W(110) and Ni/W(110), which awaits for experimental confirmation. This clearly demonstrates that our formalism is ideal for studying the angular momentum transfer dynamics in spin-orbit coupled systems as it goes beyond the "spin current picture" by naturally incorporating the spin and orbital degrees of freedom on an equal footing. Our calculations reveal that, in addition to the spin and orbital torque, other contributions such as the interfacial torque and self-induced anomalous torque within the ferromagnet are not negligible in both material systems.

## References

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# Frequency Stability of Spin-Hall Nano-Oscillators with Realistic Grain Structure

27 Aug
10:30
GMT+2
2-1-3

C. C. M. Capriata[1], S. Jiang[2], J. Åkerman[2] and G. B. Malm[1]

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Nano-constriction spin-Hall nano-oscillators (NC-SHNOs) are one of the most encouraging nano-oscillator alternatives among the spintronics devices, in fact, they are compatible with the standard CMOS processing techniques [1,2] and provide highly coherent and widely tunable microwave signals at room temperature [3]. Considering some of the most promising SHNOs applications (the multi-constriction [4] and the array [5]), the frequency output stability of each SHNO is crucial to guarantee the synchronization with the other oscillators. In this work, we focus on the influence of a realistic grain structure on variability in oscillatory frequency. The exchange coupling of the metal film changes at the grain boundaries influencing the SHNO as the shape of the oscillating volume changes. Compared to previous studies [2, 4, 6, 7, 8], this work provides a novel simulation method for systematic investigation of frequency instability and device-to-device variability. We performed MuMax3 [9] micromagnetic simulations including the random thermal field (at 300K) of an SHNO composed of 6 nm Pt, and 5 nm Py ($Ni_{80}Fe_{20}$). To include the grains into the simulation, we used a novel technique based on atomic force microscope (AFM) measurements. First, a real sample was analysed with an AFM, revealing a grain size of ∼30 nm. Then, the grains were digitalized, completed by using a Voronoi tessellation technique. Finally, the grains were imported into the micro magnetic simulator, allowing to randomly change the exchange coupling of every single grain. During the study, different constriction sizes were considered, we carried out investigations about the influence of the applied field (and its angle), and the grain size. Comparing different simulated devices (created by varying the grain-to-grain exchange), the frequency variability is ∼100 MHz, this variability is only due to the grains we included in the simulations. Experimental data show a similar variability too. To summarize, we found a noticeable device-to-device output variability by implementing a grain structure. The origin of this difference in oscillating frequency is due to the shape of the oscillating volume and marginally to the reflection of the wave. The presentation will include a comprehensive analysis of the different variability sources. The influence of the grains and reduced exchange will be compared to these results in order to conclusively identify the most dominant variability mechanism.

## References

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## Spin-wave instabilities induced by surface acoustic waves

27 Aug
10:45
GMT+2
2-1-4

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Surface acoustic waves (SAW) are strain waves which are located close to the surface of a media. They are widely used in band filters up to the GHz regime because of their tunability and narrow bandwidth provided by the wavevector selection during excitation and detection [1]. One further strength is that the transduction of microwaves into SAWs via piezoelectric materials is extremely energy efficient. If a magnetic film is placed on the surface of the media where the SAW is propagating in, an effective magnetic field can be generated by the magnetoelastic interaction. This field can be used to excite spin waves [2]. We present the investigation of spin wave excitation in a CoFeB film on top of a GaN layer. Both, the SAWs and the spin waves, have been measured by Brillouin light scattering microscopy [3]. With this technique spatially resolved measurements are possible and the signals exhibiting from phonons and magnons can be separated by the polarization of the scattered light. The efficiency of the excitation process of spin waves via SAWs is evidenced by the observation of spin wave instabilities. These nonlinear scattering processes only occur if a certain excitation threshold is overcome [4]. We characterize the SAW-induced spin wave instabilities via field and power dependent measurements and proof the SAW driven-excitation via time resolved experiments.

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# Charge - spin conversion in layered semimetal

27 Aug
11:00
GMT+2
2-1-5

M. A. Hoque[1], D. Khokhriakov[1], B. Karpiak[1], B. Zhao[1] and S. P. Dash[1]

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A spin-polarized current source using nonmagnetic layered materials is promising for next-generation all-electrical spintronic science and technology. Here, we electrically created a spin polarization in a layered semimetal $TaTe_2$ via the charge-spin conversion process. Using a hybrid device of $TaTe_2$ in a van der Waals heterostructure with graphene, the spin-polarization in $TaTe_2$ is efficiently injected and detected by nonlocal spin-switch, Hanle spin precession, and inverse spin Hall effect measurements. Systematic experiments at different bias currents and gate voltages in a vertical geometry prove the $TaTe_2$ as a nonmagnetic spin source at room temperature. These findings demonstrate the possibility of making an all-electrical spintronic device in two-dimensional van der Waals heterostructure, which can be essential building blocks in energy-efficient spin-orbit technology.

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# Effect of Re doping on giant enhancement of spin mixing conductance at Ru/FeCo/Ru interfaces

27 Aug
11:15
GMT+2
2-1-6

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The quantity to measure the average energy consumed per switching event is described by the energy-delay product for in-plane spin-logic devices. The interfacial properties of ferromagnetic and non-ferromagnetic bilayers, spin mixing conductance (SMC), in spin-logic devices play a vital role to reduce the average consumed energy, as the SMC is inversely proportional to the energy-delay product [1]. Here, we have deposited polycrystalline Re-doped FeCo thin films grown on $SiO_2$/Si substrate, sandwiched between Ru thin layers. We found 98 % enhancement in the real part of effective SMC with Re doping [2]. Conversely, it does not change with Re doping in thin films, which are seeded and capped with Cu layers. The enhancement of Re-doped FeCo thin films sandwiched between thin layers of Ru is linked to the Re doping-induced change of the interface electronic structure in the nonmagnetic Ru layer. Moreover, a comparison of the effective damping in in-plane (IP) and out-of-plane (OP) ferromagnetic resonance spectroscopy indicates that the IP damping is affected by two-magnon scattering, which overestimates the real part of the effective spin mixing conductance. The saturation magnetization decreases 35 % with increasing Re doping up to 12.6 at. % [2]. This study opens a direction of tuning the spin mixing conductance in magnetic heterostructures by doping of the ferromagnetic layer, which is essential for the realization of energy-efficient operation of spintronic devices.

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# Practical demonstration of quantitative magnetic force microscopy

27 Aug
12:30
GMT+2
2-2-1

H. Corte-León[1], S. Sievers[2], X.Hu[2], A. Fernández-Scarioni[2], P. Klapetek[3], V. Neu[4], H. W. Schumacher[2] and O. Kazakova[1]

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Magnetic force microscopy (MFM) is an easy-to-use imaging technique for magnetic stray fields at the nanoscale. It employs a magnetically coated atomic force microscopy tip as sensing element and can achieve a spatial resolution down to 10 nm. The measurements can be performed at ambient conditions or vacuum, and at a broad range of temperatures (up to 200 °C and down to low temperatures of a few K). MFM can be used with an applied external magnetic field, and even allows to apply electrical currents passing through the sample [1]. This versatility has made it a popular tool, e.g. for studying the stray field of magnetic nanostructures. However, despite being commonly used, it is being considered as being only a qualitative technique. A comprehensive approach for the calibration of MFM images and thus for obtaining quantitative MFM (qMFM) measurements of the magnetic stray field [2] has been presented by Hug and co-workers more than two decades ago. However, few groups attempted their regular use, due to the lack of step-by-step procedures, and standardization documents to guide them through the measurement and calibration process. To overcome these obstacles, several national metrology institutes developed a qMFM protocol where specific magnetic reference samples are used to perform a calibration of the MFM system. The calibration process is implemented as a module of the freely available scanning probe microscopy analysis software called Gwyddion) [6] and has been validated in a recent interlab comparison of qMFM [4]. Furthermore, the qMFM protocol is the main core of a newly developed IEC standard (IEC TS 62607-9-1 ED1) on quantitative nanoscale magnetic field measurements. This makes qMFM a validated technique that can be adopted by every laboratory. Here, with the aim of increasing the awareness of the magnetism community towards the new status of this technique, we discuss the calibration protocol along with the results of the interlab comparison. We put an emphasis on showing the step by step process of calibrating measurements with the objective of enabling other groups to use qMFM self-sufficiently in their labs. The complete process from sample preparation and calibration of the probe up to the data analysis performed in Gwyddion is presented. As an example, the calibration of a wide range of commercial probes (including the test of the calibration by predicting the interaction of the probes with electrically active samples) [4] is discussed.

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# 3D magnetometry using XMCD-PEEM microscopy

27 Aug
12:45
GMT+2
2-2-2

S. Ruiz-Gómez[1], A. Quesada[2], M. Foerster[3], A. Mascaraque[1], J. de la Figuera[4], L. Perez[1,5] and L. Aballe[3]

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One of the main trends in the magnetism roadmap is the study of the magnetic configuration and magnetization dynamics of magnetic nanoelements. The development of magnetic nanostructures requires methods capable of resolving their magnetization. Different microscopy techniques like magnetic force microscopy can be used to explore the magnetic configuration of these nanoobjects. However, these techniques normally do not provide us with information about the 3D configuration of the magnetic moments, which could be crucial in many cases. The combination of soft X-ray magnetic imaging with circular magnetic dichroism (XMCD) allows the characterization of nanostructures with chemical sensitivity down to a lateral resolution of 20nm.In this work we combine the use of XMCD-PEEM and micromagnetic simulation to obtain 3D information of the magnetic configuration of in-situ grown single crystal nanometer-thick magnetite islands [1] and of magnetic nanowires [2]. The experiments have been performed at the CIRCE beamline of the Alba synchrotron. This beamline is equipped with a photoemission microscope in which, by taking XMCD images, is possible to acquire nanometer resolution maps of the magnetization of nanosystems. Combining measurements at different azimuthal angles, the full magnetization vector can be determined. Combining the experimental magnetization maps with micromagnetic simulations, the magnetic configuration of the systems can be completely determined. We will show how the combination of XMCD-PEEM with imaging and data analysis is a very powerful tool for the study of magnetic configurations of nanometer sized objects.

