The 2021 Around-the-Clock Around-the-Globe Magnetics Conference

Program Booklet
24th of August 2021

IEEE MAGNETICS

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Contents

Program Overview

Welcome to the 2021 Around-the-Clock Around-the-Globe Magnetics Conference (AtC-AtG), which will be held online on the 24th of August 2021. AtC-AtG is a 24-hour non-stop virtual conference with speakers from all over the world passing the baton to each other. Join, interact, and network at any time – for free. The contributed talks are reserved for students and post-doctoral researchers only.

The scope of the conference is to bring together early-stage researchers through a series of oral and poster presentations and networking opportunities and provide an international platform to discuss recent progress and trends in the field of magnetism, ranging from fundamental to applied aspects.

The technical program includes 9 invited talks and 3 tutorials from senior scientists in the international magnetics community, and 69 contributed oral presentations and [INSERT NUMBER HERE] contributed poster presentations from graduate students and post-doc researchers worldwide. This conference is organized by the newest generation of magnetics professionals (featuring graduate students and postdocs 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 virtual sessions based in three geographic locations and time zones; they are 1) Asia / Pacific, 2) Europe / Middle East / Africa, and 3) Americas. Oral presentations will be hosted on the Zoom virtual conferencing platform by subcommittees located in different regions of the world. In parallel, interactive poster sessions and networking will be held in the Gather.Town virtual platform.

To register and for more information, please go to ieeemagnetics-atc-atg.

The AtC-AtG conference is sponsored by:

IEEE MAGNETICS

Follow us on social media:

Poster Sessions / Networking in Gather.Town

We are very excited to add poster sessions and networking opportunities to this year's conference using gather.town. Gather.town is a proximity-based video conferencing tool. Every participant has a video-game like "avatar" which you use to walk around the map, and when you get close to people you can talk to them. The link is shared with registrants only.

The map (see Figure 1) contains a Lobby, Poster Session Rooms, a Lecture Hall, which can be used to connect directly to the Zoom call of the oral presentations, as well as some Lounges for post-talk extra questions, unstructured conversation and networking.

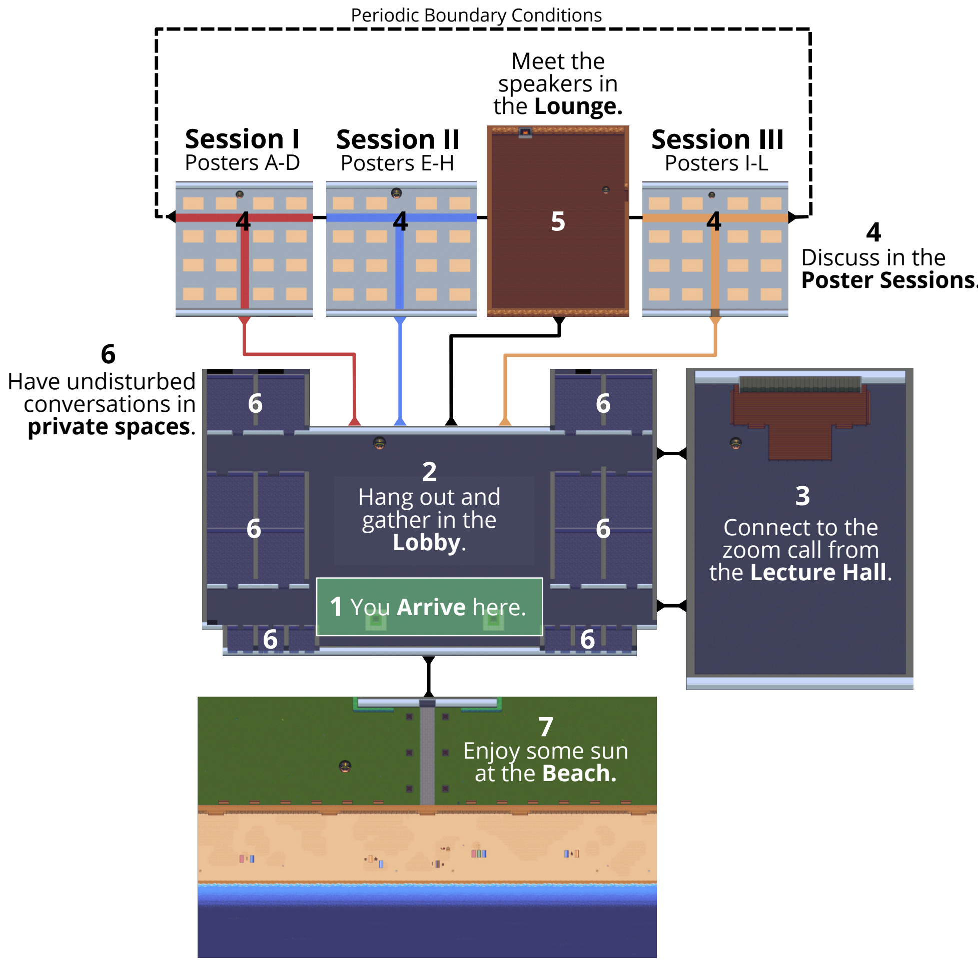

Figure 1: Map of the Gather.Town to be used for both poster sessions and networking

Here are some conference-specific getting-started instructions.

- Use your arrow keys or WSDA to walk around the map
- Get close to a person to talk to them
- Press “X” to interact with objects such as posters or whiteboards
- Use the chat on the left side, if you need help. Also look out for people with “ProCom” in their name
- You can select a person to chat privately with them, or send messages to everyone nearby who you are conversing with
- Share your screen with the share screen button in the toolbar at the bottom of the screen
- Looking for a specific person? Find their name in the list of participants on the left, click it and press “Locate on map”. Stop locating them the same way
- Automatically follow a person by clicking their name in the list and selecting “Follow”
- If a person is in another tab, or in the Zoom for oral sessions, their avatar will be greyed out and their microphone and video will be off. You can chat with them or “ring” them to get their attention to come back to the gather.town
- Click on a person’s avatar to start a “bubble” side conversation with them. Other people can still hear you at a lower volume, but you will not be talking over others. You can also enter private rooms (marked by squares on the floor) to talk undisturbed
- Use Chrome or Firefox for best results. Do not use Safari.

Conference Policies

Attendees should not record the talks given during this conference. All participants will enjoy a comfortable experience, and will treat each other with respect at all times.

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 oral and poster presentations are automatically enrolled in the competition. Winners will be selected by the program committee and will be announced at the end of the conference.

Other Upcoming Conferences

2022 Joint MMM-INTERMAG. The 15th Joint MMM-INTERMAG Conference (2022 Joint) is sponsored jointly by AIP Publishing and the IEEE Magnetics Society. Members of the international scientific and engineering communities interested in recent developments in fundamental and applied magnetism are invited to attend and contribute to the technical sessions. The technical program will include invited and contributed papers in oral and poster sessions, invited symposia, a plenary session, and an evening session, with about 1500 presentations overall. This Conference provides an outstanding opportunity for worldwide participants to meet their colleagues and collaborators and discuss developments in all areas of magnetism research. For registration and more information, please go to magnetism.org.

The Online Spintronics Seminar Series (OSSS). 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. For more information, please go to spintalks.org.

Organizing Committee

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Sai Li
Beihang University, China

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New York University, USA

AtC-AtG Conference Program Agenda

Region 1: Asian/ Pacific Area	
00:00 to 08:15 UTC	
	→ Oral Sessions
23:45 – 00:00	**Introduction/ Welcome**
00:00 – 00:35	**Invited Talk:** Naoya Kanazawa (University of Tokyo, Japan)
00:35 – 02:30	Session 1
02:30 – 03:05	**Invited Talk:** Min-Fu Hsieh (National Cheng Kung University, Taiwan)
03:05 – 05:00	Session 2
05:30 – 07:00	Session 3-1
07:00 – 07:35	**Invited Talk:** Subhankar Bedanta (National Institute of Science Education and Research, India)
07:35 – 08:15	Session 3-2
	→ Poster Sessions
05:00 – 07:00	Poster Session A: *Gather Town*
Region 2: Europe/Middle East/Africa	
08:15 to 17:15 UTC	
	→ Oral Sessions:
08:15 – 09:00	**Tutorial 1:** Thomas Schrefl (Danube University Krems, Austria)
09:00 – 09:35	**Invited Talk:** Sebastian Gliga (Paul Scherrer Institute, Switzerland)
09:35 – 10:05	Session 4-1
10:30 – 12:00	Session 4-2
12:00 – 12:35	**Invited Talk:** Franziska Scheibel (Technical University Darmstadt, Germany)
12:35 – 14:30	Session 5
14:30 – 15:05	**Invited Talk:** Ester Palmero (IMDEA Nanoscience, Spain)
15:05 – 17:15	Session 6
	→ Poster Sessions:
10:05 – 12:00	Poster Session B: *Gather Town*
Region 3: North/South America	
17:15 to 03:00 UTC	
	→ Oral Sessions:
17:15 – 18:00	**Tutorial 2:** Christoph Klewe (Lawrence Berkeley National Laboratory, USA)
18:00 – 18:45	Session 7-1
18:45 – 19:20	**Invited Talk:** Vivek Amin (Indiana University, USA)
19:50 – 21:20	Session 7-2
21:20 – 21:55	**Invited Talk:** Elin Winkler (Centro Atómico Bariloche, Argentina)
21:55 – 23:30	Session 8
23:30 – 00:05	**Invited Talk:** Emilie Jué (National Institute of Standards and Technology, USA)
00:05 – 02:15	Session 9
02:15 – 03:00	**Tutorial 3:** David Cortie (Australian Nuclear Science and Technology Organisation, Australia)
	→ Poster Sessions:
19:20 – 21:20	Poster Session C: *Gather Town*

Conversion for Common Time Zones

Time Zone	UTC +
New Zealand	12
Australia (Eastern)	10
Japan / Korea	9
China	8
India	5.5
Eastern Europe	3
Central Europe	2
Argentina	-3
East Coast	-4
Colombia	-5
Mountain Time	-6
Pacific time	-7
Hawaii	-10

UTC	Oral sessions	Poster sessions	Speaker	Title	Country
23:45			Welcome		
00:00	Session 1		Invited speaker - Naoya KANAZAWA	*Emergence of spin-orbit-coupled surface state derived from topological polarization and its spintronic functionality in a nonmagnetic insulator FeSi*	Japan
00:15					
00:35			Alberto DE LA TORRE	*Nearly itinerant electronic ground state in the intercalated honeycomb iridate Ag3LiIr2O6*	USA
00:50			Vijay Sankar KALAPPATTI	*Large Magneto-Electric Resistance in the Topological Dirac Semimetal α-Sn*	USA
01:05			Sinéad RYAN	*New techniques for probing the static and dynamic properties of magnetic materials*	USA
01:20			Peggy SCHOENHERR	*Dislocation-Driven Relaxation Processes at the Conical to Helical Phase Transition in FeGe*	Australia
01:35			Martin SPASOVSKI	*Tuning Magnetic Frustration in Toroidal magnet Cu3TeO6*	New Zealand
01:50			Jia XU	*Optical imaging of antiferromagnetic domains and dynamics switching in CoO film by magneto-optical birefringence effect*	China
02:05			Max HIRSCHBERGER	*Topological Nernst effect from spin chirality: Skyrmions for thermoelectric conversion*	Japan
02:20			Discussion		
02:30	Session 2		Invited speaker - Min-Fu HSIEH	*Development of High Power Density Traction Motors for Electric Vehicles*	Taiwan
02:45					
03:05			Haydar SAHIN	*N-th Root Topological Lattices*	Singapore
03:20			Shao Syuan SYU	*Design of an Uniform Magnetic Field Electromagnet*	Taiwan
03:35			Syamlal S K	*Effect of Dzyaloshinskii-Moriya Interaction on Magnetization Reversal in Triangular Nanodot*	India
03:50			Zhuo LI	*Electron magnetic circular dichroism, antiphase boundary, electron microscopy*	Hong Kong
04:05			Rekha AGARWAL	*THz emission from NiO/Pt heterostructures*	India
04:20			Iltaf MUHAMMAD	*Strain- and Doping-Tunable Half-Metallicity and Magnetic Structure in Monolayer CrSeCl*	China
04:35			Hari Prasanth P	*Mechanism of Domain Wall Pair to Skyrmion Conversion in Typical Junction Geometry*	India
04:50			Xiaoqian ZHANG	*Room-temperature intrinsic ferromagnetism in epitaxial CrTe2 ultrathin films*	China
05:05		Poster Session I	Discussion		
05:15			Discussion		
05:30	Session 3		Vipul SHARMA	*Growth Controlled Structural Influence on the Magnetization Dynamics of PLD Grown Co2FeSi Heusler Alloy Thin Films*	India
05:45			Rajeswari ROY CHOWDHURY	*Unconventional Hall effect in van der Waals ferromagnet Fe3GeTe2*	India
06:00			Tong LI	*Measurement of Thin Films Magnetic Properties Based on Spin Hall Effect of Light*	China
06:15			Molongnenla JAMIR	*Dextran and Chitosan coated on Cobalt Ferrite (CoFe2O4) for Hyperthermia applications*	India
06:30			Narek SISAKYAN	*Synthesis, Structure, Magnetism and Magnetic Particle Heating Characterization of Fe/Fe3C Nanoparticles in Carbon Matrix*	Armenia
06:45			Sergej SOLOVYOV	*Sperimagnetism of GdFeCo Amorphous Alloys: H–T Phase Transitions*	Russia
07:00			Invited speaker - Subhankar BEDANTA	*Spintronics with Fullerene*	India
07:15					
07:35			Antonios MAKRIDIS	*A Novel Two-Stage 3D-Printed Halbach-Array Based Device for Magnetomechanical Applications*	Greece
07:50			Richa MUDGAL	*Spin-Orbit Torque in PtSe2/NiFe Heterostructure*	India

08:05			Discussion		
08:15	Tutorial 1		Invited speaker - Thomas SCHREFL	*Tutorial: An introduction to machine learning for solving micromagnetic problems*	Austria
08:30					
08:45					
09:00	Session 4		Invited speaker - Sebastian GLIGA	*Artificial spin systems: towards functional materials in 2D and 3D*	Switzerland
09:15					
09:35			Santhosh SIVASUBRAMANI	*A Magnetic Exploration towards Rebooting Computing Mixed Signal IC Design for AI Compute on the Edge – Material & Architectural Perspective*	India
09:50			Anna PASYNKOVA	*Tailored Anisotropy of Amorphous Ribbons for Magnetoimpedance*	Russia
10:05		Poster Session II	Discussion		
10:15			Discussion		
10:30			Shaktiranjan MOHANTY	*Synthetic Antiferromagnetic coupling of Co/Pt multilayers with varying Ir spacer*	India
10:45			Héloïse DAMAS	*Self-Spin-Orbit Torque in GdFeCo ferrimagnet*	France
11:00			Deepak DAGUR	*Photostrictive/photovoltaic effects on magnetostrictive films in multiferroic heterostructures under UV light*	Italy
11:15			Alberto CASTELLANO	*New Sol-gel Synthesis Route for Iron Carbide Nanoparticles Core-shell/Fe3C-grahite Embedded on a Continuous Carbon Matrix.*	Spain
11:30			Binh NGUYEN	*Higher-order Magnetic Anisotropy in Soft-hard Nanocomposite Materials*	UK
11:45			Tobias HULA	*Spin-wave frequency combs*	Germany
12:00	Session 5		Invited speaker - Franziska SCHEIBEL	*Magnetocaloric effect and martensitic transformation in ferromagnetic Heusler alloys*	Germany
12:15					
12:35			Dan GUO	*First- and Second-Order Phase Transitions in RE6Co2Ga (RE = Ho, Dy or Gd) Cryogenic Magnetocaloric Materials*	Spain
12:50			Alexandra HUXTABLE	*Hall Effects From Skyrmions in [Pt/(Co|CoB)/Ir]xN Magnetic Multilayers*	UK
13:05			Hamutu OJIYED	*Structural and Magnetocaloric Properties in Mn5SiB2-Mn5PB2 Compounds*	Netherlands
13:20			Vivian Andrade	*NiCu/FeCo Multisegmented Cylindrical Nanowires asWritting Heads in Racetrack Memories*	Portugal
13:35			Sumit GHOSH	*Ultrafast optical generation of antiferromagnetic spin spiral*	Germany
13:50			Kamil KOLINCIO	*Thermal fluctuations induced scalar spin chirality in a spin-trimer ferromagnet*	Poland
14:05			Bing ZHAO	*Van der Waals magnet based spin-valve devices at room temperature*	Sweden
14:20			Discussion		
14:30	Session 6		Invited speaker - Ester PALMERO	*Advances in developing alternative rare earth-free permanent magnets: from composites synthesis to additive manufacturing*	Spain
14:45					
15:05			Martin LANG	*Multiple Stable Bloch Points in Confined Helimagnetic Nanostructures*	UK
15:20			Hangboce YIN	*Non-Equiatomic Fe-Containing GdTbCoAl High-Entropy-Metallic-Glass Microwires with Tunable Curie Temperatures and Enhanced Cooling Efficiency*	Spain
15:35			Md. Shadab ANWAR	*Magnetostructural Phase Transition in Fe60V40 Alloy Thin Films*	Germany
15:50			Kehileche BRAHIM	*Magneto, Electro and Mechano-Caloric Materials: Comparative Study of Refrigeration Systems*	Algeria
16:05			Maria ALMEIDA	*Laser annealing for TMR applications: locally triggered crystallization of CoFeB*	Germany
16:20			Francisco Gonçalves	*Agility of spin Hall nano-oscillators*	Germany

16:35			Franz HERLING	*Electrical control of spin-orbit coupling-induced spin precession and spin-to-charge conversion in graphene proximitized by WSe2*	Spain
16:50			Jun-young KIM	*Tuning spin-orbit torques across the phase transition in VO2/NiFe heterostructure*	Germany
17:05			Discussion		
17:15	Tutorial 2		Invited speaker - Christoph KLEWE	*Tutorial: Static and dynamic magnetic properties illuminated by polarized soft x-rays*	USA
17:30					
17:45					
18:00	Session 7		Marijan BEG	*Manipulation of Bloch Points in Helimagnetic Nanostructures*	UK
18:15			Daniel ACTIS	*Comparison of Electromagnetic SAR in Melanoma Tumor and Agarosa Gel, both Loaded with Fe3O4 Nanoflowers*	Argentina
18:30			Jie WANG	*Heat Induction Behavior of Injected Superparamagnetic Nanofluid Interpreted by Mass and Heat Transfer for Clinical Magnetic Hyperthermia Applications*	USA
18:45			Invited speaker - Vivek AMIN	*Electrical spin current generation in ferromagnets and antiferromagnets*	USA
19:00					
19:20		Poster Session III	Discussion		
19:35			Discussion		
19:50			Ruihao LI	*Tunable Spin and Anomalous Hall Effects in Topological Dirac Semimetals*	USA
20:05			Agustin Gabriel LÓPEZ PEDROSO	*Strain effect on the magnetism of CaMnO3*	Argentina
20:20			Lucas Javier ALBORNOZ	*Universal Critical Exponents of the Magnetic Domain Wall Depinning Transition in Thin Films*	Argentina
20:35			Alexander KOSSAK	*Voltage Modulated RKKY Interaction through Magneto-Ionic Gating*	USA
20:50			Carlo Antonio TAMANAH VEGAS	*Magnetic Simulations of Core–Shell Ferromagnetic Bi-Magnetic Nanoparticles: The Influence of Antiferromagnetic Interfacial Exchange*	Peru
21:05			Patricia Carolina RIVAS ROJAS	*AC vs DC Temperature Dependence Magnetization Measurements: Effect of Size and Dipolar Interactions on the Energetic Parameters When Analyzing Real Systems*	Argentina
21:20	Session 8		Invited speaker - Elin WINKLER	*Design of core/shell nanoparticles for optimizing the magnetic hyperthermia and the catalytic activity*	Argentina
21:35					
21:55			M. RAJU	*Magnetic skyrmions and their topological Hall effect in thin film multilayers*	USA
22:10			Esteban IROULART	*Effective skyrmion interaction and hard-core states mediated by electronic dynamics*	Argentina
22:25			Md Golam MORSHED	*Positional Stability of Skyrmions in a Racetrack for Memory Applications*	USA
22:40			Santiago OSORIO	*Metastability and creation of single chiral soliton states in monoaxial helimagnets*	Argentina
22:55			Samuel LIU	*Controllable reset behavior in domain wall-magnetic tunnel junction neurons for task-adaptable computation*	USA
23:10			Hannah BRADLEY	*Spike Pattern Association Neuron Using Antiferromagnetic Artificial Neurons*	USA
23:25			Discussion		
23:30			Invited speaker - Emilie JUÉ	*Magnetic Josephson Junctions for artificial synapses*	USA
23:45					
00:05			Weipeng WU	*Manipulation of terahertz spectrum using microfabricated magnetic heterostructures*	USA
00:20			Zulfidin KHODZHAEV	*Hopfion Dynamics in Chiral Magnets*	USA

00:35	Session 9		Ana Maria SCHÖNHÖBEL	*Magnetoelectric effect in composite of piezoelectric ceramics and Ni-Mn-Ga ferromagnetic shape memory alloy: design and measurement*	Spain
00:50			Jonathan GIBBONS	*Large Exotic Spin Torques in Antiferromagnetic Iron Rhodium*	USA
01:05			Mojtaba Taghipour KAFFASH	*Observation of mode splitting in artificial spin ice: A comparative ferromagnetic resonance and Brillouin light scattering study*	USA
01:20			Jan MASELL	*Moving Skyrmions with a Small Thermal Gradient*	Japan
01:35			Bryce MULLENS	*Structural and Magnetic Studies of the Layered Perovskite CsMnF4: A Combined Experimental and Computational Study*	Australia
01:50			Jian LIANG	*Anisotropic Magneto-resistance in 2D Van der Waals Nano-flakes of Fe3GeTe2*	China
02:05			Discussion		
02:15	Tutorial 3		Invited speaker - David CORTIE	*Techniques for investigating magnetism in ultra-thin films: Polarised neutron reflectometry and density functional theory*	Australia
02:30					
02:45					
03:00	*Closing remarks*				

About

AtC-AtG is a 24-hour non-stop virtual conference with speakers from all over the world passing the baton to each other. Join, interact, and network at any time – for free. The scope of the conference is to bring together early-stage researchers through a series of oral and poster presentations and networking opportunities and provide an international platform to discuss recent progress and trends in the field of magnetism, ranging from fundamental to applied aspects.

Invited Speakers

Asia-Pacific

Subhankar Bedanta
NISER (India)

David Cortie
ANSTO (Australia)

Min-Fu Hsieh
NCKU (Taiwan)

Naoya Kanazawa
University of Tokyo (Japan)

Europe, Middle East and Africa

Sebastian Gliga
PSI (Switzerland)

Ester Palmero
IMDEA Nanoscience (Spain)

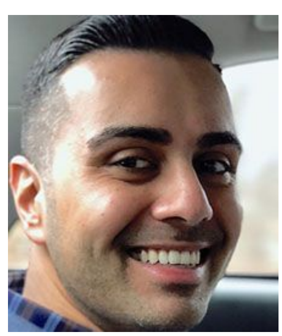
Franziska Scheibel
TU Darmstadt (Germany)

Thomas Schrefl
Danube University Krems (Austria)

Americas

Emilie Jué
NIST (USA)

Christoph Klewe
LBNL (USA)



Vivek Amin
IUPUI (USA)

Elin Winkler
Bariloche Atomic Center (Argentina)

List of Invited Talks

Emergence of spin-orbit-coupled surface state derived from topological polarization and its spintronic functionality in a nonmagnetic insulator FeSi

Naoya KANAZAWA*[1]

[1]University of Tokyo, Japan

A chiral compound FeSi is a prototypical example of the strongly-correlated d electron insulators. Its peculiar charge and spin dynamics, which cannot be explained by a simple mean-field picture of nonmagnetic insulators, have provoked many important physical concepts such as d-electron Kondo insulator and insulator-to-metal (reversed Mott) transition due to on-site strong Coulomb interaction.

Triggered by recent new insights into topological aspects of correlated insulators, FeSi is attracting renewed attention for its unusual properties. However, it remains highly nontrivial that compounds made of light (and usually common) elements, like FeSi, can bear topological characteristics. As evidenced by the recent numerous researches, the topological insulators necessarily contain heavy (and generally rare) elements with strong spin-orbit coupling (SOC) to protect their topological band structure.

In this study, we successfully demonstrate a novel surface state hosting metallic conduction and ferromagnetic order in FeSi thin film with nonmagnetic bulk state [1]. We identify that the surface state is not categorized into the class of topological insulators but can be described by the modern theory of topological polarization, i.e., Zak phase. Owing to the unique dipolar charge distribution of Zak-phase origin, the surface state produces the strong SOC properties despite the absence of heavy-metal elements. By taking advantage of the emergent SOC, we also realize spintronic functionalities such as unidirectional magnetoresistance and current-induced magnetization switching with high efficiency.

Our results shed light on compounds made of common elements and demonstrate another route utilizing the new type of topological polar surface states as platforms for SOC-based spin manipulation. Our findings are applicable to a wide variety of materials and also bring a new perspective to the modern theory of surface polarization which incorporates the Zak phase.

Acknowledgments

This work was done in collaboration with Y. Ohtsuka, M. Hirayama, A. Matsui, T. Nomoto, R. Arita, T. Nakajima, T. Hanashima, V. Ukleev, H. Aoki, M. Mogi, K. Fujiwara, A. Tsukazaki, M. Ichikawa, M. Kawasaki and Y. Tokura.

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Naoya Kanazawa Naoya Kanazawa received his Ph.D. from the University of Tokyo in 2014. He was appointed Research Associate in 2014 and Lecturer in 2018 at Department of Applied Physics, the University of Tokyo. The focus of his research concerns the exploration of new electronic and magnetic properties with topological characteristics, combining bulk crystal/thin film growth, electric/heat transport and neutron scattering methods. He has been awarded the 2021 Young Scientists' Prize from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in Japan.

References

[1] Y. Ohtsuka, N. Kanazawa *et al.*, arXiv:2104.12438 [cond-mat.str-el], Apr. 2021

Development of High Power Density Traction Motors for Electrical Vehicles

Min-Fu Hsieh*[1]
[1]National Cheng Kung University

With the advantages of high torque and power density, wide speed range, high efficiency, high reliability, permanent magnet (PM) synchronous motors have become one of the most suitable candidates for traction of Electric Vehicles (EVs) in recent years. In PM motors, design parameters involving electromagnetic, thermal, and structural aspects are key factors affecting power density of EV traction motors. However, the tradeoff of these factors in the design of traction motors to achieve high power density is complicated. Therefore, in this study, two types of PM motors with various topologies are investigated and compared to evaluate the performance and power density considering the design parameters such as the PM amount and flux barriers under prescribed temperature limits. Furthermore, to improve the performance and power density of these motors, using high thermal conductivity materials and the cooling systems is evaluated. The analysis results show that improving electromagnetic design and using high thermal conductivity materials and cooling systems can significantly improve the power density of traction motors. Finite element method (FEM) is used to validate the analysis.

Min-Fu Hsieh was born in Tainan, Taiwan. He received the B.Eng. degree in mechanical engineering at National Cheng Kung University (NCKU), Tainan, Taiwan, in 1991, and the M.Sc. and Ph.D. degrees in mechanical engineering at the University of Liverpool, Liverpool, U.K., in 1996 and 2000, respectively.

From 2000 to 2003, he served as a Researcher with the Electric Motor Technology Research Center, NCKU. In 2003, he joined the Department of Systems and Naval Mechatronic Engineering, NCKU, as an Assistant Professor. In 2012, he was promoted to Full Professor and he then moved to the Department of Electrical Engineering, NCKU in 2017. His areas of interest include electric machine design, drives and mechatronics.

He is a Senior Member of the IEEE Industry Applications, IEEE Magnetics, and IEEE Power Electronics Societies. He has been also an Editor with IEEE Transactions on Magnetics and Associate Editor with IEEE Transactions on Industry Applications.

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Spintronics with fullerene

Subhankar Bedanta*[1]

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Interface induced phenomenon in ferromagnetic/organic semiconductor is an emerging topic towards organic spintronics [1], [2]. Buckminsterfullerene (C_{60}) is a potential candidate for organic spintronics due to many desirable properties viz. low spin orbit coupling, large spin diffusion length at room temperature etc [3]. It has been observed that C_{60} exhibits ferromagnetism at the interface of FM/C_{60} [3]–[6].

We have prepared single layers of Fe, Co and CoFeB, and compared the magnetic properties to the bilayers of Fe/C_{60}, Co/C_{60} and CoFeB/C_{60}. The films were prepared on both MgO (001) and Si (100) substrates. Finite magnetic moment was obtained in the C_{60} layer at the interface between the Fe/C_{60} and Co/C_{60} layers by polarized neutron reflectivity measurements [4]–[6]. Magneto optic Kerr effect (MOKE) based microscopy was performed to observe the effect of the magnetic C_{60} layer on the hysteresis loop shape and the domain images of the FM (Fe, Co or CoFeB) layers [4]–[7]. We also study the change in magnetic anisotropy due to the presence of spinterface in these bilayer systems [5]–[7]. It has been found that anisotropy increases with C_{60} thickness [7]. We have also studied the FM/OSC having perpendicular magnetic anisotropy (PMA). In this context we have taken Pt/Co/C_{60} as a model system. It has been observed that introducing a C_{60} layer increases the anisotropy and decreases the domain size of the system [8]. We have also observed spin pumping and inverse spin hall effect (ISHE) at the CoFeB/C_{60} interface [9]. Further we also show that ferromagnetism can be observed at the interface between Cu/C_{60} interface. In this case due to the charge transfer from Cu to C_{60}, density of states of Cu get modified which leads to ferromagnetism in Cu [10].

Acknowledgments

I like to sincerely acknowledge my co-workers Dr. Srijani Mallik, Dr. Braj Bhusan Singh, Dr. Sagarika Nayak, Ms. Esita Pandey, Ms. Purbasha Sharangi, and my collaborators Prof. Thomas Brueckel, Dr. Stefan Mattauch, Dr. Biswarup Satpati for their continuous support. I also thank various funding agencies (DAE, DST-SERB, DST-Nanomission etc.) for their generous funding to support our work.

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An Introduction to Machine Learning for Solving Micromagnetic Problems

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Machine learning is becoming an increasingly important tool for materials scientists. Machine learning uncovers correlations in data, speeds up material simulations, bridges length scales, and provides answers by merging results from experiments and simulations. In this talk, I will give an overview of different machine learning methods and their application in materials science. Then I will give examples where the methods are used to solve micromagnetic problems:

1) I will present a random forest model to identify regions of low local coercivity in granular magnetic materials. Methods for model interpretation help to understand how various microstructural features affect the coercivity.
2) I will show how machine learning models can bridge length scales and how macroscopic demagnetization curves can be estimated from microstructural images.
3) I will present a neural network model for predicting magnetization dynamics. Time integration can be performed in a low-dimensional latent space. Thus, the magnetic response to an external field can be quickly calculated.
4) I will introduce physically informed neural networks as an alternative to the finite difference or finite element method for solving magnetostatic problems, inverse magnetostatic problems, and calculating demagnetization curves and coercive fields.

Machine learning and physics informed neural networks bring several advantages as compared to traditional numerical methods: No mesh generation is required. Inverse problems can be solved effectively. An entire family of problems can be solved with a single neural network.

Because of its ability to solve multiple problems simultaneously, machine learning offers great potential for optimizing and adjusting the internal structure and local chemistry of a magnet to achieve the desired macroscopic magnetic properties.

Acknowledgments

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Thomas Schrefl Thomas Schrefl received his PhD from the TU-Wien in 1993 where he completed his Habilitation in 1999 in “Computational Physics”. He worked on the development of numerical micromagnetic solvers for application in magnetic recording and permanent magnet. He is head of the Christian Doppler Laboratory for magnet design through physics informed machine learning at Danube University Krems, Austria

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Artificial spin systems: towards functional materials in 2D and 3D

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The study of emergent phenomena in two-dimensional artificial spin systems is presently the focus of intense research. Artificial spin ices are a class of spin systems composed of geometrically frustrated arrangements of nanomagnets that have so far mainly been used to investigate fundamental aspects of the physics of frustration. Recently, it has become clear that artificial spin ices enable the creation of functional materials with technological applications. As a first example, I will present a spin-ice based active material –consisting in a repeating pattern of chiral units –- in which energy is converted into unidirectional dynamics, thus functioning like a ratchet [1]. X-ray imaging shows that thermal relaxation proceeds through the rotation of the average magnetization in a unique sense. Micromagnetic simulations demonstrate that this emergent chiral behavior is driven by the topology of the magnetostatic field at the boundaries of the nanomagnet array, resulting in an asymmetric energy landscape. This opens the possibility of implementing a Brownian ratchet, which may find applications in nanomotors, actuators or memory cells. As a second example, I will discuss the potential application of artificial spin ices as magnonic crystals, where spin waves are functionalized for logic applications by means of band structure engineering [2]. This interest stems from the need for disruptive concepts requiring significantly lower energy consumption than traditional CMOS-based technology, in which information is processed using charge currents that dissipate significant power. Finally, I will discuss perspectives for functionalizing artificial spin ices in three dimensions in light of recent experimental advances in X-ray imaging techniques, such as magnetic tomography and laminography [3].

Sebastian Gliga. Sebastian Gliga is a Scientist in the Microspectroscopy Group at the Paul Scherrer Institute. His research focuses on nanomagnetism, including the investigation of emergent phenomena in two- and three-dimensional artificial spin systems, aiming to create energy efficient functional materials. Focus is on simulation, nanofabrication and characterization using synchrotron-based tools.

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Magnetocaloric Effect and Martensitic Transformation in Ferromagnetic Heusler Alloys

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The demand for environmentally friendly and efficient cooling makes the search for alternative technologies more important than ever. Magnetocaloric refrigeration, utilizing magnetocaloric effects, can be more energy efficient and environmentally friendly than current vapor compression technology. Ni-Mn-X Heusler compounds display excellent magnetocaloric properties - high adiabatic temperature changes ΔT_{ad} and isothermal entropy changes Δs - upon the field-induced phase transformation from non-magnetic martensite to ferromagnetic austenite.

The understanding of the magneto-structural transition and the direct measurement of the magnetocaloric effect is essential for optimizing Ni-Mn-X Heulser compounds. In our research we are focusing on the effect of thermal hysteresis on the magnetocaloric effect under cyclic conditions and high magnetic fields with high field sweep rates. Since the thermal hysteresis limits the cyclic performance, we propose a new multi-stimuli cooling cycle which benefits from the thermal hysteresis by using two stimuli to trigger the magneto-structural phase transition in a multicaloric material like Ni-Mn-X Heusler alloys. As a result, higher temperature changes can be achieved for fully reversible first-order phase transitions by an alternating application of magnetic field and uniaxial stress.

Franziska Scheibel Dr. Franziska Scheibel is currently a postdoctoral researcher at the department of materials science at the Technical University of Darmstadt. Since January 2018 she is working on the ERC Advanced Grant Cool Innov in the field of multicaloric materials. Before, she was working at the University Duisburg-Essen in the department of experimental physics she did her doctoral study on the topic of the influence of hysteresis at magnetostructural transitions on the magnetocaloric properties of Heuslers, Antiperovskites, and Pnictides. She finished her Diploma in physics in the department of experimental physics at the University of Ulm on the topic of preparation and characterization of FePt(Cu) thin films prepared by pulsed laser deposition. Her current research focusses on the optimization and design of multicaloric Heusler alloys for a so-called multi-stimuli cooling cycle using both magnetic field and uniaxial compressive stress to induce the magneto-structural phase-transition.

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Advances in Developing Alternative Rare Earth-Free Permanent Magnets: from Composites Synthesis to Additive Manufacturing

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Additive manufacturing (AM) combined with developing composite materials is attracting much interest in high-tech sectors such as transport, energy, aerospace, and medicine as it allows fabricating complex objects with tuned properties and high performance [1]. In the permanent magnet (PM) sector, the fabrication of magnets with no geometrical constrictions and no deterioration of their magnetic properties is a key point and a challenge at present [2], in addition to finding alternatives to rare earth (RE)-based PMs [3]. Improved ferrites and the promising MnAlC-based alloys are expected to partially fill the gap between conventional ferrites and NdFeB, provided a successful development of PM properties [3].

Different alternative PM materials (gas-atomized τ-MnAlC, strontium ferrite and, by comparison, hybrids −Sr ferrite/NdFeB) have been studied in collaboration with the companies Höganäs AB (Sweden) and IMA (Spain). The process for developing RE-free magnets by AM will be explained, going from the composites synthesis (PM particles/polymer) using the different precursor materials to the 3D-printing of magnets. The influence of particle size and its distribution, polymer and fabrication parameters on the properties of the resulting magnetic products has been analysed. These have been shown to be key factors that need to be considered and optimized for obtaining flexible filaments with a high filling factor and non-deteriorated magnetic properties [4]. Optimized MnAlC-based filament (with a high MnAlC content of 80 wt.%) was used for 3D-printing objects under controlled printing temperature, demonstrating that alternative PM materials can be efficiently synthesized and processed to develop novel PMs by AM [4].

Acknowledgments

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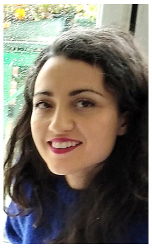

Ester M. Palmero Dr. Ester M. Palmero is a postdoctoral researcher in the Group of Permanent Magnets and Applications at IMDEA Nanociencia since 2017. Before joining IMDEA she worked in the Group of Nanomagnetism and Magnetization Processes at the ICMM-CSIC, where she was involved in the synthesis of magnetic nanowires and the study of their magnetization reversal processes. She obtained her Ph.D. in Advanced Materials and Nanotechnologies from Universidad Autónoma de Madrid in 2016, being her Ph.D. thesis awarded the Extraordinary Doctoral Award by UAM. At IMDEA Nanociencia, Dr. Palmero is responsible of the research lines of 3D-printing of magnetic composites, and electrochemical synthesis of nanostructures for developing novel permanent magnets with no or reduced content of rare-earth elements. Her activity has contributed to the results of the project NEXMAG, coordinated by IMDEA and awarded as Success Case by the M-ERA.NET Network in 2018. She is responsible of electrodeposition and MEMS fabrication in the on-going H2020 FET-Open Project UWIPOM2 aiming to develop microrobotic mechanisms for microsurgery.

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Static and Dynamic Magnetic Properties Illuminated by Polarized Soft X-Rays

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To date, x-rays are one of the most powerful and versatile tools available to researchers. With the advent of sophisticated x-ray sources like modern synchrotron facilities a plethora of new and advanced measurement methods was established that enabled a non-destructive insight into regions buried deep within complex structures and helped to shed a light on a wide variety of different material properties such as chemical composition, crystal structure, electronic structure, as well as magnetic ordering.