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# Engineering of magnetic properties and magnetoimpedance effect in Fe-rich microwires by reversible and irreversible stress-annealing anisotropy

27 Aug
13:00
GMT+2
2-2-3

P. Corte-León[1,2], V. Zhukova[1,2], J. M. Blanco[2], M. Ipatov[1,2], S. Taskaev[3], M. Churyukanova[4], J. González[1] and A. Zhukov[1,2,5]

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Herein, by using both hysteresis loops and the Giant magnetoimpedance, GMI, measurements, the magnetic properties of amorphous FeSiBC microwires have been thoroughly analyzed paying attention on the influence of annealing (under stress or without stress) on the GMI effect and magnetic properties of Fe-Si-B-C microwires. We observed that stress annealing allows the induction of transverse magnetic anisotropy and the GMI effect improvement. This stress-annealing induced anisotropy depends on the stress-annealing conditions: annealing temperature, time and stress applied during the annealing and can be partially annealed out by subsequent furnace annealing [1]. In fact, reversibility studies can help understand the origin of stress-annealing induced anisotropy. However, the reversibility of the stress-annealing induced anisotropy depends on the stress-annealing conditions. Particularly, most of the transverse induced magnetic anisotropy obtained by stress-annealing at high stresses values is irreversible. Stress-annealing followed by annealing without stress allows further improvement of the GMI effect in Fe-Si-B-C microwires in a wide frequency range [2]. Coercivity, remanent magnetization, and magnetoimpedance ratio of FeSiBC microwires can be tuned by annealing conditions: annealing temperature and time. All studied microwires present GMI hysteresis. The sample with the highest GMI ratio presents the lowest GMI hysteresis.

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# Electric current- and field- induced magnetization switching and control of the vortex structures in cylindrical magnetic nanowires

27 Aug
13:15
GMT+2
2-2-4

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Cylindrical magnetic nanowires are candidates for the building blocks of 3D information technologies such as shift registers, magnetic recording, spintronics, logic gates, and sensing architectures [1-4]. Spin-polarized current is an energy-efficient way to excite magnetization dynamics in planar nanostructures, however, in cylindrical nanowires, this research is doing its first steps [5]. We investigate the magnetization dynamics in a cylindrical nanowire of Permalloy (100 nm diameter and 1 m length) under the simultaneous application of electric current and magnetic field by micromagnetic simulations. The magnetization reversal process starts with the creation of open vortex structures with different rotation senses at the ends of the nanowire. We conclude that the electric current by itself enlarges or reduces the length of these vortex structures according to the rotational sense of the associated Oersted field. Large enough current densities produce a vortex structure that covers the whole nanowire surface. At the same time, the magnetization in the very core of the nanowire remains the same, i.e. no complete magnetization reversal is possible in the absence of an external magnetic field. The simultaneous action of the applied electric current and magnetic field allows the complete control of the vortex structures in terms of setting the polarity and vorticity. We present the resulting diagram of magnetic states obtained after the application of field and electric current. The state diagram shows the values required for the vorticity and axial magnetization switching and will become very useful for future experiments on current-induced domain wall dynamics in cylindrical magnetic nanowires.

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# Interaction of single molecule magnets monolayer with a superconductor

27 Aug
13:30
GMT+2
2-2-5

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The interaction of magnetic materials with superconductors recently disclosed novel phenomena interesting for spintronics and quantum technologies.[1] In particular, molecular spins deposited on superconductive surfaces led to the observation of localized magnetic states, known as YuShibaRusinov bound states,[2] or enhanced molecular spin lifetimes.[3] Single molecule magnets (SMMs), e.g. tetrairon(III) propeller-shaped complexes ($Fe_4$), represent an interesting class of magnetic molecules for their magnetic bistability properties that can be retained at the single molecule level even when deposited on a substrate.[4,5] Here we report the investigation of a sub-monolayer of $Fe_4$ SMMs deposited on a Pb(111) surface. We reveal that the transition of lead to the superconducting state affects the magnetization of the SMMs that locally switch from a blocked magnetization state to a resonant quantum tunneling regime.[6] These findings open intriguing perspectives for controlling single molecule magnets in devices as well as for their use as local probes for superconducting materials.

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# Nanoparticle effects on magnetic lateral flow assays: size and clustering for improved inductive biosensing

27 Aug
13:45
GMT+2
2-2-6

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The ongoing COVID-19 pandemic has made the 'rapid test' very familiar. Based on a Lateral Flow Immunoassay (LFIA), a paper-based architecture whose until now most popular use was the pregnancy test. Beyond health care, they are increasingly being used in food safety and environmental settings for the determination of biomarkers, allergenic pathogens, drugs and metabolites [1]. Their sensitivity, selectivity, quickness and ease of use make them ideal for Point-of-Use (PoU) testing. One of the key points of the LFIAs is the labelling of the biomarker, traditionally by latex or gold nanoparticles that provide a visible signal. These are essentially qualitative (presence/absence) or semi-quantitative analyses. To add quantification capacities to LFIAs, the use of Magnetic Nanoparticles (NPs) has been lately proposed [2].To account for a good PoU testing, the magnetic LFIAs must be associated to a magnetic reader that should be itself fast and portable. A radio-frequency inductive sensor has been developed for this purpose which takes advantage of the superparamagnetic character of the NPs [3,4]. The clue parameter of this technique is the initial magnetic permeability of the particles at the frequency of detection. The particle size has a crucial influence on the magnetic permeability, while the agglomeration degree determines the number of particles per molecule of interest. Thus, both size and agglomeration have a great importance in this type of test. The purpose of this work has been to elucidate the effects of the magnetic core size and particle agglomeration before and after the biofunctionalization process in the magnetic LFIA. To do so, three different iron oxide particles with core sizes of 8, 12 and 23 nm and different initial agglomeration have been evaluated as labels in LFIAs functionalized with neutravidin and immobilized by a biotin test line.

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# Picosecond Spin Orbit Torque Switching

27 Aug
15:00
GMT+2
2-3-1

K. Jhuria [1], J. Hohlfeld[1], A. Pattabi[2], E. Martin[1], A. Y. A. Córdova[1,3], X. Shi[4], R. Lo Conte[3], S. Petit-Watelot[1], J. C. Rojas-Sanchez[1], G. Malinowski[1], S. Mangin[1], A. Lemaître[5], M. Hehn[1], J. Bokor[2], R. B. Wilson[4], J. Gorchon[1]

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Reducing energy dissipation while increasing speed in computation and memory is a long-standing challenge for spintronics research [1]. In the last 20 years, femtosecond lasers have emerged as a tool to control the magnetization in specific magnetic materials at the picosecond timescale [2]. However, the use of ultra-fast optics in integrated circuits and memories would require a major paradigm shift. An ultrafast electrical control of the magnetization [3] is far preferable for integrated systems. Here we demonstrate reliable and deterministic control of the out-of-plane magnetization of a 1 nm-thick Co layer with single 6 ps-wide electrical pulses that induce spin orbit torques on the magnetization. We can monitor the ultrafast magnetization dynamics due to the spin orbit torques with sub-picosecond resolution, thus far accessible only by numerical simulations. Due to the short duration of our pulses, we enter a counter-intuitive regime of switching where heat dissipation assists the reversal. Moreover, we estimate a low energy cost to switch the magnetization, below 50 pJ for our micrometer sized device. These experiments show that spintronic phenomena can be exploited on picosecond time-scales for full magnetic control and should launch a new regime of ultrafast spin torque studies and applications.

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# Strong interfacial exchange field in a heavy metal/ferromagnetic insulator system determined by spin Hall magnetoresistance

27 Aug
15:15
GMT+2
2-3-2

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Spin-dependent scattering transport at heavy metal (HM)/magnetic insulator (MI) interface can be described in terms of three parameters: the spin-sink conductance Gs and the real and imaginary part of the spin-mixing conductance, $G = G_r + iG_i$ [1,2]. Each parameter is relevant for different spin-dependent phenomena. For instance, $G_s$ originates from spin-flip processes and therefore is the leading parameter in electrical biasing of magnons [3], whereas $G_r$ accounts for the spin-transfer (Slonczewski) torque to the magnetization and plays a fundamental role in spin-pumping experiments [4]. On the other hand, $G_i$ quantifies the interfacial exchange field, which induces a field-like torque in the conduction electrons of the HM and is important for example in spin-splitting field experiments in superconductivity [5]. These conductances are broadly studied in ferrimagnetic insulators, where usually the contribution of $G_r$ is much larger than that of $G_i$ [6], leading to only few reports on the exchange field at HM/MI interfaces [7,8]. In this work [9], we study the three spin conductance terms by spin Hall magnetoresistance (SMR) in a new system: a ferromagnetic insulator (FMI) such as EuS. By SMR measurements as a function of the temperature, and taking advantage of the newly developed microscopic theory for SMR [2], we can extract relevant microscopic parameters such as the exchange interaction between the 1s electrons in Pt and the localized magnetic moments in EuS (Jint $\sim$ 18 meV) [9]. An interfacial exchange field of the order of 1 meV ($\sim$ 15 T) acting upon the conduction electrons of Pt can be estimated from $G_i$, which is at least three times larger than $G_r$ below the Curie temperature [9]. Our work provides an easy method to quantify this interfacial spin-splitting field, which is of interest in different areas of Condensed Matter Physics, such as proximity effects in superconducting hybrid systems.

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# Gate-tunable Spin-Galvanic Effect in Graphene-Topological insulator van der Waals Heterostructures at Room Temperature

27 Aug
15:30
GMT+2
2-3-3

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Unique electronic spin textures in topological states of matter are promising for emerging spin-orbit driven memory and logic technologies. However, there are several challenges related to the enhancement of their performance, electrical gate-tunability, interference from trivial bulk states, and heterostructure interfaces. We address these challenges by integrating graphene [1] with a 3D topological insulator (TI) in a van der Waals heterostructure [2] to take advantage of their remarkable spintronic properties and engineer proximity-induced spin-charge conversion phenomena. In these heterostructures, we experimentally demonstrate a gate-tunable spin-galvanic effect at room temperature due to the efficient conversion of nonequilibrium spin polarization into a transverse charge current [3]. Systematic measurements of SGE in various device geometries via a spin switch, spin precession, and magnetization rotation experiments establish the robustness of spin-charge conversion in the Gr-TI heterostructures. Importantly, using a gate voltage, we reveal a strong electric field tunability of both amplitude and sign of the spin-galvanic signal. These findings provide an efficient route for realizing all-electrical and gate-tunable spin-orbit technology using TIs and graphene in heterostructures, which can enhance the performance and reduce power dissipation in spintronic circuits.

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# First-principle framework for studying Heisenberg and Dzyaloshinskii-Moriya interactions in correlated magnetic systems

27 Aug 15:45 GMT+2 2-3-4

V. Borisov[1], Y. Kvashnin[1], D. Thonig[2], P. Thunström[1], M. Pereiro[1], A.Bergman[1], E. Sjöqvist[1], A. Delin[1,3], L. Nordström[1], O. Eriksson1,2

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Magnetic systems with low-dimensional skyrmionic spin structures can find promising applications, e.g. in the next-generation electronics and spintronics devices. The microscopic picture of magnetic skyrmions is usually discussed in terms of the competition between the isotropic (Heisenberg) and anisotropic antisymmetric exchange, also known as the Dzyaloshinskii-Moriya (DM) interaction [1,2]. Large DM interaction is advantageous for stabilizing smaller skyrmions and requires a considerable spin-orbit coupling and broken space-inversion symmetry of the crystal structure. This limits the range of systems where significant DM interaction and magnetic skyrmions can be observed, with most prominent examples being the B20 compounds MnSi and FeGe and 3d/5d transition metal bilayers, such as Fe/Ir(111) (for recent review, see [3]). Therefore, it is of paramount importance to find further materials with more stable skyrmionic behavior. The search for new materials can be guided by the data obtained from first-principle calculations which address in detail the magnetic exchange interactions. While the Heisenberg interaction is well understood and the magnetic properties of concrete materials can be accurately simulated [4], also in the presence of dynamical correlations, the effect of these correlations on the DM interaction is largely an open question.

In this work, we propose a general theoretical framework for obtaining a detailed picture of the isotropic and anisotropic, e.g. DM, interactions in correlated systems. This framework is based on a combination of the density functional (DFT) [5] and dynamical mean-field theories (DMFT) [6] and the relativistic formulation of the magnetic force theorem [7], implemented in the RSPt electronic structure code [8]. The proposed theoretical approach is used to study the magnetic interactions in selected bulk systems (MnSi and FeGe compounds with the B20 structure and artificial CoPt and FePt alloys) and the low-dimensional systems Co/Pt(111) and Mn/W(001). Our results indicate that the dynamical electronic correlations, captured here on the level of the fluctuation-exchange approximation, can lead to rather non-trivial changes of the magnetic interactions in some of the studied systems. As an outlook, it may be noted that a more accurate description of correlations can be achieved in our theoretical framework by using more advanced DMFT solvers, based e.g. on the quantum Monte Carlo and exact diagonalization methods.

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# Stability and dynamics of in-plane Skyrmions

27 Aug
16:00
GMT+2
2-3-5

V. K. Bharadwaj[1], R. Zarzuela[1], K-W. Kim[2], J. Sinova[1,3], K. Everschor-Sitte[1]

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Magnetic skyrmions are topological magnetic whirls with a trivial magnetization configuration at their boundary. Recent years have witnessed a growing interest in their potential usage as building blocks for spintronic applications. In thin films, most studies consider skyrmions with an out-of-plane easy axis anisotropy, where the magnetization at both the skyrmion center and boundary is pointing perpendicular to the plane. In this work we analyze skyrmions in in-plane magnets, [1] which have recently been observed [2,3]. We offer possible material candidates to observe in-plane skyrmions through symmetry analysis and provide the phase diagram of such crystal systems. Via micromagnetic simulations we show that in-plane skyrmions, similar to their out-of-plane analogues can be produced by two mechanisms, namely: i) the blowing bubbles technique [4], i.e. the creation of skyrmions due to current flow through constricted geometries and ii) shedding of skyrmions from a magnetic impurity driven by spin-transfer torques [5]. We also study the spin-orbit-driven skyrmion dynamics both analytically and through micromagnetic simulations. The dynamical behavior of in-plane skyrmions driven by spin-orbit torques is intrinsically different from that of conventional Néel skyrmions. Furthermore, we show the possibility to control the skyrmion speed by changing the relative angle between current and uniform background magnetization direction which could be advantageous in racetrack memories.

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# Thermally superactive nanomagnets obtained with interfacial Dzyaloshinskii-Moriya interaction

27 Aug
16:15
GMT+2
2-3-6

K. Hofhuis[1,2], A. Hrabec[1,2,3], H. Arava[1,2], N. Leo[1,2,4], Y.-L. Huang[5], R. .V. Chopdekar[6], S. Parchenko[1,2,7], A. Kleibert[7], S. Koraltan[8], C. Abert[8], C.Vogler[8], D. Suess[8], P. M. Derlet[9], L. J. Heyderman[1,2]

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Thermally active artificial spin ice systems fabricated from ultra-small dipolar-coupled nanomagnets are an ideal model system to study emergence of long-range magnetic ordering [1], for example in the artificial square ice [2]. In contrast, in the highly frustrated artificial kagome ice, the predicted long-range charge and spin ordered phases, be it the ground state of several kagome rings or the theoretically predicted long-range order of the extended array, have not yet been observed. This is due to the fact that the lowest achievable temperature at which the magnetic macrospins are free to order is defined by the blocking temperature $T_B$ of the individual nanomagnets and, if this temperature is above the critical transition temperatures for long-range ordering $T_C > T_B$, then the system freezes in a metastable state. We have fabricated the nanomagnets on top of a heavy metal to induce an interfacial Dzyaloshinskii-Moriya interaction (DMI). Utilizing interfacial DMI, we show that we can independently lower the blocking temperature $T_B$ down to 50 K without strongly affecting the magnetostatic interactions and thus maintain the system's critical ordering temperatures [3]. We demonstrate the ground state ordering of a kagome system consisting of 30 nanomagnets arranged in seven hexagon rings. Furthermore, the spin-ice correlations extracted from magnetic imaging of the extended kagome lattice are found to exhibit quantitative signatures of long-range charge order, thereby giving strong evidence for the theoretically predicted continuous transition to a charge-ordered state.

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# Ni-Mn-In Heusler alloys with artifact-like magnetocaloric effect due to overlapped thermomagnetic phase transitions

27 Aug
17:30
GMT+2
2-4-1

Á. Díaz-García[1], J. Y. Law[1], L. M. Moreno-Ramírez[1], V. Franco[1], A. Conde[1], and A. K. Giri[2]

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Heusler alloys are promising multifunctional materials due to their outstanding properties for magnetooptical, magnetoelectronic, or magnetocaloric applications. Regarding the magnetocaloric effect (MCE), some Heusler-type alloys are of high interest due to a giant response associated with a first-order phase transition (magneto-structural FOPT) from a low temperature martensitic phase to a high temperature austenite with higher magnetization. Ni-Mn-based compounds is one of the families of Heusler alloys exhibiting magneto-structural transformation for which the transition temperatures can be tuned through compositional changes. For these systems, it is usually accepted that the MCE response is enhanced when magneto-structural and Curie phase transitions coincide. In this work, the phase transitions and the magnetocaloric responses of $Ni_{49+x}Mn_{36-x}In_{15}$ (x=0-2) Heusler alloys were studied [1]. Upon heating, samples of this series show a low temperature conventional MCE, an inverse MCE due to the FOPT then followed by another conventional MCE associated with the Curie transition of the austenite. With increasing the electron-per-atom ratio (e/a), the FOPT shifts to higher temperatures and becomes tightly overlapped with the high temperature Curie transition for the sample with e/a=7.874. These concurrent thermomagnetic phase transitions produce magnetocaloric responses of opposite sign, leading to a spike embedded in the region of the high temperature conventional MCE that resembles an experimental artifact. The field dependence of the AC susceptibility and the exponent n, obtained from the isothermal entropy change, have been used to analyze these overlapping phase transitions. As the magnetic field promotes the austenitic ferromagnetic phase and shifts the FOPT to lower temperatures, the phase transitions could be deconvoluted demonstrating that the spike is due to the magneto-structural transformation. In this case, the coincidence of both types of phase transitions results in compensated effects.

Work supported by AEI/FEDER-UE (grants MAT-2016-77265-R and PID2019-105720RB-I00), US/JUNTA/FEDER-UE (grant US-1260179), Consejeria de Economia, Conocimiento, Empresas y Universidad de la Junta de Andalucia (grant P18-RT-746), Army Research Laboratory under Cooperative Agreement Number W911NF-19-2-0212 and Sevilla University under the VI PPIT-US program.

**References**

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# Experimental characterization of saturable ferrite inductor for DC-DC converter applications

27 Aug
17:45
GMT+2
2-4-2

L. Solimene[1]

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Ferrite inductors are essential components in the design of switched-mode power supply (SMPS) because they provide a controlled energy transfer between a source and a load, through charge and discharge cycles. SMPS are widely adopted in the automotive or the aerospace field, where the demand to minimize weight and volume of the devices is crucial. A substantial reduction of the size of the inductors can be obtained if the component operates in the non-linear portion of the magnetic characteristic [1-2]. As a consequence, the conventional approach for the evaluation of the current ripple appears to be inadequate. In addition, for commercial inductors the specifications of the magnetic material adopted for the manufacture of the core, its geometry, and the winding properties, are often not completely known. To solve this problem, we propose an experimental methodology for the identification of the magnetic characteristic of power inductors [3] and a numerical algorithm for the computation of current ripple under saturation conditions [4], suitable for ferrite inductors used in DC-DC buck converters. In this devices, the inductor is subjected to a quasi-rectangular voltage waveform at a relatively high switching frequency and to a current waveform where a DC component, determined by the load current, is superimposed to an oscillating component, depending on the magnetic characteristic of the inductor. Measuring a set of experimental voltage and current waveforms, and performing a two-step optimization process, a parametrized magnetic flux vs current curve is obtained, suitable for the simulation of the inductor behaviour in a DC-DC buck converter.