Among this flurry of novel techniques, especially the realization of magnetic dichroism in x-ray absorption was a milestone achievement in the investigation of magnetic interactions, as it could provide detailed magnetic information with element and valence state specificity directly sensitive to the absorber site. As such, magnetic X-ray dichroism (MXD) quickly became a standard probe of magnetic properties. The magnetic contrast in MXD originates from the difference in x-ray absorption by a magnetic material for different photon polarizations. While X-ray magnetic circular dichroism (XMCD) using circularly polarized x-rays is largely useful for the study of materials with finite net magnetization and can provide detailed information on orbital and spin magnetic moments, X-ray magnetic linear dichroism (XMLD) using linearly polarized x-rays can provide information on long range magnetic order even in the absence of a net magnetization and has proven indispensable in the study of antiferromagnetic materials and anisotropies.

Lately, the combination of ferromagnetic resonance (FMR) with X-ray absorption spectroscopy (XAS) as the underlying detection mechanism has marked another breakthrough development in the study of magnetic interactions, as it expands the capabilities of MXD to the dynamic range and enables the direct study of magnetization dynamics and spin current effects with sensitivity to individual elements.

In this tutorial talk I will give an introduction into the fundamentals of soft x-ray absorption spectroscopy and magnetic x-ray dichroism and their utilization for the study of static magnetic properties and magnetization dynamics.

Christoph Klewe Christoph Klewe is a physicist at the Advanced Light Source (ALS) of the Lawrence Berkeley National Laboratory. He received his PhD from Bielefeld University (Germany) in 2016, working in the field of spincaloritronics. In 2016 he joined the Berkeley National Lab to work as a postdoctoral researcher at beamline 4.0.2 of the ALS, where he focused his studies on the investigation of magnetic materials and effects using polarized soft x-rays. Since 2019 he is a project scientist at beamline 4.0.2.

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Electrical Spin Current Generation in Ferromagnets and Antiferromagnets

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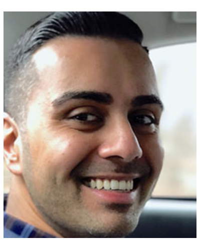
Electrical control of magnetic order has widespread applications for information and communications technology. One way to manipulate magnetic order in layered structures is to generate a spin current in a source layer that is absorbed by a nearby magnetic layer, causing a transfer of spin angular momentum or spin torque. In this talk, we discuss theoretical and experimental evidence suggesting that magnetic materials can be simultaneously the source and receiver of spin torques, paving the way for single layer magnetic memories.

We present first principles transport calculations demonstrating that, under an applied electric field, ferromagnetic and antiferromagnetic materials generate spin currents with spin directions misaligned with the magnetic order parameter. In some cases, these symmetry-allowed spin currents can flow into the layer boundaries and exert substantial torques that can be measured through optical techniques such as MOKE. We study both intrinsic and extrinsic contributions to electrically generated spin currents in magnetic systems to help disentangle the key physical mechanisms. Shedding light on the spin currents and spin torques generated within magnetic materials will help optimize the electrical control of magnetic order and could lead to exciting applications in information and communications technology



Vivek Amin Vivek Amin is an Assistant Professor in the Department of Physics at Indiana University –Purdue University, Indianapolis (IUPUI). He received his B.S. in Electrical Engineering at The University of Texas at Austin and his PhD in Physics at Texas A&M University. His group theoretically investigates using the spin and associated magnetic moment of electrons to create new electronic, or "spintronic," devices, with applications to magnetic memories and hardware implementations of artificial intelligence.

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Design of core/shell nanoparticles for optimizing the magnetic hyperthermia and the catalytic activity

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Magnetic nanoparticles are widely studied for their potential applications in biology and medicine. In particular, the use of ferrite nanoparticles has been approved by regulatory agencies, such as the FDA, for different clinical protocols as contrast agent in MRI, anemia treatment and magnetic hyperthermia of glioblastoma. Even considering the important advances in magnetic hyperthermia for oncology treatment, there are many aspects that have to be improved until the method could be widely applied. One of these challenges is the optimization of the physical characteristics of the magnetic nanoparticles in order to increase the heating efficiency in media with different viscosities.

Nowadays, new synthesis and physical fabrication methods allow to combine in a single nanoparticle two or more components, with controlled size and high quality of interfaces, which open a wide range of new possibilities to develop bifunctional materials. The presence of interfaces in core/shell bimagnetic nanoparticles also introduces additional interactions that could radically modify the static and dynamic magnetic behavior of the systems, and provides supplementary tools to optimize and control their physicochemical properties.

In this talk, I will present the strategies followed to design and fabricate core/shell nanoparticles for tuning their magnetic anisotropy. In this way, the Brown or Néel relaxation mechanism can be syntonized, and also the heating efficiency can be optimized in magnetic hyperthermia experiments, even in a high viscosity medium. This can be done by changing the shell composition in $Fe_3O_4/Zn_xCo_{1-x}Fe_2O_4$ core/shell bimagnetic nanoparticles, where the effective anisotropy can be adjusted by the substitution of Co^{2+} by Zn^{2+} in the shell.

Moreover, the ferrite nanoparticles present catalytic activity where highly oxidative free radicals are generated. The radical species formed during heterogeneous Fenton reactions, have an effective oxidative ability that can induce oxidative stress and could promote tumor cell death in cancer therapies. Here we will analyze the free radical production catalyzed by different ferrites nanoparticles by Electron Paramagnetic Resonance spectroscopy, and they dependence with the nanoparticles surface to volume ratio, the surface composition and also the pH and temperature of the media. The synergy between the magnetic and catalytic properties of these nanoparticles makes them very promising materials to further applications in nanomedicine.

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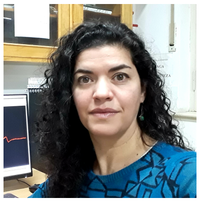

Elin L. Winkler. Researcher of National Council for Scientific and Technical Research (CONICET) since 2005, Researcher of National Atomic Energy Commission (CNEA), since 2016; Professor at the Balseiro Institute, Cuyo National University (IB-UNCuyo) since 2021, at Argentine. Ph.D. in Physics from the IB-UNCuyo Argentine (2000); Postdoctoral Fellows at the Texas Material Institute, University of Texas at Austin (2001-2002), and Postdoctoral Fellows at the Magnetic Resonance Laboratory at the Bariloche Atomic Center (2003-2004). Co-author of more than 70 papers in peer-review journals, two book chapters and more than 100 contributions to local and international conferences. Supervisor of 10 undergraduate, graduate students and postdoctoral researchers since 2006. Her research area focus on the development of new nanostructured materials based on magnetic nanoparticles and the study of its physic-chemical properties in order to tune the response for different electronic and biomedical applications.

Magnetic Josephson Junctions for Artificial Synapses

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The performance of artificial intelligence (AI) technologies has improved significantly over the last decade in such a way that AI is now everywhere in our daily life via software neural networks. However, this continual growth in computational performance of these networks comes with large increases in the computational time and energy needed to train them. Developing AI at the hardware level has the potential to bend this curve and provide fast and lower energy computing. In this talk, I will present a new hybrid magnetic-superconducting device that can be used as an artificial synapse in neuromorphic circuits. The device is a magnetic Josephson Junction that consists of a barrier of magnetic nanoclusters between two Nb electrodes. The critical current of these junctions can be tuned by varying the magnetic order of the clusters, which can be used to perform synaptic weighting. I will describe the properties of the MJJ and show that its synaptic properties can be obtained in different material systems with an energy cost as low as 10^{-19}J. Finally, I will present circuit simulations where MJJs are included in a neural network for image recognition operating at speeds over 100GHz, and show some preliminary experimental validation of the simulations.

Emilie Jué. is an Associate of the National Institute of Standards and Technology (NIST) and a Research Associate at The University of Colorado Boulder. She obtained her PhD from the University of Grenoble with SPINTEC in 2013, after which she did a post doc at NIST-Boulder. Her current research focuses on spintronic devices for neuromorphic applications at the hardware level. She is a Senior Member of IEEE.

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Techniques for Investigating Magnetism in Ultra-Thin Films: Polarised Neutron Reflectometry and Density Functional Theory

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Thin magnetic films play an increasingly important role in a range of existing commercial technologies (e.g., magnetoresistance random access memories). Recently a new generation of two-dimensional magnets have been discovered, including candidates that host exotic quantum effects and topological electronic structures [1]. In the first part of my talk, I will discuss the novel physical and electrical phenomena of ultra-thin magnets, including the possibilities for engineering zero dissipation electronics using topological magnetism. As the net magnetic moment of these structures is often extremely low, I will show they pose a challenge to measure with traditional direct magnetometry such as superconducting quantum interference devices. I will briefly survey how various nanoscale magnetometry techniques address this challenge, including x-ray circular dichroism, nanodiamond microscopy, muon spectroscopy, β-NMR spectroscopy and polarised neutron reflectometry (PNR).

The second part of the talk will focus on how polarised neutron reflectometry can measure ultra-thin magnetic films to quantify magnetization in absolute units and simultaneously reveal complementary chemical information such as the degree of local oxidation. I will discuss both the advantages and disadvantages of PNR relative to other techniques and how this method is implemented at the Australian Centre for Neutron Scattering. A new approach to using ab initio calculations to support PNR experiments by constructing slab models of thin films will be demonstrated. Finally, I will explain the process for gaining access to the PNR equipment at the Australian Nuclear Science and Technology Organisation via a peer-review process that is freely open to international users.

David Cortie obtained his PhD in Physics from the University of Wollongong in 2013, and went on to postdoctoral work at the University of British Columbia, the Max-Planck Society, the Australian National University and the Australian Nuclear Science and Technology Organisation. In 2017, he was awarded an Australian Research Council (ARC) Discovery Early Career Research Fellowship. He is also an associate investigator with the ARC Centre for Future Low Energy Electronics Technologies (FLEET). In 2021, David joined the Australian Nuclear Science and Technology Organisation as a neutron scientist specialising in the applications of neutron scattering to characterize magnetic and thermoelectric materials, exploring the link between quantum phenomena and functionality.

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List of Oral Presentations

Emergence of spin-orbit-coupled surface state derived from topological polarization and its spintronic functionality in a nonmagnetic insulator FeSi

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A chiral compound FeSi is a prototypical example of the strongly-correlated d electron insulators. Its peculiar charge and spin dynamics, which cannot be explained by a simple mean-field picture of nonmagnetic insulators, have provoked many important physical concepts such as d-electron Kondo insulator and insulator-to-metal (reversed Mott) transition due to on-site strong Coulomb interaction.

Triggered by recent new insights into topological aspects of correlated insulators, FeSi is attracting renewed attention for its unusual properties. However, it remains highly nontrivial that compounds made of light (and usually common) elements, like FeSi, can bear topological characteristics. As evidenced by the recent numerous researches, the topological insulators necessarily contain heavy (and generally rare) elements with strong spin-orbit coupling (SOC) to protect their topological band structure.

In this study, we successfully demonstrate a novel surface state hosting metallic conduction and ferromagnetic order in FeSi thin film with nonmagnetic bulk state [1]. We identify that the surface state is not categorized into the class of topological insulators but can be described by the modern theory of topological polarization, i.e., Zak phase. Owing to the unique dipolar charge distribution of Zak-phase origin, the surface state produces the strong SOC properties despite the absence of heavy-metal elements. By taking advantage of the emergent SOC, we also realize spintronic functionalities such as unidirectional magnetoresistance and current-induced magnetization switching with high efficiency.

Our results shed light on compounds made of common elements and demonstrate another route utilizing the new type of topological polar surface states as platforms for SOC-based spin manipulation. Our findings are applicable to a wide variety of materials and also bring a new perspective to the modern theory of surface polarization which incorporates the Zak phase.

Acknowledgments

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Nearly itinerant electronic ground state in the intercalated honeycomb iridate $Ag_3LiIr_2O_6$

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The introduction of atomic species between honeycomb planes in insulating Iridium oxide Kitaev magnets is emerging as a powerful approach to engineer magnetic interactions with the end goal of suppressing long-range order. Here, we use x-ray spectroscopy at Ir L_3/L_2 absorption edges to study powder samples of the intercalated honeycomb magnet $Ag_3LiIr_2O_6$ [1]. We argue that the topo-chemical exchange of interlayer Li atoms with Ag in $Ag_3LiIr_2O_6$ [2], [3] atoms result in a nearly itiner-ant electronic structure with enhanced Ir-O hybridization that fundamentally alters the magnetism. X-ray absorption reveals that the magnetism in $Ag_3LiIr_2O_6$ is characterized by an asymmetric spin density with strong spin-orbit coupling and a larger orbital component than the parent compound α-Li_2IrO_3. Resonant inelastic X-ray scattering spectra probing the Ir electronic structure of $Ag_3LiIr_2O_6$ is captured by incorporating Ir-Ir hopping integrals, demonstrating that the local j_{eff} = 1/2 picture is not a valid basis. $Ag_3LiIr_2O_6$ must be understood as a new type of nearly itinerant model quantum magnet. We posit that similar effects may be at play in other intercalated honeycomb iridates. Our results provide an empirical foundation to develop suitable effective Hamiltonians in these next-generation frustrated and confirm the importance of metal - ligand hybridazation in the magnetism of transition metal oxides.

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Large Magneto-Electric Resistance in the Topological Dirac Semimetal α-Sn

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The spin-momentum locking of surface states in topological quantum materials can produce a resistance that scales linearly with magnetic and electric fields and also depends on the current direction relative to the crystalline axes [1], [2]. Such a bilinear magneto-electric resistance (BMER) effect offers a completely new approach for magnetic storage and magnetic field sensing applications. The effects demonstrated so far, however, are relatively weak or only for low temperatures [1]–[3]. In this presentation, we report a strong room-temperature BMER effect in topological Dirac semimetal α-Sn thin films [4]. The epitaxial α-Sn films were grown by magnetron sputtering on single-crystal silicon substrates at room temperature. They showed room-temperature BMER responses that are 106 times larger than previously reported at room temperature [2], and also larger than that previously reported at low temperatures [1], [3]. These results represent a major advance toward realistic BMER applications. Our experimental data also made possible the first characterization of the three-dimensional, Fermi-level spin texture of topological surface states in α-Sn thin films.

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New Techniques for Probing the Static and Dynamic Properties of Magnetic Materials

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We present an overview of two new techniques that can probe the properties of magnetic materials on very short spatial and temporal scale lengths. The first technique is a pump-probe spectroscopy method utilizing tabletop extreme UV (EUV) light produced by high harmonic generation. This EUV source allows us to spectroscopically probe ferromagnetism with multi-element specificity and a time resolution on the order of a few-femtoseconds. This made it possible to uncover that surprisingly, it is possible to excite the spin system in pure ferromagnets and alloys on few-femtosecond time scales [1], [2].

The second technique is a spatially-resolved magnetic imaging technique implemented at the COSMIC coherent soft X-ray beamline at Lawrence Berkeley National Laboratory's Advanced Light Source. A novel x-ray vector ptychography technique is utilized to produce a 3D nanoscale map of the magnetization vectors within a Ni metalattice, without the need for any a priori knowledge of the sample. This made it possible to visualize topologically-stabilized hedgehog and anti-hedgehog pairs [3].

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Dislocation-Driven Relaxation Processes at the Conical to Helical Phase Transition in FeGe

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Competing magnetic interactions can lead to complex chiral spin textures. Such chiral magnets possess a well defined wavelength, which makes them a striking nanoscopic analogue to liquid crystals, possessing lamellar phases and with intriguing topological defects. These topological defects are of great importance as they play a key role for the order and dynamics of spin systems.

Here, we present a combination of ac susceptibility measurements, magnetic force microscopy, and micromagnetic simulations which reveal a variety of 1D and 2D topological defects in the near-room temperature chiral magnet FeGe [1], [2]. We study the relaxation mechanism at the conical-to-helical phase transition, which is closely related to the motion of edge dislocations (1D defects) [3]. We find that although the dislocations can move with velocities of about 100 m/s, their impact on the formation of a stable helimagnetic spin structure is detectable on the timescale of minutes. These long timescales are a result of pinning on randomly distributed structural defects. The motion and pinning of dislocations also has a substantial impact on the formation of helimagnetic domains and domain walls.

Thus, our experiments reveal a multitude of magnetic nano-objects with non-trivial topology and their impact on the nanoscale spin structure in chiral magnets. These topological objects are an extension of the family of previously known magnetic topological patterns like skyrmions.

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Tuning Magnetic Frustration in Toroidal magnet Cu_3TeO_6

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The cubic bixbyite structure (α-Mn_2O_3) has a deep history in solid-state chemistry, the first structural solution was completed by Zachariasen and later corrected by Pauling [1].

The ternary oxide Cu_3TeO_6 is an ordered bixbyite that has been the focus of intense study due to its interesting magnetic spin-web structure [2]–[5]. We have synthesized powders and single crystals of the solid solution $Cu_{2.25+3x/4}Sb_{1-x}Te_xO_{4.75+5x/4}$. Through X-ray diffraction (XRD) and neutron diffraction (ND) experiments we have been successful in identifying the mechanisms employed by the bixbyite lattice to accommodate the large dopant pressure [6]. As a direct result of Sb dopant concentration there is a strong transition from the Antiferromagnetic structure of Cu3TeO6 to a clear canonical spin-glass order. Alternating current magnetic susceptibility experiments help to elaborate how the balance between order and disorder of the nuclear lattice manifests itself in a more complex frustrated state at intermediate dopant concentrations. We will provide evidence in support of a proposed toroidal magnetic structure present in Cu_3TeO_6 from our own neutron diffraction studies in support of a previous magnetic study which proposes a toroidal structure as an explanation for the unexpected presence of the linear magnetoelectric effect [7].

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Optical imaging of antiferromagnetic domains and dynamics switching in CoO film by magneto-optical birefringence effect

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Spintronic devices based on antiferromagnetic (AFM) materials has drawn significant attention due to its potential for information storage with low power consumption and ultrafast switching speeds [1], [2]. However, most experimental investigations on the switching of AFM spins relies on electrical detection means, like the anisotropic magnetoresistance, spin Hall magnetoresistance, and the related planar Hall resistance due to the difficulty of AFM spin detection. Recent works reported that the changes of electrical signals are not necessary correlated with the evolution of AFM domain states [3]. So, there is an urgent need to directly measure the AFM domain in real space during the spin switching process for further understanding the mechanism of AFM domain switching.

In this contribution, we report the studies on the AFM domains in single crystal CoO thin films grown on MgO(001) substrates with the magneto-optical birefringence effect. The finite size effect of ordering temperature for ultrathin single crystal CoO film is revealed by the thickness and temperature dependent measurement of birefringence contrast. The magneto-optical birefringence effect is found to strongly depend on the photon energy of incident light. Moreover, we report the direct imaging on evolution of AFM domains under an external field in single-crystalline Fe/CoO bilayer. By manipulating the AFM spins with different types of magnetic fields, we discovered that with the alternating fields, it is easier to overcome pinning energy barrier and the AFM domain switching process is dominated by domain wall motion, while for constant fields, domain nucleation dominates the switching process. We also confirmed the effect of alternating field on domain wall motion in AFM CoO film through micro-magnetic simulations. Furthermore, we study the multiple switching processes in AFM CoO domain, and domain wall motion gradually suppressed with increasing switching number. Our studies demonstrate that the spin properties in AFM films under external fields can be measured in real time, which could be helpful for the understanding of the dynamics of AFM materials and the development of AFM spintronics.

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Topological Nernst effect from spin chirality: Skyrmions for thermoelectric conversion

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Spin textures such as skyrmions in spiral magnets or canted phases in pyrochlore lattices have been in the spotlight recently. They generate new physical phenomena and giant responses via the emergent electromagnetic field, i.e. an effective vector potential a_i which influences the motion of quasiparticle excitations through the background of noncoplanar spins. One famous consequence of a_i is a sideways deflection of charges moving through a skyrmion [1] or a pyrochlore lattice [2], termed topological (or geometrical) Hall effect. The corresponding thermoelectric response, the topological Nernst effect (TNE), is much less understood.

We present experimental evidence for the TNE of skyrmion lattices in two prototypical silicides: Firstly, hexagonal, centrosymmetric Gd_2PdSi_3, where conduction electrons coupled to local rare earth moments drive skyrmion formation [3], [4]. And secondly, MnSi, a chiral magnet with a skyrmion lattice stabilized by the Dzyaloshinskii-Moriya interaction (DMI). While the signal in the latter material is small – on account of MnSi's long-period spin texture (λ=18 nm) and further weakened by strong spin dynamics – the former compound shows a gigantic Nernst response on par with the largest signals observed in 'topological ferromagnets'; i.e. with collinear magnets where large a_i emanates from protected crossings of electronic bands (Weyl nodes or line nodes).

We verify Mott's relation for thermoelectric transport in the skyrmion phase of Gd_2PdSi_3 in a series of electron- and hole-doped single crystal specimens. On the electron-doped side, the emergent electromagnetic response is strongly enhanced, indicating the coexistence of nontrivial electronic bands with the noncoplanar skyrmion spin texture in Gd_2PdSi_3.

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Development of High Power Density Traction Motors for Electrical Vehicles

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With the advantages of high torque and power density, wide speed range, high efficiency, high reliability, permanent magnet (PM) synchronous motors have become one of the most suitable candidates for traction of Electric Vehicles (EVs) in recent years. In PM motors, design parameters involving electromagnetic, thermal, and structural aspects are key factors affecting power density of EV traction motors. However, the tradeoff of these factors in the design of traction motors to achieve high power density is complicated. Therefore, in this study, two types of PM motors with various topologies are investigated and compared to evaluate the performance and power density considering the design parameters such as the PM amount and flux barriers under prescribed temperature limits. Furthermore, to improve the performance and power density of these motors, using high thermal conductivity materials and the cooling systems is evaluated. The analysis results show that improving electromagnetic design and using high thermal conductivity materials and cooling systems can significantly improve the power density of traction motors. Finite element method (FEM) is used to validate the analysis.

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N-th Root Topological Lattices

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Square root topological insulators (TIs) host non-zero topological modes, in contrast to the typical midgap zero modes found in conventional topological insulators. In recent years, square root versions of well-known topological lattices such as the 1D Su-Schrieffer-Heeger (SSH) and Kitaev chains [1] and the 2D honeycomb lattice [2], [3] have been introduced in various platforms such as photonic [4] and acoustic systems [5], and in topolectrical circuits (TE) [6]. The equivalence between the tight-binding (TB) model of a lattice and its graph structure enables us to construct the N^{th} root Hamiltonian on the original lattice by simply introducing $N-1$ new sites between the parental sites (i.e., 1 and 3 new sites for square-root ($N=2$) and quartic-root ($N=4$), respectively) and taking the N^{th} root of the hopping parameters [7], [8]. The resultant Hamiltonian (H_{Nroot}) inherits the topological properties of the original Hamiltonian and its N^{th} power takes the form of $(H_{Nroot})^N = H_{parental} \oplus H_{residual}$, where $H_{parental}$ is the original TB Hamiltonian on the parental lattice up to an additive constant and $H_{residual}$ contains only interactions between the newly introduced sites. When the power of the root is 2^N, subdividing the graph by the new sites results in a bipartite property which ensures that the new Hamiltonian has chiral symmetry. While this bipartite property preserves the Hermiticity, odd roots require breaking the Hermiticity (i.e., $t_{a,b}=t$ and $t_{b,a}=0$, with t being the coupling strength) in order to preserve the forms of $H_{parental}$ and $H_{residual}$. We introduce a new method which makes every order of roots accessible, including prime number roots. Our method also utilises the graph construction used previously for taking the square root where the key criteria to be satisfied is that H_{Nroot} takes the form of the direct sum $H_{parental} \oplus H_{residual}$. Apart from the 2^N root operation, in our model, the $N-1$ new sites with one-directional couplings between two parental sites are ordered in such a way as to create a closed-loop. These non-reciprocal couplings result in non-Hermiticity and bring forth new properties absent in the square root systems. In conclusion, our N^{th} root models give rise to various new types of topological phases with potential applications for magnetic sensing due to the multiplicity of topological states and the sensitivity of the non-Hermitian N^{th} root topological insulator system.

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Design of an Uniform Magnetic Field Electromagnet

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This research shows the designing process of the electromagnet. The design process starts with the three-dimensional computer aided design (CAD) and progress towards the magneto-static finite element method (FEM) analysis and an electromagnet design for the experiments. The first step in the design of an Electromagnet is to ensure the cross-sectional area of the magnetic circuit can reaches the target value. The magnetic circuit of an electromagnet is includes the pole, pole piece and yoke. FEM methods are widely used in electromagnets designing process [1]. Usually, FEM analysis is uses as a second step in the designing process. The magnetic transient studies are quick FEM analysis models, so various design iterations were calculated to ensure that magnetic flux density at the middle of the two pole pieces by changing different air gaps and also different currents. These FEM analysis ensures that once the electric current in electromagnet coils are reaches to the steady-state value the magnetic flux density arises at the airgap. The core material of an electromagnet shows a significant effect on electromagnet response. The SS400 material has shown the better performance than the other materials in FEM simulations. The B-H curve relationship, resistivity and permeability are the main factors in the development of an electromagnet. The B-H curve is measured to the SS400 sample (Outer diameter = 38.10mm, Internal diameter = 31.75mm and thickness = 8.40mm) with the help of MPS Remagraph C. It ensures the material properties are same with the FEM method to maintain the good accuracy. An Electromagnet prototype was developed with the help of FEM simulation results [2]–[4]. The magnetic flux density values are measured with the MPS FH 55 gauss meter and compared with the FEM simulation values observed the allowable error percentage.

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Effect of Dzyaloshinskii Moriya Interaction on Magnetization Reversal in Triangular Nanodot

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Thorough understanding of magnetization reversal mechanism in isolated magnetic nanostructures in the presence of Dzyaloshinskii Moriya Interaction (DMI) is crucial for the development of energy efficient magnetic storage devices [1]. In recent time, a few experimental and theoretical works have attempted to address the combined effect of in plane magnetic field and DMI (*D*) on magnetization reversal and reported interesting modification in the hysteresis loop [2] Here we investigate the effect of DMI and in plane field on the magnetization reversal mechanism in perpendicularly magnetized equilateral triangular nanodot using micromagnetic simulation $Mumax^3$ [3]. The side length of the triangle is chosen as 128 nm and thickness as 1 nm . In plane magnetic field (H) is applied parallel to the base of the triangle and snap shot of the spin configuration is analyzed to infer the changes in the nucleation center for the magnetization reversal in the presence of *H* and *D*. Our results indicate a monotonic reduction in the coercive field (H_c) as the strength of the *D* increases. Interestingly, due to the presence of DMI, chirality induced nucleation of magnetization reversal from the oblique side edges, where the sign of the DMI determines the chirality is observed In the absence of *D*, we note that the nucleation of reverse domain initiates at the center of the triangle and the reversed domain expands towards the sides of the triangle. In the presence of *H* and *D* both we observe an asymmetry in the hysteresis loop. Also, during Up-Down or Down-Up magnetization reversal, the side of the triangle where the nucleation of the reversal initiates (either left or right) is governed by the sign of *H*. The non-zero *H* assist in reducing the energy barrier by tilting the magnetization and the presence of *D* allows a particular chirality induced reversal. Overall, our study suggests that the direction of the H with respect to the side of the triangle i.e. whether it is parallel or perpendicular with respect to a particular side of the triangle substantially modifies the amount of asymmetry in the hysteresis loop and nucleation center for the reversal in the triangular nanodot. These results are important in understanding the energy efficient magnetization reversal mechanism in the presence of *D* which may have significant application potential.

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Atomic Structure and Electron Magnetic Circular Dichroism of Individual Rock Salt Structure Antiphase Boundaries in Spinel Ferrites

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Functional oxides are ubiquitous and exhibit a wide range of electric, magnetic, optical, and structural properties. Controlling of the defects and interfaces in thin-film devices are the new challenges in multifunctional oxides. Antiphase boundaries are the interfaces between two crystallographically identical regions with shifted phases. Based on previous studies, the correlation between existence of antiphase boundary and decreased saturation magnetization in oxides has been discussed [1], [2]. Due to the resolution limitation of magnetism measurement, it is difficult to investigate the structure-property relationship at high spatial resolution.

EMCD, first experimentally verified by Schattchneider et al. [3], is a magnetism measurement method in a transmission electron microscope and is confirmed with the ability to reach spatial resolution better than 2 nm using convergent beam [4], [5]. This significant breakthrough enables us to study the magnetic properties of interfaces and boundaries on nanometer scale. In the meanwhile, our group have developed site-specific EMCD [6] and atomic plane resolved EMCD [7] in complex oxides such as spinel and double perovskite. Intensity analysis of antiphase boundary (APB) in HAADF (high angle annular dark-field imaging) STEM (scanning transmission electron microscopy) images suggests that only half of the octahedral interstices are occupied at the rock salt structure interlayer of a new type APB in NiFe2O4 with a relative translation of (1/4)*a*[011]. High-spatial-resolution EMCD have been used to experimentally demonstrate reductions of $\sim 46.8\%\pm8.2\%$ and $\sim 38.8\% \pm 14.5\%$ in the EMCD strengths of Fe and Ni in APB, respectively, compared to perfectly ordered $NiFe_2O_4$ [8]. DFT calculations and dynamical diffraction calculations suggest that the reduced EMCD strengths result from the fact that Fe ions at the APB interlayer are antiferromagnetically coupled with each other, whereas Ni ions show a significant decrease in magnetic moment as a result of the formation of low-spin state Ni^{4+} (d^6) ions. Our combined approach of using element specific EMCD under high-spatial-resolution and first-principles calculations to resolve and identify the atomic structure and magnetic coupling of an individual APB in spinel ferrite is applicable to studies of a broad spectrum of other defects in magnetic materials.

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THz emission from NiO/Pt heterostructures

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When a femtosecond laser is incident on a ferromagnet/heavy metal (FM/HM) structure, it produces THz pulses [1], [2]. This phenomenon has been studied in several FM/HM systems. Very recently, antiferromagnetic (AFM) material has been used as a spin source material instead of FM layer for THz emission [3]. In this work, we use high-quality epitaxial NiO (17 nm)/Pt (3 nm) heterostructure for THz emission. Pulse laser deposition (PLD) technique with KrF excimer laser source of wavelength 243 nm is used to deposit NiO film on sapphire substrate at 500 °C. X-ray diffraction technique has been used to characterize the crystal structure of NiO. We observe NiO (111) peak at $2\theta = 36.89$°, together with Pendellosung oscillations, which signifies smooth interface quality between NiO and substrate. The Φ-scan measurement of NiO films show the formation of two types of domains rotated by 60°. The Pt layer was grown by sputtering in a separate chamber. We observe THz emission from NiO/Pt structure but no emission was observed for pure NiO film. We compare the THz amplitude of NiO/Pt with Fe/Pt bilayer. The signal strength in the NiO/Pt system was found to be 80 times weaker compared to the Fe/Pt system. The results show that NiO can generate THz signal similar to ferromagnets. The results are important for the field of antiferromagnetic spintronics.

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Strain- and Doping-Tunable Half-Metallicity and Magnetic Structure in Monolayer CrSeCl

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Artificial electronic materials provide a fascinating platform for the exploration of exotic physical phenomena not existing in nature. One example is half metallicity, which refers to electronic systems acting as a conductor to one type of spin electrons, but as an insulator or semiconductor to those of the opposite spin type [1]. This phenomenon offers great potential for achieving fully spin-polarized current for high-performance spintronic applications. However, the realization of robust half metallicity remains very challenging in artificial materials, such as ultrathin films with reduced dimensions, partly due to unavoidable spin-mixed edges or surface states in vicinity to the Fermi level [2]–[4].

Here, using first-principles calculations [5], we predict, for the first time, doping- and strain-induced half metallicity in monolayer CrSeCl, a two-dimensional (2D) ferromagnetic semiconductor. With a biaxial tensile strain of over 2%, the monolayer magnet undergoes a phase transition from magnetic semiconductor to half-metal. We find that its Curie temperature and magnetic anisotropy are also sensitively dependent on external strains. For instance, its intrinsic ordering temperature of 328 K shows a remarkable increase to 549 K with 10% strain. It is even possible to switch its magnetic easy axis from in-plane to out-of-plane by using a tensile strain of 9%.

Our results further indicate doping as an approach for triggering half-metallicity in monolayer CrSeCl. Essentially, spin-polarized band structure calculations reveal half-metallicity to emerge in Mn- and Fe-doped CrSeCl monolayers, with an associated spin-down bandgap of 2.296 or 1.172 eV, respectively. Compared with the pristine case, the Mn-doped monolayer exhibits a stronger in-plane magnetic anisotropy, whereas the Fe-doped monolayer has a preferred out-of-plane magnetization geometry. Considering its layered structure akin to those in the huge family of 2D materials, we foresee the strain- and doping-induced half-metallicity in monolayer CrSeCl to be practically examined in van der Waals epitaxial systems and designer heterostructures.

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Mechanism of Domain Wall Pair to Skyrmion Conversion in Typical Junction Geometry

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Topologically protected spin textures, namely, skyrmions are envisioned to play crucial role in new generation magnetic memory devices. In the last decade, a number of experimental and theoretical works have attempted to create and annihilate skyrmions controllably in different magnetic nanotrack. In particular, efforts have been dedicated towards achieving the tunable dynamics of the skyrmion which is one of the crucial requirements for skyrmion based racetrack memory [1]. Among the various method of perturbing the system to stabilize the skyrmion, conversion of domain-wall (DW) pair to skyrmion is of fundamental interest due to the non-trivial mechanism associated in this process [2]. Here, we study the mechanism of domain wall to skyrmion conversion in a typical geometry which consists of the combination of two narrow nanotracks (length –400 nm, width –20 nm, thickness –1 nm) and a wide track (width 200 nm). The separation between the narrow channels is varied from 10 nm to 60 nm in steps of 10 nm. Using micromagnetic simulation package Ubermag we investigate the magnetization dynamics and the Zhang-Li torque evolver is implemented in Landau-Lifshitz-Gibert equation to drive the DWs using spin polarized current [3]. We address the influence of fixed Gilbert damping parameter (α) and various values of non-adiabatic spin torque parameter (β) on DW pair to skyrmion conversion at different separation between the narrow track. We find that the interplay between α, β and separation between the narrow channel play crucial to in the conversion of DW pair to skyrmion. Our results suggest that though $\alpha = \beta$ minimizes the skyrmion Hall effect, but for certain geometries it does not favor the conversion of DW pair to skyrmion. However, at optimal separation between the narrow channels, conversion of domain wall pair to skyrmion can be facilitated. Overall, our results suggests that with more than one narrow channel in a junction geometry, number of skyrmion and its dynamics in the nanotrack can be precisely controlled by tuning the separation between the nanochannel [4]. We believe, these results will be helpful in implementing the topologically protected spin textures in low power consumption racetrack memory.

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Room-temperature intrinsic ferromagnetism in epitaxial $CrTe_2$ ultrathin films

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While the discovery of two-dimensional (2D) magnets opens the door for fundamental physics and next-generation spintronics [1]–[3], it is technically challenging to achieve the room temperature ferromagnetic (FM) order in a way compatible with potential device applications. Here, we report the growth and properties of single- and few-layer $CrTe_2$, a van der Waals (vdW) material, on bilayer graphene by molecular beam epitaxy (MBE). Intrinsic ferromagnetism with a Curie temperature (T_C) up to 300 K, an atomic magnetic moment of 0.21 μB/Cr and perpendicular magnetic anisotropy (PMA) constant (Ku) of 4.89 × 105 erg/cm^3 at room temperature in these few-monolayer films have been unambiguously evidenced by superconducting quantum interference device and X-ray magnetic circular dichroism. This intrinsic ferromagnetism has also been identified by the splitting of majority and minority band dispersions with 0.2 eV at Γ point using angle-resolved photoemission spectroscopy. The FM order is preserved with the film thickness down to a monolayer ($T_C \sim$ 200 K), benefiting from the strong PMA and weak interlayer coupling. The successful MBE growth of 2D FM $CrTe_2$ films with room-temperature ferromagnetism opens a new avenue for developing large-scale 2D magnet-based spintronics devices.

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Growth Controlled Structural Influence on the Magnetization Dynamics of PLD Grown Co_2FeSi Heusler Alloy Thin Films

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Cobalt-based full Heusler compound Co_2FeSi (CFS) is a spectacular material system that can be integrated into functional spintronic devices owing to their theoretically predicted half-metallic band structure, high curie temperature, and low Gilbert damping [1]–[3]. The dynamic magnetic properties of CFS, which play a critical role in spin-controlled magnonics, are inherently affected by the change in its structural ordering. The influence of the growth temperature variation from 500°C to 650°C on the chemical, crystalline, and magnetic ordering of CFS film (50 nm) on (001) MgO substrate fabricated via Pulse Laser deposition was systematically investigated. Out-of-plane XRD measurement shows the evolution of superlattice (002) and (004) peaks indicating a highly textured epitaxial growth of CFS film with B2 or $L2_1$ type ordering. The degree of chemical ordering, which is given by integrated intensity ratio of (002) and (004) reflection peak, suggests an improvement in Co-site atomic ordering in CFS film deposited at 600°C [4]. The static magnetization M-H loop indicates an increment in magnetic saturation with growth temperature due to crystalline and structural improvement in CFS film. The out-of-plane M-H loop suggests an easy axis and hard axis exist in (110) and (001) crystallographic orientation. The dynamic magnetization was investigated by Microwave excitation of ferromagnetic resonance (FMR) in CFS film measured in in-plane geometry. The resonance position and peak to peak field spacing obtained from FMR spectra were analyzed by the Kittle equation to obtained effective magnetization in CFS film, which is in close agreement with VSM data. The linewidth vs. frequency data was fitted to the Landau-Lifshitz-Gilbert (LLG) equation [5] to obtain the Gilbert damping parameter (α), and a reasonably low value of α (9×10^{-3}) was obtained for the CFS film grown at 600°C. The low value of α results from improved chemical ordering and a relaxed lattice structure along with a low density of defect states in the CFS film fabricated at 600°C. In conclusion, we have established that growth temperature inherently affects the structural and crystalline quality of the CFS thin film, which directly influences not only static but dynamic magnetic response in the film. This investigation is crucially important and plays a centric role in the fabrication of energy-efficient Spin-Transfer Torque (STT) based memory and processing devices.

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Unconventional Hall effect in van der Waals ferromagnet Fe_3GeTe_2

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Topological magnetic textures provide an attractive platform for the realization of future spintronic [1] and quantum information processing [2] devices. The discovery of 2D layered van der Waals (vdW) magnetic materials have enunciated the possibility for the realization of a variety of unconventional non-collinear spin textures, down to the monolayer limit. Among the family of quasi-2D vdW ferromagnets (FMs), metallic Fe_3GeTe_2 (FGT, hereafter) is promising owing to its high Curie temperature [3], large magnetic anisotropy, and stabilization of skyrmion and chiral spin-spiral structures [4], [5]. However, an understanding of the physics responsible for the generation of these exotic spin textures and associated magnetoresistive manifestations have remained elusive. Here, we clarify the underlying factors responsible for the stabilization of these spin textures by investigating the impact of doping at the transition metal (Fe) site of 2D FM FGT.