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# The Influence Of Finite-Size Effects On The Curie Temperature Of $L1_0$-FePt

27 Aug
18:00
GMT+2
2-4-3

N. T. Binh[1], S. Ruta[1], O. Hovorka[2], R. F. L. Evans[1], R. W. Chantrell[1]

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Iron Platinum in $L1_0$-phase ($L1_0$-FePt) has been widely studied [1] for application in Heat-Assisted Magnetic Recording (HAMR). An important aspect for successful HAMR media is controlling the Curie temperature dispersion, which for $L1_0$-FePt a strong dependence on finite-size effects is reported [2-3]. This poses a serious problem as the inevitable grain size distribution causes a Curie temperature ($T_c$) distribution which potentially limits recording density. Therefore, it is important to investigate finite-size effects and their governing mechanisms. We employed an atomistic model based on the VAMPIRE code [4] to study finite-size effects in $L1_0$-FePt grains using nearest-neighbour Heisenberg Hamiltonian exchange. Our grains had variable surface geometries (cylindrical, parallelepiped, and randomly-generated "voronoi" shape) and sizes (from 1 to 10nm). Importantly, our model gives access to the magnetisation properties of each atomic layer of the grains which provides insights into the magnetisation profile along a specific dimension. We hypothesised a correlation between the $T_c$ distribution of $L1_0$-FePt and the percentage of atomistic bond loss on the grain surface as a function of grain size. Our result establishes a size threshold at 2.5nm below which the impact of finite-size effects starts to permeate into the centre of the grain and contributes to the overall drop of the grain $T_c$. We observed that above this threshold the magnetisation loss due to surface effects was proportional to the percentage of atomistic bonds loss on the grain surface. Contrarily, below 2.5nm the Curie temperature decreases much faster as a function of bond loss, suggesting that in this limit the finite size effect has propagated into the entire grain. This effect is further illustrated in the grain magnetisation profile in which for larger grains surface disorder (lower magnetisation) is seen to penetrate only a few atomistic layers, whilst for smaller grains surface effects begin to dominate. Consequently, the grain $T_c$ profile was also found to follow a similar trend. Our findings are consistent with semi-analytical mean-field calculations and have been extended to incorporate different crystal structures, which strongly suggests that if using a suitable correlation factor the $T_c$ distribution of a generic material can be correlated to the percentage of atomistic bond loss on the surface as a universal parameter.

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More information about VAMPIRE can be found at:
http://vampire.york.ac.uk/features/

# Concurrent magneto-optical imaging and magneto-transport readout of electrical switching of insulating antiferromagnetic thin films

27 Aug
18:15
GMT+2
2-4-4

F. Schreiber[1], L. Baldrati[1], C. Schmitt[1], R. Ramos[2], E. Saitoh[2,3], R. Lebrun[1,4], M. Kläui[1,5]

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Electrical writing and read-out of information in antiferromagnetic (AFM) insulators is a key prerequisite in view of using this class of materials in applications. Only recently, the electrical read-out of the orientation of the Néel order has been demonstrated in insulating AFM/heavy metal bilayers by utilizing the transverse spin Hall magnetoresistance effect (SMR).[1–3] By electrical measurements and by using current pulses to switch the Néel order, a steplike signal resulting from a magnetic SMR contribution was observed in NiO,[1] $\alpha$-$Fe_2O_3$[2] and CoO.[3] On the other hand, non-magnetic contributions due to artifacts in the heavy metal layer were found to mimic the signal expected from the magnetic switching.[4,5] These results have generated a debate on the magnitude of the magnetic contributions, the reliability of the SMR readout mechanism and even on the possibility of switching domains in AFMs by a current. In our work[6] we use a table-top approach to demonstrate stable and reversible current-induced switching of large-area antiferromagnetic domains in NiO/Pt by direct imaging in a Kerr microscope.[7] Concurrent transport and magneto-optical imaging measurements allow us to correlate the AFM domain switching fraction and magneto-transport signal response. While the observation of magnetic domain switching indicates the presence of a magnetic SMR response, we also confirm the presence of artificial resistance changes in the Pt layer. The introduction of a simple procedure to subtract these non-magnetic contributions from the transverse resistance signal yields the disentanglement of magnetic and non-magnetic contributions. Across many different current densities, we find an accurate correlation of post-treated electrical signal and domain switching fraction, calculated from the imaging. This corroborates the validity of the subtraction procedure and allows us to distinguish the presence of a significant electrical SMR response, directly correlated with the switching of the antiferromagnetic domains. We thus highlight the possibility to quantify the antiferromagnetic domain switching fraction from simple transport measurements. These results emphasize the potential of AFMs and can both motivate and simplify additional research to enable using insulating AFMs in applications where electrical reading and writing are required.

## References

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# Voltage-Switchable Superparamagnetism

27 Aug
18:30
GMT+2
2-4-5

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[2]Institute of Physics, University of Graz, (Austria)

Voltage-control of magnetism has attracted attention in the scientific community, as it promises an energy-efficient magnetic switching, with potential application in magnetic data storage. Nanoparticles below the superparamagnetic threshold are particularly interesting for that purpose, as they can be 'pinned' in their ferromagnetic state by increasing the particle's magnetic anisotropy energy. Indirect voltage-control of superparamagnetism has already been demonstrated via an electrically generated strain in a substrate, which affects the magnetic particles anisotropy constant [1,2]. Here, we present a novel approach to voltage-switchable superparamagnetism, utilising magneto-ionic hydrogen intercalation as the key affecting the effective magnetic volume of the embedded superparamagnetic entities.For that purpose, we prepared nanoporous palladium containing clusters of cobalt -npPd(Co)- via electrochemical dealloying from a CoPd alloy. Palladium as a high-susceptibility paramagnet is easily magnetically polarised, but also known for its high affinity for hydrogen intercalation in the crystal lattice. High-resolution TEM in combination with EDS mapping techniques revealed that Co clusters with an average size of 1.5-2 nm well below the superparamagnetic limit are embedded in the nanoporous Pd matrix. The main idea motivating our study was that changes in the electronic structure due to hydrogen intercalation can affect the magnetic properties of the buried Co clusters.Hydrogen-intercalation into the Pd substrate was conducted in our customised in situ electrochemical cell in a SQUID-magnetometer [3], allowing the direct determination of changes in magnetisation. Voltage-induced electrochemical hydrogenation reversibly altered the magnetic moment by more than 600 % , corresponding to a complete On- and Off-switching of magnetism. A new magneto-ionic concept, based on a RKKY-mediated superparamagnetic cluster growth upon hydrogen intercalation, is suggested to explain for the giant changes in magnetisation upon hydrogenation [4]. Zero field cooled magnetisation curves before and after hydrogenation give strong support for the proposed cluster growth mechanism.

This work is financially supported by the Austrian Science Fund (FWF): P30070-N36.

## References

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# Contributed talks from Americas

**All contributed talks in this session will follow the Eastern Daylight Time (New York, GMT -4). The session will start at 11:50 and end at 21:15.**

# PROGRAM SCHEDULE

## Region 3: North/South America

**11:50 to 21:15 - New York Time (GMT -4)**

| | |
|---|---|
| **11:50 - 12: 00** Opening Remarks | **Session 3-3** |
| **Session 3-1** | **16:00 - 17:00**<br>Prof. Amal El-Ghazaly, Cornell, (USA) |
| **12:00 - 12:15**<br>Martin Lonsky, UIUC (USA) | **17:00 - 17:15**<br>Yassine Quessab, NYU (USA) |
| **12:15 - 12:30**<br>Kai Litzius, MIT (USA) | **17:15 - 17:30**<br>Lijun Zhu, Cornell (USA) |
| **12:30 - 12:45**<br>Cristina Psaroudaki, Caltech (USA) | **17:30 - 17:45**<br>Junwen Xu, NYU (USA) |
| **12:45 - 13:00**<br>Dhritiman Bhattacharya, VCU (USA) | **17:45 - 18:00**<br>Isaiah Gray, Cornell (USA) |
| **13:00 - 13:15**<br>Md Golam Morshed, UVA (USA) | **18:00 - 18:15**<br>Elizaveta Tremsina, MIT (USA) |
| **13:15 - 13:30**<br>Guruprasad Jayachandran, UF (USA) | **18:15 - 18:30**<br>Alexander Kossak, MIT (USA) |
| **Session 3-2** | **Session 3-4** |
| **13:30 - 14:30**<br>Dr. Mark Stiles, NIST (USA) | **18:30 - 19:30**<br>Dr. Guohan Hu, IBM (USA) |
| **14:30 - 14:45**<br>Hannah Bradley, OU (USA) | **19:30 - 19:45**<br>Adnan Raza Syed, CBPF (Brazil) |
| **14:45 - 15:00**<br>Cody Trevillian, OU (USA) | **19:45 - 20:00**<br>Vuk Brajuskovic, ANL (USA) |
| **15:00 - 15:15**<br>Gilvânia Vilela, UPE (Brazil) | **20:00 - 20:15**<br>Breno Malvezzi Cecchi, UNICAMP (Brazil) |
| **15:15 - 15:30**<br>Jackson Bauer, MIT (USA) | **20:15 - 20:30**<br>Richa Pokharel Madhogaria, USF (USA) |
| **15:30 - 15:45**<br>Corisa Kons, USF (USA) | **20:30 - 20:45**<br>Chuanpu Liu, CSU (USA) |
| **15:45 - 16:00**<br>Daniela P. Valdés, CNEA (Argentina) | **20:45 - 21:00**<br>Valery Ortiz Jimenez, USF (USA) |

**21:00 - 21:15** Closing Remarks

# Coupled Skyrmion Breathing Modes in Synthetic Ferri- and Antiferromagnets

27 Aug
12:00
GMT-4
3-1-1

Martin Lonsky[1] and Axel Hoffmann[1]

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Magnetic multilayers can combine strong spin-orbit interaction with lacking inversion symmetry, which may give rise to the presence of topologically nontrivial spin textures, so-called magnetic skyrmions. Recent studies have indicated strongly enhanced propagation velocities of skyrmions in antiferromagnets and compensated ferrimagnets [1]. At the same time, it is unclear how magnetic compensation affects the dynamic eigenexcitations of magnetic skyrmions, such as breathing modes, which entail an oscillation of the skyrmion size at GHz frequencies [2]. Here, we present comprehensive micromagnetic simulations of these resonance modes in synthetic ferri- and antiferromagnets that are excited by either out-of-plane microwave magnetic fields or spin torques. The observed features in the calculated power spectra exhibit a systematic dependence on the strength of the RKKY-like antiferromagnetic coupling between the individual magnetic layers and are related to pure in-phase and anti-phase breathing modes as well as to hybridizations of breathing and spin wave modes that are characteristic for the considered circular-shaped geometry [3]. As a simplified classical analog, the coupled skyrmion breathing modes can be viewed as two harmonic oscillators that are connected by a spring. The experimental detection of these resonant oscillation modes may provide a means for skyrmion sensing applications and for the general characterization of skyrmion states in multilayer stacks with antiferromagnetic interlayer exchange coupling.

This work is supported by the Deutsche Forschungsgemeinschaft (DFG) through the research fellowship LO 2584/1-1.

## References

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# Universal High-speed Dynamics of Distorted Bubble Skyrmions in an Uncompensated Amorphous Ferrimagnet

27 Aug
12:15
GMT-4
3-1-2

Kai Litzius[1], Felix Büttner[1], Angela Wittmann[1], Wei Zhou[2], Chung Ting Ma[2], Joachim Gräfe[3], Nick A. Träger[3], Simone Finizio[4], Yassine Quessab[5], Daniel Suzuki[1], Lucas Caretta[1], Mantao Huang[1], Sara Scheffels[1], Siying Huang[1], Hans T. Nembach[6], Grant A. Riley[6], Justin M. Shaw[6], Manuel Valvidares[7], Pierluigi Gargiani[7], Gisela Schütz[3], Andrew D. Kent[5], S. Joseph Poon[2], and Geoffrey S. D. Beach[1]

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Magnetic skyrmions are topologically stabilized spin configurations that, like domain walls (DWs), can react to external stimuli by collective displacement, which is both physically intriguing and bears promises to realize next generation non-volatile data storage technologies. [1] However, skyrmions in ferromagnets are challenging to implement in wire devices due to their movement at an angle to the current direction (skyrmion Hall effect) and comparably low speeds. [2] Antiferromagnetically coupled systems with compensated angular momentum (such as compensated ferrimagnets and natural antiferromagnets) can reduce this skyrmion Hall effect to zero and provide high speed dynamics to move spin structures at unprecedented speeds, thus making them promising candidates for spintronic devices. [3,4]

Besides the compensation of perpendicular motion of skyrmions with respect to the drive, the predictability and thus the study of the stochasticity of their trajectories is also of major importance for applications. Most notably, the models describing rigid, circular bubble domains and skyrmions differ significantly from those for straight 180°DWs, leading to different speed predictions for skyrmions and DWs at a given drive. [5] However, DWs and skyrmions are often not perfectly straight or circular, making predictions potentially difficult as it is not always clear which model describes a given deformed skyrmion with the highest accuracy. Here, we study how deformed DWs and bubble skyrmions move in uncompensated ferrimagnetic Pt/CoGd/W in response to current pulses. We find that all 1D spin textures as well as all fully enclosed spin textures, reach speeds $\geq 500 m/s$ and display identical dynamics, independent of their exact shape. While high speeds are indeed reached, the predicted differences between skyrmion and DW dynamics could not be observed. We attribute this deviation from the commonly used model to significant deformations of the skyrmions during their motion.

## References

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# Spin Wave Radiation by a Topological Charge Dipole

27 Aug
12:30
GMT-4
3-1-3

Sebastián A. Díaz[1], Tomoki Hirosawa[2], Daniel Los[1], and Christina Psaroudaki[3]

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The use of spin waves (SWs) as data carriers in spintronic and magnonic logic devices offers operation at low power consumption, free of Joule heating. Nevertheless, the controlled emission and propagation of SWs in magnetic materials remains a significant challenge. Here, we propose that skyrmion-antiskyrmion bilayers form topological charge dipoles and act as efficient sub-100 nm SW emitters when excited by in-plane ac magnetic fields. The propagating SWs have a preferred radiation direction, with clear dipole signatures in their radiation pattern, suggesting that the bilayer forms a SW antenna. Bilayers with the same topological charge radiate SWs with spiral and antispiral spatial profiles, enlarging the class of SW patterns. We demonstrate that the characteristics of the emitted SWs are linked to the topology of the source, allowing for full control of the SW features, including their amplitude, preferred direction of propagation, and wavelength.

**References**

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# Voltage Control of Fixed Magnetic Skyrmions

27 Aug
12:45
GMT-4
3-1-4

Dhritiman Bhattacharya[1], Seyed Armin Razavi[2], Hao Wu[2], Bingqian Dai[2], Kang L. Wang[2], and Jayasimha Atulasimha[1]

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Current induced motion of magnetic skyrmions can be utilized to implement racetrack memory devices and therefore have been extensively studied in recent years [1-3]. These devices are of large footprint as they require to accommodate skyrmion motion. On the other hand, this problem can be alleviated if skyrmions that are fixed in space are used to implement such devices. In this regard, we will first show using micromagnetic simulation that, skyrmion core reversal and switching between ferromagnetic states via an intermediate skyrmion state can be achieved in the free layer of a Magnetic Tunnel Junction (MTJ) [4-5] using Voltage Control of Magnetic Anisotropy (VCMA). Due to VCMA, upon application of an electric field, the perpendicular magnetic anisotropy (PMA) changes at the ferromagnet/oxide interface. When the PMA is increased by applying a voltage pulse, skyrmions are annihilated while skyrmions can be recreated using a voltage pulse that decreases the PMA of the system.

Next, we will show proof of concept experiment of our proposed switching method in an heterostructure film stack consisting of IrMn/CoFeB/MgO layers [6]. The magnetization configurations are imaged using Magnetic Force Microscopy (MFM). Due to exchange bias at the antiferromagnetic IrMn and the Ferromagnetic CoFeB interface, skyrmions could be stabilized without any external magnetic field. These skyrmions were annihilated when a negative voltage pulse was applied. When opposite polarity pulse was applied some of the skyrmions were recreated. However, the number of skyrmions were fewer compared to the initial state. These skyrmions also formed in the same location which they occupied before being annihilated. Finally, the formation and annihilation of skyrmions were non-volatile. These observations can be explained considering the inhomogeneity of magnetic parameters across the film. We will also present micromagnetic simulations where we incorporate this inhomogeneity which reveal the detailed magnetization dynamics of this switching.

In future, our proposed mechanism of manipulating fixed magnetic skyrmions using electric field could lead to the implementation of energy efficient skyrmion based MTJ memory device.

Acknowledgement: NSF CCF collaborative grants: 1909030 and 1909416.

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# Effective Tailoring of the Dzyaloshinskii-Moriya Interaction in Ferrimagnetic GdCo through Capping Layer Engineering

27 Aug
13:00
GMT-4
3-1-5

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Novel chiral spin textures such as topologically protected magnetic skyrmions have emerged as a potential candidate for next-generation memory and logic applications. Controlling the inversion symmetry breaking interfacial Dzyaloshinskii-Moriya Interaction (DMI) is the key to stabilizing skyrmions in magnetic multilayers. We investigate the DMI of compensated ferrimagnetic GdCo alloy using Density Functional Theory (DFT), and explain the impact of Tungsten (W) alloying in a Pt/GdCo/Pt1-xWx structure. We find that a small amount of W ($\sim 10\,\%$) is sufficient to give rise to a non-zero DMI by breaking the inversion symmetry of Pt/GdCo/Pt. We also find that the DMI increases as a function of W composition (x), but saturates at higher W composition, in agreement with experiment. We show that the vanishing of spin-orbit coupling (SOC) energy to the adjacent metal layers of the top interface and the simultaneous constancy of the bottom interface is responsible for such saturating behavior of the DMI. Additionally, we investigate Pt/GdCo/X, where X=Ta, W, Ir to demonstrate the effect of capping layer heavy metals on the DMI. Our results predict that W in the capping layer favors a higher value of the DMI than Ta and Ir. Our results open up exciting combinatorial possibilities for controlling the DMI in ferrimagnets to nucleate and manipulate ultrasmall high-speed skyrmions.

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# Investigating the Relationship between Dzyaloshinskii-Moriya Interaction and Proximity Induced Magnetism in Pt/Co Superlattices

27 Aug
13:15
GMT-4
3-1-6

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At metallic multilayer interfaces between 3d elemental ferromagnet (eg. Co, Fe) and 5d nonmagnetic heavier elements (eg. Ir, Pd, Pt), Skyrmions can form due to broken inversion symmetry and large spin-orbit coupling that create a nonzero Dzyaloshinskii-Moriya interaction (DMI) and generate chiral magnetic structures. The topological protection inherent to Skyrmions makes them attractive candidates for nanoscale magnetic memory bits that can be moved by relatively small spin currents resulting in high-density, non-volatile, and low-power data storage. However, there remain open questions about the interplay between proximity induced magnetism (PIM) present in the Stoner-susceptible 5d metal layers and the net DMI of the multilayer, and previous reports have come to contradicting conclusions. Here we investigate this relationship using two superlattices composed of symmetric (Pt/Co/Pt) and asymmetric (Pt/Co/Ir) repeat units. Our X-ray magnetic circular dichroism measurements at the Pt L-edges, point towards an inverse relationship between DMI and PIM, in agreement with previous theoretical work. To control for the effect of interfacial mixing, we examined the roughness of the Pt/Co interfaces in these superlattices using both lab and synchrotron X-ray reflectometry data. Our initial results indicate nearly identical roughnesses in both superlattices, suggesting that the inverse DMI-PIM trend we observe is not dominated by interfacial mixing.

# Inertial artificial neural networks based on antiferromagnetic oscillators

27 Aug
14:30
GMT-4
3-2-1

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Antiferromagnetic (AFM) spin Hall oscillators driven by an external sub-threshold current can create ultra-short spikes in response to a weak external stimulus and, therefore, can be used as ultra-fast artificial neurons [1, 2]. The duration of the output neuron spike is determined, mainly, by the anisotropy of the AFM material and typically is of the order of a few ps, while the strength of the external bias current determines the minimum possible delay between two consecutive spikes ("refractory time" of an AFM neuron), which can be as low as $\sim 100$ ps.

One of specific features of AFM oscillators is the effective inertia that originates from exchange coupling between two AFM magnetic sublattices [3]. In this work, we investigate dynamical behavior of such inertial AFM-based neural networks and show that the AFM exchange inertia can be harnessed to create results impossible with conventional neural networks.

One of the manifestations of the exchange inertia is the delay of the spike generated by an AFM neuron relative to the input stimulus signal. The delay time decreases with the increase of the coupling strength between AFM neurons and can vary from several 100s ps to $\sim 10$ ps. This effect can be used to create a continuously tunable periodic spike generator by coupling several AFM neurons in a ring structure, in which output of one neuron serves as an input for the next neuron. The output spike delay also allows one to create an 'inhibitor" neuromorphic circuit, in which propagation of a spike is suppressed in the presence of another ("inhibiting") signal. The inhibitor works by splitting the signal into two branches and controlling the delay time in one branch by the inhibiting signal. In the presence of the inhibiting signal, the spikes in two branches arrive at the output neuron at different times and do not induce an output spike. The inhibitor is an example of a neuromorphic circuit with non-monotonic dependence of the output signal on input spikes and, thus, is impossible to realize using conventional inertia-less "integrate-and-fire" artificial neurons. By combining the inhibitor circuit with a ring structure, one can create a controllable neuromorphic memory loop, which can be turned on and off.