Single crystalline $(Co_xFe_{1-x})_3GeTe_2$ (x = 0, 0.05, 0.45, 0.55) samples and a reference sample (FGT) were grown by chemical vapor transport method. Magnetotransport measurements under applied H ∥ c-axis result in a sizeable anomalous Hall effect, possibly originating from the topological nodal lines in the band structure. On the other hand, transverse resistivity under applied H ⊥ c-axis results in an unconventional behavior with a prominent cusp-like feature, shifting to lower field values with increasing x. Concomitant magneto-optical Kerr effect measurements indicate the emergence of an aggregate of skyrmion-bubble-like lattice structures along with trivial circular or stripe domain patterns. Angle-dependent magnetotransport measurements (at constant H) confirms the 2D nature of these non-trivial spin configurations. A separation of the various magnetoresistive effects indicates a significant contribution originating from an unconventional topological Hall effect behavior [6], much larger than that previously observed either in vdW material [3] or other skyrmion-hosting material systems [7], [8]. These results provide a deeper understanding of magnetoresistive responses originating from complex spin textures and offer a route towards the realization of non-collinear spin texture-based spintronic devices using vdW FMs.

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Measurement of Thin Films Magnetic Properties Based on Spin Hall Effect of Light

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Spin Hall effect of light originates from the spin-orbit coupling between the spin polarization and the trajectory of the photon [1]–[4] and explains how, when a linearly polarized light beam is reflected or transmitted at an interface, the two spin components split perpendicular to the refractive index gradient [5]. The beam shift of spin Hall effect of light is of extreme sensitivity to material properties and environment making it a strong candidate as a high precision detector for many parameters. Using the spin Hall effect of light, this work proposes a measurement technique of the magnetic properties of thin films. The beam shift of the spin Hall effect of light is used to replace the magneto-optical Kerr rotation angle as a parameter to characterize the magnetism of thin films. The technique can easily achieve an accuracy of 10^{-6} rad of the magneto-optical Kerr rotation angle which can, in theory, be further improved to 10^{-8} rad. We also proposed two methods to solve the problem of the exceeding linear response region of the measurement under high magnetic field intensity, making it more conducive to practical application. This technique has great potential for application in the magnetic measurement of ultra-thin films with particular emphasis on thicknesses within several atomic layers [6].

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Dextran and Chitosan coated on Cobalt Ferrite ($CoFe_2O_4$) for Hyperthermia applications

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Magnetic fluid hyperthermia, a modular strategy for disease treatment have received a lot of attention in biomedical application, owing to its lower clinical symptoms and likelihood specifically in harmful malignancy tumour [1], [2]. In recent times many researchers have been working on biocompatible, non-toxic, and chemically stable magnetic nanoparticles for hyperthermia applications however few attention have been given on ferrites nanoparticles.

In this work, cobalt ferrite nanoparticles ($CoFe_2O_4$) was successfully prepared via solvo-thermal method. Chitosan (C2) and dextran-coated (C3) cobalt ferrite nanoparticles ($CoFe_2O_4$) were also prepared by a facile solvo-thermal approach. The x-ray diffraction (XRD) technique was used to characterize the structural properties of the samples. Using, scherrer's formula [3], the crystallite size of bare and coated nanoparticles was calculated, and it was found to be in the range of 10 to 20 nm. VSM (vibrating sample magnetometry) was used to study the magnetic measurement at room temperature. The magnetization values of $CoFe_2O_4$ obtained from a VSM investigation at room temperature are 70.286 emu/g, while the magnetization values of chitosan and dextran coated samples are 38.574 and 50.600 emu/g, respectively. The reduction in Ms for the coated samples C2 and C3 is expected as surface functionalization with organic compounds like chitosan and dextran increases the quantity of non-magnetic material, resulting in a reduction in MS [4]. The surface absorption rate (SAR) was also determined for both the nanoparticles using the following equation [5], $\mathbf{SAR} = \frac{c}{m}\frac{\delta T}{\delta t}$. The specific absorption rate (**SAR**) is used to calculate the efficiency of magnetic hyperthermic. The results indicate that $CoFe_2O_4$ nanoparticles (NPs) coated with chitosan have a maximum SAR value of 173.5 W/g, while dextran coated on $CoFe_2O_4$ NPs have a SAR value of only 172.4 W/g and $CoFe_2O_4$ has a SAR value of 161.0 W/g. Our findings highlight the relevance of MNP surface functionalization, maintaining magnetic behaviour and, as a result, increases their heating ability.

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Synthesis, Structure, Magnetism and Magnetic Particle Heating Characterization of Fe/Fe_3C Nanoparticles in Carbon Matrix

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Increasing the number of oncological diseases requires the development of new methods of dealing with them. In recent decades, various methods have been established like chemotherapy, radiation, surgery. Recently, therapeutic hyperthermia has made some progress, but this method is not considered as a standard treatment. During hyperthermia treatment one uses light and AC magnetic fields for high temperature treatment (about 42-45^oC) of cancer cells in different parts of the human body, which leads to the destruction of cancer cells [1,2]. In magnetic hyperthermia, based on the use of magnetic nanoparticles, a similar principle is used in which magnetic nanoparticles are injected into the tumor tissue to produce heat under the influence of alternating electromagnetic field (AMF) [3]. This means that the magnetic hyperthermia based on the use of magnetic nanoparticles, does not differ in principle from the conventional hyperthermia, and leads to a local heating of an organism.

In this work, carbon coated iron-cementite ($Fe-Fe_3C$) nanoparticles were synthesized by a solid-phase pyrolysis of iron phthalocyanine ($FeC_{32}H_{16}N_8$). The morphology and sizes of the fabricated composite has been investigated using high resolution transmission and scanning transmission electron microscope (HRTEM, STEM). The mean diameter of $Fe-Fe_3C$ nanoparticles is around 10 nm. The structure and composition of $Fe-Fe_3C$ nanoparticles in the carbon matrix were analyzed by XRD, Mössbauer and XPS spectroscopies. The total magnetization of $Fe-Fe_3C$ nanoparticles can be approximated with magnetizations of Fe and Fe_3C bulk materials. Magnetic hysteresis loops of the $Fe-Fe_3C$ nanoparticles at temperatures of 10 and 300 K exhibit a demagnetization jump at low applied fields that can be associated with a core-shell architecture of Fe and Fe_3C. The study of the magnetic heating properties of an aqueous solution of nanoparticles was carried out in an AC magnetic field with different amplitudes and frequencies. The estimation of the Specific Loss Power (SLP) showed that the Fe content is the determining factor in the heating efficiency. Thus, we assume that with further optimization of the synthesis process, the SLP value could be increased and make such nanoparticles suitable for magnetic hyperthermia of cancer cells.

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Sperimagnetism of GdFeCo Amorphous Alloys: H–T Phase Transitions

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The progress in ultrafast magnetization reversal by femtosecond laser pulses has attracted attention to various types of magnetic materials. One of the first materials which has shown an ultrafast switching by laser pulses was the "rare earth"-"transition metal" type (RE-TM) ferrimagnetic amorphous alloy GdFeCo [1]. Like other amorphous compounds, these alloys are characterized by the absence of long-range order of atomic structure, which turns out into microscopic stochasticity of magnetic properties causing the sperimagnetic structure.

In our work we describe a body of amorphous RE-TM type ferrimagnet as a grid of N interacting particles of quite small volume V_0. Particles are composed from RE and TM ions with concentrations n_{RE} and n_{TM}, which depend on the stoichiometric coefficient z of the formula $\mathrm{Gd}_z(\mathrm{FeCo})_{1-z}$. Exchange interactions in RE-TM type ferrimagnets obey the interaction hierarchy, which could be described as an inequality of exchange integrals of d- and f- sublattices: $J_{\text{d-d}} > J_{\text{f-d}} > J_{\text{f-f}}$. In our work we take into account only d-d and f-d exchange interactions, and the d-d exchange is ferrimagnetic, and the f-d exchange is antiferromagnetic. The system of interacting ferrimagnet particles can be described with the use of the Hamiltonian, which includes the d-d and f-d exchange Heisenberg-like interactions, stochastic uniaxial magnetic anisotropy for the f-sublattice, and the Zeeman interaction of f- and d-sublattices with the external magnetic field. The description of thermal properties is done by the use of the Gibbs distribution function and the molecular field theory for d-sublattice.

The suggested model allows to describe the magnetic phases and phase transitions in amorphous ferrimagnet in external magnetic field for different temperatures and RE ions concentrations. We present results of temperature-driven phase transitions and of impact of sperimagnetic structure on critical temperatures and magnetic fields. The presented model is of interest for discovery of equilibrium and metastable states in amorphous ferrimagnets of RE-TM type.

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Spintronics with fullerene

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Interface induced phenomenon in ferromagnetic/organic semiconductor is an emerging topic towards organic spintronics [1], [2]. Buckminsterfullerene (C_{60}) is a potential candidate for organic spintronics due to many desirable properties viz. low spin orbit coupling, large spin diffusion length at room temperature etc [3]. It has been observed that C_{60} exhibits ferromagnetism at the interface of FM/C_{60} [3]–[6].

We have prepared single layers of Fe, Co and CoFeB, and compared the magnetic properties to the bilayers of Fe/C_{60}, Co/C_{60} and CoFeB/C_{60}. The films were prepared on both MgO (001) and Si (100) substrates. Finite magnetic moment was obtained in the C_{60} layer at the interface between the Fe/C_{60} and Co/C_{60} layers by polarized neutron reflectivity measurements [4]–[6]. Magneto optic Kerr effect (MOKE) based microscopy was performed to observe the effect of the magnetic C_{60} layer on the hysteresis loop shape and the domain images of the FM (Fe, Co or CoFeB) layers [4]–[7]. We also study the change in magnetic anisotropy due to the presence of spinterface in these bilayer systems [5]–[7]. It has been found that anisotropy increases with C_{60} thickness [7]. We have also studied the FM/OSC having perpendicular magnetic anisotropy (PMA). In this context we have taken Pt/Co/C_{60} as a model system. It has been observed that introducing a C_{60} layer increases the anisotropy and decreases the domain size of the system [8]. We have also observed spin pumping and inverse spin hall effect (ISHE) at the CoFeB/C_{60} interface [9]. Further we also show that ferromagnetism can be observed at the interface between Cu/C_{60} interface. In this case due to the charge transfer from Cu to C_{60}, density of states of Cu get modified which leads to ferromagnetism in Cu [10].

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A Novel Two-Stage 3D-Printed Halbach-Array Based Device for Magnetomechanical Applications

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The generation of mechanical forces via magnetic fields, the so-called magneto-mechanical effect (MME), is a promising method for the manipulation of magnetic nanoparticles inside varying environments. The combination of static, alternating, or rotating magnetic fields with magnetic nanoparticles allows the transformation of electromagnetic to mechanical energy. Such an aspect may be exploited for biomedical purposes provided nanoparticles successfully bind to the cancer cell membrane and eventually affect cells by exerting magneto-mechanical stress. Unlike hyperthermia, which requires high frequencies to induce heating (above 100 kHz to several MHz), MME can be achieved at frequencies below 100 Hz. To produce these fields and to quantify the corresponding forces, tunable magnetic field applicators have been constructed [1], [2], typically with moderate field intensity and field inhomogeneity. To overcome this, a novel 3D printed magneto-mechanical system designed to produce stronger homogeneous magnetic fields, is manufactured. It consists of two polymer rotating holders, both having 8 circular symmetry sites in which 8 commercial Nd-Fe-B rectangular magnet blocks are placed to form a special Halbach arrangement. By using the unique array, this "sandwich" like configuration produces an highly homogeneous magnetic field within the area where a cell flask plate or a small living specimen can be placed. Meanwhile, by taking advantage of the high magnetic field amplitudes ($\leq$ 0.5 T) as well as of the high spatial gradients of the magnetic flux density (120 T/m) strong mechanical forces and torques can be applied on cells when incubated with magnetic nanoparticles. The 3D polymer rotating turntable printouts operate with DC motors at variable voltage amplitude (3–12 V) resulting in a tunable physical rotation frequency (0–16 Hz). To characterize quantitatively the Halbach configuration of the magnetic field exposure in the device, numerical simulations were carried out using COMSOL V3.5. By considering the estimated magnetic field amplitudes, simulations were validated with experimental measurements. Based on our device's configuration, the spatial gradient of the magnetic flux density was also calculated numerically, in the volume of a typical culture cell petri dish, in order to estimate the force acting on a single MNP of variable size or stoichiometry.

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Spin-Orbit Torque in $PtSe_2$/NiFe Heterostructure

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Transition metal dichalcogenides (TMDs) are potential materials for exerting efficient spin-orbit torque (SOT) on the adjacent ferromagnetic (FM) layer due to their high spin-orbit coupling (SOC) and broken structural symmetry at the interface [1]. Besides a conventional SOT in TMDs, unconventional torque is recently observed in low symmetry TMDs [2]. $PtSe_2$ is one of the TMDs having high SOC with some other intriguing properties such as its type-II Dirac semi-metallic nature [3] and asymmetric Fermi velocity in two in-plane directions [4]. In this work, we measure spin Hall angle of $PtSe_2$ using spin-torque ferromagnetic resonance (STFMR). $PtSe_2$ was synthesized by salinization of a sputtered Pt (3 nm) film. The growth of $PtSe_2$ was confirmed using Raman spectra which shows two peaks at 176 cm^{-1} (Eg) and 206 cm^{-1} (A1g). Subsequently, a NiFe (6 nm) layer was deposited in ultra-high vacuum (at base pressure of 5×10^{-7} Torr) on $PtSe_2$ using magnetron sputtering. Device for STFMR measurement was fabricated using mask less lithography followed by lift-off. For STFMR measurements, RF current of frequency varying from 3 to 7 GHz was applied to the device in the presence of external magnetic field and corresponding voltage across the device, which is attributed to the mixing of AMR and RF current, was measured. When resonance condition is satisfied maximum voltage across the device is observed. To see the change in damping for $PtSe_2$ case, damping parameter was extracted by fitting of linewidth vs. frequency curve and found to be .044. An enhancement of 144% in damping, found in case of $PtSe_2$/Py/Pt compared to its reference Py/Pt, indicates large spin pumping. Spin Hall angle was calculated using ratio of symmetric and antisymmetric component of Vmix and is found to be 0.26, which is 53% greater than the reference Py/Pt (.17), which indicate the suitability of using $PtSe_2$ as a potential candidate for spintronic applications.

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An Introduction to Machine Learning for Solving Micromagnetic Problems

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Machine learning is becoming an increasingly important tool for materials scientists. Machine learning uncovers correlations in data, speeds up material simulations, bridges length scales, and provides answers by merging results from experiments and simulations. In this talk, I will give an overview of different machine learning methods and their application in materials science. Then I will give examples where the methods are used to solve micromagnetic problems:

1) I will present a random forest model to identify regions of low local coercivity in granular magnetic materials. Methods for model interpretation help to understand how various microstructural features affect the coercivity.
2) I will show how machine learning models can bridge length scales and how macroscopic demagnetization curves can be estimated from microstructural images.
3) I will present a neural network model for predicting magnetization dynamics. Time integration can be performed in a low-dimensional latent space. Thus, the magnetic response to an external field can be quickly calculated.
4) I will introduce physically informed neural networks as an alternative to the finite difference or finite element method for solving magnetostatic problems, inverse magnetostatic problems, and calculating demagnetization curves and coercive fields.

Machine learning and physics informed neural networks bring several advantages as compared to traditional numerical methods: No mesh generation is required. Inverse problems can be solved effectively. An entire family of problems can be solved with a single neural network.

Because of its ability to solve multiple problems simultaneously, machine learning offers great potential for optimizing and adjusting the internal structure and local chemistry of a magnet to achieve the desired macroscopic magnetic properties.

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Artificial spin systems: towards functional materials in 2D and 3D

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The study of emergent phenomena in two-dimensional artificial spin systems is presently the focus of intense research. Artificial spin ices are a class of spin systems composed of geometrically frustrated arrangements of nanomagnets that have so far mainly been used to investigate fundamental aspects of the physics of frustration. Recently, it has become clear that artificial spin ices enable the creation of functional materials with technological applications. As a first example, I will present a spin-ice based active material –consisting in a repeating pattern of chiral units –in which energy is converted into unidirectional dynamics, thus functioning like a ratchet [1]. X-ray imaging shows that thermal relaxation proceeds through the rotation of the average magnetization in a unique sense. Micromagnetic simulations demonstrate that this emergent chiral behavior is driven by the topology of the magnetostatic field at the boundaries of the nanomagnet array, resulting in an asymmetric energy landscape. This opens the possibility of implementing a Brownian ratchet, which may find applications in nanomotors, actuators or memory cells. As a second example, I will discuss the potential application of artificial spin ices as magnonic crystals, where spin waves are functionalized for logic applications by means of band structure engineering [2]. This interest stems from the need for disruptive concepts requiring significantly lower energy consumption than traditional CMOS-based technology, in which information is processed using charge currents that dissipate significant power. Finally, I will discuss perspectives for functionalizing artificial spin ices in three dimensions in light of recent experimental advances in X-ray imaging techniques, such as magnetic tomography and laminography [3].

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A Magnetic Exploration towards Rebooting Computing Mixed Signal IC Design for AI Compute on the Edge – Material & Architectural Perspective

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Dipole coupled in-plane magnetic quantum-dot cellular automata (MQCA)-based nanomagnetic logic (NML) design has been gaining attention due to its ability to augment traditional charge based CMOS devices for rebooting computing and propagating information [1]–[4]. Such NML devices offer non-volatility, as well as no energy requirement to maintain data states when not performing computation. In correspondence to the adverse effects of More than Moore and with the emerging demands of computing on the edge device, necessitates a significant improvement in the energy and area efficient rebooting computing architecture design. To address this, the holistic approach from the architectural and system perspective to explore various design methodologies by exploiting those aforementioned inherent natures of nanomagnets for performing arithmetic computation is introduced for the first time to the best of the author's knowledge [3], [4]. This work presents the theoretical modelling and micromagnetic simulation analysis of such nanomagnetic logic-based arithmetic architectures and their corresponding implementation considering the constraint of resources in terms of the number of nanomagnets, majority gates and clock-cycles leading to energy and area efficiency. In consequence, a design methodology and mapping logic have been proposed along with the micromagnetic software implementation, validation of the binary full adder architecture built using two-three inputs MQCA MGs. Besides, the proposed designs have been analysed for switching errors to ensure bit stability and reliability [5], [6]. Electronic and magnetic properties of graphene have been further investigated in this study using experimental and theoretical [7] means. Fabrication of graphene based interconnects was done and the maximum breakdown current density was found to be $1.8 \times 10^8 A/cm^2$ [8] which lies in par with the theoretical results. These results suggest that single layer graphene can generate magnetic field in the same range of bulk copper, with its widely proven mechanical stability and thermal conductivity. In a MQCA framework, though nanomagnet switching could be achievable with very low energy, yet to help the state change of the nanomagnets, CMOS current sources and clock lines are required. They devour the vast majority of the power and furthermore produce significant heat. Thus our examinations show that graphene can very likely be a material of decision for check lines in MQCA [7], [8].

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Tailored Anisotropy of Amorphous Ribbons for Magnetoimpedance

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Amorphous ribbons is one of the most versatile soft magnetic materials with possibilities of magnetic properties customization [1]. In particular, the effective magnetic anisotropy of the ribbons can be changed in a well-controlled way by the additional treatments. The advantages of this material is used in sensors of weak magnetic fields, including those based on the giant magnetoimpedance (GMI) phenomenon [2], [3]. GMI is known as the change in the impedance of a ferromagnetic conductor when an alternating current is passed through it and an external magnetic field is applied. Three-layered structures, where a highly conductive central lead separates the ferromagnetic layers, have been proven to achieve the highest GMI effect [4]. In this work, rapidly quenched amorphous ribbons with different types of the effective magnetic anisotropy and multilayered composites fabricated on their basis were investigated with a focus on the development of sensitive elements for multifunctional sensors of low magnetic fields. $Fe_3Co_{67}Cr_3Si_{15}B_{12}$ amorphous ribbons obtained by rapid quenching. Post-fabrication thermal or stress annealing at 350°C resulted in formation of GMI sensitive elements with either longitudinal (L) or transverse (T) uniaxial magnetic anisotropy. Their magnetostatic properties, magnetic domains and magnetodynamic properties have been investigated. GMI characteristics were comparatively analyzed for composites consisting of a pair of ribbons with transverse anisotropy or a pair of ribbons with different types of effective magnetic anisotropy separated by a layer of highly conductive polymer composite (C). Less than 5% difference was observed for a T/C/T composites. The key features of both types of anisotropy were present for a T/C/L composites: i) a two-peak field dependence of the GMI ratio, which is lower than GMI ration for a ribbon with transverse anisotropy due to the inductive contribution; ii) "dip" in zero field, as a consequence of surface anisotropy contribution, which characterizes ribbons with longitudinal anisotropy. However, useful increase of the field interval for maximum of GMI sensitivity was observed in T. In addition, composites of a more complex shape such as L/C/T/C/L and T/C/L/C/T and a comparison of experimental results with modeling by the finite element method will be also given.

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Study of spin pumping in sputtered MoS_2/CoFeB bilayers

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Inter-layer coupling in ferromagnetic(FM)/non-magnetic (NM) multilayers has been a vivid subject of research from both fundamental science of view as well as its implication in spintronic applications. In this context, synthetic antiferromagnets (SAFs) have drawn much attention in last 2 decades. SAFs are basically with Ferromagnetic (FM) layers periodically interleaved with metallic or insulating spacers, where the magnetization of adjacent FM layers alternates owing to the antiferromagnetic (AF) interlayer exchange coupling (IEC) [1] i.e. $[FM/NM/FM]_N$ where N stands for number of repetitions. For metallic spacers, IEC is achieved via Ruderman-Kittel-Kasuya-Yosida (RKKY) type exchange interaction mediated by spin polarized charge carriers in the spacer [2]. SAFs gives extra degree of freedom over antiferromagnetic materials for the, measurements, manipulation of stray field, which helps to tune stability and sensitivity of the devices. Here we show the study of SAF nature in Co/Pt multilayers separated by Ir as a spacer. Also, we have studied the effect of stress on its coupling when it is deposited on a flexible substrate [3].

Here we fabricated SAF samples with Co as FM layer and Ir as a spacer layer and studied the magnetic properties. The sample structures are Si/Ta(3 nm)/ [Pt(3.5 nm)/Co(0.8 nm)]2/Ir(tIr = 0.5, 1.0 1.5, 2 nm)/Co(0.8 nm)/ Pt(3.5 nm). All the layers were deposited using dc magnetron sputtering. Domain imaging and hysteresis loop measurements have been performed by using magneto optic Kerr effect (MOKE) microscopy. Magnetization vs field was measured in a SQUID (Superconducting Quantum Interference Device) VSM. The samples with Ir 1.5 nm thick spacer layer is found to be antiferromagnetically coupled and very small bubble domains are found compared to the other samples which are ferromagnetically coupled. We have also calculated the exchange coupling energy for the SAF samples and the maximum value among our samples is found to be 0.456 erg/cm^2.

We then prepared the similar structure taking one FM layer both below and above the Ir spacer on a flexible polymide substrate. With the application of both compressive and tensile stress, we observed a substantial change in the interlayer exchange coupling of the SAF layers.

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Self-Spin-Orbit Torque in GdFeCo ferrimagnet

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Spin-orbit torque has been widely studied in ferromagnet/heavy metal bilayers due to their high application potential regarding modern electronic devices [1,2]. The heavy metal is presented as a primordial element of the structure since it is the source of spin current. However, magnetic materials with large spin-orbit coupling, like GdFeCo ferrimagnetic alloys, can be a source of spin currents as well.

A distinction can be drawn between the SAHE-like spin current [3,4] with the Spin Anomalous Hall Effect symmetry and the SHE-like spin current [5] with the Spin Hall Effect symmetry. In the SAHE symmetry, the spin current J_s emitted from the magnetic material has the spin polarization aligned with the magnetization while in the SHE symmetry the spin polarization is perpendicular to J_s and the injected charge current J_C [3-6]. Only the SHE-like symmetry emission could produce damping-like self-torque.

In this talk, we present the study of the self-torque performed by means of harmonic Hall voltage measurements in bi- or tri- layers where the GdFeCo layer displays out-of-plane magnetization. We first focus on the temperature dependence of the effective fields associated to the self-torque. We show that the effective fields are magnified near the magnetic compensation temperature TM and reverse sign across it (see Fig). In a second part, we compare the self-torque in GdFeCo/Cu with torques induced by an additional heavy metal in GdFeCo/Cu/Pt and GdFeCo/Cu/Ta structures. We show that the addition of a spin-sink can improve the damping-like self-torque. Thus, in our work [6], we estimate the global efficiency of GdFeCo spin emission as $\theta_{(SAHE+SHE)}$=0.78. Moreover, the SHE-like spin emission results θ_{SHE}=0.16. The latter is of the same order of magnitude as heavy metals efficiencies [1]. Our results pave the way to exploit spin-orbit torque generated in single magnetic layer, which we coined self-torque.

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Photostrictive/photovoltaic effects on magnetostrictive films in multiferroic heterostructures under UV light

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The concept of designing multiferroic (MF) heterostructures for controlling the magnetization with application of an electric field has driven a tremendous research effort for applications in nano-magnetism and spintronics. Many exciting results obtained from MF with new concepts of fabrication have so far been reported, exploiting the ferroelectric switching via electric bias to modify the ferromagnetic (FM) behavior, therefore avoiding high currents and offering low energy consumption with large endurance. Recently photostriction [1]–[3] has being used as an additional parameter to play on the FM properties, both on multiferroic materials and heterostructures, since visible light excitation can induce nonthermal changes in the lattice parameter, with direct implications to magnetostrictive properties. In particular, very recently Zhang et al. [4] showed that photostriction can modify the magnetic properties of a FM layer via interfacial magnetoelectric coupling, proving that light-controlled strain of a PMN-PT ferroelectric substrate [5] can be an additional reversible parameter to control magnetism in MF heterostructures. In this framework, here we report our on-going systematic study on tailoring the magnetic properties on a FM/PMN-PT heterostructure via the application of UV light as the function of the ferroelectric polarization, for different FM materials and PMN-PT compositions and orientations. Polarization switching of the MF in absence and presence of UV light showed, together with the appearance of reversible surface cracks, [6] large photopolarization under UV. Together with this, MOKE measurements revealed how the modification of the magnetic properties under the application of UV light strongly depends on the magnetostrictive properties of the FM layer, on the PMN-PT composition, and on the quality of the interfacial coupling, becoming larger as a function of increasing laser power. These results showed that the change induced by the ferroelectric substrate under UV on the magnetic properties is maximized in the case of PMN-PT/Ni heterostructures.

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New Sol-gel Synthesis Route for Iron Carbide Nanoparticles Core-shell/Fe_3C-grahite Embedded on a Continuous Carbon Matrix

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Transition metal carbides have historically been valued for their hardness and high chemical resistance. However, more recently they are being investigated for their magnetic properties [1], among others. Specifically, in the nano-intermetallic iron carbide (IC) compounds, the carbon content protects IC nanoparticles (ICNPs) from oxidation and corrosion, avoiding a saturation magnetization (M_s) decrement as marked as bulk iron oxides values regarding pure $\alpha - Fe$. Particularly, core-shell nanocomposites of metastable phase called cementite, orthorhombic IC $\theta - Fe_3C$ (Pnma 62), coated by carbon shells, draw attention of researchers due to their high saturation magnetization, moderate coercivity and chemical stability [2]. Lately, traditional sol-gel method for metal-oxides NPs synthesis [3] has turned around in some different variants like the so called "urea-glass-route" for obtaining ICNPs. Based on a starting homogeneous gel-like-network made of organic gelators, in which the metal precursor is dispersed, is followed by the achievement of Fe_3C NPs by the carbothermal reduction of the xerogel under inert atmosphere, turning prior NPs nucleation of Fe_3O_4 into Fe_3C-graphite NPs [4,5]. As a variant of "urea-glass-route", the replacement of urea gels-like can be accomplished by the introduction of organic macromolecules like oleic acid (OA) and oleylamine (OY), that have recently shown its capacity for acting as a surfactant in sol-gel synthesis for nickel-carbon nanoparticles by a calcination process at 320^oC [6]. In this study, we propose a novel easy handling, reproducible, and low-cost-scalable non-conventional sol-gel synthesis route, based on two steps, using OA and OY as a surfactant in a ratio of 1:1. On a first step, gellification, we introduce an excess of carbon through the surfactants concentration which enables that carbon acts as a reductor, for the final Fe_3C ICNPs obtention, when its oxidation begins (resulting in CO_2) by rising temperature around 600^oC at the second step, densification. We sweep the densification temperature from 500 to 800$^oC$and our X-Ray Diffraction-Rietveld analysis and magnetic measurements of the samples, confirms that 700$^oC$is the limit for the consolidation of a pure Fe_3C phase with $M_s = 43emu/g^{-1}$ and $H_c = 500Oe$. Finally, from High Resolution Transmission Electron Microscopy is inferred a core-shell structure for monocrystalline NPs of 20 nm embedded on a carbonaceous 3D-matrix with a bluntly interface free of secondary phases for each Fe_3C core coated by multiple graphene layers as a shell.

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Higher-order Magnetic Anisotropy in Soft-hard Nanocomposite Materials

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The origin and behaviour of higher-order magnetocrystalline anisotropy constants in soft-hard nanocomposite materials are still open to debate [1]. We investigated the magnetic anisotropy in a $L1_0$/A1 FePt system using the VAMPIRE atomistic simulation package [2]. We constructed an elongated, faceted cylindrical coreshell with a $L1_0$-FePt core of variable size surrounded by an A1-FePt shell. Our simulation incorporated a 3-dimensional exchange interaction which accounted up to the third-nearest neighbours and was set to yield a Curie temperature at around 700K as for bulk fcc A1-FePt. In additional to the local phase anisotropies, we introduced a 2-ion Fe-Pt anisotropy component to our system Hamiltonian following Mryasov et al. calculation [3]. The magnetisation distribution was calculated from 0K to 1000K in a 5K step using a constraint Monte-Carlo integrator in which the system magnetisation was constraint at an angle to the easy axis. The anisotropy constants were determined from fitting to the torque on the system as a function of the system constraint angle. We find that the presence of the soft-magnetic A1-FePt phase polarises the magnetisation of the hard-magnetic $L1_0$-FePt core which gives rise to higher-order anisotropy constants. Varying the $L1_0$-FePt core size is demonstrated to skew the torque curve, an effect comparable to an earlier experimental study [4]. In particular, the K_2/K_1 ratio as a function of the core size ratio (R) is observed to display a non-monotonic pattern with a peak occurring at $R \sim 0.55$. Remarkably, we discover a new fourth-order anisotropy constant K_4 which scales with $\sim \langle M/Ms \rangle^2$ at temperature below the Curie temperature. This deviates significantly from the established Callen-Callen theory [5] which instead predicts a scaling with $\langle M/Ms \rangle^{10}$. We are able to explain and quantify this new fourth-order anisotropy by hypothesising a perturbation of the soft and hard phase from the system constraint angle in order to minimise the energy. Our analytical model can be extended to a generalised soft-hard composite material from which the higher-order anisotropy constants are showed to originate from the interface interaction and exhibit a strong dependence on the system geometry, thus suggesting that the Callen-Callen power law might not be universal.
Keywords: *$L1_0$/A1 FePt, soft-hard, higher-order anisotropy, Callen-Callen theory*

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Spin-wave frequency combs

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Optical frequency combs are powerful tools used for synchronization, stabilization and frequency conversion in both fundamental science and technical applications. In this work, we present experimental observations on the generation of a spin wave frequency comb in a low damping $Co_{25}Fe_{75}$ conduit measured using Brillouin light scattering microscopy. By driving the magnetization to large precession angles, nonlinear interactions such as four magnon scattering can be observed. When applying two RF signals with independently tunable frequencies and amplitudes to our microstructure, we can actively control the final states that will be populated by these scattering processes. Our results show the generation of a frequency comb, consisting of several spin wave modes with adjustable frequency spacing and amplitude.

We demonstrate that the known effect of frequency mixing for $k = 0$ modes [1] can be extended towards propagating spin waves. This enables simultaneous information transport and processing. This behaviour is studied for different sample geometries, which allow mixing of co-propagating as well as counter-propagating spin waves. Our observations are in qualitative agreement with micromagnetic simulations.

The presented data encourage a deeper understanding of the interaction of propagating spin waves in the nonlinear regime and propose utilization of spin wave frequency combs as broadband tunable clocks for information processing [2].

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Magnetocaloric Effect and Martensitic Transformation in Ferromagnetic Heusler Alloys

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The demand for environmentally friendly and efficient cooling makes the search for alternative technologies more important than ever. Magnetocaloric refrigeration, utilizing magnetocaloric effects, can be more energy efficient and environmentally friendly than current vapor compression technology. Ni-Mn-X Heusler compounds display excellent magnetocaloric properties - high adiabatic temperature changes ΔT_{ad} and isothermal entropy changes ΔS - upon the field-induced phase transformation from non-magnetic martensite to ferromagnetic austenite.

The understanding of the magneto-structural transition and the direct measurement of the magnetocaloric effect is essential for optimizing Ni-Mn-X Heulser compounds. In our research we are focusing on the effect of thermal hysteresis on the magnetocaloric effect under cyclic conditions and high magnetic fields with high field sweep rates. Since the thermal hysteresis limits the cyclic performance, we propose a new multi-stimuli cooling cycle which benefits from the thermal hysteresis by using two stimuli to trigger the magneto-structural phase transition in a multicaloric material like Ni-Mn-X Heusler alloys. As a result, higher temperature changes can be achieved for fully reversible first-order phase transitions by an alternating application of magnetic field and uniaxial stress.

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First- and Second-Order Phase Transitions in *RE*$_6$Co$_2$Ga (*RE* = Ho, Dy or Gd) Cryogenic Magnetocaloric Materials

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The magnetocaloric effect (MCE) has attracted the interest of the scientific community due to its promising practical application in magnetic refrigeration (MR) devices, including cryogenic applications such as gas liquefaction [1, 2]. Regarding this, the use of natural gas as well as H_2, He, N_2, and O_2, is widely extended with several scientific, industrial and commercial purposes. Moreover, their consumption is expected to increase in future years. For better gas storage and transport, gas liquefaction is required despite being a complex process. In recent years, it has been shown that MR technology could overcome some of the issues related to the conventional methods.

In this work, we synthesized and characterized a series of rare-earth rich RE_6Co_2Ga (RE = Ho, Dy or Gd) cryogenic magnetocaloric compounds [3]. Rietveld refinement proved that all the compounds crystallize in the Ho_6Co_2Ga-type crystal structure (I_{mmm} space group) without the presence of impurities. By tuning the rare-earth element, the nature of the thermomagnetic phase transition is modified, having metamagnetic anti-to-paramagnetic (AF to PM) transitions for Ho and Dy while a ferro-to-paramagnetic (FM to PM) transition is obtained for Gd. The ferromagnetic ground state for Gd_6Co_2Ga is confirmed by DFT calculations as well as experimental observations. Using the novel MCE field dependence method [4] and conventional Banerjee's criterion, Ho_6Co_2Ga and Dy_6Co_2Ga are found to undergo first-order phase transition whereas a second order phase transition is observed for Gd_6Co_2Ga. Ho_6Co_2Ga and Gd_6Co_2Ga compounds show maximum isothermal entropy change ($|\Delta S_{iso}^{max}(5T)|$) of 10.1 and 9.1 J kg^{-1} K^{-1} at 26 and 75 K, which falls in the range of H_2 and N_2 liquefaction, respectively. The outstanding MCE performance together with the working temperature range makes the RE_6Co_2Ga series a potential material for gas liquefaction applications.

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Hall Effects From Skyrmions in $[Pt/(Co|CoB)/Ir]_{xN}$ Magnetic Multilayers

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Understanding electrical transport measurements of skyrmions, and interpreting their connection to the magnetic state at the time of measurement, is essential for their application in data storage. The topology of the magnetisation of skyrmions is defined by the winding number, S, which takes an integer value dependent upon the number of topological 'twists' in the magnetisation. It has been predicted that topologically non-trivial magnetisations can provide an extra contribution to the Hall resistance (RH), called the topological Hall effect (THE) [1]. However, Maccariello et al. observed only effects that could be attributed to the anomalous Hall effect (AHE) [2], in contrast with work by Zeissler et al. which saw an extra contribution beyond the AHE, and was larger than the THE predicted by theory [3]. In my work, in-situ Hall transport measurements combined with XMCD-STXM imaging of the magnetic texture were used to identify such contributions in an effort to understand discrepancies between the predicted [1], and observed [2], [3], magnitudes of the topological contribution. The out-of-plane magnetisation (Mz) in 0.8-1 μm diameter Hall discs was measured using XMCD-STXM imaging during Hall transport measurements. Measurement during a major hysteresis loops allowed the normalisation of Mz and RH in the presence of skyrmions, identifying any topological contribution to the Hall effect from different numbers of skyrmions present in the Hall devices. Transport measurements were also performed in films with different repeat values, N, over a range of temperatures from 290K to 2K. These measurements allowed the investigation of the effects of multilayer structure, and temperature, on the topological Hall signal due to skyrmions in $[Pt/CoB/Ir]_{xN}$ multilayers. Results from Hall transport measurements, analysed in combination with SQUID magnetometry, will be presented suggesting a possible topological Hall contribution in $[Pt/CoB/Ir]_{xN}$ multilayers. The dependence of this topological Hall signal on temperature and multilayer repeat number will also be discussed.

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Structural and Magnetocaloric Properties in Mn_5SiB_2-Mn_5PB_2 Compounds

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The M5XB2 materials system has been widely studied as permanent magnetic materials [1],[2]. As permanent magnetic materials, their coercivity and magnetic energy product are lower than those of the mainstream permanent magnetic materials. Xie *et al.* [3] and Cedervall *et al.* [4] proposed that the Mn_5PB_2 and $(Fe_{1-x}Co_x)_5PB_2$ compounds have the prospect of being applied as magnetocaloric materials due to their near room temperature Curie temperature. In this work, the structure and magnetocaloric properties of the $Mn_5(SiP)B_2$ compounds of the M_5XB_2 material system were studied. According to a refinement of the XRD data the $Mn_5(Si_{1-x}P_x)B_2$ compounds all crystallize in the Cr5B3–type body-centered tetragonal structure, with a small amount of Mn2P as a secondary phase (less than 7%). The lattice parameters and the unit-cell volume of the compounds change linearly with the increase in P content. These experimental results are consistent with calculated DFT results. The Curie temperature of the compounds can continuously be adjusted between 305 and 411 K by changing the Si/P ratio. The introduction of P also caused a decrease in saturation magnetization. The magnetic phase transition of these compounds was determined using Arrot plots and the field exponent n for the magnetic entropy change based on Landau's theory. The studied compounds all show a second-order magnetic phase transition. Since the compounds show a second-order phase transition, the magnetic entropy change caused by the phase transition was not large: 1.9 and 1.4 J/kgK for Mn5SiB2 and Mn5PB2, respectively. However, the advantage of this series of compounds is that the Curie temperature can be adjusted continuously around room temperature.