These examples demonstrate the potential of using the AFM inertial effects for development of highly efficient artificial neural circuits.

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# Magnon mediated coherent quantum information operations

27 Aug
14:45
GMT-4
3-2-2

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Real applications of quantum computing systems rely on coherent quantum information transduction between many coupled subsystems that are subject to quantum decoherence. Strong coupling can prevent quantum decoherence by increasing the rate at which quantum information is transferred between subsystems allowing for more operations per second and leading to less time for quantum decoherence to occur. Strong coupling rates ($\kappa$ >100 MHz) are easily achieved in hybrid quantum systems of coupled magnetic elements and superconducting qubits and resonators [1-6]. These approaches utilize the wide-ranged tunability of the resonant frequencies of their magnetic elements through changes in bias magnetic fields. While successful, these investigations focus on static tuning of the magnetic resonance frequencies that limit their functionality.

Here, we show a new method of coherent quantum information transduction in quantum hybrid systems of coupled magnetic and superconducting resonator elements. The proposed method uses dynamic tuning of the magnetic resonance frequencies at timescales less than or comparable to characteristic coherence times. Such fast tuning of magnetic resonance frequencies can realize coherent operations that are not possible to perform with static tuning, such as, e.g., magnon-mediated entanglement generation, quantum information manipulation, processing, and transfer between disparate systems. By controllably bringing the magnetic subsystem into and out of resonance with the mutually uncoupled superconducting subsystems, the magnetic and superconducting elements become coupled and uncoupled with one another, respectively.

The coherence of such dynamically-coupled hybrid quantum systems is then dependent on the coupling rate between the magnetic and superconducting subsystems. Our numerical simulations of this dynamically controlled hybrid superconducting/magnetic system show a dependence of the maximum transfer fraction of quantum information on the coupling between the subsystems. This means that the maximum transfer rate of quantum information is proportional to the coupling rate between the magnetic and superconducting resonator elements. Because the magnon damping rate dictated by the material parameters cannot be readily controlled, optimization of the coupling rate between subsystems is necessary to increase the operation speed of the hybrid quantum system and limit the time during which decoherence can occur.

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# Spin transport in $Tm_3Fe_5O_{12}$/Pt with perpendicular magnetic anisotropy for magnon spintronics

27 Aug
15:00
GMT-4
3-2-3

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Thulium iron garnet (TIG – $Tm_3Fe_5O_{12}$) thin films with perpendicular magnetic anisotropy is a material with great potential for application in magnon spintronics where the transport and process of information is performed by magnons that are quanta of spin waves [1]. The development of wave-based computing technologies could provide more efficient devices free of Joule heating. TIG is a ferrimagnetic insulator with a critical temperature of 549 K, a magnetic intrinsic Gilbert damping on the order of 0.01, and negative magnetostriction constant of -5.2 x 10-6 that favors a perpendicular magnetic anisotropy (PMA) even for films with a thickness of 60 nm [2]. A magnetic film with PMA presents more uniform magnetization that is preferable for patterned devices. It allows smaller data-storage magnetic bits when compared with in-plane magnetic films leading to higher information density [3]. Moreover, PMA benefits the spin-orbit torque (SOT) effect in FM/HM structures where an in-plane charge current flowing in a heavy metal (HM) with a strong spin-orbit coupling can switch the magnetization of a ferromagnetic (FM) layer. When the FM presents PMA, the switching process becomes faster, and the needed current becomes lower, which makes this novel way of manipulating the magnetic states of thin films very useful for magnetoresistive random access memories based on SOT (SOT-MRAM) [4]. We have successfully fabricated TIG thin films with a robust PMA over GGG (Gd3Ga5O12) substrates using the rf sputtering technique. The films presented very flat surfaces with an RMS roughness of 0.1 nm, a magnetization saturation of 100 emu/cm3, and magnetic damping constant of $\sim 0.02$. Subsequently, we combined TIG with a 4 nm-thick platinum film for exploring the transport of pure spin currents mediated by spin waves, and excited by microwaves via the spin pumping effect (SPE) and by thermal currents via the spin Seebeck effect (SSE). The pure spin currents excited in TIG travels through the TIG/Pt interface and are converted into charge currents inside the Pt film by means of the inverse spin Hall effect (ISHE). These charge currents can be detected as microvolts at the edges of the Pt film. We investigated the dependence of these voltages with the orientation of the dc applied magnetic field, the microwave power, and the thermal gradient. The results showed a spin Seebeck coefficient of 0.54 V/K, and a ratio between the microwave-driven voltage and the microwave power of 4 V/W.

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# Temperature dependence of the magnetic proximity effect in magnetic insulator/platinum heterostructures by polarized neutron reflectometry

27 Aug
15:15
GMT-4
3-2-4

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The magnetic proximity effect (MPE) in nonmagnetic heavy metal/magnetic heterostructures has received much recent attention. The MPE is believed to play a role in the spin Hall magnetoresistance (SMR) and may also be leveraged to control the emerging phenomena associated with topological insulators. Pt is most commonly used due to its vicinity to the Stoner criterion, and its use as a source of spin-orbit torques in spintronic measurements. However, much is still unknown about the properties of the MPE, such as the temperature dependence and the coupling to magnetic layers when multiple magnetic sublattices are present. To explore this, we examined pulsed laser deposited 25 nm thick dysprosium iron garnet (DyIG)/sputtered 10 nm Pt heterostructures using polarized neutron reflectometry (PNR), above (200K) and below (15 K) the magnetic compensation temperature (Tcomp = 190 K) [1]. Below Tcomp, the Dy3+ sublattice dominates the net moment, and above Tcomp, the net Fe dominates. The MPE magnetization has only small effects on the fit to the data, but the results are consistent with a small Pt moment antiparallel to the net DyIG moment at 15 K, i.e. the Pt moment is parallel to the net Fe moment, whereas at 200 K the Pt magnetization is negligible. The MS obtained from the PNR fits is 605 kA/m at 15 K (literature value = 622 kA/m) and 10 kA/m (VSM value = 10 kA/m) [1]. The scattering length density profile suggests interdiffusion at the GGG substrate interface over a 2-3 nm region, consistent with previous studies. This is accounted for with a layer of composition intermediate between DyIG and GGG. A dip in density at the DyIG/Pt interface is also present, indicating the presence of surface contamination due to the ex situ Pt deposition, or a translational growth region.

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# Spin Distributions in $Fe_3O_4/CoFe_2O_4$ Nanoparticle Variants

27 Aug 15:30 GMT-4 3-2-5

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Magnetic nanoparticles (NPs) exhibit unique properties compared to those of the bulk; of particular interest are core-shell NPs where tailoring of magnetic properties can be achieved by careful selection of the constituent materials. This work focuses on bi-magnetic NPs with spinel structures composed of a soft and hard material. Two NP variants are considered; first, where the core and shell are composed of the magnetically soft and hard materials, respectively, and the inverted structure where the core and shell materials are reversed. Due to its high anisotropy and prevalence in forming uniformly canted layers [1] CoFe2O4 was selected as the hard material and paired with Fe3O4. The anistropy differences between the core and shell materials will play a role in influencing the spin dynamics within each layer as well as at the core/shell interface. Each NP had an overall diameter of 10.5 nm with a core radius of 3.0 - 3.5 nm, the magnetic properties were investigated using conventional magnetometry, polarized small angle neutron scattering (SANS), and macrospin Monte Carlo simulations of long-range dipolar interactions.

Magnetometry shows both NPs are in or near the superparamagnetic state at room temperature and become ferromagnetic below the blocking temperature with a two-step spin reversal process occurring at low fields. Analysis of magnetic contributions to the SANS scattering indicate strong spin ordering perpendicular to the applied field at remanence that disappears rapidly at low fields. Ordering parallel to the applied field emerges with increasing field in agreement with hysteresis loops. Monte Carlo simulations indicate that the development of dipolar-coupled long range order may be associated with the steps observed in the field hysteresis loops. Combining analysis of magnetic SANS results with macrospin simulations can provide insight to the complex spin ordering throughout the NPs as well as interparticle interactions. Access to NG-7 SANS was provided by the Center for High Resolution Neutron Scattering, a partnership between the National Institute of Standards and Technology and the National Science Foundation under Agreement No. DMR-1508249. The authors acknowledge the support of University of South Florida Nexus Initiative (UNI) Award, US Department of Energy, Office of Basic Energy Sciences (Award No. DE-FG02- 07ER46438) and the Knut and Alice Wallenberg Foundation (Grant No. 2018.0060).

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# Combination of Magnetic Fluid Hyperthermia and Magneto-Mechanical Destruction: Particle characterisation, interaction study and in vitro testing

27 Aug
15:45
GMT-4
3-2-6

Daniela P. Valdés[1,2], Irati Rodrigo[3,4], Michael Stanton[5], Emma N. Welbourne[5], Borja Herrero de la Parte[6], Teobaldo E. Torres[1], José Á. Garcia[7], Roberto D. Zysler[1,2], Fernando Plazaola[4], and Russell P. Cowburn[5]

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Magnetic hyperthermia and magneto-mechanical destruction are two emerging cancer therapies [1-2]. We studied the combination of these treatments to develop a new and more efficient therapy. For hyperthermia, we synthesised magnetic iron-oxide nanoparticles (MIONs) with a diameter of 26 nm by the thermal decomposition of Fe(acac)3 [3] and coated with dextran in a post-synthesis procedure. Magnetic DC characterisation shielded that the MIONs are not completely superparamagnetic at room temperature due to size distribution. Experimental specific power absorption (SPA) measurements were made in a custom-built AC magnetometer resulting in SPA around 150 $Wg^{-1}$ for a 0.5 mg $ml^{-1}$ solution of MIONs in water (at 226 Oe and 301 kHz) as obtained from the area of the measured hysteresis loop times the frequency. For magneto-mechanical destruction, we fabricated synthetic antiferromagnetic microdiscs (MDs) with perpendicular anisotropy and diameter 2 um using a combination of sputtering and lithography techniques [4] and they were magnetically characterised using MOKE and VSM.

Using an optical microscope with an integrated dipole electromagnet, we corroborated the formation of linear arrangements due to interactions between MDs and the coated MIONs under DC fields from 30 to 3500 Oe and the magneto-mechanical response of MDs under low frequency magnetic fields.