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NiCu/FeCo Multisegmented Cylindrical Nanowires as Writting Heads in Racetrack Memories

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Multisegmented nanowire (NW) arrays have already shown their potential to improve the memory storage capacity due to their lower magnetic bit area [1]. But writing and reading information on such devices is a still a challenge. Recently, micromagnetic simulations revealed that the integration of a soft magnetic segment (with lower coercivity) along the racetrack wire could ease the writing process by using external magnetic fields [2]. Although these evaluations seem promising, a thorough experimental investigation of multisegmented NW arrays composed of soft and hard magnetic segments should be performed.

Here, we aim to demonstrate the feasibility of using a NiCu/FeCo/Au arrays for racetrack memory devices application through the evaluation of the behavior of coupled and decoupled bi-segmented NiCu/Feco NWs. Using nanoporous alumina template assisted DC electrodeposition method [3], four samples of NW hexagonal arrays with 50 nm in diameter and 100 nm of center-to-center distance were produced: *i)* $Ni_{90}Cu_{10}$ (6.0 μm); *ii)* $Fe_{20}Co_{80}$ (3.5 μm); *iii)* bi-segmented NiCu(2.4 μm)/FeCo(4.4 μm) (coupled system); and *iv)* a multisegmented sample with NiCu(1.0 μm) / [FeCo(4.2 μm)/Au(20 nm)]$_3$. The magnetic hysteresis loops acquired at room temperature for all NW arrays present the easy magnetization axis along the parallel direction, evidencing a typical strong shape anisotropy. The magnetic properties of single-layer FeCo and NiCu NWs are in agreement with previous reports, where very high parallel coercive fields (hard segments) are obtained for $Fe_{20}Co_{80}$ NWs [4], and very low parallel coercivities (soft segments) are found in $Ni_{90}Cu_{10}$ NWs [5]. For the NiCu/FeCo coupled and decoupled systems, a reduction on the parallel coercive field occurs. However, for the decoupled NWs, the reversal of each component becomes more prominent given the lack of magnetic interaction between the layers [6]. Finally, by growing three FeCo/Au segments on top of 1 μm NiCu layer, we are able to create a racetrack memory similar to the device simulated in [2], revealing experimentally its potential. Further research is being performed to better comprehend the interplay between the NiCu and FeCo layers into the NW arrays and study domain wall movement (writing and recording processes) along the multisegmented NWs.

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Ultrafast optical generation of antiferromagnetic spin spiral

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The recent demonstration of generation of skyrmions with femtosecond laser pulse [1] has opened new possibilities in ultrafast generation of magnetic texture. Although the experimental findings are quite robust, theoretical understanding of underlying mechanism is not quite clear yet. Most of the existing theoretical descriptions in this regard are based on the magnetisation dynamics only and completely overlook the role of electronic degrees of freedom. We bridge this gap by employing a quantum classical hybrid approach [2], [3] which consider both electronic and magnetic degrees of freedom on equal footing. By combining the time evolution of quantum states with classical magnetisation dynamics we show that how a stable spin spiral can be generated from a collinear spin configuration with the help of an ultrafast laser pulse [4]. We use a minimal tight binding model to demonstrate how the laser not only change the magnetic order by changing the occupation of different quantum states, but also induces a *chiral spin mixing interaction* which in time can establish a long range spiral order that can survives up to the order of nanoseconds. We demonstrate that this mechanism is inherently different form the thermal repopulation and provides more coherent chiral order. This spiral order can be manipulated by tuning the laser parameter and can survive against significant ambient temperature which makes our findings feasible for experiments.

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Thermal fluctuations induced scalar spin chirality in a spin-trimer ferromagnet

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The continuously expanding field of spintronics has led to the increased interest of spin-chiral materials. The scalar spin chirality (SSC), being their common thread, is defined by a mixed product of three neighbouring, non-coplanar spins: $\chi_{ijk} = \boldsymbol{S}_i \cdot (\boldsymbol{S}_j \times \boldsymbol{S}_k)$. In the most well-known, yet not common cases, a non-zero net χ is produced by long range magnetic orders with periodically canted spins [1] or spin textures such as magnetic skyrmions [2]. In contrast to the static magnetic order or structures, the finite SSC can be also produced by the correlation of fluctuating spins agitated by thermal fluctuations. Here, the key example is colossal magnetoresistance manganites, with conduction carriers hopping in the background of fluctuating spins [3].

We present the evidence for the emergence of finite scalar spin chirality in a conducting ferromagnetic material, $Nd_3Ru_4Al_{12}$ [4], with magnetic structure based on spin trimers forming a breathing kagomé lattice [5]. Supported by the results of Monte Carlo simulations of a classical spin model, we find that the SSC created by thermal fluctuations in the vicinity of the Curie temperature leads to strong geometrical responses in Hall and Nernst effects, paralleling the scale or even exceeding their spin-orbit coupling driven anomalous counterparts [4].

We also compare the sign and magnitude of the geometrical Hall and Nernst conductivities, finding arguments for the necessity of using k-space Berry curvature approach [6], [7] to describe the impact of SSC on itinerant electrons in this highly conducting system. We thus demonstrate that, the mechanism of thermal fluctuations induced scalar spin chirality is not an exclusive domain of magnets in which conduction electrons are strongly Hund-rule coupled to the local magnetic moments, but can be realized in broader group of materials, such as spin-trimer magnets characterized with weak coupling scheme.

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Van der Waals magnet based spin-valve devices at room temperature

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The discovery of van der Waals (vdW) magnets opened up a new paradigm for condensed matter physics and spintronic technologies [1], [2]. However, the operations of active spintronic devices with vdW magnets are so far limited to cryogenic temperatures, inhibiting its broader practical applications. Here, we demonstrate room temperature spin-valve devices using vdW itinerant ferromagnet Fe_5GeTe_2 in heterostructures with graphene. The tunnel spin polarization of the Fe_5GeTe_2/graphene vdW interface is detected to be significantly large 45% and negative at room temperature. Lateral spin-valve device design enables electrical control of spin signal and realization of basic building blocks for device application such as efficient spin injection, transport, precession, and detection functionalities. Furthermore, measurements with different magnetic orientations provide unique insights into the magnetic anisotropy of Fe_5GeTe_2 and its relation with spin polarization and dynamics in the heterostructure. These findings open opportunities for the applications of vdW magnet-based all-2D spintronic devices and integrated spin circuits at ambient temperatures [3], [4].

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Advances in Developing Alternative Rare Earth-Free Permanent Magnets: from Composites Synthesis to Additive Manufacturing

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Additive manufacturing (AM) combined with developing composite materials is attracting much interest in high-tech sectors such as transport, energy, aerospace, and medicine as it allows fabricating complex objects with tuned properties and high performance [1]. In the permanent magnet (PM) sector, the fabrication of magnets with no geometrical constrictions and no deterioration of their magnetic properties is a key point and a challenge at present [2], in addition to finding alternatives to rare earth (RE)-based PMs [3]. Improved ferrites and the promising MnAlC-based alloys are expected to partially fill the gap between conventional ferrites and NdFeB, provided a successful development of PM properties [3].

Different alternative PM materials (gas-atomized τ-MnAlC, strontium ferrite and, by comparison, hybrids −Sr ferrite/NdFeB) have been studied in collaboration with the companies Höganäs AB (Sweden) and IMA (Spain). The process for developing RE-free magnets by AM will be explained, going from the composites synthesis (PM particles/polymer) using the different precursor materials to the 3D-printing of magnets. The influence of particle size and its distribution, polymer and fabrication parameters on the properties of the resulting magnetic products has been analysed. These have been shown to be key factors that need to be considered and optimized for obtaining flexible filaments with a high filling factor and non-deteriorated magnetic properties [4]. Optimized MnAlC-based filament (with a high MnAlC content of 80 wt.%) was used for 3D-printing objects under controlled printing temperature, demonstrating that alternative PM materials can be efficiently synthesized and processed to develop novel PMs by AM [4].

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Multiple Stable Bloch Points in Confined Helimagnetic Nanostructures

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Stable topological magnetic objects are a promising route towards new fast, non-volatile memory devices such as racetrack memory. The most researched candidates are domain walls and skyrmions, both of which require precise control over the distance between neighbouring objects.

In 2019, Beg et al. [1] have predicted the existence of a stable Bloch point (BP) at the interface of two nanodisks with Dzyaloshinskii-Moriya-interaction of opposite chirality in the absence of an external magnetic field. Two different configurations, head-to-head and tail-to-tail, were discovered and switching between them was demonstrated using an external magnetic field. The two co-existing distinct stable configurations naturally facilitate the representation of binary data without the need to rely on precise positioning, making BPs another possible candidate for future memory devices. Mandatory for any application is both finding multiple BPs in a single sample and manipulating them individually.

In this work, we show using micromagnetic simulations that a nanostrip consisting of two layers with opposite chirality (opposite sign of D) can host multiple BPs. We simulate strips with various lengths l and widths w and relax multiple initial configurations for each (l, w) pair. We obtain a (l, w) parameter-space diagram showing the metastable configurations. We find that the number of BPs in the energetically most favourable BP configuration increases with increasing strip length. Furthermore, our simulations show that all different combinations of head-to-head and tail-to-tail BPs can be stabilised in suitable geometries and that the corresponding energy densities vary depending on the exact configuration, with same-type BPs being energetically less favourable. Our findings contribute to both possible application and theoretical understanding.

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Non-Equiatomic Fe-Containing GdTbCoAl High-Entropy-Metallic-Glass Microwires with Tunable Curie Temperatures and Enhanced Cooling Efficiency

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High entropy alloys (HEAs), using the new concept of multiple principal elements design, which differs from traditional alloys (as they are based on one or two main constituents), has been reported for excellent mechanical properties, phase stability, wear and corrosion resistance, where some of them even surpasses the conventional alloys. For the aspect of functional properties, there has been a recent increase in reports about the magnetocaloric properties of HEAs. In particular, their studied compositions evolve from first generation equiatomic to second generation non-equiatomic, in which first-order magnetostructural phase transition in magnetocaloric HEAs is recently found [1,2]. In this work, through selections of non-equiatomic HEA compositions and processing approach, a series of non-equiatomic $(Gd_{36}Tb_{20}Co_{20}Al_{24})_{100-x}Fe_x$ (x = 0, 1, 2 and 3 at.%) high-entropy-metallic-glass (HE-MG) microwires were successfully found with tunable Curie temperatures [3,4], surpassing the typical working temperature limit of rare-earth (RE) containing HEAs (at least 60% higher). Furthermore, the peak magnetocaloric response values of Fe-containing GdTbCoAl microwires range 7.6-8.9 J $kg^{-1}K^{-1}$ (5 T), which are comparable to those of many outstanding RE-containing magnetocaloric HEAs. The characteristics of the melt-extraction processing method, in combination with compositional selection, favor the appearance of amorphous and nanocrystalline phases in the microwires. Thus, it enables tunable Curie temperatures in RE-containing HEAs towards a temperature range of natural gas liquefaction while maintaining good magnetocaloric properties. This also shows that non-equiatomic compositions in the large HEA space is worth exploring as we have demonstrated that Fe-containing GdTbCoAl HE-MG composite microwires have great potential as high-performance magnetic refrigerants.

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Magnetostructural Phase Transition in $Fe_{60}V_{40}$ Alloy Thin Films

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In selected B2-ordered alloy films such as B2 $Fe_{60}Al_{40}$ [1] and B2 $Fe_{50}Rh_{50}$ [2], that are initially paramagnetic and antiferromagnetic, respectively, ferromagnetism can be generated at the nanoscale via local disordering of the lattice. In case of B2 $Fe_{60}Al_{40}$ films, the disorder is caused by site-swapping, whereas in B2 $Fe_{50}Rh_{50}$, disorder comprises sub unit-cell displacements of atoms. Lattice disordering can be achieved locally by the application of highly-focused ion-beams, realizing a powerful path for rapidly producing nanoscale ferromagnets, embedded within para- or antiferromagnetic surroundings. Here we demonstrate a drastic rise of ferromagnetism in structurally disordered $Fe_{60}V_{40}$ thin films, caused by irradiation-induced crystallization. The spatial distribution of the structural phase transition and the corresponding magnetic behavior are directly observed. The applicability of this material is demonstrated by the high Ms and the low-damping realized in the transformed films. Fe60V40 films of 40 nm thickness were grown onto SiO_2/Si substrate heated at 573 K, using magnetron sputtering from a stoichiometric target. The as-grown films possess a low Ms of 17 kA/m; whereas irradiation with 25 keV Ne+ - ions at fluences of $\sim 5 \times 10^{15}$ ions/cm2 leads to a drastic increase of Ms to $\sim$ 750 kA/m. X-ray diffraction as well as transmission electron microscopy reveal a structural short-range order in the as-grown films, that transform to A2 Fe60V40 with increasing Ne^+ fluence. The A2 region appears to nucleate at the film top surface and with increasing fluence, it propagates deeper down into the film. The transition has been tracked using conversion electron Mössbauer spectroscopy as well as ferromagnetic resonance, to observe the variation of local magnetic ordering and dynamic behavior, respectively. These results form the basis for further investigations on nanomagnets embedded within $Fe_{60}V_{40}$ thin films through the application of focused ion beams. Funding by the Deutsche Forschungsgemeinschaft (DFG) - 322462997 (BA 5656/1-2 | WE 2623/14-2) is acknowledged. Ion-irradiation was performed at the Ion Beam Centre of the HZDR.

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Magneto, Electro and Mechano-Caloric Materials: Comparative Study of Refrigeration Systems

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The refrigeration sector, including the air conditioning and air cooling sector, faces several major challenges today. We have already mentioned the immediate and growing need for the use of cold in very diverse fields such as food security, health, transport, as well as for the development of information technologies and microelectronics, to name just a few. In the medium and long term, the need to reduce greenhouse gas emissions with a negative impact on global warming was obvious to the national and international scientific community.

Solid-state refrigeration is a promising technology for the production of cold. The main element of Solid-state refrigeration is the Active Caloric Refrigerator (ACR) made of magnetocaloric, electrocaloric, elastocaloric, and barocaloric. The study of the behavior of the active regenerator is essential for the optimization of ACR refrigeration systems. Furthermore, the operation of a regenerator is complex because it is characterized by transient and steady state operation and by mico-scale and macro-scale models. The objective of this paper is to compare the energy efficiency of an ACR based on MCE, ECE, eCE, and BCE using a 2D numerical model by COMSOL multiphysics in term the temperature spain (ΔT), the coefficient of performance (COP) and cooling power.

This analysis of the functioning of the model and the sensitivity of the parameters helps us to improve understanding, to highlight the influencing parameters and to study the interactions between the parameters and their impacts on the total performance of the system. It makes it possible to draw parametric behavior maps to help design future ACR refrigeration systems at room temperature with better performance and at lower cost.

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Laser annealing for TMR applications: locally triggered crystallization of CoFeB

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In recent years, Co-Fe-B alloys have found a wide range of applications in spintronic devices, in particular as electrodes for CoFeB/MgO/CoFeB magnetic tunnel junctions (MTJs). In practical terms, Co-Fe-B is a particularly suitable material for the electrodes, as its amorphous nature allows the growth of a well (001)-oriented crystalline MgO barrier, which serves as a template for the formation of a bcc Co-Fe phase upon post-annealing of the full MTJ layer stack. As a result, the symmetry of the wave functions in the Co-Fe electrodes and the MgO barrier results in large tunneling magnetoresistance (TMR) ratios [1,2]. Rather than using typical annealing techniques, we employ laser irradiation to induce the required thermal energy locally [3]. Initially, this method was developed envisioning the definition of a unidirectional magnetic exchange anisotropy –- the so-called exchange bias (EB) effect –- at the interface between one of the ferromagnetic electrodes and an antiferromagnet (AFM) on the µm-scale. In the meantime, laser annealing has proven to be the ideal technique to define a reference magnetization locally on GMR and TMR layer stacks [4,5], enabling the realization of sensors with two dimensional sensitivity [6]. In the current work, we present direct proof of locally triggered, fast crystallization of Co-Fe-B thin films by means of continuous wave (cw) laser irradiation [7]. A systematic investigation of the crystallization of Co-Fe-B was performed by X-ray diffraction (XRD) measurements and the evaluation of magnetic properties with SQUID magnetometry. Samples with different Co-Fe composition and different capping layers (Ta, MgO) were studied, in order to verify the formation of distinct Co-Fe textures and investigate its dependence on adjacent layers. A systematic variation of different laser intensities and scanning speeds, and a comparison to vacuum oven annealing, allowed the range of process parameters to be determined for laser annealing with comparable crystallization yields Co-Fe-B. It was demonstrated that the thermal conductivity of the different layer stacks influences the window of laser parameters, at which crystallization of Co-Fe-B is obtained, significantly. The interplay between laser energy absorption and the local heat distribution due to the different characteristics of the neighboring layers will be discussed in view of slight differences of the obtained Co-Fe lattice parameters, changes of the magnetic properties and elemental diffusion studied in our earlier work [8].

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Agility of spin Hall nano-oscillators

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Spin Hall nano-oscillators (SHNOs) have the unique ability to convert a direct current input to microwave signals by means of spin hall effect and spin orbit torque [1]. These typically consist of one ferromagnetic thin layer adjacent to a non-ferromagnetic metallic layer with a large spin Hall angle, such as Pt. A direct charge current flowing in the latter generates a pure spin current, via the spin Hall effect. Due to spin orbit torque, a torque is transferred from the pure spin current to the magnetization of the ferromagnetic layer. Upon correct choice of current and magnetic field polarity, this torque counteracts the Gilbert damping, giving rise to magnetization auto-oscillations (AOs) [2].

Usually, the operation of an SHNO is driven by constant direct currents [3]–[6]. However, the use of pulsed input signals would result in short operation times and the possibility to encode multi-frequency signals in the operation cycle of SHNOs. For these reasons, it is important to learn about the temporal evolution of the AOs under pulsed stimuli.

We report the temporal response of nano-constriction SHNOs while subject to voltage pulses as well as microwave pulses, measured using time resolved Brillouin light scattering (BLS) microscopy. First, we discuss how few-nanosecond pulses can still efficiently induce AOs. Then, we proceed to showing how AOs can synchronize to external microwave pulses in a way that multi-level frequency and amplitude signals can be obtained.

Our findings suggest that the operation time of processes such as synchronization and logic using SHNOs can be reduced to the nanosecond timescale and that at least two-level microwave outputs can be achieved by combination of voltage and RF pulses.

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Electrical control of spin-orbit coupling-induced spin precession and spin-to-charge conversion in graphene proximitized by WSe_2

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Two-dimensional (2D) materials are an exciting new material family that has the capability to advance toward the implementation of novel spin-based devices. For these atomically-thin layers, the proximity effect is especially important and opens ways to transfer properties from one material into another. In van der Waals heterostructures, transition metal dichalcogenides (TMD) can be used to enhance the spin–orbit coupling of graphene, resulting in strong spin anisotropy [1] and long, gate tunable spin diffusion. These properties provide unique control knobs to manipulate coherent spin precession in the absence of an external magnetic field. Remarkably, we observe in graphene/WSe_2 devices that the sign of the precessing spin polarization can be tuned electrically by a back gate voltage and by a drift current [2]. This realization of a spin field-effect transistor at room temperature in a diffusive system, a long-awaited goal of spintronics, could be a cornerstone for the implementation of energy efficient spin-based logic. Another notable consequence of transferring TMD flakes onto graphene and increasing the spin-orbit coupling due to proximity effect is the occurrence of gate controllable spin-to-charge conversion (SCC) due to the Rashba-Edelstein effect and the spin Hall effect (SHE) [3,4], even with unconventional symmetries [5,6]. To quantify the SCC, the significant figure of merit is the SCC length given by the ratio between the charge current and spin current densities. In case of the SHE it can also be calculated by the product of spin Hall angle, θ_{SH}, and the spin diffusion length, λ_2. We report an unprecedented SCC length of up to 41 nm solely due to spin Hall effect in graphene proximitized with WSe_2. Such highly efficient SCC up to room temperature will play a crucial role for the future integration of spintronic devices into existing electronic infrastructure.

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Tuning spin-orbit torques across the phase transition in VO_2/NiFe heterostructure

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The emergence of spin-orbit torques as a promising approach to energy-efficient magnetic switching [1], [2] has generated large interest in material systems with easily and fully tunable spin-orbit torques [3]. Here, we investigate current-induced spin-orbit torques in VO_2/NiFe heterostructures using spin-torque ferromagnetic resonance, where the VO_2 layer undergoes a prominent insulator-metal transition in a narrow temperature range [4]. Across the VO_2 phase transition, we observe a roughly two-fold increase in the Gilbert damping parameter, α, from (0.035 ± 0.010) in the insulating (290 K) phase to (0.06 ± 0.01) in the metallic (355 K) phase, which is attributed to the change in the VO_2/NiFe interface spin absorption due to the metal-insulator transition [5]. More remarkably, we observe a large modulation (± 100%) and a sign change of the current-induced spin-orbit torque with temperature across the VO_2 phase transition, suggesting two competing spin-orbit torque generating mechanisms. We verify the bulk spin Hall effect in metallic VO_2, supported by our first-principles calculation of spin Hall conductivity $\sigma_{\mathrm{SH}} \sim -10^4(h/2\pi e)\,\Omega^{-1}\,\mathrm{m}^{-1}$ as the main source of the spin-orbit torque in the metallic phase, while the self-induced/anomalous torque in NiFe, similar to that observed in Ni [6], could be the other competing mechanism that dominates at the insulating phase. For applications, the strong tunability of the torque strength and direction observed here opens a new route to tailor spin-orbit torques of materials which undergo phase transitions for new device functionalities.

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Static and Dynamic Magnetic Properties Illuminated by Polarized Soft X-Rays

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To date, x-rays are one of the most powerful and versatile tools available to researchers. With the advent of sophisticated x-ray sources like modern synchrotron facilities a plethora of new and advanced measurement methods was established that enabled a non-destructive insight into regions buried deep within complex structures and helped to shed a light on a wide variety of different material properties such as chemical composition, crystal structure, electronic structure, as well as magnetic ordering.

Among this flurry of novel techniques, especially the realization of magnetic dichroism in x-ray absorption was a milestone achievement in the investigation of magnetic interactions, as it could provide detailed magnetic information with element and valence state specificity directly sensitive to the absorber site. As such, magnetic X-ray dichroism (MXD) quickly became a standard probe of magnetic properties. The magnetic contrast in MXD originates from the difference in x-ray absorption by a magnetic material for different photon polarizations. While X-ray magnetic circular dichroism (XMCD) using circularly polarized x-rays is largely useful for the study of materials with finite net magnetization and can provide detailed information on orbital and spin magnetic moments, X-ray magnetic linear dichroism (XMLD) using linearly polarized x-rays can provide information on long range magnetic order even in the absence of a net magnetization and has proven indispensable in the study of antiferromagnetic materials and anisotropies.

Lately, the combination of ferromagnetic resonance (FMR) with X-ray absorption spectroscopy (XAS) as the underlying detection mechanism has marked another breakthrough development in the study of magnetic interactions, as it expands the capabilities of MXD to the dynamic range and enables the direct study of magnetization dynamics and spin current effects with sensitivity to individual elements.

In this tutorial talk I will give an introduction into the fundamentals of soft x-ray absorption spectroscopy and magnetic x-ray dichroism and their utilization for the study of static magnetic properties and magnetization dynamics.

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Manipulation of Bloch Points in Helimagnetic Nanostructures

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Recently, it was demonstrated that confined helimagnetic nanostructures, composed of grains of different chirality (and consequently, a different sign of Dzyaloshinskii-Moriya energy constant), can host stable Bloch points [1]. In addition, it was shown that Bloch points undergo hysteretic behaviour and that their type can be changed using an external magnetic field. In this work, using Ubermag [2], [3] micromagnetic simulations with OOMMF [4] as a computational backend, we explore if Bloch point magnetisation states can be manipulated using external magnetic fields and spin-polarised currents in nano-disk and nano-strip FeGe samples. We start by showing that a zero-field stable Bloch point emerges not only in thin-film disk samples [1] but also in an extensive range of planar geometries, including nanostrips. We then demonstrate that Bloch point's type in confined FeGe disk structures can be switched using an external magnetic field as well as spin-polarised current pulses. Besides, we apply in-plane external magnetic fields and in-plane spin-polarised currents, and we show that Bloch points can be moved in an arbitrary in-plane direction in nanostrips. Finally, we demonstrate how Bloch points can be nucleated using the same excitations. Our demonstration of the stability, manipulation, and nucleation of Bloch points in planar samples, apart from being of fundamental physical interest, suggests possible use in future spintronics, data storage, and information processing devices. We acknowledge the financial support from the EPSRC Programme grant on Skyrmionics (EP/N032128/1) and Horizon 2020 European Research Infrastructures OpenDreamKit project (676541).

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Electromagnetic SAR Determination for Fe_3O_4 Nanoflowers Loaded in Melanoma Tumor and Comparison with Disipation in Agarose Ferrogel

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Radiofrequency magnetic cycles of *ex vivo* melanoma tumor tissue loaded with Fe_3O_4 nanoflowers (NF) were measured for several field conditions and compared with the cycles of a ferrogel (FG) obtained incorporating the NF in agarose gel. Such cycles were obtained via an ac electromagnetic technique [1]–[3]. Results were studied in order to understand usually reported SAR values differences between the actual application environment (tumor) and a typical characterization model (FG) for magnetic hyperthermia [4]–[6]. The linearity of the response, coercive field and SAR values were analyzed. Additionally, a novel method for the determination of the NF mean relaxation time from the cycles is presented. Results show a systematic difference in magnetic response at therapeutic field setting (98 kHz, 17.4 kA/m) between the NF incorporated in tumors and those in the FG.

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Heat Induction Behavior of Injected Superparamagnetic Nanofluid Interpreted by Mass and Heat Transfer for Clinical Magnetic Hyperthermia Applications

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Homogenous heating of cancer tumors with sufficiently high temperature during magnetic nanofluid hyperthermia (MNFH) is the most critical issue to clinically apply MNFH for highly efficient cancer treatment modality [1]–[3]. Accordingly, various research activities focused on how to predict and analyze the concentration and spatial distribution of injected superparamagnetic nanofluids (SPNP-MNFs) and its dependent distribution of heat induction temperature in cancer tumors have been intensively made by numerical simulation based on different theoretical models [4]–[6]. However, despite huge efforts, the current models are still faced with inaccuracy and ineffectiveness in estimating the concentration distribution of injected SPNP-MNFs and the distribution of heating temperature in cancer tumors due to the challenge in acquiring the distribution of SPNP-MNFs in the cancer tumors. Particularly, insufficient experimental verification or visualization for the practical feasibility of the models is critically restricted its application for analyzing clinical MNFH. In this study, a mass and heat transfer model considering time and concentration gradient induced diffusion was introduced to theoretically investigate the effects of concentration and spatial distribution of injected SPNP-MNFs on the distribution of heating temperature in cancer tumors. In addition, the practical feasibility of the model was experimentally demonstrated using agarose phantom studies. According to the theoretical and experimental results, this model is technically feasible and promising to accurately interpret the concentration distribution of injected SPNP-MNFs and the distribution of AC heat induction temperature in cancer tumors for precisely predicting the physical and thermal behavior of injected SPNP-MNFs for clinical MNFH applications.

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Electrical Spin Current Generation in Ferromagnets and Antiferromagnets

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Electrical control of magnetic order has widespread applications for information and communications technology. One way to manipulate magnetic order in layered structures is to generate a spin current in a source layer that is absorbed by a nearby magnetic layer, causing a transfer of spin angular momentum or spin torque. In this talk, we discuss theoretical and experimental evidence suggesting that magnetic materials can be simultaneously the source and receiver of spin torques, paving the way for single layer magnetic memories.

We present first principles transport calculations demonstrating that, under an applied electric field, ferromagnetic and antiferromagnetic materials generate spin currents with spin directions misaligned with the magnetic order parameter. In some cases, these symmetry-allowed spin currents can flow into the layer boundaries and exert substantial torques that can be measured through optical techniques such as MOKE. We study both intrinsic and extrinsic contributions to electrically generated spin currents in magnetic systems to help disentangle the key physical mechanisms. Shedding light on the spin currents and spin torques generated within magnetic materials will help optimize the electrical control of magnetic order and could lead to exciting applications in information and communications technology

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Tunable Spin-charge Conversion in Topological Dirac Semimetals

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We theoretically study the spin-charge conversion in type-I topological Dirac semimetals (TDSMs) [1], where a pair of Dirac points, i.e., four-fold degenerate band touching points, emerge on a uniaxial rotation axis (specified as z-axis here). With time-reversal symmetry, the z-component of spin is approximately conserved. A pure spin Hall current, whose spin polarization is fixed in the z-direction, can be induced by applying an electric field perpendicular to the z-axis, with the spin Hall conductivity proportional to the separation of the two Dirac points in momentum space. The application of a magnetic field, which breaks the time-reversal symmetry, will generally drive the TDSM into a Weyl semimetal phase and, consequently, partially convert the pure spin current to a charge Hall current. Such spin-charge conversion is highly tunable, as both the spin and topological characters of the energy bands are rather sensitive to the direction of the external magnetic field.

Using the standard Kubo formulas, we numerically evaluate the the spin and charge Hall conductivities based on an effective low-energy Hamiltonian for typical type-I TDSMs (e.g., Cd_3As_2) together with the Zeeman coupling. Besides the conventional tensor element of the spin Hall conductivity σ^z_{xy}, whereby the applied electric field, the spin polarization, and the spin Hall current are mutually orthogonal, we find that unconventional components –such as σ^x_{xy} and σ^y_{xy} –also exist and vary as the magnetic field is rotated, despite the high crystalline symmetries. Their angular dependence can be inferred from symmetry analysis. Likewise, the charge Hall conductivity in type-I TDSMs also shows great tunability upon variation of the magnetic field direction, at variance with that in the other type of TDSMs (i.e., type-II TDSMs with a single Dirac point at a time-reversal invariant momentum), which exhibits a step-function-like dependence on the angle formed by the magnetic field and the z-axis [2], [3].

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Strain effect on the magnetism of $CaMnO_3$

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Bulk $CaMnO_3$ (CMO) has an orthorhombic crystalline structure and is weak ferromagnetic below $T_N \approx$120K [1]. This structure can be described, in the pseudocubic approximation, with a $a_c \approx$3.73Å lattice parameter. Ab-initio calculations have recently shown that the magnetic behavior of CMO depends on surface conditions. In fact, Keshavarz et al demonstrated that the Mn atoms at the surface and the sub-surface of the compound are very sensitive to structural changes, giving rise to ferromagnetic couplings [2]. Additional experimental results made by Chandrasena et al over a set of thin films of CMO, showed a substantial change of the valence state of Mn atoms due to the effect of strains between the substrate and the film [3].

With the aim of studying the effect of substrate-induced strains onto the magnetic behavior of CMO thin films we grew a series of samples by pulse laser deposition onto $SrTiO_3$(001) single-crystalline substrates. In order to examine the effect of strains on the magnetism of CMO, the film's thickness was varied from 3nm to 30nm.

Structural, magnetic and electric measurements were performed to characterize the sample's properties. The film's structure, analyzed by X-ray diffraction and transmission electron microscopy (TEM) measurements, reveals a strongly textured growth along the (00k) direction and remarkable substrate-induced strains effects on the lattice parameters of the compound [4]. The mismatch between bulk CMO $a_c \approx$3.73Å and SrTiO3 $a_{STO} \approx$3.905Å lattice parameters is 4.8. Due to the considerable mismatch, two main regions can be observed in the TEM images, with a significant variation of the lattice parameter of CMO. Near the interface both the in-plane (IP) and out-of-plane (OOP) parameters are larger than the bulk value and match the STO lattice parameters. 2nm away from the interface, the film's structure relaxes and the lattice parameters reduce to the bulk values. The magnetic properties of the films were found to be strongly dependent of their thickness, t. Magnetization loops, measured with a SQUID magnetometer and low temperature, reveal a strong enhancement of the saturation magnetization, Ms, for the thinner films. The different magnetic behaviours observed in the CMO thin films are discussed in terms of structural distortions and local composition variations within the layers.

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Universal Critical Exponents of the Magnetic Domain Wall Depinning Transition in Thin Films

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Magnetic domain walls in thin films with perpendicular anisotropy may be described as one-dimensional elastic interfaces which move in a two-dimensional disordered medium. In this context, their dynamics and morphology under the uniform driving force induced by an applied field H may be understood by considering a bunch of key ingredients as elasticity, disorder and thermal energy. This allows for the description of a rich behavior in which different regimes of motion arise depending on the field and temperature conditions [1]. In particular, domain walls experience a depinning transition at a characteristic applied field H_d. Remarkably, the critical exponents of this transition are universal: their numerical values are defined by the universality class to which domain walls belong. In this work, using the polar magneto-optical Kerr effect (PMOKE) microscopy, we experimentally study the dynamics of magnetic domain walls at low temperatures in a ferrimagnetic thin film of GdFeCo. We have found that thermal activation is negligible in a large range of temperatures below $100\,\mathrm{K}$, allowing us to directly observe and characterize the depinning transition in quasi-athermal conditions. Remarkably, we independently determine the values of two universal critical exponents of the depinning transition: the exponent β describing the power-law behavior of domain wall velocity, and the exponent ν_{dep} describing the divergence of the depinning correlation length [1]. The obtained values, $\beta = 0.30 \pm 0.03$ and $\nu_{\mathrm{dep}} = 1.3 \pm 0.3$, strongly suggest that the domain wall depinning transition of magnetic domain walls in the studied sample belongs to the quenched Edwards-Wilkinson universality class [2].

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Voltage Modulated RKKY Interaction through Magneto-Ionic Gating

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The voltage modulation of magnetic properties has been proposed a solution to the energy efficiency issues with current controlled methods for spintronic devices. Using a synthetic antiferromagnetic heterostructure, we employ this low energy solution through magneto-ionic control. The foundation for magneto-ionic control has been demonstrated using oxygen, lithium, nitrogen, and hydrogen in rare-earth transition metal (RE-TM) metal-oxide/metal heterostructures [1-3]. However, a solid-state, reversible approach has not been shown for the voltage-control of the Ruderman–Kittel–Kasuya–Yosida (RKKY) interaction. Our heterostructure is a synthetic antiferromagnet made of two ferrimagnetic gadolinium cobalt layers separated by a ruthenium layer. We demonstrate reversible pumping of hydrogen into the spacer layer altering the exchange interaction between the two ferrimagnet layers. Moreover, we show that the coupling can be switching from antiferromagnetic to ferromagnetic and vice versa. 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 spintronic applications.

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Magnetic Simulations of Core–Shell Ferromagnetic Bi-Magnetic Nanoparticles: The Influence of Antiferromagnetic Interfacial Exchange

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Magnetic properties of ferromagnetic nanostructures were studied by atomistic simulations following Monte Carlo and Landau–Lifshitz–Gilbert approaches. First, we investigated the influence of particle size and shape on the temperature dependence of magnetization for single cobalt and gadolinium nanoparticles and also in bi-magnetic Co@Gd core–shell nanoparticles with different sizes. The Landau–Lifshitz–Gilbert approach was subsequently applied for inspecting the magnetic hysteresis behavior of 2 and 4 nm Co@Gd core–shell nanoparticles with negative, positive, and zero values of interfacial magnetic exchange. We were able to demonstrate the influence of finite-size effect on the dependence of the Curie temperature of Co and Gd nanoparticles. In the Co@Gd core–shell framework, it was possible to handle the critical temperature of the hybrid system by adjusting the Co core size. In addition, we found an improvement in the coercive field values for a negative interfacial exchange energy and for a different core size, suggesting an exchange spring behavior, while positive and zero values of interfacial exchange constant showed no strong influence on the hysteresis behavior.

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AC vs DC Temperature Dependence Magnetization Measurements: Effect of Size and Dipolar Interactions on the Energetic Parameters When Analyzing Real Systems

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Traditional techniques to measure the temperature dependence of magnetization in superparamagnetic nanoparticles, comprises measurements subjected to AC and DC magnetic fields that can provide information related to the activation energy of the system. Typically, the zero-field cooling and field-cooling routines (DC), and the frequency dependent temperature evolution of the magnetization (AC). The characteristic parameters obtained from the analysis of these measurements depend on the nature of the magnetic material, the size distribution of the nanoparticles, the interactions among them, the surface spin disorder, and any other feature that modifies the effective anisotropy of the system [1]. Thus, understanding the mechanisms involved strongly depends on the model implementation and the proper interpretation of the obtained results. In this work, the effect of the size and the dipolar interactions in the activation energy of iron oxide (IO) nanoparticles was studied, which was achieved by tuning the synthesis of core-shell IO-SiO_2 nanoparticles to obtain different dimensions [2]. Two distinct core size batches (8.5nm and 12.6nm) and three shell thicknesses for each one was prepared, with a core to core-shell diameter ratio that ranges from 1.1 to 3.7, comprising the transition above which dipolar interactions can be neglected [3], ≈ 2.4 for spherical nanoparticles. Comparisons between the values obtained from the analysis of AC and DC measurements for the blocking temperature, activation energy, and dipolar energy yield consistent results, and throw complementary information related to the nature of the anisotropic contributions. These kinds of comparisons are not often exploited in the literature, probably given the difficulties induced by competing effects occurring in the same temperature range, as evidenced in the differences in the results from the two core-sized systems analyzed here.

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Design of core/shell nanoparticles for optimizing the magnetic hyperthermia and the catalytic activity

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Magnetic nanoparticles are widely studied for their potential applications in biology and medicine. In particular, the use of ferrite nanoparticles has been approved by regulatory agencies, such as the FDA, for different clinical protocols as contrast agent in MRI, anemia treatment and magnetic hyperthermia of glioblastoma. Even considering the important advances in magnetic hyperthermia for oncology treatment, there are many aspects that have to be improved until the method could be widely applied. One of these challenges is the optimization of the physical characteristics of the magnetic nanoparticles in order to increase the heating efficiency in media with different viscosities.

Nowadays, new synthesis and physical fabrication methods allow to combine in a single nanoparticle two or more components, with controlled size and high quality of interfaces, which open a wide range of new possibilities to develop bifunctional materials. The presence of interfaces in core/shell bimagnetic nanoparticles also introduces additional interactions that could radically modify the static and dynamic magnetic behavior of the systems, and provides supplementary tools to optimize and control their physicochemical properties.

In this talk, I will present the strategies followed to design and fabricate core/shell nanoparticles for tuning their magnetic anisotropy. In this way, the Brown or Néel relaxation mechanism can be syntonized, and also the heating efficiency can be optimized in magnetic hyperthermia experiments, even in a high viscosity medium. This can be done by changing the shell composition in $Fe_3O_4/Zn_xCo_{1-x}Fe_2O_4$ core/shell bimagnetic nanoparticles, where the effective anisotropy can be adjusted by the substitution of Co^{2+} by Zn^{2+} in the shell.

Moreover, the ferrite nanoparticles present catalytic activity where highly oxidative free radicals are generated. The radical species formed during heterogeneous Fenton reactions, have an effective oxidative ability that can induce oxidative stress and could promote tumor cell death in cancer therapies. Here we will analyze the free radical production catalyzed by different ferrites nanoparticles by Electron Paramagnetic Resonance spectroscopy, and they dependence with the nanoparticles surface to volume ratio, the surface composition and also the pH and temperature of the media. The synergy between the magnetic and catalytic properties of these nanoparticles makes them very promising materials to further applications in nanomedicine.

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Magnetic skyrmions and their topological Hall effect in thin film multilayers

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Stabilization of nano-scale magnetic skyrmions at room temperature (RT) is essential for skyrmion based applications. Recent experimental reports on controlling skyrmion formation in thin film heterostructures at RT are indeed a promising development [1]–[3]. The electrical signature of a skyrmion spin texture manifested by a topological Hall effect (THE) [4], [5], is extensively used to characterize these particles. However, the factors controlling the magnitude of THE in technologically useful architectures remain to be clarified [5]–[8]. Using detailed magnetotransport and magnetic force microscopy imaging of magnetic skyrmions in a series of carefully grown Ir/Fe/Co/Pt multilayers, we developed a comprehensive picture of the evolution of the topological Hall signal associated with the skyrmion spin textures. We find that chiral spin fluctuations can result in a power-law divergence in topological Hall resistivity by up to three orders of magnitude, revealing the dominant role of skyrmion stability and configuration in determining the magnitude of THE. Our results also reconcile the large discrepancy between topological Hall transport and magnetic imaging experiments reported in recent years for skyrmions in thin film heterostructures.

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Effective skyrmion interaction and hard-core states mediated by electronic dynamics

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The magnetic skyrmion, a topological protected spin texture, gained a lot of interest in recent years [1]. It has some unique properties such as the particle like behavior, current-driven motion. And since it is topologically protected, a defect cannot stop the motion of skyrmion [2]. Skyrmions have so far been observed in a variety of magnets that exhibit nearly parallel alignment for neighbouring spins, but theoretically skyrmions with anti-parallel neighbouring spins are also possible. Such antiferromagnetic skyrmions may allow more fexible control than conventional ferromagnetic skyrmions [3], [4].

In this work, we study the effective interactions between different type of skyrmions mediated by the dynamics of travelling electrons. We analyze the behavior of the energy of the electronic ground state and the effective force between skyrmions, generated by the electronic dynamics, as a function of the electronic filling and the distance between the centers of the skyrmions. We consider three types of skyrmions: ferromagnetic, ferrimagnetic and antiferromagnetic, and the results were compared with those of ferromagnetic domains.

On the other hand, we compute the local electron density for all magnetic textures as a function of the electronic filling. It could be indicated, based on what was obtained, that the arrays of antiferromagnetic skyrmions tend to be more stable than that of skyrmions or ferromagnetic domains. Moreover, it shows that the antiferromagnetic skyrmions remain in a hard-core state for electrons.

Based on the results obtained, the arrangement of antiferromagnetic skyrmions can be highlighted above other types of magnetic textures, which makes them promising candidates for the use of electronic devices and other potential applications.

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Positional Stability of Skyrmions in a Racetrack for Memory Applications

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Magnetic skyrmions are chiral spin textures stabilized by the Dzyaloshinskii–Moriya interactions (DMI) in systems lacking inversion symmetry. The attractive features of skyrmions, such as ultra-small size, solitonic nature, and easy mobility with small electrical currents, make them promising as information-carrying bits in low power high-density memory and logic applications [1], [2]. In a skyrmion-based boolean racetrack memory, information can be encoded by the presence (bit "1") and absence (bit "0") of skyrmions at a particular position in the track. For an unconventional use of skyrmion racetrack, such as for native temporal memory [1], the information is encoded into the spatial coordinates of the skyrmions, which then can be translated into the timing information needed for race logic operations. The thermal stability of skyrmions is a critical issue for both of these applications. A randomly displaced skyrmion can alter the sequence of the "0" and "1" bits in boolean memory applications. Similarly, for race logic applications, the displacement of skyrmions would change the spatial coordinates of the skyrmions and hence the encoded analog timings. For reliable information extraction, it is essential to guarantee the positional stability of skyrmions for a certain amount of time. For example, for a long-term memory application, it would require positional stability of years, while for cache memory, hours would be sufficient. One way to control the stability of skyrmions is by engineering confinement barriers such as notches etched into the racetrack, which ensure the pinning of skyrmions. By employing micromagnetic simulations [3] and analytical equations [4], we present a systematic analysis of racetrack geometries with different types of notches to calculate the minimum energy barriers associated with them. We vary material parameters, specifically, the DMI and the geometry of the notches, to get the optimal barrier height. We find a range of energy barriers (up to ~ 45 k_BT) that can provide a long enough positional lifetime (years) of skyrmions for long-term memory applications while requiring a moderate amount of current ($\sim 10^{10} - 10^{11}$ A/m^2) to move the skyrmions. Our results open up possibilities to design practical skyrmion-based racetrack geometries for spintronic applications.

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Metastability and Creation of Single Chiral Soliton States in Monoaxial Helimagnets

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Topology and chirality are the principal avenues along which the field of spintronics currently transits. While topology is usually related to the presence of robust states against continuous or weak fluctuations, chirality refers to the handedness of a state that are commonly encountered in systems whose inversion symmetry is broken. In magnetic systems, both, topological and chiral features, meet together in systems where the antisymmetric Dzyaloshinskii-Moriya interaction plays a key role. This is the case of monoaxial helimagnets, where the Dzyaloshinskii-Moriya interaction favors inhomogeneous distributions of the magnetization with chiral modulations termed chiral solitons. In addition to the helicoidal magnetic state at zero field, a chiral soliton lattice can be stabilized when a magnetic field perpendicular to the chiral axis is applied [1]. When the magnetic field is increased the system undergoes a phase transition to the uniform state at a critical field B_c [2]. Above B_c, a single chiral soliton comprises the lowest level excitation over the stable uniform state, surviving as a metastable configuration [3]. We study the metastability of individual chiral solitons through micromagnetic simulations based on the Landau-Lifshitz-Gilbert equation. The characteristic field for metastability limit and the instability mechanism are determined. Finally, we put forward a feasible protocol to obtain a state with a single chiral soliton from the chiral soliton lattice. We show that using spin-polarized currents chiral solitons in the chiral soliton lattice can be pushed against each other and it is possible to annihilate the solitons one-by-one in a controlled way. We also show how to supress the current induced creation of chiral solitons at the edges of a finite system. A state with one chiral soliton can be obtained by these means for a suitable choice of the external field and the current density. Remarkably, our proposal exhibits a strong robustness against the magnetization distribution in the initial state, even if the initial state is metastable. Our proposal could be relevant in the study of metastable solitons from both the experimental and technological applications.

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Controllable reset behavior in domain wall-magnetic tunnel junction neurons for task-adaptable computation

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Due to the limitations of CMOS-driven von Neumann computing in tasks like image processing, there has been significant research effort in devices for neuromorphic computing. In particular, spintronic devices are of interest due to high write endurance, low power consumption, and small size [1]. Domain wall–magnetic tunnel junction (DW-MTJ) devices can implement leaky integrate-and-fire artificial neurons and have already been shown to intrinsically capture advanced biological neuron behavior of lateral inhibition, enabling winner-take-all computation [2]–[5]. An additional behavior of mammalian pyramidal neurons is edgy-relaxed behavior, where a frequently firing neuron experiences a lower firing threshold [6], [7]. In artifical neural networks (ANNs), this behavior can aid in inference tasks with repeated inputs [8].

We demonstrate that this behavior can be captured by DW-MTJ artificial neurons via three mechanisms: shape anisotropy, magnetic field, and current. These are used to implement a soft-reset mechanism where the domain wall is not completely reset to the initial position, in contrast to the typical hard reset applied between inference tasks in ANNs. Edgy-relaxed behavior is first demonstrated in micromagnetics using all three mechanisms. An analytical model of domain wall dynamics is then used to apply the DW-MTJ neurons on a perceptron pre-trained on the Optdigits handwritten dataset. The dataset is modified to have a varying degree of order, from randomized to fully grouped by class to introduce repeated inputs. It is found that for ordered datasets, the soft reset behavior can significantly improve classification accuracy over hard reset behavior and the effect can be tuned to only slightly impact ANN performance on randomized datasets. Inference speed is also improved for ordered datasets, with a significant improvement using external magnetic field due to timing limitations with current-driven reset. We are able to show that by utilizing intrinsic magnetic properties of DW-MTJ artificial neurons, task-dependent inference optimization for ANNs can be achieved.

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Spike Pattern Association Neuron Using Antiferromagnetic Artificial Neurons

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It has been shown that antiferromagnetic (AFM) spin Hall oscillators driven by a sub-threshold spin current produce ultra-short ($\sim$ 5 ps) spikes in response to a weak external stimulus and can be used as ultra-fast artificial neurons [1]. These AFM neurons can be connected by passive synapses to create simple neuromorphic circuits, such as memory loops and inhibitors [2]. The next step in creating a neural network based on AFM neurons would be to find a learning algorithm that works with AFM neurons. Many rate-based training algorithms seen in spiking neural networks would not be possible with AFM neurons due to their refraction time which stems from an effective internal inertia [2] . Spike pattern association neurons (SPANs) are trained with a novel supervised learning rule [3], [4]. This learning rule is based on the Widrow-Hoff (or Delta) learning rule, commonly used in traditional neural networks. Unlike traditional rate-based algorithms, this rule is based on temporal coding to train an artificial neuron to map input spatiotemporal spike patterns to desired output spike patterns. This learning rule makes use of reservoir computing, as only the weights connected to the output neuron are altered. An AFM SPAN was created successfully using this learning algorithm. Additionally, an AFM SPAN can be trained to recognize letters using the Morse code alphabet. Letters in Morse code are based on a series of dashes or dots. These dashes and dots were encoded into spatiotemporal spike trains and fed into the AFM SPAN. This singular SPAN is then trained to recognize one unique letter. Multiple AFM SPANs can be trained to individual letters while still being connected to the same inputs. Effectively leading to a neural network which can translate encoded words.

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Magnetic Josephson Junctions for Artificial Synapses

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The performance of artificial intelligence (AI) technologies has improved significantly over the last decade in such a way that AI is now everywhere in our daily life via software neural networks. However, this continual growth in computational performance of these networks comes with large increases in the computational time and energy needed to train them. Developing AI at the hardware level has the potential to bend this curve and provide fast and lower energy computing. In this talk, I will present a new hybrid magnetic-superconducting device that can be used as an artificial synapse in neuromorphic circuits. The device is a magnetic Josephson Junction that consists of a barrier of magnetic nanoclusters between two Nb electrodes. The critical current of these junctions can be tuned by varying the magnetic order of the clusters, which can be used to perform synaptic weighting. I will describe the properties of the MJJ and show that its synaptic properties can be obtained in different material systems with an energy cost as low as 10^{-19}J. Finally, I will present circuit simulations where MJJs are included in a neural network for image recognition operating at speeds over 100GHz, and show some preliminary experimental validation of the simulations.

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Manipulation of terahertz spectrum using microfabricated magnetic heterostructures

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Terahertz (THz) radiation has attracted great attention due to various advantages in this frequency range that fills the gap between the optical and radio frequency. Conventional THz emitters, including photoconductive antennas (PCA) and non-linear crystals, employ only the electron's charge. However, studies on demagnetization phenomena showed that spin-based effects occur on the ultrafast time scale. In particular, THz spin current pulses can be created in magnetic heterostructures comprising a ferromagnetic and a heavy metal layer such as Pt. When excited with a femtosecond laser pulse, a diffusive ultrafast spin current is created in the ferromagnet, which is then converted into THz transients in the adjacent heavy metal layer via the inverse spin Hall effect [1].

Here, we demonstrate the generation and control of THz radiation using microstructured Fe/Pt bilayers [2]. Using time-domain THz spectroscopy, we compare the THz emission spectra of different patterned arrays with an unpatterned control film. We find that the THz spectrum can be altered by a proper choice of the microstructure dimensions. The results are interpreted using a simplified multi-slit interference model that is capable of capturing the general experimentally observed behavior. Our results show that the emitted THz light can be efficiently controlled using microstructured magnetic heterostructures. These results pave the way for on-chip spin-based THz sources that can be manipulated.

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Hopfion Dynamics in Chiral Magnets

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Resonant spin dynamics of topological spin textures are correlated with their topological nature, which can be employed to understand this nature. Topological spin textures, e.g., skyrmions, attract considerable interest in condensed matter physics because of their non-trivial physical properties and promising applications in memory and storage technologies [1], [2]. One kind of these topological spin textures is a Hopfion, which wraps the surface of a toroid with an integer winding number. Hopfions haven' t been studied thoroughly and started to receive attention very recently [3]–[5]. In this study, we present resonant spin dynamics of two versions of three-dimensional topological spin texture hopfion in chiral magnet, i.e., Bloch and Neel Hopfions. First, using micromagnetic simulations, the ansatz for Bloch and Neel Hopfions were established. Bloch and Neel Hopfions were stabilized using bulk and interfacial DMI, respectively. We identified the ground state spin configuration of both hopfions, effects of anisotropies, geometric confinements, and demagnetizing fields. For Neel Hopfion, to distinguish between different topologies, the Hopf number was calculated for each simulation. Then, we calculated the resonance frequencies under various magnetic fields using ring-down method and Fourier transform. Moreover, spin-wave modes of spin precession dynamics under multiple magnetic fields for both hopfions were calculated. By including the demagnetizing energy, we stabilized Bloch Hopfions in a 128-nm-diameter nanodisc, which was previously claimed for the discs with the diameters larger than 280 nm [3]. Scalable growth and device fabrication of Hopfion systems require more stable substrates (e.g., Si), which will, however, make imaging studies more complicated. When imaging is not possible, unique resonance frequencies and specific magnetic field dependence can help to guide experimental studies to identify the three-dimensional topological spin texture of hopfions in functioning chiral magnets.

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Magnetoelectric effect in composite of piezoelectric ceramics and Ni-Mn-Ga ferromagnetic shape memory alloy: design and measurement

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Magnetoelectric composites made of magnetostrictive and piezoelectric elements have a high technological interest because their potential applications in multifunctional devices such as transducers, actuators, and sensors [1], [2]. The highest magnetostriction material known is Terfenol-D, which is a rare-earth iron alloy that requires magnetic fields larger than 1 T to achieve deformations around 2,000 ppm [3]. In this work we designed a set-up based on a double coil and an electromagnet to measure the magnetoelectric effect of a composite fabricated from piezoelectric PZT ceramics and a $Ni_{49.3}Mn_{29.6}Ga_{21.1}$ single crystal shape memory alloy (a kind of materials that can show several percent deformations under moderate fields [4], [5], i.e. a quite superior response as compared to Terfenol-D). The single crystal showed the martensitic transformation at TM = 298 K; as well as TC = 368 K, and μ (302 K) = 2.87 μ_B/f.u. The maximum strain response at room temperature was of 4% for magnetic fields larger than 0.4 T. As for the magnetoelectric effect, the induced magnetoelectric voltages were very moderate, increasing linearly with the frequency. There was only a slight change in the response with the DC applied magnetic field. For low frequencies (f $<$ 1 kHz) the magnetoelectric voltage were on the order of 10 mV and for higher frequencies about 50 mV. The best magnetoelectric response ($\sim$ 210 mV/cm Oe) was obtained under an AC field of 10 Oe and a static magnetic field of 0.7 T.

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Large Exotic Spin Torques in Antiferromagnetic Iron Rhodium

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Magnetically ordered materials show great potential for spin torque generation, as magnetic ordering can break underlying crystal symmetries and allow exotic torques well-suited for switching nanomagnets or driving spin torque oscillators [1], [2]. We use spin torque ferromagnetic resonance and second harmonic Hall techniques to characterize spin-orbit torques generated in anti-ferromagnetically ordered iron rhodium alloy and report the generation of spin currents with exotic spin polarizations defined by the magnetic ordering direction. Our results show highly temperature-dependent spin torque efficiencies with values above 90% at room temperature and above 300% at 170K.

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Observation of mode splitting in artificial spin ice: A comparative ferromagnetic resonance and Brillouin light scattering study

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Artificial spin ices (ASIs) consist of periodically arranged nanomagnetic elements with proximity to interact with one another. They have been envisioned as reconfigurable magnonic crystals in which bandgaps can be modified on demand [1], [2].

Here, we study the angular-dependent magnetization dynamics in a square ASI structure made of permalloy (NiFe) elements using two complementary experimental techniques: broadband ferromagnetic resonance spectroscopy (FMR) and micro-focused Brillouin light scattering (BLS) spectroscopy. The experimental results are complemented by micromagnetic simulation using MuMax3 [3]. Our results reveal a mode splitting in the resonant spectra at particular in-plane field angles. Time-dependent micromagnetic simulations further indicate that the mode splitting is due to the spin-wave dynamics localized in different regions of the lattice vertex. Furthermore, we demonstrate that micro-focused BLS is a powerful technique to detect spin-wave excitations in ASI. The thermal BLS spectrum is strong enough to detect the spin-wave modes that are inaccessible by other commonly used techniques such as FMR. Our findings open a new path to explore spin-wave dynamics in ASI structures and highlight the possibility to disentangle spatially-separated modes [4].

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Moving Skyrmions with a Small Thermal Gradient

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Magnetic skyrmions are topological whirls in the magnetization which have become an intensively studied field in magnetism [1], [2]. In contrast to antiskyrmions which have a very restricted set of host materials [3], [4], skyrmions were now observed in a large variety of materials, ranging from bulk chiral magnets to specifically designed multilayers, from metals to insulators, and from micrometer scales to the scale of the atomic lattice [1]. They also hold great potential for applications due to their particle-like nature, emergent electrodynamics, and topological stability, for example, in unconventional computing or magnetic memory devices. Skyrmions have also proven to be mobile and easily manipulable, for example, by electrical currents or magnetic field gradients. Thermal gradients can also be used to manipulate skyrmions. Recent works observed a rotational motion of skyrmion clusters in radially symmetric temperature fields, but a controlled linear motion has never been demonstrated.

In my talk, I will present our recent achievements [5] in driving skyrmions in the chiral magnetic insulator Cu_2OSeO_3 by using a well-controlled temperature gradient. In a temperature gradient, various mechanisms are activated that can lead to the motion of magnetic textures: In metals, the diffusion of conduction electrons leads to a spin-transfer torque [6]. In magnetic insulators, however, this mechanism is absent and the main driving force is a spin-transfer torque exerted by magnons which propagate from the hot to the cold end of the sample (and entropic forces). It was previously demonstrated that the magnonic spin-transfer torque can drive magnetic domain walls towards the heat source [7] and a similar behavior was theoretically predicted for skyrmions [8]. Using Lorentz transmission electron microscopy (LTEM) on thin specimens we could film the motion of small skyrmion clusters in a thermal gradient and found that the critical temperature gradient is only $\nabla T_c \approx 10$mK/mm, i.e., two orders of magnitude smaller than the critical temperature gradient for the motion of domain walls. I will also present our quantitative evaluation of the skyrmion velocity as function of the temperature gradient which shows reasonable agreement with our theoretical estimates.

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Structural and Magnetic Studies of the Layered Perovskite $CsMnF_4$: A Combined Experimental and Computational Study

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The investigation of possible two-dimensional magnetic materials has become important for the development and application of spintronic and topological devices. Here, we present a combined theoretical and experimental study of $CsMnF_4$ – an easily-synthesised layered perovskite material. This material is of interest in that it is predicted to be a ferromagnetic insulator, despite isostructural compounds such as $A\mathrm{MnF}_4$ (A = Na, K, Rb) being anti-ferromagnetic [1].

A polycrystalline sample of $CsMnF_4$ was prepared via the dehydration of $CsMnF_4{\cdot}2H_2O$. The latter was synthesised using a co-precipitation method. Laboratory source X-ray diffraction shows the structure to be of high purity and complete dehydration was achieved. Magnetic data from a physical properties measurement system (PPMS) equipped with a vibrational sample magnetometer (VSM) has confirmed ferromagnetic ordering at 20 K, with an opening of the hysteresis loop also present below 20 K.

Computational studies using density functional theory and Hubbard Coulomb interaction (DFT + U) calculations reveal that the $CsMnF_4$ system consists of in-plane ferromagnetism [2]. This is partnered with the observation of two nodal rings associated with unusual Mexican hat-like dispersions and band-flipping. These properties are potentially due to the strong Jahn-Teller effects and spin-orbit coupling from the structural and magnetic properties of the Mn^{3+} ions, as well as the superexchange angle between Mn–F–Mn [3].

These insights can be used in the development and engineering of potential materials for memory device applications.

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Anisotropic Magneto-resistance in 2D Van der Waals Nano-flakes of Fe_3GeTe_2

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The intrinsic ferromagnetic two-dimensional van der Waals (2D-vdW) materials have aroused attentions widely in the area of spintronics due to its excellent properties such as magnetic stability with relative high Curie temperature in bulk crystals for Fe_3GeTe_2 (T_C=220 K) [1]. Fe_3GeTe_2 has a layered structure and weak van der Waals bonding between layers, which is easy to exfoliate, transfer and to fabricate the nano-devices. Although a lot of works on magnetism of Fe_3GeTe_2 have been studied in recent years, the electric transportation is a more crucial factor for spintronics devices, especially on field orientations dependence of electric transport and spin related transport. However, the research reports are limited. In this research, an investigation of resistivity with different magnetic field orientations for 2D-vdW Fe_3GeTe_2 nanoflakes are performed at different temperature.

Fe_3GeTe_2 nanoflakes are fabricated by CVT and mechanical exfoliation method with metal-assisted [2]. The measurements of electric transport are carried out in Quantum Design physical property measurement system (PPMS) with changing temperature from 5 K to 300 K. From anomalous hall resistance R_{xy} (AHR), we see that the magnetic ordering temperature TC near 220K. The resistance ($R_{||}$) when magnetic moment is parallel to current in the flake plane is invariably smaller than the resistance ($R_{\perp}$) when magnetic moment is perpendicular to current, which exhibits a negative anisotropic magneto-resistance (AMR) behaviors. To quantitatively characterize the value of AMR, a theoretical fitting has been performed with traditional AMR $cos^2\theta$ expression by dividing the contribution of spin hall magnetoresistance (SHMR) [3]. The absolute value of AMR reaches the maximum value at 50 K. It is interesting that a minimum value of Rxx is observed at 20 K on the temperature dependence of R_{xx} curve, which is illustrated by Kondo effect [4]. Abnormal behaviors are found for all of the temperature dependent AHR and AMR curve. The discussion will be presented in the full paper.

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Techniques for Investigating Magnetism in Ultra-Thin Films: Polarised Neutron Reflectometry and Density Functional Theory

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Thin magnetic films play an increasingly important role in a range of existing commercial technologies (e.g., magnetoresistance random access memories). Recently a new generation of two-dimensional magnets have been discovered, including candidates that host exotic quantum effects and topological electronic structures [1]. In the first part of my talk, I will discuss the novel physical and electrical phenomena of ultra-thin magnets, including the possibilities for engineering zero dissipation electronics using topological magnetism. As the net magnetic moment of these structures is often extremely low, I will show they pose a challenge to measure with traditional direct magnetometry such as superconducting quantum interference devices. I will briefly survey how various nanoscale magnetometry techniques address this challenge, including x-ray circular dichroism, nanodiamond microscopy, muon spectroscopy, β-NMR spectroscopy and polarised neutron reflectometry (PNR).

The second part of the talk will focus on how polarised neutron reflectometry can measure ultra-thin magnetic films to quantify magnetization in absolute units and simultaneously reveal complementary chemical information such as the degree of local oxidation. I will discuss both the advantages and disadvantages of PNR relative to other techniques and how this method is implemented at the Australian Centre for Neutron Scattering. A new approach to using ab initio calculations to support PNR experiments by constructing slab models of thin films will be demonstrated. Finally, I will explain the process for gaining access to the PNR equipment at the Australian Nuclear Science and Technology Organisation via a peer-review process that is freely open to international users.

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List of Poster Presentations

Magnetoresistance Irreversibility in R_5Pd_2 (R=Tb, Dy)

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The compound R_5Pd_2 (R = Tb, Dy, Ho & Er) has been subject matter of interest for their complex magnetic ground state. These compounds crystallize in Dy_5Pd_2 type cubic crystal structure with space group Fd3m. Early studies showed antiferromagnetic ground state with transition temperature varying from 15 K (for Er_5Pd_2) to 63.5 K (for Tb_5Pd_2) [1]. However, using magnetic susceptibility and neutron diffraction measurement on Ho and Tb compounds, Gubkin et al. claimed cluster glass like magnetic state for these two systems [2]. Subsequent studies verified their speculation of similar magnetic state for remaining members of the series [3]. In addition to magnetic state, transport behaviour remains relatively unexplored with some conflicting reports e.g. opposite sign of temperature coefficient of resistivity (TCR) in Dy_5Pd_2 [1], [4].

Here, we present magneto-transport study of Dy_5Pd_2 and Tb_5Pd_2. Our study shows negative TCR below 60 K for Dy_5Pd_2, which becomes positive in the presence of high ($\geq$ 3 Tesla) magnetic field. In contrast to it, TCR is found to be positive at low temperatures for Tb_5Pd_2. Path dependent (in H-T space) magnetoresistance (MR) measurement brings out the metastable nature of magnetic state at low temperature. Isothermal MR measured at 5 K shows metamagnetic transition with increase in magnetic fields for both the samples. However, with reducing magnetic field MR remains negative even at zero field, showing an open loop. Further field cycling generates an envelope curve lying below the virgin curve. The open loop in the isothermal MR vanishes at higher temperature. In analogy to kinetic arrest of first order transition, presence of open loop in the present system can be taken as the signature of remnant field induced magnetic state at zero field. These field induced transformations may be occurring within the cluster as proposed by Gubkin et al. to explain magnetization data [2].

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Dielectric, Magnetic and Ferroelectric Properties of Nickel Substituted Gadolinium Ferrites

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Multiferroicity is a phenomenon that has recently attracted attention due to the exhibition of two or more ferroic properties such as ferromagnetic, ferroelectric, ferroelasticity and ferrotoroidicity properties in a single-phase material [1]. Combining ferromagnetism and ferroelectricity in a single phase is challenging due to their existence depends on entirely different microscopic conditions [1]–[3]. Therefore, the independent existence of ferromagnetism and ferroelectricity in a single phase is the rarest case in materials. $GdFeO_3$ is an orthoferrite which shows canted antiferromagnetism (T_N =661 K) and ferroelectricity (T_C = 442 K) at room temperature [4]. The present work focusses on the effect of Ni substitution in the dielectric, magnetic and ferroelectric properties of $GdFeO_3$, synthesized via sol-gel method. The structural properties of pristine and Ni substituted gadolinium ferrites were studied by X-ray Diffraction technique. Dielectric measurements of $GdFe_{1-x}Ni_xO_3$ at different temperatures were carried out by impedance analyzer. Magnetic measurements were carried out by VSM SQUID and ferroelectric measurements were carried out by P-E Loop tracer.

XRD pattern confirmed that pristine and Ni substituted $GdFeO_3$ exhibit orthorhombic structure with pbnm space group. From cation distribution calculation, it is seen that some Fe^{3+} ions in $GdFeO_3$ converted into Fe^{2+} ions with Ni substitution. This conversion of Fe ions influences the dielectric, magnetic and ferroelectric properties of $GdFeO_3$. The dielectric permittivity of $GdFeO_3$ enhances with Ni substitution in Fe sites. Magnetic studies shows that pristine and Ni substituted $GdFeO_3$ exhibit ferrimagnetism at low temperature, and it becomes canted type antiferromagnetic behaviour at room temperature. The FC-ZFC curve shows that at x = 0.04 Ni substituted $GdFeO_3$ samples shows a magnetic reversal phenomenon. P-E loop shows that pristine $GdFeO_3$ exhibits improper ferroelectricity and it become lossy ferroelectric behaviour with Ni substitution. The results obtained out of this investigation will be correlated and will be discussed here.

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Nonlinear Quantum Electrodynamics in Dirac Materials

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Classical electromagnetism is linear. However, fields can polarize the vacuum Dirac sea, causing quantum nonlinear electromagnetic phenomena, e.g., scattering and splitting of photons that occur only in very strong fields found in neutron stars or heavy ion colliders. We show that strong nonlinearity arises in Dirac materials at much lower fields $\sim 1\,\mathrm{T}$, allowing us to explore the non-perturbative, extremely high field limit of quantum electrodynamics in solids. We explain recent experiments in a unified framework and predict nonlinear magneto-electric response, including a magnetic enhancement of dielectric constant of insulators and a strong electric modulation of magnetization. We propose experiments and discuss the applications in novel materials [1].

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Cr Cations Anchored Carbon Nanosheets: Synthesis and Magnetic Behavior

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A strategy of Cr cations solely anchored on two dimensional carbon nanosheets by Cr-N bond is developed. The atomically dispersed Cr cations and Cr-N_3 coordination are demonstrated by extended X-ray absorption fine structure characterization. Furthermore, the Cr-N_3 anchored carbon nanosheets exhibits ferromagnetism. The X-ray magnetic circular dichroism and first-principle calculation indicate that the magnetism is caused by the Cr^{3+} component of the anchored Cr atoms. In short, the key points of our work could be summarized as follows:

1. By using a facile sintering method, we successfully synthesized graphene support and a series of contents of Cr anchored graphene-samples (Cr-1.1, Cr-1.3 and Cr-2.0, The numbers marked in the samples' names are Cr contents). The extended X-ray absorption fine structure (EXAFS) and spherical aberration correction transmission electron microscope (AC-TEM) image demonstrated the Cr single-atoms distributing in graphene.

2. The as-synthesized samples exhibit robust ferromagnetism at room temperature. (~300 K) And the magnetization increases with the Cr content. Cr-2.0 exhibit the largest magnetism with magnetization of 0.132 emu/g under the magnetic filed of 3 T. While in low temperatures, paramagnetic feature is more evident in the samples. For instance, the maximum magnetization of Cr-2.0 under 3 T achieves to 0.859 emu/g at 50 K. The Curie temperature of Cr-2.0 was estimated to be more exceed than room temperature (>600 K).

3. Through X-ray absorption spectroscopy (XAS) and X-ray magnetic circular dichroism (XMCD), we experimentally demonstrated that the magnetic moments in the sample are introduced by anchored Cr^{3+}. The first-principle calculation results also indicate that the Cr^{3+} cations are responsible for the origination of magnetism of graphene nanosheets.

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Magnetization-Orientation Dependent Terahertz Emission from the Fe/Pt (110) Single-crystal Film

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The ferromagnetic (FM)/heavy metal (HM) heterostructure has been demonstrated to be an efficient and broadband Terahertz (THz) source, which has attracted much attentions in the ultrafast spintronics field [1], [2]. The THz polarization from the spintronics THz emitter is easy to be manipulated by rotating the magnetic field, but in all the previous studies, the THz intensity was expected to be independent of the magnetization orientation. However, the spin-orbit coupling in the film system with lower in-plane symmetry may depend on the crystalline orientation, which can induce the magnetization (**M**) orientation dependent THz emission.

In this contribution, we systematically investigated THz emission from the Fe(211)/Pt(110) crystalline bilayer grown on MgO(110), and demonstrate for the first time that the intensity of the emitted THz wave depends on the **M**-orientation. The measured THz field is 11% stronger for **M**// Pt[$1\bar{1}0$] than that for **M**//Pt[001] (Fig.1). Experimental measurements and first-principle calculations combined with the superdiffusive spin transport model indicate that both spin current generation and the following spin current injecting into the Pt layer are independent of the **M**-orientation, but the spin-to-change conversion efficiency in the Pt layer and the following THz wave radiation can be strongly influenced by the **M**-orientation due to the anisotropic spin Hall effect and longitudinal conductance in Fe/Pt bilayer, which give rise to the anisotropic THz emission. The theoretical calculation clarifies that the emergent anisotropic THz emission is mainly attributed to the lattice distortion in the film induced by the epitaxial strain. The calculated anisotropy of THz wave well agrees with the experimental results. Our studies provide a new route to modify the THz emission utilizing the intrinsic crystalline structure degree of freedom.

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Magnetization-Dependent Spin Hall Effect in a Perpendicularly Magnetized Film

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It is known that the spin Hall effect (SHE) rigorously follows the vector cross-product relation, where the charge current, the spin current, and the spin polarization are mutually orthogonal. Recently, this restriction has been lifted in the magnetization-dependent spin Hall effect (MDSHE) in magnetic materials [1], [2], where the charge-induced spin polarization can be additionally manipulated by the magnetization directions, opening new perspectives for spintronics. Nevertheless, the existing reports of the MDSHE have various competing contributions and artifacts due to their all metallic heterostructures. As a result, experimentally, the MDSHE remains unequivocally established, not to mention the quantitative analyses.

In this work [3], we unambiguously established the MDSHE by utilizing the magnetic insulator YIG to thermally inject the pure spin current into a perpendicular magnetized Pt/Co/Pt layer. We excluded the occurrence of any possible artifact and clearly demonstrated that the spin polarization of pure spin current induced by the MDSHE could be arbitrarily and independently controlled by the magnetization direction. Furthermore, we explicitly identified the strength of the MDSHE, compared its size with the SHE, and further estimated the magnetic spin Hall angle to be -0.36%. Our approach provides a versatile and controllable route to explore the unconventional spin and charge conversions in magnetic materials and benefit next-generation spintronic applications.

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Cluster-glass behavior in $Ca_3Co_2O_6$ and its substituents

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Polycrystalline samples of $Ca_{3-x}Dy_xCo_2O_6$ (x = 0, 0.1, 0.2, and 0.3) were prepared by standard solid-state reaction method. Rietveld refinement of XRD data confirms the single-phase formation, and the compound crystallizes in the Rhombohedral structure with space group $R\bar{3}$c. The lattice parameter 'a' decreases while 'c' increases with Dy substitution, and the overall 'c/a' ratio increases. The increased cell volume (V) due to the substitution of Dy^{3+} (1.05 Å) ions for Ca^{2+} (1.14 Å) ions indicates, the partial transform of Co^{3+} (0.61 Å) to Co^{2+} (0.745 Å) ions to maintain the charge neutrality [1]. DC magnetization and magnetic relaxation measurements were performed to illustrate the magnetic properties and spin dynamics of the system. M(T) ZFC-FC data revealed that the system undergoes paramagnetic to a partially disordered antiferromagnetic state ($T_{c1} =$ 25 K), followed by a glassy transition ($T_{c2} =$ 9 K) [2]–[4]. The magnetic properties were found to be sensitive to Dy substitution due to which the transition temperatures T_{c1} and T_{c2} decreases, and the glassy behavior gradually suppressed with Dy concentration. In the high temperature region (175 K –300 K), the DC susceptibility obeys Curie-Weiss law. The higher experimental value of μ_{eff} for Dy doped samples indicates the strong anisotropic magnetic character identified from the non-equilibrium nature of magnetic properties [5]. On the other hand, the Curie temperature (θ) decreases from 31 K for the parent compound to 2 K for x = 0.3 doped samples, indicates the reduced ferromagnetic coupling along the c-axis with Dy content. The isothermal magnetization curve depicts step-like change indicative of the first-order transition, which decreases with the increase of substitution. The Brillouin function was used to determine the 'spins', participating at this first-order transition $\left(J\left(\frac{1}{2}\right) \rightarrow J\left(\frac{3}{2}\right)\right)$. Magnetic relaxation measurements confirms the presence of intermediate anisotropic metastable states due to spin-freezing phenomena. Interestingly, the Vogel-Fulcher model provides evidence for this state to be formed from cluster of spins rather than a single spin [6]. Analyzing the results using Vogel-Fulcher law shows that the Vogel-Fulcher temperature (T_0) and the relaxation time is around 10 K and 10^4 s, respectively.

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Systematic Difference in the Local Magnetic Anisotropy of Rare-Earth (R) on Inequivalent Sites in $R_2Fe_{14}B$ Systems

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In relation to an origin of smaller coercivity in Nd-Fe-B magnets, weakened magnetic anisotropy (MA) of the Nd moment on the f site of the main $Nd_2Fe_{14}B$ phase was argued, as compared with that on the *g* site, both experimentally [1] and theoretically [2], [3]. We take notice of a reduction of the rare-earth (R) moment estimated from the difference in saturation magnetization M_s between easy and hard directions [4], [5], since the reduction rate would be different in inequivalent R sites reflecting the difference in the local MA. In this work, we measured the magnetization curves in $R_2Fe_{14}B$ single crystals with R = Y, Pr, Nd at 300 K $\sim$ 600 K, and the paramagnetic susceptibility χ up to 900 K. We obtained the following results.

(1) In the R=Pr [4] and Nd [5] systems, M_s[100] was reduced as compared with M_s[001] at 300 $\sim$ 500 K, with the reduction rate $\Delta M = 2\% \sim 6\%$. χ[100] was also reduced with the reduction rate $\Delta\chi = 2\% \sim 10\%$.

(2) By reevaluating the published data [6], [7] for R=Tm system, we found that $M_s[001] > M_s[100]$ at 200 K $\sim$ 310 K, with $\Delta M = –12\% \sim –6\%$.

(3) In the R=Y [4] system, M_s[001] = M_s[100] at 290 $\sim$ 500 K ($\Delta M \sim 0$).

(4) From the results (1) $\sim$ (3), we conclude that R moments are reduced when oriented to the hard axis, by taking account of the parallel and antiparallel couplings of the Fe and R moments in light and heavy R systems, respectively.

(5) First-principles calculations were performed to obtain crystalline electric field ($A_n^m\langle r^n\rangle$) and molecular field parameters for R = Pr, Nd, Sm, Tb, Dy, Ho, Er, Tm systems [3]–[5]. Based on them, magnetization curves were calculated [6] at finite temperatures.

(6) Calculated temperature dependence of ΔM and $\Delta\chi$ well reproduced the experiments, which ensure that the local information about the R moment is reliable enough.

(7) According to the calculation, the reduction rates of the R moment Δm_R for the *f* and *g* sites were estimated. At 300 K, $\Delta m_{\mathrm{Pr}}(f)$, $\Delta m_{\mathrm{Pr}}(g)$, $\Delta m_{\mathrm{Nd}}(f)$, $\Delta m_{\mathrm{Nd}}(g)$ values were 22.5%, 44.5%, 12%, 17%, respectively.

(8) Local MA energy of the Pr on the *f* site was found to be about one half of that at the Pr(*g*), which leads to the results of $\Delta m_{\mathrm{Pr}}(f) \ll \Delta m_{\mathrm{Pr}}(g)$. This result originates primarily from the smaller $A_2^0\langle r^2\rangle$ value for the Pr(*f*) site as compared with that for the Pr(*g*) site.

We thus conclude that the local MA of the Pr on the *f* site is decreased crucially as compared with that on the Pr(*g*) site. This would be the case for other $R_2Fe_{14}B$ systems with the negative second-order Stevens factor (R = Nd, Tb, Dy and Ho).