In rat colorectal cancer cell line CC531 incubated for 24 h with MDs and MIONs, we performed internalisation studies using TEM imaging and cytotoxicity experiments, finding that both MDs and coated MIONs are internalised and have minimal effects ($<10\,\%$) on the viability of the culture, making them suitable for in vitro testing. A preliminary in vitro treatment shows that hyperthermia and magneto-mechanical destruction can induce cell death, decreasing the viability up to 30 % (10 min of hyperthermia in the aforementioned experimental conditions and 10 min of magneto-mechanical destruction at 1 T and 20 Hz with 30 MDs per cell).

Acknowledgements: The authors want to acknowledge IEEE Magnetics Society for the full founding of this project.

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# Resolving the Role of Magnetic Circular Dichroism in Multishot Helicity-Dependent All-Optical Switching

27 Aug
17:00
GMT-4
3-3-1

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The ultrafast optical control of the magnetic order rapidly emerged as a promising approach in ultrafast magnetism. Yet, more than a decade after the discovery of complete and deterministic magnetization switching induced by femtosecond circularly polarized laser pulses [1], many fundamental questions remain unanswered. In particular, the issue of the relative contribution of pure thermal or nonthermal effects induced by the laser pulses is crucial for the understanding of the magnetization reversal mechanism. Several theoretical models have been developed for multipulse all-optical helicity-dependent switching (AO-HDS) without reaching a consensus. Using circular polarization, transfer of light angular momentum and the emergence of an effective magnetic field via the inverse Faraday effect (IFE), a nonthermal optomagnetic effect, may occur [2]. In contrast, it has been argued that AO-HDS could originate from a purely heating mechanism [3]. In this case, the asymmetry would arise from the difference in light absorption between left- and right-circular polarization due to the magnetic circular dichroism (MCD).By conducting helicity-dependent ultrafast magnetization dynamics in a CoTb ferrimagnetic alloy that exhibits AO-HDS, we are able to quantitatively determine the MCD and resolve its role in the switching mechanism [4]. We find a MCD of 1 % from time-resolved Kerr effect measurement. Unequivocal interpretation of the sign of the dichroism is provided by performing AOS and, for the first time in a ferrimagnet, femtosecond laser-induced domain wall motion experiments. We demonstrate that AOS occurs when the magnetization is initially in the most absorbent state, according to the light helicity. Moreover, we evidence that the MCD creates a thermal gradient that drives a domain wall toward hotter regions. Our experimental results are in agreement with the purely thermal models of AOS reported in the literature.

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# Effective Spin-Mixing Conductance of Heavy-Metal/Ferromagnet Interfaces

27 Aug
17:15
GMT-4
3-3-2

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The effective spin-mixing conductance ($G_{eff}^{(\uparrow\downarrow)}$) of a heavy metal/ferromagnet (HM/FM) interface characterizes the efficiency of the interfacial spin transport. Accurately determining $G_{eff}^{(\uparrow\downarrow)}$ is critical to the quantitative understanding of measurements of direct and inverse spin Hall effects. $G_{eff}^{(\uparrow\downarrow)}$ is typically ascertained from the inverse dependence of magnetic damping on the FM thickness under the assumption that spin pumping is the dominant mechanism affecting this dependence. Here we report that this assumption fails badly in many in-plane magnetized prototypical HM/FM systems in the nm-scale thickness regime. Instead, the majority of the damping is from two-magnon scattering at the FM interface, while spin-memory-loss scattering at the interface can also be significant. If these two effects are neglected, the results will be an unphysical "giant" apparent $G_{eff}^{(\uparrow\downarrow)}$ and hence considerable underestimation of both the spin Hall ratio and the spin Hall conductivity in inverse/direct spin Hall experiments.

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# Charge-to-spin Conversion Efficiency in Ferromagnetic Nanowires by Spin Torque Ferromagnetic Resonance: Reconciling Lineshape and Linewidth Analysis Methods

27 Aug
17:30
GMT-4
3-3-3

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Spin orbit torques (SOTs) are being actively considered for use in the next generation memory devices for magnetization switching, spin oscillators and racetrack memories, including those using magnetic skyrmions. SOTs are fundamentally based on charge-to-spin conversion by the spin-Hall or Rashba effect. Taking advantage of the spin current, the torques can be used to switch magnetic insulators or the free layer of magnetic tunnel junctions with high energy efficiency. Therefore, it is important to accurately measure the charge-to-spin conversion efficiency. SOTs are principally of interest in nanostructured samples, samples with minimum dimension less than a micron. However, the magnitude and form of the torques are most often characterized in micron scale samples, using spin torque ferromagnetic resonance (ST-FMR), a technique that involves analyzing the resonance linewidth [1] or lineshape [2]. On microstructures, these two analysis methods are quite consistent. Here we present ST-FMR results on permalloy Ni80Fe20 nanowires — with widths varying from 150 to 800 nm — that show that the standard model used to analyze the resonance linewidth and lineshape give different results [3]. From the ST-FMR spectra, we find that the efficiency of nanowires with different width, which shows greatly enhanced efficiency when the lineshape method is used. We present a ST-FMR model that properly accounts for the sample shape. It shows a much better consistency between the two methods. Micromagnetic simulations are used to verify the model. These results and the more accurate nanowire model presented are of importance for characterizing and optimizing charge-to-spin conversion efficiencies in nanostructures.

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# Imaging Uncompensated Moments and Locally Controlling Magnetic Phases in FeRh using Anomalous Nernst Microscopy

27 Aug
17:45
GMT-4
3-3-4

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The metallic alloy FeRh undergoes an unusual 1st-order phase transition from antiferromagnet to ferromagnet, with transition temperature $T_C$ near 400 K at 50/50 stoichiometry [1]. This transition makes FeRh interesting both for studying the interaction between coexisting magnetic phases [2] and for applications in local control of magnetic order [3] and antiferromagnetic memory [4]. We present a set of experiments [5,6] imaging FeRh/MgO(001) thin films with magneto-thermal microscopy, based on the anomalous Nernst effect [7]. We first study $Fe_{0.50}Rh_{0.50}$. In the antiferromagnetic phase, we image uncompensated moments within antiferromagnetic domains [8]. We find that some uncompensated moments are pinned to the bulk Néel order, while others are unpinned and rotate with applied magnetic field. In the ferromagnetic phase above $T_C$, we image the emergent ferromagnetism. Within the transition region, we image unusual metastable states of exchange bias between coexisting antiferromagnetic and ferromagnetic phases within the same film. We then study $Fe_{0.52}Rh_{0.48}$ films, where the stoichiometry is tuned such that both phases are stable at room temperature. We locally heat with a focused pulsed laser at room temperature to pattern ferromagnetic shapes within the antiferromagnetic background, which can be erased by cooling the sample below room temperature. We show that local ferromagnetic regions can be patterned using single 3 ps-wide laser pulses, that they are stable for at least several days in ambient conditions, and that the film can be repeatedly erased and repatterned with no measurable degradation of the magnetic structure.

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# Electrical Characterization of Multi-Domain States and Current-Driven Domain Wall Motion in Ferromagnetic Multi-Layers based on Harmonic Hall voltage Measurements

27 Aug
18:00
GMT-4
3-3-5

E.A.Tremsina[1], A.Wittmann[2], M.R.A. Peters[3], F.Büttner[2],*R. Lavrijsen[3], H.J.M. Swagten[3], D.H.Suzukii[2], and G.S.D.Beach[2]

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The harmonic Hall voltage measurement technique is frequently used to study the role of Spin Orbit Torque (SOT) which arises from an in-plane current flowing through heavy metal/ferromagnetic heterostructures(1). In particular, current-induced domain wall motion (CIDWM) due to the Spin Hall effect(2,3), as well as current-driven skyrmion generation and manipulation(4), have shown great potential for developing domain-wall-based shift registers, logic and racetrack memory devices. However, these non-uniform magnetization dynamics are difficult to probe electrically due to their extremely short time scales, and require synchrotron-based X-ray imaging techniques.

In this study, we have found that in specifically designed multi-layer magnetic stacks, high stray fields cause multi-domain states to be stabilized, thus enabling their manipulation through the injection of AC current. Furthermore, we demonstrate that the multi-domain switching behavior can be probed electrically, using simultaneous measurements of the first and second harmonic Hall voltages. Hall bars consisting of Ta(4 nm)/Pt(4 nm)/[Co(1 nm)/Gd(0.3 nm)/Ru(1.2 nm)/Pt(0.8 nm)]3/Ta(4 nm) were patterned. These multi-layer devices exhibit: 1) gradual magnetization switching apparent from the first harmonic signal, and 2) a significant secondary peak in the second harmonic. In fact, these peaks appear at the critical switching field inferred from the first harmonic, and persist in the range of magnetic fields where multi-domain switching occurs. We identify and characterize CIDWM in the second harmonic response as a function of external field applied at various angles relative the injected current. We develop a qualitative model, based on domain wall creep motion(5), to explain the presence of these peaks at different geometries of the applied magnetic field. In addition, we demonstrate that in these devices, short pulses of out-of-plane external magnetic field cause fully uniform magnetization switching between up/down states. The mentioned peaks are no longer present in the second harmonic signal, confirming the disappearance of multi-domain patterns.

To our knowledge, the harmonic Hall voltage measurement procedure has not been used to study the temporal behavior of multi-domain patterns, and this new method enables more easily accessible experimental investigation of the internal fields and SOT-driven magnetization dynamics in such multilayer stacks without advanced imaging techniques.

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# Voltage Modulated RKKY Interaction through Solid-State Hydrogen Ion Gating Synthetic Antiferromagnets

27 Aug
18:15
GMT-4
3-3-6

Alexander E. Kossak[1], Pooja Reddy[1], and Geoffrey S. D. Beach[1]

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Access to data, and its storage, is annually becoming of greater concern to consumers, companies and their governments. As the volume and generation of data incessantly grows, the technology that writes, reads and secures it must become faster, more compact and more efficient. This emphasizes the importance of creating energy-efficient data storage and logic devices. Fortunately, magnetic storage, through voltage-controlled magnetism (VCM), uses orders of magnitude less energy than traditional current-controlled SRAM and DRAM. Herein, we aim to demonstrate new heterostructures which employ this low energy solution through magneto-ionic control. The foundation for this has been demonstrated through oxygen, lithium and hydrogen magneto-ionic control of rare-earth transition metal (RE-TM) anisotropy in metal-oxide/metal heterostructures [1-3]. In this work, we demonstrate dynamic magnetic control of the Ruderman–Kittel–Kasuya–Yosida (RKKY) interaction through electric fields. Our heterostructure is a synthetic antiferromagnet made if cobalt and gadolinium cobalt separated by a ruthenium layer. We are able to reversibly pump hydrogen into the spacer layer altering the exchange interaction between the ferromagnetic and ferrimagnet layer. Using magneto-optical Kerr effect (MOKE) microscopy we are able to observe the voltage-induced changes in the exchange coupling field. This work provides a promising way to realize fast, compact and energy-efficient devices for next generation AF spintronic applications.