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Theoretical Evaluation of Shell Thickness on the Heating Characteristics of Fe and FeCo Core for Magnetic Hyperthermia

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Iron oxide (Fe_3O_4) nanoparticles with various surface functionalization and substitution have been established as an appealing heat mediator in cancer therapy utilizing magnetic nanoparticle hyperthermia (MNH) [1], [2]. However, to minimize the treatment duration and particle concentration in MNH, highly magnetic nanoparticles such as Fe or FeCo are preferable. Although Fe and FeCo nanoparticles up to 20 nm are realizable, they are prone to oxidation [3], [4], and the heating efficiency is affected by the oxide shell. In this study, we have investigated the various parameters that affect the specific absorption rate (SAR) of highly magnetic core-shell nanoparticles.

Fe and FeCo core with Fe_3O_4 shell of various core sizes from 6 to 23 nm and shell thickness (t) from 1 to 10 nm at a practical applied field and frequency of 4 kA/m and 500 kHz, respectively, have been considered in this study. The estimated SAR for pure Fe with an optimum particle diameter (Dopt) of 9 nm is 350 W/g, which far exceeds the value of 90 W/g, corresponding to Fe_3O_4. Although the SAR of oxidized Fe reduces drastically about 3-4 times, it still exceeds the value of Fe_3O_4, which is promising for future applications.

SAR of Fe, FeCo/Fe_3O_4 reaches a characteristic maximum of 200-240 W/g at t = 5 nm for a particle diameter of 13 nm. Even though the theoretical Dopt for 1 nm shell thickness is at 10 nm for the Fe core, a broad range of particle sizes from 5 to 15 nm can give closer SAR values of 60-80 W/g. The optimum SAR for each shell thickness of various Fe and FeCo core sizes is found to increase up to t = 5 nm and then decreases further. The results suggest the validity of linear response theory to be applicable even to core-shell particles, where the Néel-Brown relaxation mechanisms of both the core and shell contribute to the heating characteristics. The scope of the theory can be extended to experiments provided the control of core size between 10-20 nm and shell thickness within 5 nm is achieved.

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Room-temperature Antiskyrmions and Sawtooth Domain Walls in a Magnet with S_4 Symmetry

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Magnetic skyrmions are whirls in the magnetization with an integer topological 2d winding number [1]. Within the last decade, skyrmions became a hot topic in magnetism [2] due to their particle-like nature, topological stability, and potential for applications, for example, in high-performance magnetic memory. By now, skyrmions with Bloch-type or Néel-type helicity were observed in a large variety of materials with various symmetries [3]. Their anti-particles, dubbed antiskyrmions, have a multi-chiral texture in the sense that they are not pure Bloch- or Néel-type but comprise all helicities, similiar to an anti-vortex. Both antiskyrmions and skyrmions were theoretically predicted to exist in magnets with broken spatial inversion symmetry [4] where, more precisely, the Dzyaloshinskii-Moriya interaction in crystals with D_{2d} or S_4 symmetry would stabilize antiskyrmions. However, so far antiskyrmions were only reported in the Heusler alloy $Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ and related materials with D_{2d} symmetry [5].

In my talk, I will present our recent observations [6] in materials with S_4 symmetry, in particular Schreibersite $(Fe, Ni)_3P$ (space group I-4). By doping small amounts of the heavier element Pd in order to increase the spin-orbit coupling, we prepared single crystal samples of $Fe_{1.9}Ni_{0.9}Pd_{0.2}P$, which turn out to be rather soft magnets with a weak uniaxial anisotropy. Lorentz transmission electron microscopy (LTEM) on thin specimens revealed square-shaped antiskyrmions and elliptically distorted skyrmions in a wide temperature range, including room temperature, in agreement with previous observations in D_{2d} systems [7]. Moreover, magnetic force microscopy (MFM) on thick samples revealed a sawtooth-shaped magnetic domain structure which reflects the S_4 symmetry. This novel magnetic domain structure was also reproduced by micromagnetic simulations which confirm that it is a surface effect which requires anisotropic Dzyaloshinskii-Moriya interaction, magnetic dipole interaction, and a weak uniaxial anisotropy.

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Crystallographic and multiferroic features of $SrCo_2Zr_2Fe_8O_{19}$ hexaferrites

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In this work, an experimental study of the M-type hexaferrite material $SrCo_2Zr_2Fe_8O_{19}$ produced by the solid-state reaction technique. The structural properties were studied by Rietveld analysis of X-ray diffraction data. The results reveal that the material crystallizes in an M-hexaferrite type structure with a hexagonal symmetry defined by means of the space group $P6_3/mmc$ (#194, Z=2). Transmission Electron Microscopy was used to study the morphology of the sample, observing the distribution of ferromagnetic domains through electron holography, as well as the polycrystalline distribution of the material. The multiferroic character of the material was established by observing ferromagnetic hysteresis curves in magnetization measurements as a function of the applied magnetic field strength and hysteretic behavior of the electric polarization as a function of the external electric field. The results reveal that the $SrCo_2Zr_2Fe_8O_{19}$ material exhibits multiferroic response at room temperature.

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Effect of static magnetic field on the adhesion and migration of neural stem cells to different substrates

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Neural stem cells (NSCs) as the highly pluripotent cells with the ability of self-renewal and potential for multidirectional differentiation have been widely investigated for their potential in the treatment of various diseases and transplantation therapy [1]–[5]. However, NSCs growth regulation including directed cell migration, adhesion and differentiation are outstanding challenges. Here, the preliminary study focused on the effects of exposure to static magnetic fields (SMF) on adhesion and migration of neural stem cells to develop a regulatory approach applicable to certain chemical reagents sensitive elements, such as chips. Two kinds of substrate were used to analyze cell behavior in this study, with no SMF stimulation used as control. The results shown that a static magnetic field of 4mT induce cells attached on the silicon substrate after three days, and with the prolongation of growth time to five days, abundant protrusion formed on the surface of cells during migration and connected with each other to form a network structure. For Au substate, the same conditions were used. The results shown that cells attached on the surface after five days stimulation which was slowly than the silicon ones, and no significant cell migration appeared. Moreover, cells without SMF stimulation showed few cell-like structures. The present study suggests that static magnetic field can stimulate the behavior of NSC as the adherence and migration and has the selectivity of substrate materials. Further cell differentiation behavior induced by SMF is still under investigation, and our findings may provide the reference for studying a cerebral neural network on chip in vitro.

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Giant Shifts of Crystal Field Excitations with Temperature as a Consequence of Internal Magnetic Exchange Interactions

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Crystal field theory, already established in the 1930s (Bethe [1]), has proven to an outstanding tool for the explanation of crystal field excitations (CFE) observed by inelastic neutron scattering (INS) of rare-earth compounds. However, some long withstanding problems remain. Our INS experiments on vanadates $CeVO_3$ and $TbVO_3$ reveal an unexpected large shift of CFE energies as a function of temperature. Thus far, only few publications on INS experiments mention shifts in crystal field excitation (CFE) energy in spectra above and below magnetic phase transition temperatures, e.g. in [2]. Recent IR transmission measurements also identified a CFE energy shift in hexagonal $DyMnO_3$ with temperature [3]. However, to our knowledge no study reports on the detailed microscopic theory. The vanadates $CeVO_3$ and $TbVO_3$ share the same orthorhombic Pbnm crystallographic structure featuring tilted, corner-sharing octahedra and possess a C_z-type antiferromagnetic structure below Néel temperatures 124 K and 110 K, respectively [4]–[7]. In both vanadates the CFE energies increase strongly below the magnetic phase transitions. We have used quantum-mechanical point-charge calculations to determine the energies of observed CFEs to model their large shift as a function of temperature. Two mechanisms have been simulated: (i) distortions of the crystallographic lattice due to magnetostriction, or (ii) internal magnetic exchange (IME) interactions with CF levels at the onset of the magnetic order. The effect of lattice distortions measured by neutron diffraction [5], [6] produces a negligibly small shift of CFE energy, therefore cannot drive the shift. Results accounting for IME fields arising from the ordered V^{3+} spins reveal a shift which agrees excellently with INS data, reproducing the same shift in CFE energy and intensity. Therefore, the unexpected large shift of CFE energies with temperature has been confirmed by point-charge calculations and can be attributed to an IME interaction. Additionally, spin-wave excitations are present in both vanadate materials below the magnetic phase transition. In $TbVO_3$ there appears to be an anticrossing-like behaviour between magnon and CFE at 14 meV. Such behaviour has been reported in far-IR transmission investigations in $Tb_3Fe_5O_{12}$ garnet [8]. To investigate this observation in $TbVO_3$, magnon dispersion calculations have been performed to clarify the exact nature of the interaction. The obtained data will also

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provide an insight into the influence of rare-earth ions on multiferroic properties of materials such as $TbMnO_3$ or $TbMn_2O_5$.

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Growth of ferromagnetic and antiferromagnetic phases of Fe_3Sn_2 thin films

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Formation of magnetic skyrmions without Dzyaloshinskii–Moriya interaction [1], spin reorientation with temperature [2] and, large anomalous Hall effect (AHE) [3], can be found in topological materials such as centrosymmetric ferromagnet Fe_3Sn_2.Depending on the stoichiometry of Fe and Sn in Fe_xSn_{x-1}, it may show ferromagnetic or antiferromagnetic phase. In this work we show that by optimizing the growth conditions we can control the stoichiometry and hence the magnetic phase of the Fe_xSn_{x-1} thin films. We deposited two thin film samples on (Si-SiO_2) substrate using magnetron sputtering with a working pressure of 3 mTorr : 1) S1: Fe_3Sn_2 (60 nm) with substrate temperature 500°C and no annealing, and 2) S2: Fe_3Sn_2 (60 nm) without substrate temperature and 500 °C post annealing temperature. X-Ray diffraction measurements has been performed on these two samples to investigate crystal structure. We found sample S1 has a dominated phase of antiferromagnet (FeSn), while the sample S2 shows the ferromagnetic phase (Fe_3Sn_2) embedded inside the antiferromagnetic (FeSn) domains. The presence of ferromagnetic phase (Fe_3Sn_2) in sample S2 has been confirmed both by room temperature magneto-optic Kerr effect (MOKE) and vibrating sample magnetometer (VSM) measurements, showing a clear hysteresis loop with a coercive field ($H_c \approx$ 170 Oe) and low saturation magnetization ($M_s \approx$ 200 emu/cc) which is due to polycrystalline nature of Fe_3Sn_2. For sample S1, we don' t observe any hysteresis loop, which concludes that the effect of substrate temperature lead to the growth of an antiferromagnetic phase (FeSn), which is the most stable phase. We have also qualitatively studied the effect of saturation magnetization M_s for thin film Fe_3Sn_2 grown on two different heavy metal seed layers (Ta, Pt). We observed two times enhancement of M_s for Fe_3Sn_2 grown with Pt seed layer as compared to Ta seed layer. Pt seed layer provides a good lattice matching with Fe_3Sn_2 and increases the crystallinity of the Fe_3Sn_2 film, leading to higher M_s.

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Spin Pumping and Inverse Spin Hall Effect in Iridium Oxide

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With charge based electronics reaching their limitations, more attention is now being given to devices and materials which employ spin currents. Devices based on spintronics have shown potential application in data storage, non-volatile magnetic random access memories (MRAMs) etc. To interface spin based devices with charge based devices, we need spin to charge current conversion. This can be made possible via inverse spin Hall effect (ISHE) [1]. ISHE can be used to detect pure spin current generated by spin pumping (SP) [2]. In SP the spin angular momentum from a ferromagnet (FM) is transferred to an adjacent non-magnetic (NM) material in an external magnetic field and an excitation microwave field. The precessing magnetic moments in the FM pump pure spin current into the NM layer.

Materials with high spin orbit coupling (SOC) are used for spin current detection, the popular ones being high Z metals like Pt, Ta, W, etc. However, for efficient spin to charge conversion high spin hall resistivity (ρ_C) is required, which lacks in these materials. It has been shown that 5d transition metal oxides, such as Iridium oxide, also exhibit high SOC, which originates due to the 5d electrons in the conduction band. Further, Fujiwara et. al. [3] have shown a high ρ_C of 38 Ω.cm at room temperature in IrO_2 nano-wires using spin-valve geometry. To the best of our knowledge we report, for the first time, observation of ISHE in IrO_2/CoFeB thin films via SP through FMR. The individual contribution of spin pumping and other spin rectification effects were disentangled in IrO_2/CoFeB bilayers by investigating the in-plane angle dependence of ISHE signal with the external magnetic field. Our analysis shows significant contribution of spin pumping effect to the ISHE signal [4].

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Controllable and reproducible vertical hysteresis loop shift in $Ni_{80}Fe_{20}/SrRuO_3$ heterostructure

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Exchange Bias (EB), based on the concept of hysteresis (MH) loop shift, discovered in 1956, is one of the most studied phenomenon [1]. The shift in the MH loop has gained a lot of interest due its huge applications in spintronic devices [2]. The shift along the vertical, i.e., magnetization axis has also gained curiosity among the researchers in EB regime [3], [4]. But, so far, no concrete results have been found. Here, we report a novel vertical MH loop shift or vertical bias (VB) in $Ni_{80}Fe_{20}/SrRuO_3$ (1:2 thickness ratio) heterostructure. A thin film of 13 unit cells (t = 5nm) of $SrRuO_3$ (SRO) was grown epitaxially by pulsed laser deposition on $SrTiO_3$ (STO) (100) substrate. Further, a polycrystalline $Ni_{80}Fe_{20}$ thin film of t = 2 nm was grown by DC/RF sputtering. We observe a clear VB at 2 K after a field cooled measurement from room temperature (300 K) to low temperatures similar to conventional EB measurement. There is a positive (negative) shift of the MH loop on applying a positive (negative) bias field of around 1 T. Essentially, there is no VB for zero field cooling (ZFC). The VB was only observed when the MH loop was measured with low field range (±0.5 T). No loop shift is found for both ZFC and FC measurements for higher field range (e.g., ±7 T) MH measurement. There is also a threshold in field tracing range (< SRO's saturation field) below which we can observe VB only. The vertical shifts are observed only below the Curie temperature (T_C) of SRO ($\sim$125 K) which increases on decreasing the temperature found from the temperature dependent MH loop measurements. The reason for such asymmetry along the vertical direction of MH loop is attributed to the field play and anisotropy difference of the two films. Further, micromagnetic OOMMF simulations were performed to understand the VB mechanism. It is found that the simulated results agree with the experimental results [5]. It is realized from the simulations that the relative thicknesses and the anisotropies of the two films are governed by the Spring thickness law and Imperial law, respectively. A quantitative and qualitative model is developed for such tuneable, controllable and reproducible VB incorporating relationship between temperature, thickness and anisotropy data extracted experimentally and computationally. This research will enable the understanding of VB in different magnetic systems and will open up new possible applications in spintronic devices [6].

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Extensive studies of magnetic and magneto-optical properties of Co_2FeSn Heusler alloy films

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Heusler alloy (HA) is a kind of material that shows the half metallicity behavior i.e. one spin channel is conducting while another spin channel is non-conducting near the Fermi surface. Those materials have huge potential applications in the field of magnetic recording and storage media, thermoelectricity, spintronics or spin electronics, magneto-optics, shape memory alloy, etc. All these properties and applications strongly depend on the chemical/atomic ordering or the so-called antisite disordering. However, to grow these materials using methods other than the conventional physical vapor deposition techniques is a challenge in the field of spintronics. So, here we have proposed a modified three step electrochemical growth method to grow thermodynamically unstable Co_2FeSn and studied their structural, magnetic, magneto-optical properties.

The electrodeposited films show a large degree of magneto-optical Kerr rotation (MOKE) as well as high saturation magnetization at room temperature. The Kerr measurements show rotation reaching up to a maximum value of $\sim 0.3^\circ$ [1] for films grown on polycrystalline copper substrate and $\sim 0.8^\circ$ [2] for those grown on a single crystalline silicon substrate, which is comparable with the films grown by conventional techniques. Kerr microscopy images clearly show the formation of the magnetic domains in these films. The static MOKE measurements also reveal that both samples possess very strong uniaxial magneto-crystalline anisotropy, which is very important from device point of view. Further angle dependent MOKE measurements were performed in longitudinal mode by varying the angle between the external magnetic field and the easy axis at 10° interval. These measurements on the electrodeposited films grown on silicon substrate reveal a two-fold symmetry [2]. The results presented here open up an opportunity to further explore electrochemically grown low dimensional intermetallic alloy films on oriented crystalline substrates for realizing possible magneto-optical and spintronics applications.

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Injection Locking of Spin Torque Nano Oscillators (STNO) Using Surface Acoustic Waves (SAW)

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The STNO devices work on the principle of the Spin Transfer Torque (STT) and are being researched actively all over the world due to their potential applications [1]. They offer several advantages like ultrasmall size, high tunability etc. over the conventional oscillators [1]. Their major drawbacks are lower output powers & phase noise [1]. Injection locking is a proposed solution to overcome these problems [2]. AC currents or magnetic fields have been explored to injection lock the STNO device to a desired frequency. AC magnetic fields can be generated by using coplanar waveguides (CPW) [3]; they need additional fabrication steps & large currents maybe required to generate these fields, resulting in significant power dissipation. AC currents need to be passed through the ultrathin tunnel barrier layer of the devices like Magnetic Tunnel Junctions (MTJ) & can cause reliability issues [4]. In this work, we explore Surface Acoustic Waves (SAW) for injection locking of the STNO, this can be an extremely energy efficient alternative [5] & can be used to lock an array of STNO devices at the same time.

The magnetoelastic coupling between the piezoelectric substrate & the ferromagnetic free layer of the MTJ produces effective magnetic field (H_{SAW}) of the form 2Bε(t), where B is the magnetoelastic coupling constant & ε(t) is the time dependent strain produced by the SAW [6]. The STNO in this work is based on a MTJ device with in-plane pinned layer & out-of-plane free layer with parameters from [7]. The magnetization dynamics of the STNO can be given by the famous Landau-Lifshitz-Gilbert-Slonczewski (LLGS) equation. We have done the numerical simulations by solving this equation considering the effect of the H_{SAW}. We have also included temperature effects by considering the random magnetic fields generated due to the thermal fluctuations. We have done a detailed study of the effect of acoustic strain ε(t) on various parameters like power spectral density (PSD), locking range, time required to lock (locking time) etc. We found that for a strain of 100 ppm, the locking rage was 55 MHz & the locking time was 100 ns. We also investigated the effects of frequency (within the locking range) & phase difference (between SAW & the STNO) on the final phase of the STNO oscillations & the locking time. We found that the frequency or phase difference do not change these things significantly suggesting that the SAW can be a very good energy efficient alternative for injection locking of the STNO devices.

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Magnetic Dynamic Properties in $Ni_{80}Fe_{20}$/Holmium at Room Temperature

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Ferromagnetic and non-magnetic heterostructures(FM/NM) have attracted more interests due to its unusual properties such as spin torque transferring in the spintronics devices. In this research, by considering larger spin-orbit coupling(SOC) in rare earth metal, focusing on the $Ni_{80}Fe_{20}$ (Py)/Holmium (Ho) bilayers, the influence of interface on the magnetization dynamic properties are investigated systematically. Various SiO_2/Ta/10Py/ d_{Ho} Ho /Ta multilayers with d from 0-40nm are prepared by magnetron sputtering. The saturation magnetization (M_S) decreases with capping Ho thickness in Py/Ho bilayers, implying that a non-zero magnetic moment of Ho at the interface near adjacent Py layer is induced by magnetic Py layer, which is found that the induced magnetic moment of Ho layer is antiparallel to the magnetization direction of moment of Py and forms an antiferromagnetic configuration at the interface. From the frequency dependence of ferromagnetic resonance(FMR) linewidth, the damping coefficient (α) with respect to the thickness of Ho is obtained. With increasing Ho thickness, α is found to exhibit an extreme enhancement. Through fitting, the interfacial mixing conductivity ($g^{\uparrow\downarrow}_{\mathrm{Py/Ho}}$) and spin diffusion length (λ_{SD}) of Ho are obtained. By comparing with that of Py/Pt and Py/Pd bilayers, we find that $g^{\uparrow\downarrow}_{\mathrm{Py/Ho}}$ is one order of magnitude larger, implying that a self-assembled antiferromagnetic coupling interface plays an important role in enhancement of spin dynamic damping. Furthermore, by inserting Cu thin layer into the interface between Py and Ho, we find that the magnetization dynamic damping enhancements are dramatically decreased. This work is essential for optimizing the operation efficiency of spintronics devices.

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Probing Spin-flipping based Magnetoresistance in Intrinsic 2D Ferrimagnet System

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Devices based on two-dimensional (2D) magnets are a promising candidate as it opens up the new venture of flexibility, opacity, and higher electrical controllability in spintronics [1]. In this regard, the non-destructive spin properties of 2D ferrimagnet provide great anisotropic and tunable magnetization, which could provide a wide range of spin configurations [2]. Herein, we visualized the intrinsic spin contribution and magneto-resistive response (MR) of 2D Chromium Sulfide (Cr_2S_3). Here, we have performed chemical vapor deposition on an Al_2O_3 substrate for large area spintronics and carried out transport measurements under an external magnetic field applied out-of-plane [3]. The microscopic and Raman investigations suggest layered non-van der Waal crystal growth along the c-axis (001) easy axis i.e., similar to that reported in CrI_3 [4], [5]. Two distinct spin coupling have been observed and described as (a) spin-polarized ($T \leq T_N$) and (b) spin-flipping ($T \ll T_N$) regimes. The low field MR of 13% has been detected in FiM ordered multilayered Cr_2S_3 with the resistance state difference of 3000 Ω at 10 K and dMR/dH showed the clear spin-flipping one to one mapping with the magnetization switching. These features are diverse from those observed in conventional 2D magnets and can be directly utilized as spin-flipping devices.

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Effect of Rare Earth (Ho and Er) Co-Substitution on the Magnetic Properties of Nano-crystalline Cobalt Ferrite

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Nowadays magnetic ferrite nanoparticle has attracted the researcher due to their broad application in different technological fields like high information density, drug delivery and magnetic fluids etc. Spinel ferrites offer a varied option for substitution and co-substitution at octahedral and tetrahedral sites. Rare earth substitution[1]–[3] and co-substitution[4][5] in Fe-sites are found to improve the magnetic property of cobalt ferrite due to the 4f electrons of the rare earth element which represent the unique nature of magnetism because of the shielding of the 5S and 5P shells.In this we are reporting the effect of rare earth(Ho, Er) co-substitution on the magnetic properties of nano-crystalline cobalt ferrite. Nano-crystalline (Ho,Er) co-substituted cobalt ferrite with formulae $CoEr_xHo_xFe_{2-2x}O_4$ $(0 \leq x \leq 0.04)$ have been synthesized by sol-gel method using citric acid as a chelating agent.The precursors obtain were grinded and palletized into circular disk and annealed at 800°C for 2 hrs. The XRD patterns are found to be in single phase, the patterns are refined by using Reitveld refinement technique using the space group $Fd\bar{3}m$. The average crystallite size have been estimated by fitting the value of the FWHM obtained form the Gaussian extrapolation of the XRD patterns into William-Hall equation($\beta cos\theta = \frac{k\lambda}{D} + 4\xi sin\theta$). It is found that the average crystalline size range from 10 to 35 nm. The lattice parameter have been determine from the Reitveld refinement and is found to increase with increase in Ho,Er concentration. The magnetic properties of the samples have been investigated by using vibrating sample magnetometer at room temperature with the applied magnetic field range of $-15Oe \leq H \leq +15Oe$. In order to obtain the saturation magnetization and magnetocrystalline anisotropy in the high field region, the measured M-H data are fitted to the Law of Approach to saturation,$M = M_s\left(1 - \frac{a}{H} - \frac{b}{H^2}\right)$. The fitted data shows a decrease in saturation magnetization though the magnetic moment of Ho, Er are larger compare to that Fe, so it may be due to the spin-orbit coupling effect dominating in rare earth ion. As well the strength of the spin orbit determined the magnetic anisotropy in nano-particles. In the present sample magnetocrystalline anisotropy and the magnetic coercivity are found to be increase with an increase in (Ho, Er) substitution which is due to the present of the stronger spin orbit coupling.

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Manipulation of Magnetic Nanoparticles using Strain-mediated FeGaB/PMN-PT Elliptical Ring Structures

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With rapid advancement of various lab-on-a-chip applications, there is a need for precise, remote manipulation of magnetic nanoparticles (MNPs). Conventional techniques to manipulate MNPs include an external magnet or current based methods, which suffer from thermal issues and inefficient manipulation. Lately, an attractive alternative that has emanated is based on strain-mediated magnetoelectric heterostructures [1]. In magnetic nanostructures, manipulation of MNPs is possible due to the high magnetic energy density gradient of the onion state. However, the onion state is less thermally stable and cannot be obtained easily [2]. Recent studies suggest that an elliptical ferromagnetic ring can easily generate the onion state due to its large shape anisotropy with improved thermal stability [3]. However, MNP manipulation using the ferromagnetic elliptical ring structures in ME devices is not investigated extensively. In this work, dimensionally varied elliptical rings of FeGaB on single-crystal PMN-PT piezoelectric substrate are analyzed. The outer diameter along the major axis of the elliptical ring is fixed, while the trackwidth (t) and the outer diameter along the minor axis are varied. Initially, an external magnetic field is applied along the minor axis and removed after saturation. The DWs containing onion state are observed at a remanent state upto a certain trackwidth (t_o) where demagnetization energy to flip the magnetization 180^o is higher. By applying an external voltage across PMN-PT, DWs are rotated at different angles depending on the elliptical ring dimensions. For lower trackwidth $(t \leq t_o)$, in-plane 45^o rotation and reversibility towards initial position are observed as stress anisotropy energy dominates the exchange and demagnetization energies to reorient the DWs toward the new easy axis. For larger trackwidth $(t > to)$, complete in-plane 90^o rotation is observed without DW reversibility as the shape anisotropy energy originated from demagnetization energy is dominant contribution of total energy. Using an analytical model, the transport dynamics of the MNPs is also studied. The proposed work can have more profound implications for precise and remote manipulation of MNPs for next-generation lab-on a chip application and can be further extended to manipulate different binding molecules such as proteins and DNA for various medical applications.

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Performance Enhancement on Direct Drive Non-oriented Laminated Core and Ferrite Material Switched Reluctance Motor for Electric Transportation Systems

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The outer rotor switched reluctance machine (SRM) for cognitive enhancement is described in this research study at 250W, 12/10, 500 rpm. The SRM has notable characteristics such as no rotor windings, isolated phase windings, and high beginning torque, but it also has shortcomings such as torque ripple, acoustic noise, and heat dispersion. The torque ripple, iron losses, and machine power density are all reduced in this article by using a laminating core material and inserting a permanent magnet in the motor. The electromagnetic (EM) examination of a traditional SRM reveals increased torque ripple and iron losses. When choosing among M19, M15-26Ga, M45-24Ga, 64F190, M1000-100A, and M700-65A laminating core materials with classical SRM, EM analysis is used to infer high stability based on lower torque ripple and iron losses. Furthermore, research is being conducted to obtain the optimal density by embedding a permanent magnet into the stator core. The PM is located in the stator's auxiliary poles, which might be horizontal, vertical, or L-shaped. The magnetization orientation of the PM alternates with that of nearby auxiliary poles, ensuring that the motor generates torque regularly. The stator core's vertically positioned PM delivers higher average torque and low cogging torque, leading to an increase in power density. With characteristics such as torque ripple, iron losses, and cogging torque, numerical equations are used to evaluate the finite element analysis results. The laboratory setup is designed to verify FEA results under no load and load scenarios. The FEA results are satisfied by the torque transducer results validated with the average torque and the weight arrangement for cogging torque measurements with the proposed PM SRM.

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Coupled lattice vibration and exchange bias in rare-earth substituted $NdCrO_3$

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This study demonstrates the correlation of crystal structure and magnetic properties of the Eu doped $NdCrO_3$ sample. The polycrystalline $Nd_{0.9}Eu_{0.1}CrO_3$ sample synthesized by standard solid-state reaction method, crystallizes in an orthorhombically distorted perovskite structure with the space group *Pnma*. The X-ray diffraction and Raman analysis confirmed the pure phase sample exhibiting the unit cell decrement and development of the structural distortions compared to the parent $NdCrO_3$ sample [1]. The microstructural analysis revealed the good quality of the homogenous bulk sample with an average grain size of 0.792 μm. The magnetization measurements confirm the antiferromagnetic ordering of Cr^{3+} spins occurring at T_N = 224.1 K and the spin reorientation transition due to reorientation of Cr^{3+} spins at T_{SR} = 39.2 K similar to the parent sample [2]. The magnetic ordering of Nd^{3+}/Eu^{3+} ions at T_{RE} = 11.9 K is also found in our sample. The negative exchange bias effect with the maximum exchange bias field of H_{EB} = -1297 Oe is obtained between T_N and T_{SR}. The effect spin-reorientation on the exchange bias is observed in the non-monotonic trend of the exchange bias field. The shifts of field cooled M-H loops along the H- and M- axis manifest the exchange bias along the H, M- axis, very few compounds such as weak ferrimagnet $LuFe_{0.5}Cr_{0.5}O_3$ exhibits exchange bias along both the axis [3]. We have also studied phonon modes as a function of temperature using temperature-dependent Raman spectroscopy for the first time in $NdCrO_3$ based orthochromites, which gives remarkably strong spin-phonon coupling in the present sample, as reported in a few $RCrO_3$ with magnetic R-ion [4]. Our findings show the effect of lattice distortions on the exchange bias resulting in the direct interplay between spin and lattice in a single phase.

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Magnetism at the interface of non-magnetic Cu and C_{60}

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The signature of magnetism without having a ferromagnet in the sample stack is both novel and fascinating from fundamental research point of view. It is possible to alter the electronic states of non-ferromagnetic materials (Cu, Mn, Sc, Pt) to overcome the Stoner criterion and make them ferromagnetic at room temperature [1], [2]. In this context it is desired to quantify the magnetic moment at the interface of such non-FM/OSC. We have studied the Cu/C_{60} heterostructure and quantified the magnetic moment induced in Cu using X-ray magnetic circular dichroism (XMCD) sum rules. The multilayer of Cu/C_{60} were prepared on Si (100) substrate without breaking the vacuum using DC magnetron sputtering and thermal evaporation for Cu and C_{60}, respectively. Field dependent magnetization measurements using SQUID magnetometry show a clear ferromagnetic hysteresis even in the absence of any ferromagnetic element in the sample stack. The induced magnetic moment in the samples is corroborated to the charge transfer and the molecular coupling between the metal (Cu) and carbon. The origin of the charge state of C_{60} to a reconstructed interface is due to (4 $\times$ 4) 7-atom vacancy holes in the surface [3]. The possible reason of this induced magnetic moment is hybridization between d_{Cu} and $p_{\mathrm{C}_{60}}$ orbitals [1]. In order to evaluate the spinterfacial magnetic moment, XMCD has been performed on the samples. We have calculated the induced moment in Cu using magneto-optic sum rule [4]. Due to the charge transfer at the reconstructed Cu/C_{60} interface the density of state of Cu has been modified and exhibits $\sim$ 0.01 μ_B /atom magnetic moment [5]. Our understanding of the interface between the NM/OSC heterostructures may bring the new insights to the field of organic spintronics.

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Reentrant Spin-glass Behavior of $Tb_2Ni_{0.94}Si_{3.2}$ Alloy

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Due to the unbalanced exchange interactions, geometrically frustrated systems exhibit fascinating physical properties that mainly originate from frustration. R_2TX_3 series is one such frustrated system in rare-earth intermetallics family. Due to competing interaction between the rare-earth atoms in the hexagonal site and random occupancy of T and X atoms in $2d$ Wyckoff site, spin glass behavior is observed [1]. In this work, $Tb_2Ni_{0.94}Si_{3.2}$ alloy in its polycrystalline form has been prepared by arc melting technique followed by annealing at 1073 K for a week. Magnetic, magnetocaloric, and transport properties have been studied [2]. $Tb_2Ni_{0.94}Si_{3.2}$ alloy crystallize in AlB_2-type structure (space group = $P6/mmm$) with lattice parameters, $a = b = 3.9210(3)$ Å, and $c = 4.0044(5)$ Å, respectively, which are determined from the Rietveld refinement of room temperature powder XRD studies. Nearly unity value of the lattice parameter ratio (c/a) denotes the frustration in the alloy. In accordance with this, magnetic properties of the alloy showed an antiferromagnetic transition at T_N = 13.7 K and followed by spin-glass behavior below T_f = 5.2 K. Ac magnetic susceptibility, magnetic relaxation studies, magnetic hysteresis, and heat capacity studies have been employed to study the spin-glass behavior of the alloy. In ac magnetic susceptibility, frequency-dependent variation of peak around T_f denotes the spin-glass nature. Also, frequency shift per decade (δT_f), dynamical critical exponent (zv), and single flip time (τ_0) are determined to be 0.08, 4.0(8), and 10^{-5}s, respectively, which are in line with other spin-glass systems [3]. In addition, Vogel-Futcher law of dynamical scaling of frequency dependence of freezing temperature, $\omega = \omega_0 e^{-E_a/K_B(T_f - T_0)}$, is described well with activation energy E_a/K_B = 7.0(1) K, and Vogel-Futcher temperature T_0 = 3.4(3) K. $E_a/K_B T_0$ = 2.05, also denote the cluster dynamics in the titled alloy [4]. Analysis of remanent magnetization decay points out that the spin-glass behavior below T_f and a more stable ground state reachable at temperatures above T_f. Further, heat capacity studies and magnetic hysteresis also confirm to the alloy's spin glass behavior and antiferromagnetic transition around T_f and T_N. Hence alloy shows a long-range magnetic order followed by spin-glass behavior, which denotes the reentrant spin glass nature of the alloy. From an application point of view, alloy offers a magnetic entropy change of 8J/KgK in 5T.

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Spin-orbit Torque in Synthetic Antiferromagnets

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In view of the challenge that the ferromagnetic films used as the free layer in the traditional tunnel junction will produce magnetostatic coupling interference, we have prepared two types of antiferromagnets with Pt/[Co/Pd]/Ru/[Co/Pd] and CoFeB/Ta/CoFeB structures. Using the different contributions of the upper and lower ferromagnetic layers to the anomalous Hall effect, the electrical method clearly observes the SOT switching of the two ferromagnetic layers between the two antiparallel states [1], [2]. The near-zero magnetic moment of the artificial antiferromagnet greatly improves the SOT switching efficiency, which is 5 times higher than that of the corresponding ferromagnetic system. We report that the effective modulation of Dzyaloshinskii-Moriya interaction by the interfacial crystallinity between ferromagnets and adjacent heavy metals plays an important role in domain wall configurations. By adjusting the domain wall configuration between Bloch type and Néel type, we successfully demonstrate the field-free SOT-induced magnetization switching in [Co/Pd]/Ru/[Co/Pd] SAF devices constructed with a simple wedged structure [3]. Our work provides a practical route for using synthetic antiferromagnets as the free layer of the tunnel junction to construct a high-density, low-power magnetic memory.

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Active spintronic-metasurface terahertz emitters with tunable chirality

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We propose a novel type of laser-driven terahertz emitters, consisting of metasurface-patterned magnetic multilayer heterostructures, which can offer a flexible, broad bandwidth, terahertz chirality coherently manipulable source. Such hybrid terahertz emitters combine the advantages of spintronic emitters for being ultrabroadband, efficient and highly flexible, as well as those of metasurfaces for powerful control capabilities on the polarization state of emitted terahertz waves on a ultra-compact platform. Taking a stripe-patterned metasurface as an example, we demonstrate the efficient generation and manipulation of broadband chiral terahertz waves. High ellipticity of terahertz waves (>0.75) can be achieved over a broad bandwidth (1-5 THz), and can be continuously tuned by an external magnetic field, leading to a flexible, reliable and cost-effective chiral terahertz source. The polarization state of emitted terahertz wave is dictated by the interplay between laser-induced spintronic-origin currents and the screening charges/currents in the metasurface, which exhibit tailored anisotropic properties due to the "designed" geometric confinement effects. Our work opens a new pathway to metasurface-tailored spintronic emitters for efficient vector-control of electromagnetic waves in the terahertz regime.

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Negative Temperature Coefficient of Resistivity in Ferromagnetic $Co_{1-x}Fe_xS_2$: Role of Quench Disorder

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The metal to insulator like transition associated with paramagnetic (PM) to ferromagnetic (FM) ordering in $Co_{1-x}Fe_xS_2$ is unusual and rare. Here, FM state turns out to be the either high resistance state or insulating state [1]. In the case of parent compound CoS_2 (Curie temperature T_C = 120 K) both the state remains metallic with relatively higher resistivity in FM state around T_C [2]. With Fe substitution for Co, the temperature region of negative TCR (temperature coefficient of resistivity) increases and for x = 0.3 - 0.9 it remains negative down to the lowest temperature of measurement [1]. For x $>$ 0.9 compositions remain insulator over entire temperature range and the end member is known to be a diamagnetic insulator. The origin of negative TCR below and around T_C for intermediate compositions particularly for x $<$ 0.5 remains debatable. Here, we present our study on the role of chemical disorder in negative TCR region below T_C.

To decouple contribution of quench disorder and order parameter change in negative TCR, we tried to reduce T_C as well as change the nature of PM-FM transition from second order to first order with chemical substitution. In such system, order parameter is expected to remain nearly constant but for abrupt change at the transition. In the case of CoS_2, Se substitution for S is known to shift transition temperature to lower temperature and above a critical concentration transition becomes first order. Therefore, in this investigation y = 0.09 and 0.12 of $Co_{1-x}Fe_x(S_{1-y}Se_y)_2$ were chosen for which T_C is shifted to around 50 K and near zero K, respectively for Fe free (i.e. x = 0) composition [3], [4]. For each y, three compositions with x = 0.1, 0.2 and 0.5 are investigated.

Using XRD, resistivity and magnetoresistance study we could show the correlation between region of negative TCR and disorder for lower x. Apart from determining the role of quench disorder, this study also shows absence of hysteresis for Fe doped samples. Latter finding could be useful for applications point of view, like in reducing hysteresis losses in magnetic refrigeration.

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Laser-Controlled Real and Reciprocal Space Topology in Multiferroic Insulators

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Magnetic materials in which it is possible to control the topology of their magnetic order in real space or the topology of their magnetic excitations in reciprocal space are highly sought-after as platforms for alternative data storage and computing architectures. Here we show that multiferroic insulators, owing to their magneto-electric coupling [1], offer a natural and advantageous way to address these two different topologies using laser fields. We demonstrate that via a delicate balance between the energy injection from a high-frequency laser and dissipation processes, single skyrmions - archetypical topological magnetic textures [2] - can be set into motion with a velocity and propagation direction that can be tuned by the laser field amplitude and polarization, respectively. Moreover, we uncover an ultrafast Floquet magnonic topological phase transition in a laser-driven skyrmion crystal. To account for dissipation effects, we employ the Floquet-Magnus expansion [3], [4] to model periodically driven magnetic textures and develop a novel Floquet magnon formalism.

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SMC iron powder switched reluctance generator for small-scale direct-drive wind power applications

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In the field of hard magnetic (PM) materials an alternative choice for laminated stack is Soft Magnetic Composite (SMC) or Somaloy Prototyping Material (SPM) or Pre-fabricated SMC blanks. Here iron powder grains are separated from one another by electrically insulating layer using phenolic or silicone resin [1], [2]. As compared with laminated stacks, SMC materials offer a greater resistance to eddy current formation, as well as presenting designers with the advantage of magnetic properties which are isotropic in nature, instead of being confined to two- dimensions as with the case of laminates. This reveal exposes the possibility of creating complicated 3-D flux paths, which would be impossible or prohibitively expensive to fabricate from conventional laminated sheet [3]. This paper presents option of research the SMC iron powder as core material in a switched reluctance generator (SRG) [4], [5] that might effective in small scale, low speed, and standalone wind energy conversion system (also known as micro wind turbine) such as on rooftop. In a nutshell, it can be concluded that this research pursuit identified the advantages and disadvantages of the use of SMC in switched reluctance generator for the first time, through extensive simulation, analytical, fabrication and experimental avenues. The thermal performance and vibration behavior fared well in the prototype SMC-SRG while it exhibited poor performance on the electromagnetic front [6], [7]. It has the potential of low weight, high power and reduced voltage ripple which may promise a reliable, low cost switched reluctance generator system. The fabrication process of SMC iron powder switched reluctance generator, finite element simulation and experimental validation of the proposed prototype are delineated.

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Manipulation of Magnetocaloric Properties by Thickness Induced 3D Strain in Epitaxial $La_{0.8}Ca_{0.2}MnO_3$

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Among the various energy saving and ecofriendly innovations, low power magnetic refrigeration has led to the resurgence of interest in a new technology as an alternative to vapor-based refrigeration [1], [2]. It deals with the thermal effects induced by the application magnetic field, popularly known as magnetocaloric effect (MCE). The first order magnetic phase transition (FOMPT) assures the large MCE due to large latent heat involved [3]. The order of phase transition is sometimes determined by the epitaxial strain [4]. Here, we show the 3-dimensional strain effects on the magnetocaloric properties of epitaxial $La_{0.8}Ca_{0.2}MnO_3$ (LCMO) thin films grown on two types of substrates, $SrTiO_3$ (001) (STO) and $LaAlO_3$ (001) (LAO). They create in-plane biaxial tensile and compressive strain, respectively. We study the effect of film thickness (t) within the range of 25 –300 nm. A maximum entropy change (ΔS_M) of $\sim$12.1 J/Kg-K and $\sim$3.2 J/Kg-K for LCMO/STO and LCMO/LAO, respectively can be seen at $t\sim$75 nm (at 6 T applied magnetic field). LCMO/LAO shows a broadening of transition region compared to LCMO/STO. Along with the absence of hysteresis in magnetization vs temperature (MT) curve for LCMO/LAO this broadening indicates the second order magnetic phase transition (SOMPT) whilst the hysteresis in MT curve in LCMO/STO illustrates FOMPT [5]. It can be seen from the calculated maximum Relative Cooling Power ($\sim$361 J/Kg for LCMO/STO and $\sim$339 J/Kg for LCMO/LAO) that due to hysteresis loss, LCMO/STO does not lead to the expected large MCE, it's almost comparable to that for LCMO/LAO exhibiting the SOMPT. But, both of them show the maxima at $t\sim$75 nm. The Curie temperature (T_C) varies with t for both LCMO/STO and LCMO/LAO showing maxima at $\sim$75 nm. To explain the anomalous behavior of MCE and T_C bellow 100 nm thickness, two well-known effects are considered simultaneously-Double Exchange interaction [6] and $3d_{x^2-y^2}$ orbital stabilization [7]. These play a vital role in determining the strength of the ferromagnetic interaction and hence determine T_C as well as MCE. The maximum value of ΔS_M is found to be a Lorentz function of t showing maxima at $\sim$66±5nm. Hence, a generalized model for optimization of t is achieved to attain large MCE which can be used in other magnetocaloric devices too to maximize the MCE. Moreover, the variation in transition temperature makes the LCMO films flexible to use at different operating temperatures.

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Magnetic Ferumoxytol/Silk fibroin/Collagen Composite Scaffold with Enhanced Mechanical Property and Formability

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Although the freeze-dried silk fibroin scaffold had been widely prepared [1], [2]; its relatively large fragility and uneasy formability greatly limited its application in the field of tissue engineering [3]. In this study, we reported the preparation of a high-performance magnetic ferumoxytol (FMT)/silk fibroin (SF)/collagen (COL) composite material through an improved freeze-drying method with a gradient temperature rise. Silk fibroin-based scaffolds with high mechanical properties and formability could be a promising platform for vascular injury repair [4]–[6]. The constructed composite material first used genipin to cross-link the silk fibroin and collagen and conducted elasticity testing to screen out the best silk fibroin/collagen ratio of 97/3 (v/v). The leakage of magnetic nanoparticles FMT was evaluated using silk fibroin/collagen modified with polyquaternium-1 (PQ-1). It was proved that the scaffold containing PQ-1 showed less leakage rate of FMT and effectively ensured the role of FMT in improving the performance of the scaffold. The effects of FMT with different magnetic responsiveness on the mechanical properties and formability of the scaffold was examined, reflecting the best all-around performance of the FMT@SF@COL-2 sample, which could be used as a potential candidate material for vascular repair in the future.

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Resonant excitation of terahertz spin wave by accelerating antiferromagnetic domain walls without the Lorentz contraction

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Manipulation of antiferromagnetic (AFM) domain walls (DWs) plays a fundamental role in developing emerging spintronic devices with small size and high velocity [1]–[3]. In this work, we theoretically investigate the emission of terahertz (THz) spin waves from a moving AFM DW under the magnetic anisotropy energy gradient (dE_a/dx). The DW velocity exceeds the relativistic limit and keeps increasing, accompanying with the broadening DW width. This is different from a traditional relativistic AFM DW motion with an upper limit of velocity and Lorentz contraction. The DW acceleration effectuates the DW precession. When the frequency of DW precession is greater than the frequency gap of spin waves propagating in the AFM medium, a continuous THz spin wave is resonantly emitted. Contrary to the relativistic-like AFM spin wave, the frequency of the dE_a/dx-induced spin wave increases with the decrease of the anisotropy energy constant. Because dE_a/dx can be readily generated under a DC voltage, this work provides a feasible approach for the development of on-chip THz spintronic devices with low dissipations.

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Ultrafast Spin-charge Interconversion in Antiferromagnets Studied by Terahertz Emission Spectroscopy

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Recently, ferromagnetic/nonmagnetic heavy metal heterostructures have been intensively investigated as terahertz (THz) emitters [1]. The interconversion of spin-to-charge dynamics plays a central role for efficient emission of THz electromagnetic pulses [2]. However, a direct observation of spin-charge interconversion in antiferromagnet (AFM) occurring on the sub-picosecond time scale remains a challenge. It is worth noting that all-electrical switching of the magnetization in AFM materials with lacking the local inversion symmetry has attracted tremendous interests, which is critical for potential applications of AFM spintronics [3]–[7]. We experimentally performed laser stimulated the THz emission from Co/Mn_2Au and Co/$IrMn_3$ bilayers, using electro-optic sampling in the time domain. The inverse spin Hall effect in Mn_2Au and $IrMn_3$ antiferromagnetic layers is indispensable to explaining the dependence of THz emission on pump- and magnetic-field-directions. In details, light-launches a spin current pulse into the AFM Mn_2Au or $IrMn_3$, wherein the spin current interconverts into a radiative charge transient current due to the inverse spin-Hall effect (ISHE) [8]. To further characterize the THz emissions from Co/Mn_2Au and Co/$IrMn_3$ bilayers, we measured the dependences of the THz field on the pump fluence. The pump-fluence dependent THz amplitude shows different increasing trend for two samples. After reaching a critical pump fluence, the peak-to-peak value of THz emission from Co(3)/$IrMn_3$(5) exceeds that from Co(3)/Mn_2Au(5). Values in parentheses is the thickness of the layers in nanometers. The characteristics of THz emission provide not only the information regarding the spin-to-charge interconversion dynamics on picosecond time scale, but also a possibility of spectroscopic-based spin current detector at THz frequency range.

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First-principles Prediction of the Half-metallicity in Quaternary Heusler CoRhCrAl Thin Films

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Being the foundation and top priority of the modern information industry, the integrated circuit industry is fast evolving along with the advancement of science and technology. However, as the constituting components of electronic devices continue to be miniaturized down to the nanometer scale, quantum effects become progressively dominating, leading to the breakdown of Moore's Law that has driven the semiconductor industry for decades [1]. Spintronics, based on the spin degree of freedom in addition to charge, is considered to be a viable technology, with exciting potential for the post-Moore electronic devices featuring a multitude of excellent properties, such as high integration density, low power consumption, fast operating speed, and so forth [2].

On the other hand, an important key to a successful prototype spintronic device concerns the spin injection efficiency via the use of highly spin-polarized electrons. Heusler alloys, with their 100% spin polarization, high Curie temperature and half-metallic behavior, are ideal materials in this regard [3], [4]. However, considering that thin films are mostly employed for device applications, it is logical to question whether the half-metallicity associated with the alloys will be preserved at the surface or interface with lowered symmetry than the bulk counterpart [5].

On top of the seminal work of K. Jafari et al. [6], we perform a first-principles study of the structural, electronic and magnetic properties of the pristine bulk CoRhCrAl quaternary Heusler alloy and its (111), (001) and (110)-oriented thin films by density functional theory calculations [7]. Our results indicate that the pristine bulk structure of CoRhCrAl alloy is half-metallic in character with 100% spin-polarization. For the thin film structures with different orientations and terminations, half-metallicity only exists in the (111)-oriented thin film with Al-termination, but not with Co-, Rh- or Cr-termination; both (001)- and (001)-oriented CoRhCrAl are nearly half-metallic in thin film forms.

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High-performance Worm-like Mn-Zn Ferrite Theranostic Nano-agents and the Application on Tumor Theranostics

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Previous reports revealed the significant potential advantage of Mn-Zn ferrite nanoparticles (NPs) in the magnetic resonance imaging (MRI), while anisotropic nanoparticles reportedly increased the blood circulation time of nanocarriers [1]–[4]. Thus, anisotropic Mn-Zn ferrite displayed a huge potential in cancer synchronous diagnosis and treatment, that is, enhanced MRI observation was performed simultaneously when drug-targeted delivery therapy was applied to the tumor [5]. Here, we developed three shaped Mn-Zn ferrite ($Mn_{0.63}Zn_{0.37}Fe_2O_4$) MNPs used as cancer theranostic nano-agents and compared the effect of the three shaped MNPs on the cancer theranostics. Compared to the monodisperse sphere MNPs (S-MNPs-PPR) and the clustering MNPs (C-MNPs-PPR), worm-like Mn-Zn ferrite MNPs (W-MNPs-PPR) achieved better results in T2-weighted MRI and achieved more sustained drug release than S-MNPs-PPR and more complete drug release than C-MNPs-PPR in vitro. Additionally, polyethylene glycol (PEG) coating and RGD-modification encouraged the three shaped MNPs to evade the recruitment of macrophages more easily, while to tend to target the integrin-enriched endothelial cells instead. Meanwhile, W-MNPs-PPR coupled with Paclitaxel (PTX) exhibited more delivery of PTX in the integrin-enriched cells than the other two shaped MNPs, and the content of PTX was far more than that of the wild-type Taxol control group. What’s more, in vivo results demonstrated that PTX-coated W-MNPs-PPR not only gained good dual-mode imaging in the tumor (MRI and Fluorescence images) but also achieved longer blood circulation time and more PTX targeted delivery to the tumor, as well as more efficient in tumor cells killing. Which make the simultaneous diagnosis and treatment of tumors to be conducted. Therefore, our works further revealed the importance of nanoparticle shape on its functionality and ultimately provided an alternative and efficient worm-like theranostic nano-agent for tumor theranostics [6].

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Study of spin pumping in sputtered MoS_2/CoFeB bilayers

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2D-transition metal dichalcogenides (TMD) are known to have high spin-orbit coupling, an essential property for spintronic applications [1], [2]. In this context TMD materials can replace the heavy metals for next generation spintronic devices. MoS_2 is a popular TMD which has been of great interest in recent years due to its unique electrical and optoelectronics properties. It can be fabricated in very thin layers due to weak Van der waals forces, which makes it suitable to investigate interface dominated Rashba and Edelstein effects. However, fabrication of MoS2 by chemical or exfoliation methods makes it difficult for spintronics applications. In this work, we demonstrate spin pimping and inverse spin Hall effect in sputtered MoS_2(t)/CoFeB(6 nm)/MgO(2 nm) heterostructures where 't' varies from 6 to 28 nm.

The samples were fabricated by RF and DC sputtering for MoS_2 and CoFeB, respectively, on thermally oxidized Si substrate. MgO capping layer was deposited by thermal evaporation. Here the spin current was generated from CoFeB and injected into MoS_2 layer via spin pumping using ferromagnetic resonance (FMR). The resulting spin to charge conversion at interface was measured using nanovoltmeter. Various spin rectification effects were separated by performing angle dependent measurements [3]. For the sample with MoS_2 (9 nm), a spin pumping voltage of $\sim 5.6\ \mu$V was measured which was dominant over the rectification effects. The spin mixing conductance for this sample was found to be $\sim 3.92 \times 10^{18} \mathrm{m}^{-2}$. In order to understand the origin of this voltage, power and frequency dependent measurements were also performed. The linear increase in the symmetric component of dc voltage with the microwave power further indicated spin pumping [4].

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Geometry-dependent deterministic skyrmions generation

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Magnetic skyrmions have been flagged as promising candidate for efficient storage and information processing for their longer stability, compact size and non-volatility [1]–[3]. Various concepts and prototypes for skyrmion-based devices have been proposed to study dynamics of isolated as well as train of skyrmions [4]. The influence of edge geometries and defects on phase transitions and evolution of spin textures have already been studied earlier but still needs further investigations [5]–[7]. In our work, we have demonstrated conversion of skyrmionium (Q=0) using distinct channeled geometry can be employed to achieve from no to multi-skyrmionic (Q=+1) states. The number of skyrmionic states depend upon a threshold current density used to drive the chiral structure through the channels. We have studied the dynamics of the spin textures throughout the conversion process in single ferromagnetic layer and synthetic antiferromagnetic system. The demonstrated transformation process could lead to development in skyrmion-based spintronics.

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Strategies to minimize magnetic particle hyperthermia side effects

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Magnetic particle hyperthermia is based on the heat production of magnetic nanoparticles under an alternating magnetic field (AMF) and aims to increase the temperature of cancer tissues within 41-45°C range, resulting to thermal shocking, cell apoptosis or even necrosis. A key issue, for its successful implementation, is its selectivity, as apart from cancer tissues, surrounding healthy tissues undergo a potentially harmful thermal shock, due to itinerant eddy currents, naturally arising along with AMF application. The scope of this work is to reduce the side-effect heating of surrounding tissues without sparing the beneficial role of overheating malignant regions. Therefore, cancer regions should keep on safely entering the hyperthermia window of (37oC+Δθ=4-8 °C), while neighboring tissues should hinder their temperature increase to much smaller values (Δθ<4°C). To achieve this, we examined how we may adjust field exposure time intervals by two different approaches. First, we studied the application of pulsed magnetic field (PMF) instead of the typical AMF during magnetic particle hyperthermia, where multiple On-Offs replaced the single continuous On-Off pulse. Second, the magnetic particle hyperthermia coil was moving periodically, so the specimen remained under field exposure for limited duration. All experiments were held in a typical magnetic particle hyperthermia setup under a field of 376 kHz and 60 mT on phantom and ex-vivo samples (healthy and cancer ones). Adjustable parameters, in both cases were the time intervals of field application on sample's region. PMF application on a healthy tissue phantom results to a Δθ reduction of 7.4°C (11.2 °C for AMF to 3.8 °C for PMF). Although, an analogous decrease of 11.4 °C occurred in the cancer tissue phantom (21.8°C for AMF to 10.4 °C for PMF), yet the ultimate high enough Δθ=10.4°C outlines the successful entrance in hyperthermia window. Accordingly, the relative movement of coil-sample resulted to Δθ decrease of 4°C (9.2-5.2 °C) for the healthy tissue phantom while for the cancer one to 5.1°C (12.2-7.1 °C). Consequently, by modifying the temporal profile of field application during magnetic particle hyperthermia either by pulses or by relative movements succeeds in suppressing eddy currents in surrounding tissues and allows for application of larger field amplitudes to enhance hyperthermia efficiency confronting field constraints such as Brezovich criterion.

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Experimental and theoretical equi-sensitive approach with flexible operating field range based on NiFe/IrMn sensors

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The planar Hall effect sensors possess several desirable specifications, for instance, enhanced signal to noise ratio, reduced limit of detection, and thermal stability [1]. During the fabrication of the sensor, each layer of the subsequent deposited layers maintains a specific objective [2]. Inherently, the insertion of a spacer layer (such as Cu) [3] in the NiFe/IrMn interface has a negative impact on the exchange bias magnitude [4], conversely it owes a positive effect on the output voltage and the sensor' s sensitivity. However, the introduction of the capping layer doesn' t reflect substantial impact on the operating field range, but it affects the output voltage as it increases the shunt current [5]. Therefore, the simultaneous manipulation of output voltage and operating field range can' t be accomplished. Herein, the new approach for precisely controlling the operating field range and output voltage simultaneously in a way that the same aspect ratio is presented to affirm stable sensitivity. The calculated equation that rules the association between the thicknesses of seed and capping layers is introduced. The output voltage, sensitivity, and operating field range is estimated for two systems. NiFe/IrMn, and NiFeMo/IrMn. The coincidence between the theoretical and experimental results for both systems is clarified. This approach affirms the stability of sensitivity with a flexible operating field range as well as a reduced power consumption, which offers feasibility, saves time and cost for an end product.

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Magnetic simulations of permanent magnet drum of eddy current separator

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Electrical energy is transported from one place to another through overhead or underground transmission or distribution lines. Underground cables have several advantages such as less prone to mechanical damage, elimination of lightning strikes as well as bypass, increased reliability of supply, lower maintenance cost, less risk of breakdowns, less voltage drop and reduction of visual impact. Underground cables are generally used in densely populated urban areas where overhead transmission lines are difficult to install. These underground cables produce a strong electromagnetic field in sensitive areas in stable or transient conditions. The objective is to carry out a study on the electromagnetic pollution of electric cables, and to compare the results with international standards. As a result, this study contains an electromagnetic simulation of electric cables as a function of several parameters (distance, frequency, voltages or currents, abnormal conditions, etc.), to see the influence on these limits required by the commission international electricity. In our study, we simulate the electromagnetic effect of inductive and capacitive phenomena of underground electrical cables and by measuring the electromagnetic fields values, inside and outside from cables, the presence of important current produces a significant electromagnetic field in environment.

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Magnetic simulation of high voltage underground power cables

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Electrical energy is transported from one place to another through overhead or underground transmission or distribution lines. Underground cables have several advantages such as less prone to mechanical damage, elimination of lightning strikes as well as bypass, increased reliability of supply, lower maintenance cost, less risk of breakdowns, less voltage drop and reduction of visual impact. Underground cables are generally used in densely populated urban areas where overhead transmission lines are difficult to install. These underground cables produce a strong electromagnetic field in sensitive areas in stable or transient conditions. The objective is to carry out a study on the electromagnetic pollution of electric cables, and to compare the results with international standards. As a result, this study contains an electromagnetic simulation of electric cables as a function of several parameters (distance, frequency, voltages or currents, abnormal conditions, etc.), to see the influence on these limits required by the commission international electricity. In our study, we simulate the electromagnetic effect of inductive and capacitive phenomena of underground electrical cables and by measuring the electromagnetic fields values, inside and outside from cables, the presence of important current produces a significant electromagnetic field in environment.

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Driving skyrmions with low threshold current density in amorphous CoFeB thin film

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Magnetic skyrmions are topologically stable spin swirling particle like entities which are appealing for next generation spintronic devices [1]. The expected low critical current density for the motion of skyrmions makes them potential candidates for future energy efficient electronic devices [1], [2]. Several heavy metal/ferromagnetic (HM/FM) systems have been explored in the past decade to achieve faster skyrmion velocity at low current densities [3]–[5].

In this context, we have studied Pt/CoFeB/MgO heterostructures in which skyrmions have been stabilized at room temperature (RT). It has been observed that the shape of the skyrmions are perturbed even by the small stray field arising from low moment magnetic tips while performing the magnetic force microscopy (MFM), indicating presence of low pinning landscape in the samples. This hypothesis is indeed confirmed by the low threshold current density (0.8×10^{11}A/m^2) to drive the skyrmions in our sample.

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Understanding the Role of SiO_2 Spacer Layer on Interlayer Magnetic Coupling of FeTaC Multilayer Films

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We report systematic investigation of the effect of number of multilayer and the thickness of spacer layer on the magnetic properties of multilayer [FeTaC (y nm)/SiO2 (z = 0-6nm)]n/FeTaC (y nm) films fabricated on thermally oxidized Si substrate using magnetron sputtering technique. All the as-deposited films are amorphous in nature. Single layer FeTaC (100 nm) film exhibits transcritical loop with high coercivity (H_C) and saturation (H_S) due to the formation of stripe domain pattern. It is mainly caused by the development of effective magnetic anisotropy instigated by continuous accumulation of stress during the deposition process [1], [2]. Interestingly, the introduction of SiO_2 spacer layer in multilayers film helps reducing coercivity from 1.96 kA/m for 100 nm single layer film to 0.43 kA/m for multilayer film with n = 2 and saturation field from 66.4 kA/m to 2.42 kA/m. Therefore, SiO_2 spacer layer plays a key role in improving the soft magnetic properties in multilayer film. However, the improvement of soft magnetic properties in multilayer film majorly govern by the interlayer magnetic coupling between the ferromagnetic layer which strongly depends on number of multilayers (n) and the thickness of SiO_2 layer (z) and the measurement temperature. With increasing n, the individual thickness of ferromagnetic layer (y) in multilayer film decreases, resulting the loss of effective magnetic anisotropy and change in magnetic domain pattern from stripe domain to in-plane orientation. Kerr loops and magnetic domain images of the bilayer films (n = 1) with different spacer layer thicknesses (z = 1 and 4) along the film planes reveals the dynamics of magnetic domain due to domain wall motion which is in good agreement with the multistep magnetization reversal observed in the bilayer films [3]. A detailed and systematic analysis of change in magnetic domain structure in single layer and multilayer films and the effect of number of multilayers, SiO_2 spacer layer thickness on the interlayer magnetic coupling over a wide range of temperatures would be presented.

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Structural and Magnetic Properties of CoIrMnAl Heusler Alloy Epitaxial Films Fabricated with a Magnetron Sputtering for Spintronics Applications

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A major area of research in the field of spintronics is the development of materials used for the fabrication of magnetic tunnel junctions (MTJ). Current uses for MTJs are data storage media and non-volatile memory devices such as MRAM [1]. Emergent computing technologies are already setting the demand for new MTJ electrode materials, namely, extremely high TMR ratios at room temperature [2]. Low temperature TMR ratios in excess of 2600% have been observed experimentally in half-metallic ferromagnetic materials [3]. The reduction in TMR ratio with temperature is thought to be due to loss of spin polarisation and desirable magnetic order at the interface of the electrode and the MgO tunnelling barrier [4]. Therefore, it is critical that any potential electrode material be a close crystallographic match to MgO and present consistent electronic character across a range of interfacial conditions.

A potential candidate for MTJ electrodes are quaternary Heusler alloys with equiatomic stoichiometry [5] i.e. having chemical formula XX'YZ. Recent theoretical studies have found that quaternary Heusler alloys of the form CoIrMnZ (Z= Al, Si, Ga, Ge) have near perfect spin polarisation due their half-metallic nature and have Curie temperatures above room temperature [6]. The fully ordered bcc-structure of these alloys is an excellent match to MgO. While swap-disorder within the unit can be used to tune the magnetic properties [7].

Here we have successfully deposited thin films of CoIrMnAl (50nm) at room temperature with B2 chemical ordering using sputter deposition [8]. In-situ annealing at 500-600°C yields a lattice constant approximating the theoretical values. Magnetic measurements showed ferrimagnetic ordering and a Curie temperature of 400K; which is ∼70% of the predicted value. Cross-section scanning transmission electron microscopy reveal that *B2* ordering is localised to the interfacial region (∼17nm) of the film. An amorphous layer was present above the *B2* layer exhibiting a compositional gradient. This shows holds promise for further improvement of the magnetic properties towards the theoretical predictions.

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Modelling of Magneto-Thermoelectric Response From a Domain Wall

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Thermal magnetometry is a novel rapidly developing tool which makes use of the fact that thermoelectrical response of a nanostructure depends on its magnetic state. The use of nanometric local heat spots, e.g. from an actively and controllably heated scanning probe, with localized thermal gradients allows a nanoscale magnetization mapping of localized spin textures such as pinned domain walls [1]. The measured voltage is a convolution of magnetization and temperature distribution in the presence of several spin-caloritronic effects and thus its interpretation is not straightforward. Here, we model the thermoelectric response of Néel and Bloch domain walls in FeCoB nanostripes with or without a lithographed notch. The heat distribution is modelled by solving the Poisson heat equation for different positions of the heated probe across and along the stripe. Thermal modelling is used as an input for large scale thermal micromagnetics using the Landau-Lifshitz-Bloch approach [2]. Our modelling shows that at room temperature both Neel and Bloch domain walls represent energetically stable configurations, pinned at the notch. The presence of localized an asymmetric heat source forces the domain wall to widen and curve. Additionally, Bloch structures appear locally inside the Néel domain wall. With the aim to understand different responses, we model separately electric response of both domain walls in the presence of anomalous Nernst (ANE), perpendicular and parallel Seebeck (SE) effects and study their symmetry. The comparison with recent experiment demonstrates that only the response of the Neel domain wall under the action of both ANE and SE is compatible with the symmetry of the experimentally measured voltage.

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Manipulation of magnetism in $0.67Pb(Mg_{1/3}Nb_{2/3})O_3$-$0.33PbTiO_3/La_{0.70}Sr_{0.30}MnO_3$ multiferroic heterostructure

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A multiferroic heterostructure composed of ferroelectric and ferromagnetic layers paves the way for the development of multifunctional devices for specialised applications such as; multi-state memory devices, actuators, spintronic devices, etc. [1]. Heterostructure comprising epitaxial layers of piezoelectric $0.67Pb(Mg_{1/3}Nb_{2/3})O_3$-$0.33PbTiO_3$ (PMN-PT) and room temperature ferromagnetic $La_{0.70}Sr_{0.30}MnO_3$ (LSMO) was grown on single crystal $LaAlO_3$ (LAO) substrate with (001) orientation using pulsed laser deposition (PLD) technique. Initially, a 20 nm LSMO layer was grown on LAO, followed by a 40 nm PMN-PT layer and the film termed as PMN-PT(40)/LSMO(20)/LAO. To compare the findings a single layered LSMO(20)/LAO film was grown. X-ray diffraction and Reciprocal Space Mapping (RSM) were employed to measure the in-plane and out-of-plane lattice parameters. RSM images indicate that the middle LSMO layer is exposed by two diffrenet strain; bottom compressive strain caused by lattice mismatch between the the LSMO layer and LAO substrate, and the top tensile strain caused by the top PMN-PT layer [2], [3]. When compared to the LSMO(20)/LAO film which shows Curie transition temperature T_C = 300K, the PMN-PT(40)/LSMO(20)/LAO film displays a 33% improvement in magnetization at 5K and shifting of T_C (= 323K) towards higher temperature. These findings are ascribed to two key contributions; (i). The compressive strain in the top PMN-PT layer produces self-polarization, which accumulates the charge carriers in ferromagnetic layer near the PMN-PT/LSMO interface, enhancing the LSMO magnetization [4]. ii. The generated tensile strain on LSMO layer may alter the Mn-O-Mn bond angle and Mn-O bond length, resulting in an increase in the T_C [2], [5].

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An interactive tool for exploring magnetism

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Nowadays, magnetism appears as an educational and research field in diverse aspects with a variety of information formats either on websites or databases. This work attempts to bridge the gap of information coherence and provide magnetism-related knowledge in a simple and structured, yet concise way, via the website http://magworld.physics.auth.gr. One of the major objectives of this effort is to attract even the least experienced on magnetism visitors in a simple way and to familiarize themselves with basic concepts of the phenomenon of magnetism, to overview magnetic materials, properties, effects, and applications surrounding us, to easily collect additional information and enrich their knowledge about the history of magnetism. Online quizzes of classified difficulty have been created to enable visitors to self-assess their level of knowledge on magnetic related topics. At the same time, more experienced visitors such as physics students, professors, and researchers are given the opportunity, to overview specialized concepts, and phenomena of magnetism, the metrology of magnetic quantities as well as magnetic materials categorized on macro- micro- and nano- scale dimensions. Each of these categories of materials collects detailed information through the respective tables, properties, effects, and applications. Specific estimation routines are readily calculating magnetic quantities and assist either educational or scientific perception and achievements. The evaluation and categorization of magnetism-related information is considered an integral part of this work. Recognized international books and as well as reference articles were used as sources to search for information displayed on this website, providing in all cases the corresponding references [1]–[4]. The underlying magnetism database will be regularly updated and is anticipated to provide a great assistant for obtaining up to date reference information on modern scientific and technological magnetism-oriented areas. We hope, it will soon become a useful and practical handy tool for different age groups interested in exploring and gaining useful and essential knowledge about the wonderful world of magnetism.

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Influence of Spatial Confinement on Spin-Wave Frequency Combs

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The spin-wave system is intrinsically nonlinear. This often leads to unwanted relaxation channels via magnon-magnon scattering but also offers great potential, for example, as a tool in neuromorphic computing. Therefore, it is of great importance to understand and to find ways to manipulate nonlinear phenomena. In many experimental structures, four-magnon scattering is the lowest order scattering process. In this process, two initial magnons scatter under conservation of momentum and energy into two final magnons. The rate equation of such an event depends among other things on the amplitude of the initial and final state. In magnetic microstructures such as stripe shaped magnonic waveguides, the eigenstates of the spin system are reduced due to lateral confinement. This leads to a higher concentration of thermal magnons in fewer states. As a result, the threshold for four-magnon scattering is heavily reduced [1]. Recently, it has been shown that four-magnon scattering in a waveguide can be stimulated and utilized to generate spin wave frequency combs. Therefore, two spin-wave modes were populated by RF excitation in a microstructured waveguide, which leads to a cascade of four-magnon scattering processes and, finally, the formation of a frequency comb [2]. Here, we demonstrate that by further restricting possible eigenstates via a two-dimensional spatial confinement the stimulated four-magnon scattering can be enhanced and even a single RF excitation leads to the spontaneous formation of a frequency comb. We determine the frequency spacing of the spin-wave modes in a $Co_{25}Fe_{75}$ rectangular microconduit with micromagnetic simulations and explore the formation of spin-wave frequency combs experimentally by means of micro-focused Brillouin light scattering. Further, we show that the spontaneously generated frequency comb can be resonantly amplified by a second RF excitation. The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within program SCHU 2922/1-1.

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State of the Art High Speed Axial Flux Electrical Machines

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The first axial flux machine dates back to the 19th century. It was not much attractive back then due to several mechanicals constraints and problems, winding limitations and high manufacturing difficulties and costs. Axial flux machines rose back to light in the 1970' s due to the development of rare earth magnets resulting in a reduction in copper materials used to produce the same magnetic flux density, thus reducing machine weight and size [1]. Therefore, axial flux machines regained interest and a new field of research was born to investigate their development and integration in different applications. Nowadays, axial flux machines represent a valid alternative to traditional radial flux electrical machines due to their compact structure and their ease of integration but remain exposed at different stakes and locks that hinder its use especially those that require a high rotational speed. Despite being used for electromobility sector and extending to some generators and motors, they attract growing attention for a wide variety civil, industrial, aerospace and emerging applications as well as portable power generation and energy storage systems [2]. However, reaching high rotational speeds is still a major challenge for those machines. This is caused by the mechanical problems that can occur due to centrifugal forces, vibrations, rotor displacements and inability of the used materials to withstand great pressure and high temperatures at high rotational speeds. In addition to the thermal problems linked to the high speed and high frequency and which results in different types of losses. In this paper, a literature review of High-speed axial flux machines is presented where different machines are compared from structure, material and performance standpoints.

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Magnonic frequency comb

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Optical frequency comb is a light source consisting of a series of discrete and equally spaced frequency lines. Ever since its inception, optical frequency comb has dramatically improved the accuracy of frequency metrology [1]and thus leads to one half of the Nobel Prize in Physics in 2005. Recently, an analogue of optical frequency comb in the acoustic system has been predicted theoretically and realized in experiment [2], which provides many opportunities for both fundamental and applied research in phononics. On the other hand, magnons, as elementary excitations in ordered magnets, are similar to photons and phonons as bosonic quasiparticles. However, the frequency comb of magnons has not been realized to date. The fundamental difficulty is the smallness of nonlinearity in a normal ferromagnet, which hinders the form of frequency comb structure.

In this work [3], we predict a novel magnonic frequency comb (MFC) induced by the nonlinear coupling between magnetic skyrmion and spin waves excited by a microwave field. Here the nonlinear interaction is significantly enhanced by the topological structure of skyrmions and thus leads to the generation of MFC through three-magnon process. The mode spacing inside a MFC is equal to the frequency of the skyrmion breathing mode, which can be efficiently tuned by magnetic or electric means. The essential physics can be further extended to a wide class of magnetic solitons including antiskyrmions, domain walls, and vortices. Our findings may provide a novel avenue to study frequency comb physics combining the advantages of magnons and general magnetic textures and may further benefit its applications in the spin-wave calibration and metrology.

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Development of Dy μ-disks for magnetic Bragg-Coherent Diffraction Imaging

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Imaging non-collinear antiferromagnetic orders is of strong interest in the fields of spintronics, topological magnetism, multiferroicity, but particularly challenging [1]. The combination of Coherent Diffraction Imaging (CDI) [2] with Resonant Magnetic Scattering (RXMS) [3], enabled by the extremely brilliant 4th generation synchrotron sources, could provide a fully vectorial reconstruction of a non-collinear magnetic order. Dy epitaxial micro-objects are promising model systems to achieve this goal: Dy films exhibit a noncollinear helical phase (T_N= 179 K) and strong magnetic resonant scattering at Dy L_3 edge (7.79 keV) [4]. Micrometric dimensions are moreover required, because the incident X-ray beam must capture one single complete disk to enable a relevant magnetic reconstruction from magnetic speckles. We will first present details about the growth and patterning of epitaxial Dy µ-disks (diameter down to 1 µm). The growth of (0001) rare earth is achieved on A-plane sapphire/(110) Nb, while the patterning process is performed with optical lithography followed by Ion Beam Etching. The X-ray diffraction results indicate high crystal quality of µ-disks, with mosaicity and coherence lengths similar to the initial films, both in the plane and along the growth direction. One should however note the appearance of a new FCC phase, likely due to oxidation/hydrogenation during the patterning process. The magnetic properties of continuous and patterned films have been analyzed in combining laboratory SQUID measurements with Resonant X-ray Magnetic Scattering (BM28-ESRF). Despite slight changes in the temperature/field stability of the magnetic helical phase, this later could be observed both in the continuous films and in the patterned disks. The temperature dependence of (002-τ) magnetic satellites reveal helical turn angles in good agreement with what is observed in epitaxial films [5], in disks down to 2 µm diameter. First speckle patterns have been measured at charge and magnetic peaks (ID01-ESRF). These results would allow us to investigate the relation between structural and magnetic defects and to optimize the model patterned samples for the development of Bragg-CDI 3D imaging of non-collinear magnetic orders.

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Effect of Hubbard Energy on the Cr-O Hybridization in $LaCrO_3$

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Rare earth orthochromites $ReCrO_3$ with orthorhombic crystal structure Pnma (#62) have interesting magnetic and electric properties and the interplay between them [1]–[4]. Electronic band structure calculation using density functional theory carried out for $LaCrO_3$ with different Hubbard energy (DFT+U). Optimized lattice parameters, magnetic states, magnetic moments, and band gap values for ground state $LaCrO_3$ are calculated . Magnetic materials having Cr-O hybridization shows a significant change in their electronic properties with different Hubbard energy. By changing Hubbard energy how the hybridization of the 3d orbit of chromium and 2p orbit of oxygen forms is described with the help of density of state. The result shows that the band gap is increasing as we increase Hubbard energy. Electronic and structural properties are calculated. Magnetic properties of $LaCrO_3$ are also discussed. The Cr-O hybridization is described with the help of density of states and molecular orbital picture. How the splitting happened in 3d orbitals of Cr is shown by partial density of states.

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Magnetization reversal in individual core/shell cylindrical nanowires with non-magnetic interlayer

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Three-dimensional (3D) core-shell magnetic nanostructures are appealing for novel applications in magnetic recording, biotechnology, nanoelectronics, and spintronics devices [1-6]. While few works report on three-layered core/shell cylindrical nanowires systems recently investigated, the magnetization switching processes in these nanostructures remain yet unexplored [7-8]. In this study we investigate the switching process of an individual FM/NM/FM core/shell nanowire made of Fe50Co50(core)/ SiO2 (interlayer)/ Fe3O4(shell) that were experimentally synthesized by atomic layer deposition coupled together electrochemical deposition technique. Magneto-optical Kerr effect measurements allow to access the switching process of individual nanowires and its contrast with micromagnetic modelling of the reversal process in order to determine the switching of each layer, either the external shell or the inner core of the whole nanowire. From micromagnetic modelling performed with mumax3 code, we have found the conditions to select the first switching layer under the applied magnetic field, and to design the switching processes in this core/shell cylindrical nanowire by tailoring the thickness of the non-magnetic SiO2 interspacing layers. Our results show that while there is no direct exchange coupling between the FeCo core and the magnetite shell, their respective magnetizations may switch either simultaneously, or at different switching fields during the reversal of the nanowire/nanotube structure. The elimination of the non-magnetic layer in micromagnetic simulations confirms that the reversal mechanism of our experimental core/shell nanowires is uniquely promoted through magnetostatic dipolar coupling between the ferromagnetic layers with a complete exchange decoupling between both magnetic layers. These results set an appealing strategy for the design of novel 3D magnetic storage and spintronic devices based on core/shell cylindrical nanowires that has not been envisaged up to know.