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# Low damping and small inhomogeneous linewidth broadening in Co2FeAl films

27 Aug
19:30
GMT -4
3-4-1

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Low-damping soft magnetic films are highly desirable for high frequency aplicatioms in microwave devices [1, 2, 3]. Among several possibilities, Co based full Heusler alloy films may provide interesting properties concerning this kind of applications [4]. In this work we investigate structural, static and dynamics magnetic properties of Co2FeAl (CFA) films deposited on Si (100) with Ti buffer and capping layers. We study the evolution of the coercive field, anisotropies, damping constant and line width broadening as a function of CFA film thickness ranging from 5 nm to 200 nm. We obtain a coercive field weakly dependent on the thickness with values in the range 4.2 Oe to 7.8 Oe. All samples show roughly constant in-plane magnetic anisotropy, and out-plane anisotropy originated from the CFA/Ti interfaces. With increasing thickness we observe the emergence of a rotatable anisotropy. We found magnetic damping parameters $\alpha$ between 2.5610-3 and 3.4510-3, and inhomogeneous line width $\Delta$H0 under 10.3 Oe for the whole range of CFA film thickness. These $\Delta$H0 results are smaller when compared to the values reported for CFA in literature, especially for films with thickness above 100 nm. The present study also opens new possibilities for applications of CFA thick films.

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# Thermally-Quenched Topological Defects in Quasicrystal Artificial Spin Ices

27 Aug
19:45
GMT-4
3-4-2

V. Brajuskovic[1,2], T. E. Gage[3], H. H. Liu [3], I. Arslan[3], A. K. Petford-Long[1,2] and C. Phatak[1]

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In recent years, artificial spin ices (ASIs) have been one of the primary systems studied to understand geometric frustrations in magnetic systems. Quasicrystalline ASIs (QC-ASIs), ASIs which lack translational symmetry, allow for the study of magnetic frustrations in magnetic systems that show less ordering than traditional ASIs. In order to better understand the effects of magnetic frustration, it is necessary to first understand the ground states of the system. Observations of the ground state have been achieved through thermalization of frustrated periodic nanomagnetic systems such as ASIs above the ordering temperature, which places large regions of the ASI into the ground state. While there have been several studies of such thermalization in periodic ASIs,[1][2] relatively little work has been done studying the thermalization of QC-ASIs, particularly QC-ASIs composed of connected nano-bars rather than discrete nano-islands. In this work, we have explored in-situ thermalization and quenching of QC-ASIs composed of connected nano-bars from near the Curie temperature and we observe the formation of two sets of topological vortex defects: within the magnetic bars and within the vertices at which the bars meet. By varying the quenching rate, we show that the number of defects in the vertices follows a power law relation with respect to quenching rate and are therefore related to the paramagnetic to ferromagnetic phase transition. This observation is similar to the vortex defects that are seen when ferroelectrics are cooled from the paraelectric state to the ferroelectric state. [3] On the other hand, the number of defects formed within the bars is more strongly correlated to the underlying lattice geometry. These results provide insight into the emergence and control of topological defects in confined frustrated magnetic systems.

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# Micromagnetic Simulations of Magnetization Reversal in Kagome Artificial Spin Ice

27 Aug
20:00
GMT-4
3-4-3

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Artificial spin ice (ASI) is a magnetic metamaterial designed to exhibit frustration [1]. It consists of an array of magnetostatically interacting nanomagnets arranged in a geometry that prevents these interactions to be all satisfied simultaneously. They were originally conceived to replicate, in an artificial manner, interesting frustration induced phenomena found in natural frustrated magnets known as spin ices [2]. One of the most remarkable is the emergence of quasiparticles similar to magnetic monopoles when such materials are excited above the ground state [3]. In ASI this behavior is experimentally reproduced by subjecting the system to a magnetization cycle [4]. The magnetization reversal proceeds by creation of one-dimensional strings of flipped nanomagnets, referred as Dirac strings, that host the magnetic monopoles at their ends. This behavior was also already reproduced by Monte Carlo based simulations, where the nanomagnets are treated as Ising variables and a phenomenological random switching field distribution is employed [5]. In this work, we reproduced the same behavior using a more fundamental approach, that was lacking in literature, based on micromagnetic simulations, applied particularly to a large scale (more than a thousand magnets) kagome lattice arrangement of ASI. We regarded a more realistic description of the shape of each nanomagnet, including its finite size and roughness at the edges, in such a way that no a priori switching field distribution was required but that came out naturally. Our simulations still predict a new, bidimensional reversal mechanism that occurs if the magnetic field is applied below a certain critical angle.

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# Inertial artificial neural networks based on antiferromagnetic oscillatorsStrain-modulated helimagnetism and magnetic phase diagram in a film of highly crystalline MnP nanorods

27 Aug
20:15
GMT-4
3-4-4

Richa Pokharel Madhogaria[1], Chang-Ming Hung[1], Eleanor M. Clements[1], Anh Tuan Duong[2], Raja Das[2], Pham Thanh Huy[2], Sunglae Cho[3], Manh-Huong Phan[1], and Hariharan Srikanth[1]

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Manganese phosphide (MnP), a classical metallic helimagnet, is known to host interesting and complex magnetic properties such as multiple metamagnetic phase transition, Lifshitz critical behavior and the magnetocaloric effect [1]. The modulation of spin structure caused by Dzyaloshinskii-Moriya interaction gives rise to the non-trivial Hall effect in the fan phase of MnP [2]. Recently, MnP has been established as an unconventional superconductor in which the application of pressure allows the tuning of antiferromagnetically to ferromagnetically mediated superconductivity [3]. Mostly recently, study has shown the control of spin helicity via electric and magnetic fields in MnP [4]. The presence of exotic magnetic phases and magnetic tunability makes MnP an excellent model to probe dimensional and strain effects in helimagnetic systems. In this study, we explore strain-modulated helimagnetism in highly crystalline MnP nanorod films grown on Si (100) substrates using molecular beam epitaxy. While a bulk-like paramagnetic-ferromagnetic (FM) phase transition at TC = 276 K is observed for the MnP film, the FM-helical phase change occurs at TN = 117 K and 101 K for the corresponding in-plane and out-of-plane field directions. These values of TN are much higher than TN = 47 K for the single crystal [1], indicating strong strain-modulated helimagnetic states. The presence of significant thermal hysteresis in the helical phase indicates a coexistence of competing magnetic interactions, leading to the first order metamagnetic transition. The evolution of screw (SCR) to CONE and FAN phase is precisely tracked from magnetization versus magnetic field/temperature measurements. Unfolding of the different helical phases at T <120 K is analyzed by the temperature- and field-dependent magnetic entropy change. The comprehensive magnetic phase diagrams for both in-plane and out-of-plane magnetic measurements are established in the MnP film, revealing emergent features that are absent in the magnetic phase diagram of the single crystal.

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# High-Temperature Ferromagnetic Resonance in FePt Thin Films

27 Aug
20:30
GMT-4
3-4-5

Chuanpu Liu[1], Kumar Srinivasan[2], Antony Ajan[2], Ethan McCollum[1], and Mingzhong Wu[1]

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Understanding of damping processes in ferromagnetic thin films at temperatures (T) near the Curie temperature (Tc) has significant implications for heat-assisted magnetic recording and magnetic sensors operating at elevated temperatures. Recent ferromagnetic resonance (FMR) studies [PR Applied 10, 054046 (2018)] using out-of-plane fields showed that there are two major relaxation processes in granular L10-ordered FePt thin films at 10-45 K below Tc: two-magnon scattering and spin-flip magnon-electron scattering; with a decrease in T, the FMR linewidth increases due to the enhancement of the two-magnon scattering. This presentation reports high-T FMR studies on continuous FePt thin films with cubic structures, rather than L10 structures. The films are 6-nm thick and have Tc680 K; the FMR measurements were performed over 300-620 K in out-of-plane fields. As opposed to the L10 FePt films, the cubic FePt films show an FMR linewidth that decreases with a decrease in T. This T dependence suggests that the spin-flip magnon-electron scattering is dominant over the two-magnon scattering; the two-magnon scattering is weak because it is expected to be absent in continuous films under out-of-plane fields.

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# Light-controlled room temperature ferromagnetism in vanadium-doped tungsten diselenide semiconducting monolayers

27 Aug
20:45
GMT-4
3-4-6

Valery Ortiz Jimenez[1], Yen Thi Hai Pham[1], Mingzu Liu[2], Fu Zhang[3,4], Vijaysankar Kalappattil[1], Baleeswaraiah Muchharla[1], Tatiana Eggers[1], Dinh Loc Duong[6,7], Mauricio Terrones[2,3,4,5], and Manh-Huong Phan[1]

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Atomically thin transition metal dichalcogenides (TMD) semiconductors hold enormous potential for modern optoelectronic and ultra-low powered devices. By inducing long-range ferromagnetism (FM) in these semiconductors through the introduction of small amounts of a magnetic dopant, it is possible to extend their potential in emerging spintronic applications [1,2]. Our recent study showed that room temperature magnetism is achieved in V-doped WS2 monolayers [3], which coexists with its characteristic optical properties. In this work we demonstrate light-mediated, room temperature FM, in V-doped WS2 monolayers. This effect is probed using the principle of magnetic LC resonance[4], which employs a soft ferromagnetic Co-based microwire coil driven near resonance in the radio frequency regime. The combination of LC resonance, and an outstanding giant magneto-impedance effect, renders the coil highly sensitive to changes in the magnetic flux through its core. The V-doped WS2 monolayer is placed at the core of the coil where it is excited with a laser, while its magnetic permeability is probed by the coil. We found that the magnetic permeability of the monolayers is dependent on laser intensity, confirming light control of room temperature magnetism in this two-dimensional material. Density functional theory calculations suggests that this phenomenon is a consequence of an accumulation of excess holes in the conduction and valence bands, as well as carriers trapped in the magnetic doping states, which in turn mediates the magnetization of V-WS2 monolayers. These findings provide a promising route to exploit light-controlled FM in two-dimensional TMD based spintronic devices.

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