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Magnetization reversal in rhombohedral Ni nanotubes

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One-dimensional (1D) structures such as nanowires or nanotubes are nowadays a vast field of research. Several studies based on ferromagnetic nanowires and nanotubes, among other magnetic nanomaterials, have been carried out during last years to understand the main mechanisms that govern their magnetisation reversal process according to the geometry, material composition and size, geometry or spatial arrangement of these nanostructures [1], [2]. In this study, the magnetisation reversal mechanism for nickel nanotubes having a rhombic geometry has been investigated from both, theoretical and experimental points of view [3]–[6]. The micromagnetic simulations were performed by means of the mumax3 programme employing typical values for the magnetic parameters of the polycrystalline Ni [7], where the size of rhombic nanotubes is around 5000 nm in length, having 590 nm of major diagonal and 360 nm along the minor diagonal, while the wall thickness ranges from 10 nm up to 150 nm. The peculiar geometry exhibited by these rhombohedral Ni nanotubes induces clear differences in the magnetization reversal processes due to their different shape when compared respect to the more usual cylindrical ones. This peculiar geometry further limits the magnetic domain reversal due to sharp edge angles at the nanotube corners, which can lead to the appearance of magnetic singularities near the nanotube vertex that induce the nucleation of vortex domain walls. The nucleation and domain wall propagation appearing at the vertex of rhombic Ni nanotubes seem to be vortex-shaped, while vortex-antivortex phenomena is also occurring through the emergence of a C-state or an S-state. Therefore, the reversal mechanism is limited by the geometry of the nanotube and is anchored until the external applied field is strong enough to reverse the magnetization via a less favourable pathway. The main mechanisms that govern the magnetization reversal in these rhombic Ni nanotubes are discussed in the framework of the micromagnetic simulations and compared with experimental measurements, achieving a good agreement between the obtained results. The future of such peculiar nanotube geometries with varying their composition and size properties could lead to interesting novel magnetic phenomena related to their magnetic domain walls movement and magnetic anchoring, in the fields of electronics or computing, as well as in biomedicine or catalysis.

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Synthesis and characterization of nanostructured magnetic bioceramic scaffolds for bone tissue regeneration

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Bioactive three-dimensional scaffolds to support bone regeneration is currently an emerging biomedical field. Therefore, numerous methodologies to synthesize "smart" multifunctional materials arise, aiming to their application in tissue and bone regeneration, in targeted delivery and release of active/pharmaceutical substance, and, finally, in complementary cancer tumor therapy via magnetic hyperthermia add-on schemes. The aim of this study is to design a new magnetic bioceramic nanocomposite and subsequently fabricate a multifunctional 3D scaffold, via polymer sponge method, which will be able to address different challenging issues like bone malignant tissues through hyperthermia, bone infection through antibiotic release, desired physicochemical and biological properties, bioactivity and biocompatibility. First, synthesis of CoFe2O4 nanoparticles was carried out by one pot sol-gel route. Second, fabrication of magnetic Mg2SiO4-CoFe2O4 nanocomposite via two-pot sol-gel synthesis strategy is implemented in order to coat the magnetic nanoparticles. The solution was kept under continuous stirring for 24 h at 50 °C and then it was filtered and rinsed with deionized water and ethanol and calcined in an electric furnace. Finally, the replication template (polyurethane sponges), with an average pore size of 300-700μm, were carefully cut cubically (10 × 10 × 5 mm), washed several times, and soaked into a water-slurry containing carboxymethyl cellulose, deionized water and the nanocomposite powder. The foams were dried at 40 °C for 48 h in an oven and sintered into an electric furnace by using a multi-stage schedule. X-Ray Diffraction, SEM-EDS microscopy, FTIR spectroscopy and Static Magnetometry were performed in-between subsequent stages to outline the structural, morphological, and magnetic features of the nanocomposites. The final products were examined in a typical magnetic hyperthermia setup to quantify their AC heating efficiency. Finally, a series of biomedical tests were undertaken to evaluate their performance under realistic conditions as cytotoxicity, capability to induce in vitro cellular production of calcined extracellular matrix, antibacterial properties, hemolytic activity and oxidative profile via multiple routes. Due to the plethora of physicochemical and biological properties demonstrated by magnetic bioceramic scaffolds, they are considered very attractive for bone tissue regenerative techniques, opening a lot of possibilities in the field of bone regeneration in targeted delivery and release of active/pharmaceutical substance, and, last but not least, in complementary cancer tumor therapy via magnetic hyperthermia applications.

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Development of Cryogenic Brillouin Light Scattering Microscopy (Cryo-μBLS) System

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Brillouin light scattering microscopy (µBLS), based on inelastic scattering of photons on magnons, is a well-established tool for the characterization of spin dynamics. µBLS allows for phase resolved and time resolved analysis of spin waves with high sensitivity and submicron spatial resolution [1]. Excitations of the spin system in a magnetically ordered material are called spin waves and magnons are their associated quasiparticles. Change in saturation magnetization and dynamic damping constants with temperature can affect spin wave propagation in magnonic waveguides [2]. Phase change in chiral magnets at lower temperatures can give rise to various spin textures [3]. To observe the spin dynamics associated with spin textures with high spatial resolution, a µBLS setup with temperature control is required. Most cryogenic setups suffer from vibrations arising from the compressor and cold head parts of the cryostat. Here we present a cryogenic Brillouin light scattering microscopy (Cryo-µBLS) system that allows us to characterize spin dynamics at temperatures up to 10 K. We use a Helium closed cycle cryostat with an ultra-low vibration (ULV) interface, where the cold head and sample region are mounted separately. This feature combined with mechanical reinforcement at the sample region reduces vibrations. An optical stage consisting of three pentaprisms, such that the distance between the prisms can be varied, is used to raster the laser beam, and focus the laser spot on the sample. This system will be useful to study temperature related variation in spin textures and spin dynamics, such as, microwave emission spectra of spin Hall and spin torque nano oscillators [4], evolution of spin textures with temperature [3], [5] and spin dynamics in chiral magnets [6], [7] and other magnetic phase transitions at low temperatures.

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Effect of Tb doping on Structural, Magnetic, and Magnetic Hyperthermia efficiency of Fe_3O_4 Nanoparticles

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Tb doped Fe_3O_4 nanoparticles of crystallite sizes between 13-20 nm with various stoichiometric ratios were prepared using the co-precipitation route. The structural conformation and phase purity of the synthesized MNPs were confirmed by XRD, FTIR, TEM, SEM, and XPS analysis. TGA analysis was carried out for thermal stabilization and for verifying the formation of a stable phase. Detailed cationic distribution $(Fe^{3+})_A[Tb^{3+}{}_yFe^{2+}{}_{1-y}Fe^{3+}]_BO_4$ from Rietveld refinement, analogous with XPS findings, indicates occupancy of the Tb^{3+} ions at the octahedral sites, which can alleviate the lattice distortion. The relaxation mechanism, dipolar- dipolar interactions among the particles, and randomly directed magnetic anisotropy axes were anticipated by ESR spectroscopy. Furthermore, the magnetic results enumerate that increasing Tb doping concentration leads to an increase in saturation magnetization and a decrease in coercivity and retentivity. The self heating properties of the doped nanoparticles was characterized by measuring specific absorption rate (SAR). The improved biocompatibility showed by the samples proven their potential for the in-vivo application and enriched SAR value enables the doped MNPs for magnetic hyperthermia application with excellent efficacy.

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Effects of 200 mT Static Magnetic Field on Biofilm Formation and Motility of Pseudomonas aeruginosa

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The interaction of magnetic fields with living organisms has received remarkable attention across a broad spectrum of sciences, including biology, physics, chemistry, and medicine. Our team has previously described the effect of low intensity magnetic fields on colon cancer cells [1]. Although the effects of moderate (1 mT–1 T) static magnetic fields (SMF) have been studied in certain eukaryotic model systems, the available data regarding their interaction with bacteria is vague. Several bacterial species have the ability to form biofilms, namely, to adhere to biotic or abiotic surfaces and to be surrounded by a self-produced matrix of extracellular polymeric substances [2]. Pseudomonas aeruginosa is a biofilm-forming microbe and rises among the most commonly isolated pathogens involved in healthcare-associated infections. We have previously reported that the exposure to 200 mT SMF induces a disruption of pre-formed P. aeruginosa biofilm and enhances gentamicin's antibiofilm effect [3]. In this study we investigated the effect of 200 mT SMF on biofilm growth and formation by P. aeruginosa. Moreover, we assessed SMF's effect on bacterial membrane permeability –an indicator of toxicity and studied bacterial motility patters after the exposure to SMF. Furthermore, we examined the transcriptional levels of various genes such as pelA, pilA and fliC, which are related to the formation of biofilm and bacterial motility. Our results indicate a time-depended inhibition of biofilm formation by SMF, which is also dependent on the magnet's position. In addition, by employing three motility assays (swim, swarm and twitch), we observed a strong effect of SMF exposure, especially on the bacterial swimming ability. Our results indicate that SMF inhibits formation of biofilm by P. aeruginosa and affects bacterial motility. Additional research is required to shed light on the underlying mechanisms involved in SMF-induced biofilm growth inhibition.

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Room Temperature Non-Local Detection of Charge-to-Spin Conversion in Topological Insulator Using a Graphene Spin-Valve Device

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The main goal of spintronics is to utilise the spin degree of freedom for faster and less energy-consuming information technology. Topological insulators are a promising candidate for spin generation and detection in all-electrical spintronics applications, thanks to their strong spin-orbit coupling and non-trivial spin-momentum locking of their topological surface states [1]. Applying a bias current to induce a net carrier momentum should spontaneously generate a net spin polarization in such a system. The giant charge-spin conversion effects in topological insulators have shown excellent potential for spin-orbit torque switching based ultralow power magnetoresistive random-access memory technology [2], [3]. Although charge-spin interconversion has previously been reported using potentiometric spin measurements [4], [5], reliable non-local measurements have so far been limited to cryogenic temperatures [6]. Here, we report non-local detection of charge-spin interconversion in the topological insulator $Bi_{1.5}Sb_{0.5}Te_{1.7}Se_{1.3}$ at room temperature using a van der Waals heterostructure with graphene in a spin valve device. The observation of both spin-switch and Hanle spin precession signals in the non-local device and detailed bias and gate-dependent measurements prove the robustness of the charge-spin interconversion effects in topological insulators at room temperature. These findings demonstrate the possibility of using topological insulators to make all-electrical room-temperature spintronics devices for energy-efficient next-generation computing components [7].

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A PEEC-FEM Method for Three-Dimensional Eddy Currents Computation in the Vicinity of Ferromagnetic Media

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The scope of the present work is to develop an Integro-Differential formulation able to modeling structures having heterogeneous dimensions, as compute Three-Dimensional eddy current distribution in thin conductive magnetic or nonmagnetic plaques and eddy current techniques for Non-destructive testing of Carbon Fiber Reinforced Plastic (CFRP) materials.... The method is based in coupling of the partial element equivalent circuit method with the finite element method (PEEC-FEM coupling) which combines the main advantages of both previous methods taking into account: - Ferromagnetic materials or CFPR materials by the FEM. - Large number of conductors and eddy current by the PEEC method. Through this technique we can easily modeling the eddy current distribution created by several shapes of conductor coils which only the conducting magnetic or CFRP material (active parts) are meshed. The model is validated by comparing with numerical results issued from 3D finite element methods (Flux 3D Software) for eddy current calculation. The comparisons have proven the robustness and rapidity of this hybrid method.

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Mapping the Stray Fields of a Micromagnet Using Spin Centers in SiC

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Electron spin-based magnetometry has gathered attention in the past decades as a means for imaging and resolving nanometer-sized complex spin textures in a highly sensitive and non-perturbative way. While the nitrogen-vacancy (NV) spin center in diamond is the most known and mature system for atomic-scale sensing of magnetic fields, silicon vacancy (V_{Si}) centers in the silicon carbide (SiC) matrix have recently surged as an alternative system due to their competitive optical and electrical properties and their potential for integrated and scalable quantum photonic chips [1]. In this work [2], we use an ensemble of V_{Si} centers as a room-temperature sensor of static stray fields generated by magnetic microstructures patterned on top of a SiC substrate. We use optically-detected magnetic resonance (ODMR) to measure the impact of the stray fields on the intrinsic V_{Si} resonance frequencies. The spin resonance at the spin centers is driven by a micrometer-sized microwave antenna patterned next to the magnetic element. The antenna pattern is made to ensure that the driving microwave fields are delivered locally and more efficiently compared to conventional millimeter-sized circuits. We observe a spatially dependent frequency shift of the V_{Si} resonances which enables us to determine the field contribution from the magnetic element in its close vicinity. Our results are a first step toward developing magnon-quantum applications by deploying local microwave fields and stray fields at the micrometer length scale.

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Effects of uncompensated longitudinal field on a Co-rich microwires based orthogonal fluxgate

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The use of magnetic microwires as a core for fundamental mode orthogonal fluxgate (FM-OFG) core is limited by the excess drift of the magnetometer offset.

We observed that a component of the magnetometer offset drift is actually a settling of the output after a sudden change of the magnetic field applied in the longitudinal direction. This phenomenon is similar to the effect already observed and described in a giant magnetoimpedance (GMI) sensors based on the similar microwires [1], [2]. The magnetic after-effect (MAE) related to the GMI sensors is often defined as a relative change of the microwire impedance, after an external field in longitudinal direction is switched off; this effect itself is being associated with a change of microwire circumferential permeability due to relaxation of the domain structure [2].

We are operating the microwire based fluxgate magnetometer in the fundamental mode with a DC bias superimposed on an AC excitation current in open loop. The magnetometer sensor head is formed by an array of four 80 mm long CoFeSiB amorphous 120µm microwires annealed using the Joule heating method [3]. The inner part of the microwire core still has an axial easy axis of magnetization and exhibits a single Barkhausen jump when the microwire is longer than a critical distance [4]. This also affects the offset value: when a field large enough field (5÷10 µT) is applied in longitudinal direction, the magnetization of the inner core will switch and, as a consequence, the offset will change. Furthermore, if multiple of microwires is used in an array, then the composite offset can be switched into a limited number of different offset configurations due to existing interaction between the stray fields of individual wires in accordance with previous findings [5].

In this work, we demonstrate that the MAE and magnetization reversal of inner core domain structures in microwires affects also the output offset when used as core of the FM-OFG magnetometer. The settling time of the MAE affecting the magnetometer offset can reach tens of seconds up to minutes and can be observed even when the magnetometer excitation was previously off and sensor was exposed to external longitudinal field. We show how the dependence of the settling time and the offset value changes on the parameters of the excitation current and of the applied field.

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Voltage-controlled skyrmion Hall angle in Ferromagnetic/Piezoelectric devices

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Using magnetic skyrmions as information carriers is one of the most promising ways to conceive fast spintronic-based computing devices with less energy consumption [1]. Due to their internal structure and to the gyrotropic nature of magnetization dynamics, skyrmions move in an inclined trajectory with respect to the direction of the driving force, a phenomenon known as skyrmion Hall effect (SkHE) [2]. This effect is, in principle, detrimental for devices and, consequently, considerable efforts are being made to find ways to suppress or minimize it [3,4]. In the present work we present (use other word to not repeat "present"in the same sentence) a new route to control the skyrmion trajectory and its Hall effect via voltage-controlled strain [5]. Using electromechanical simulations we investigate the strain distribution created in a Heavy Metal/Ferromagnet/Oxide trilayer on top of a Piezoelectric (PZ) substrate when a voltage is applied between two electrodes that are on top of the PZ but transverse to the trilayer. Later on, we use the strain profile found in our micromagnetic model to investigate the skyrmion dynamics in presence of both longitudinal current along the Heavy Metal and a transversal strain gradient. The magneto-elastic contribution is included in the micromagnetic mode (code) by adding the magnetoelastic field to the full effective field in the Landau-Lifshitz-Gilbert equation $\overrightarrow{H}_{me} = \frac{1}{\mu_0 M_s}\sigma_{ij}\frac{\delta\varepsilon_m^{ij}}{\delta\overrightarrow{m}}$. We also use Thiele's model to support our results. In this model, the equation of motion for the skyrmion is given by $\overrightarrow{G} \times \overrightarrow{v} + \alpha\overrightarrow{v}\overline{\overline{D}} = \overrightarrow{F}_{SHE} + \overrightarrow{F}_{el}$ where $\overrightarrow{G}$ is the gyro-vector, $\overrightarrow{v}$ is the skyrmion speed, $\overrightarrow{F}_{SHE}$ is the spin Hall effect force and $\overrightarrow{F}_{el}$ is the force due to the strain gradient. We find, from both micromagnetic simulations and Thiele model, that the skyrmion Hall angle for any given value of the current density can be totally suppressed if the appropriate voltage is applied and also that the skyrmion speed can be enhanced using in-plane strain gradients. We checked as well the efficiency of strain gradient to control skyrmion Hall angle in granular films by including a random distribution of magnetic defects in the simulations. To sum up, the results of our study show that strain can be a promising alternative to control skyrmion dynamics in ferromagnetic systems.

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In vitro exploration of the synergistic effect of alternating magnetic field mediated thermo-chemotherapy with doxorubicin loaded dual pH- and thermo-responsive magnetic nanocomposite carriers

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Nanoparticle induced hyperthermia has been considered as a promising approach for cancer treatment for decades. The local heating ability and drug delivery potential highlight a diversified possibility in clinical application, therefore a variety of nanoparticles has been developed accordingly. However, currently, only a few of them are translated into the clinical stage indicating a ‘medically underexplored nanoparticles’ situation, which encourages their comprehensive biomedical exploration. This study presents a thorough biological evaluation of previous well-developed dual pH- and thermo-responsive magnetic doxorubicin- nanocarriers (MNC–DOX) in multiple cancer cell lines. The cytotoxicity of the nanocomposites has been determined by the MTT assay on primary cell lines. Histology and fluorescence microscopy imaging revealed the efficiency of cellular uptake of nanocarriers in different cell lines. The IC50 of MNC–DOX is significantly higher than that of free DOX without an alternating magnetic field (AMF), which implied the potential to lower the systemic cytotoxicity in clinical research. The concurrent thermo–chemotherapy generated by this platform has been successfully achieved under an AMF. Promising effective synergistic results have been demonstrated through in vitro study in multi-model cancer cell lines via both trypan blue exclusion and bio- luminescence imaging methods. Furthermore, the two most used magnetic hyperthermia modalities, namely intracellular and extracellular treatments, have been compared on the same nanocarriers in all 3 cell lines, which showed that treatment after internalization is not required but preferable. These results lead to the conclusion that this dual responsive nanocarrier has extraordinary potential to serve as a novel broad- spectrum anticancer drug and worth pursuing for potential clinical applications.

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Magneto Optical Studies of Water Based Ferrofluid

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Magnetically controllable fluids have caught the attention of many due to their unique magnetic, optical and electrical properties. Investigation of magneto optical characteristics of ferrofluid is important for the development of optoelectronic devices [1]. We report the synthesis of stable water based ferrofluid and their structural, magnetic and magneto optical properties. Stable ferrofluids of iron oxide particles with an average size of 10 nm, dispersed in water base are synthesised by well-known chemical method (Co-precipitation) [2]. The structural analysis is carried out by employing X-ray diffraction technique. The magnetic properties have been analysed by Superconducting Quantum Interference Device. The magnetization measurement signifies the super paramagnetic nature of particles [3]. The temperature dependent relaxation studies were carried out by field cooled (FC) and zero field cooled (ZFC) moment measurements at a constant applied field [4], [5]. In the absence of magnetic field, the suspensions were isotropic. Once the external field is applied, they show anisotropic behaviour and exhibit magneto-optic phenomena [6]. The magneto optical property of the iron oxide nanofluid was investigated by linear dichroism measurements. Linear dichroism arises due to the intrinsic optical anisotropy or the shape anisotropy of individual magnetic particles [7]. Dichroism measurements are carried out in water based ferrofluid, which exhibits dichroic nature.

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Degradation of domains with sequential field application

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Recent experiments show striking unexpected features when alternating square magnetic field pulses are applied to ferromagnetic samples: domains show area reduction and domains walls change their roughness. We explain these phenomena with a simple scalar-field model, using a numerical protocol that mimics the experimental one. For a bubble and a stripe domain, we reproduce the experimental findings: The domains shrink by a combination of linear and exponential behavior. We also reproduce the roughness exponents found in the experiments. Finally, our simulations explain the area loss by the interplay between disorder effects and effective fields induced by the local domain curvature [1].

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Anisotropic magneto-thermal transport in Co_2MnGa thin films

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The full Heusler compound Co_2MnGa belongs to the family of Weyl-II-semimetals. Large anomalous Nernst effect has been observed in Co_2MnGa and it was attributed to non-vanishing Berry curvature of the Weyl-points making the material a promising candidate to study exotic transport phenomena. In this work we systematically measure anisotropic magnetoresistance (AMR) and its thermoelectric counterpart anisotropic magnetothermopower (AMTP) in Co2MnGa thin-films. The data is modeled using a Stoner-Wohlfarth formalism as well as a symmetry-based phenomelogical model. Our findings show the presence of both crystalline and non-crystalline components in both magneto-transport phenomena. While the AMR is small in relative terms, the AMTP is large, which is discussed in the context of the Mott rule.

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Observation of Anti-damping and Spin Pumping in $La_{0.67}Sr_{0.33}MnO_3$/Pt Bilayer System

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Here, we have studied the damping properties of $La_{0.67}Sr_{0.33}MnO_3$ (20 nm)/Pt (t_{Pt} = 0, 3 and 10 nm) bilayer samples. These samples have been prepared on $SrTiO_3$ (001) substrate using an oxygen plasma assisted molecular beam epitaxy system. We have observed decrease in damping coefficient (α) with increase in Pt thickness. ISHE measurements were performed using home modified coplanar wave-guide (CPW) based ferromagnetic resonance (FMR) spectroscopy [1]. We have observed high spin pumping voltage for a sample with Pt thickness of 3 nm [2].

It has been observed that at certain microwave frequencies, FMR signal intensities are much high than the others frequencies, hence we performed frequency dependent ISHE in this sample (LSMO (20 nm)/Pt (3nm)) to observe the effect of FMR intensity on generated voltage. From frequency dependent ISHE analysis it has been observed that measured voltage does not follow any trend with increase in frequency, however, at certain frequency, its values are higher than the values at other frequency.

It is well known that with increase in frequency, FMR signal strength as well as spin to charge conversion efficiency decreases due to heating effect in sample [3], [4]. In the sample with t_{Pt} = 3 nm we have observed maximum voltage signal at 14 GHz. Therefore, decrease in damping constant and enhanced ISHE voltage at higher frequency makes this system very interesting for spintronic applications. It can contribute to faster dynamics in comparison to other systems, which is useful for spin to charge conversion at lower frequency.

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Nutation resonance in antiferromagnets

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The spin dynamics has so far been described by the traditional Landau-Lifshitz-Gilbert (LLG) equation that includes a spin precession around an effective field and a transverse damping [1]. However, at ultrafast timescales, an additional term has to be supplemented to account for magnetic inertial dynamics causing spin nutation [2]. The direction of spin angular momentum does not align with the direction of magnetic moment at ultrashort timescales and thus the magnetization rotates around the angular momentum direction, meaning that the spin nutates. The emergence of spin nutation has been examined through an extension of breathing Fermi surface model [3], calculated from an $s-d$-like interaction between the magnetization and conduction electron spin [4], and derived from a relativistic Dirac theory [5]. Essentially, the magnetic inertial dynamics introduces a nutation resonance peak along with the known ferromagnetic resonance (FMR) peak, however, the nutation resonance occurs at a higher frequency than the FMR [6]. The experimental observation of the nutation resonance has only been achieved very recently in NiFe and CoFeB using intense terahertz magnetic field transients [7]. In this work, we compare the effect of spin nutation in ferromagnets, antiferromagnets and ferrimagnets using linear response theory [8]. We identify the precession and nutation resonance peaks, and demonstrate that the precession resonance frequencies are reduced by the spin nutation, while the lifetime of the excitations is enhanced. We find the interplay between precession and nutation resonances to be more prominent in antiferromagnets compared to the ferromagnets, where the timescale of the exchange-driven sublattice dynamics is comparable to inertial relaxation times. Consequently, antiferromagnetic resonance techniques should be better suited for the search for intrinsic inertial spin dynamics on ultrafast timescales than ferromagnetic resonance.

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Orbital Magnetic Moment of Magnons

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

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Role of spin-glass like frustration on exchange bias effect in Fe/$Ir_{20}Mn_{80}$ and $Ni_{50}Mn_{50}$/$Co_{40}Fe_{40}B_{20}$ bilayers

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Modern spintronic based devices such as magnetic random-access memory (MRAM) and magnetic read head sensor have been designed on the principles of exchange bias effect [1]. A unidirectional interfacial exchange coupling between a ferromagnet (FM) and an antiferromagnet (AFM) is the primary reason for the shift of the magnetic hysteresis loop [2]. However, 'bulk' spins of the AFM can also have a strong impact in tuning the exchange bias properties [3]. Among the above, spin-glass-like frustration plays a significant role. The interface of the FM/AFM system can also be spin-glass-like which also tunes the magnetic properties [4]. FM/spin glass (SG) is the model system to study the role of frustration on exchange bias effects.

In both the systems, we found the decrease of exchange bias field (H_{EB}) with cooling field (H_{FC}). Also, the exponential decay of H_{EB} and coercive field (H_{C}) with temperature is found in both the systems. These studies indicate the presence of spin-glass-like frustration in the Fe/IrMn and NiMn/CoFeB exchange bias systems. Further, we performed the training effect measurements and fitted the data using various models. It is found that interfacial rotatable spins relax 8 times faster than interfacial frozen spins in Fe/IrMn systems [4] whereas the relaxation ratio of rotatable and frozen spins is 21 in NiMn/CoFeB systems [5] which increases with increase in thickness of NiMn indicating the contribution of 'bulk' NiMn spins in training relaxation.

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Bipolar Spin Hall Nano-Oscillators

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Spin Hall nano-oscillators (SHNO) convert dc currents in microwave oscillations of the magnetization [1],[2]. The frequency can be tuned by external magnetic fields, the applied dc current magnitude or by injection locking [3]-[5] if an additional microwave magnetic field is applied to the SHNO. Here, we demonstrate another approach to extend the frequency range of an SHNO by adding an additional ferromagnetic layer [6]. As a result, the auto-oscillations can be switched from one to the other ferromagnetic layer by switching the dc current polarity. A constriction-based SHNO consisting of a Py(5nm)/Pt(7nm)/CoFeB(5nm) layer stack with 2 nm Ta as seed and capping layer was used. If a dc current is applied to the structure, a pure spin current is generated by the spin Hall effect in the Pt layer [7]. For a fixed current direction the spin polarization of the pure spin currents entering in the Py and CoFeB layers have opposite directions. Therefore, only one of both ferromagnetic layers experiences a decrease of damping due to the spin orbit torque and can show auto-oscillations of the magnetization. To change the frequency of the SHNO, the dc current polarity has to be switched in order to switch the auto-oscillations from one to the other ferromagnetic layer. We demonstrate the generation of auto-oscillations for all four combinations of direct current and magnetic field polarities which is in contrast to SHNOs with only one ferromagnetic layer. We show that the combination of two materials with different saturation magnetizations extends the frequency range of SHNOs. The authors acknowledge financial support from the Deutsche Forschungsgemeinschaft within programme SCHU 2922/1-1.

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Direct Imaging of the Magnetic Structure of the Residual Ferromagnetism at the Film/Substrate Interface in B2 Ordered FeRh

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FeRh is a highly interesting material for future spintronic devices. This is due to the unusual transition between antiferromagnetic and ferromagnetic order when heating close to room temperature [1]. One key aspect of this transition that is not fully understood is the nucleation dynamics of the magnetic domains [2] [3]. Here we present a room temperature study of the magnetic domain texture of a 10nm thick film of FeRh grown on an MgO(001) substrate, measured using nitrogen-vacancy (NV) scanning magnetometry [4]. This technique allows for the mapping of the stray field emanating from the sample with nanometre resolution [4]. This study shows a magnetic domain texture in the nominally antiferromagnetic phase according to bulk magnetometry measurements. The overall domain structure of the sample is comprised of a variation of shapes, islands which are hundreds of nanometres in size and several μm length stripes. Domains of this size are consistent with previous measurements of both the ferromagnetic and antiferromagnetic phases [5] [6]. Further analysis reveals that this magnetic texture belongs to the residual ferromagnetic layer at the FeRh/MgO interface. This constitutes the first direct imaging of the magnetic structure of this interfacial layer. These results suggest that the ferromagnetic domain structure nucleates at the surface in films of this thickness and propagates into the bulk as consistent with Lorentz Transmission Electron Microscopy measurements [3].

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Structural and Magnetic Analysis of Nanostructured NiO prepared via Mechanical Milling

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Mechanical milling is a solid-state fracture technique that allows the synthesis of alloys in large quantities, in a simple way, which is also industrially scalable [1]. However, due to the fact that magnetism is govern by quantum effects, reducing the size of the alloy can cause changes in its magnetic behavior. Our objective is to investigate the relationship between milling time and the crystalline structure, microstructure, and magnetic properties of various NiO samples prepared with milling times between 1 h and 100 h. For this analysis, we employed techniques such as X-ray diffraction, transmission electron microscopy, and magnetic measurements. Starting with a NiO powder, from the Sigma-Aldrich trademark, we prepared 6 samples with the following milling times: 0 h, 1 h, 3 h, 10 h, 50 h, and 100 h. We measured the diffraction patterns of all samples using XRD (with λ_{Cu} in the 2θ range $10^\circ - 140^\circ$). Rietveld refinement of all diffraction patterns was carried out, obtaining a good fit to the rhombohedral model, with lattice parameters *a*=2.957 (0.002)Å and *c*=7.21 0.01) Å. By analyzing the high-resolution spectra taken in the ESRF synchrotron (line ID22) λ = 0.3544 Å, we confirmed that rhombohedral structure. In addition, we observed an enhancement in the width of the diffraction peaks as the milling time increased, which is due to the joint effect of size reduction and strain, to a lesser extent. The analysis of TEM images revealed that milling times of 50 h and 100 h lead to NiO NPs with mean diameters of 55 (19) nm and 45 (20) nm, respectively. Even though these results differ from those obtained by XRD [37 (2) nm and 29 (2) nm], they are within the same order of magnitude. Hysteresis curves, measured with a vibrating sample magnetometer, confirmed the antiferromagnetic behavior of the samples. However, those obtained with milling times of 50 h and 100 h, also revealed the presence of a ferromagnetic contribution due to surface spin disorder [2]. Furthermore, from the measurements of the coercive field (at room temperature), we could determine that the NiO NPs exhibit a transition from the multidomain regime into the monodomain one within the hours of milling time.

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Experimental synthesis along with ab-initio theoretical calculations of $Sm_{1-x}MM_xCo_5$ (x = 0 –1, MM = mischmetal)

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In this study the introduction of Mischmetal (Ce-La alloy) in the $SmCo_5$ system is presented. Mischmetal is a "free"rare-earth mineral, appearing as a by-product during mining and processing of other raw materials. A series of samples with nominal stoichiometry $Sm_{1-x}MM_xCo_5$ (x = 0.1 –1.0) were prepared in bulk form with conventional metallurgy techniques (Arc-Melting) and their basic magnetic and structural properties were examined. The materials retain the hexagonal $CaCu_5$-type structure with minor fluctuations in unit cell parameters as observed with X-ray diffraction. Ab initio simulations and DFT calculations were performed to determine the energetically preferable structure; mischmetal content of x=0.5. Incorporation of Mischmetal degrades intrinsic magnetic properties, Curie temperature drops from 920 to 800 K across the series and mass magnetization from 98 to 60 Am^2/kg; effects which trade off for the significantly reduced manufacturing price.

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Anomalous Hall Effect in the coplanar antiferromagnetic coloring-triangular lattice

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In the present work, we study the appearance of an anomalous Hall effect on the antiferromagnetic coloring-triangular lattice [1]. We consider a tight binding model with non uniform hoppings and a magnetic coplanar structure in which the magnetic moments form an angle of 120° with their nearest neighbors. The effects of this magnetic background is taken into account via the Hund's coupling between the electron' spin and the localized magnetic moments. We also consider a spin-orbit coupling which we introduce, at effective level, in the hopping terms through $SU(2)$ matrices that rotate the electron spin as it hops from site to site [2]. The hoppings between neighbouring lattice sites are divided in two different types: i) intra-plaquette hoppings with an amplitude t_1 and the effective spin-orbit coupling , and ii) inter-plaquette hoppings with an amplitude t_2 and no spin-orbit coupling. We observe that the spin-orbit coupling plays a key role in the electric properties of the system as the electronic bands become topologically non-trivial for finite spin-orbit couplings and suitable combinations of the hopping amplitudes. The topology of each band is characterized by the presence of non-zero Chern numbers. This, in turn, leads to a quantized Hall conductivity occurring at the global band gaps [3]. Therefore, our results reveal that in the coplanar magnetic structure, without net magnetization, a finite spin-orbit coupling leads to a significant Hall conductivity in the antiferromagnetic coloring-triangular lattice.

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Tuning of Dyzaloshinskii-Moria Interaction in Perpendicularly Magnetized Pt/Co/AlO$_x$ Heterostructure

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The interfacial Dyzaloshinskii-Moria interaction (DMI) is an antisymmetric exchange interaction that favors the non-collinear alignment of neighboring spins. It plays a crucial role in the stabilization of chiral domain walls (DW) and magnetic skyrmions which are essential for the realization of next-generation spintronics devices. The quantification of DMI for the specific material system is critical to fabricate such devices. Moreover, the enhancement of DMI in the material system is very important as it can lead to the efficacious motion of DW and skyrmion by using spin-orbit torque. In our experiment, we evaluate the strength of DMI in Pt/Co/AlO$_x$ trilayers by using three compatible measurement techniques, namely, asymmetric domain wall expansion, hysteresis loop shift, and spin-wave frequency shift. We find the strength of the interfacial DMI varies from ~ 0.09 mJ/m^2 to ~ 1.13 mJ/m^2 by optimizing oxidation time, aluminum thickness, and the nature of the substrate. In addition, we also study that the influence of oxygen content at the Co/AlO$_x$ interface of the trilayers on DMI. For that purpose, the investigation of the cobalt oxide concentration at the interface by using x-ray photoelectron spectroscopy (XPS), and low-temperature hall effect measurement techniques for the samples annealed at different time intervals are performed.

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Magnetization Switching by Spin-Orbit Torque from a Topological Dirac Semimetal

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Electrical manipulation of magnetization is of great importance for writing operations in magnetic memory. Recent works show that topological surface states (TSS) in topological insulators, which host highly mobile charge carriers with spin-momentum locking, can be utilized to manipulate magnetization. In principle, there also exist TSS for topological semimetals, but it remains unexplored as to whether such states can also be utilized for magnetization reversal. In this presentation, we report current-induced magnetization switching enabled by TSS in a topological Dirac semimetal α-Sn [1]. Our experiments made use of an α-Sn/Ag/CoFeB tri-layered structure. All the layers were grown by sputtering at room temperature. Field-free current-induced magnetization switching was demonstrated at room temperature. The data show that the switching is driven by the TSS of the α-Sn layer, rather than spin-orbit coupling in the bulk of the α-Sn layer or current-produced Joule heating or Oersted field. The switching efficiency is as high as in topological insulator-based systems. Our work demonstrates that the topological Dirac semimetal α-Sn is as promising as topological insulators in terms of spintronic applications.

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Time Domain Two-Magnon Interference

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Two-particle interference, commonly referred to as the Hong-Ou-Mandel (HOM) effect [1], is expressly quantum in nature with no classical analog. HOM is used in many quantum technologies [2]. Since HOM was first observed with photons in a 50:50 beamsplitter (BS) [1], it has been investigated in other systems of bosonic and fermionic quantum objects using various interference mechanisms [2], but the effect has not yet been investigated in magnons. Magnons have been studied for use in hybrid quantum computing systems due to the magnetic field tunability of their resonant frequencies and their efficient coupling to disparate quantum systems [3], [4].

Here, we consider a model system for two-particle interference of magnons. The system is composed of an elliptical pillar that consists of 2 ferromagnetic (FM) layers that are antiferromagnetically coupled through a thin nonmagnetic (NM) layer separating them. The FM layers in the elliptical pillar can be excited by a waveguide to oscillate with frequencies ω_1 and ω_2. The system will function as follows. In the absence of a bias magnetic field ($\vec{B} = 0$), the FM layers are strongly coupled and oscillate collectively ($\Delta\omega_{12} = \omega_1 - \omega_2 = 0$). In the presence of a bias magnetic field ($\vec{B} \neq 0$) the FM layers are weakly coupled and oscillate independently ($\Delta\omega_{12} \neq 0$). This means that, by using a time-dependent magnetic field $\vec{B}(t)$ to dynamically tune the system off-resonance ($\Delta\omega_{12} \neq 0$), magnons in each FM layer can be excited and detected individually, and by bringing the system on-resonance ($\Delta\omega_{12} = 0$) the previously independent FM layers will interact, thereby leading to interference of the magnons in each FM layer.

We numerically simulated this system and found that two-particle magnon interference can be controlled with this FM/NM/FM pillar. Specifically, a magnon was excited in each FM layer to create a $|11\rangle$ state, then the system was brought on-resonance for some time τ, such that the probability for magnon scattering between layers was $1/2$. This is analogous to a magnonic BS operation that evolves the $|11\rangle$ state to generate a maximally entangled $N00N$ state $(|20\rangle+|02\rangle)/\sqrt{2}$, up to a phase shift. The magnonic BS can also detect different phases of $N00N$ states. In summary, we found that dynamically tuned resonance of the FM layers can achieve a magnonic HOM effect. Two-magnon interference could be used to generate and detect $N00N$ states and construct a hybrid magnonic quantum computer.

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Resonant Dynamics of Three-Dimensional Topological Spin Textures

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Spin textures are the foundation of properties of magnetic materials and drive the functionality of magnetic devices. Topological spin textures have led to intense research e.g. in magnetic skyrmions [1] addressing a broad spectrum of challenging scientific and technological questions, including stability, dynamics [2], nucleation, and transport. So far, topological spin textures have been treated foremost as two-dimensional spin textures, however, recent investigations have taken a conceptual leap to three-dimensional nanoscale size magnetic spin textures. Among these spin textures are target skyrmions: double skyrmions that are more stable in three dimensions, Hopfions: linked three dimensional knots [3], [4], and torons: the un-linked pre-images of Hopfions.

Here, we report on micromagnetic simulations of fast dynamics in three dimensional spin textures. We focus on the resonant spin wave modes of magnetic Hopfions up to 15 GHz driven by external magnetic fields. A sharp transition is found around 66 mT coinciding with a transition from Hopfions to torons. The modes exhibit characteristic amplitudes in frequency space accompanied by unique localization patterns in real space, and are found to be robust to damping around topological features, particularly vortex lines in Hopfions and Bloch points in torons. Most remarkably, we have identified pronounced differences in spin wave spectra between Hopfions, torons and target skyrmions that can serve as fingerprints in future experimental validation studies of these novel 3d topological spin textures.

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World-Line Quantum Monte Carlo for Spin-1 Systems

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It is common to find in physics many-body problems impossible to tackle using analytical methods; therefore, numerical approximations become needed to handle those systems. In this work, we implement a stochastic numerical method, a quantum Monte Carlo, to study the ferromagnetic phases induced by an external magnetic field on a system of ultracold spin-1 particles in an optical lattice, restricting our study to the Mott insulator phase with unit filling. We map the partition function of the 1D quantum system into one of an effective 2D classical model through the Suzuki-Trotter decomposition [1]–[6], obtaining a summation of weights given by the classical configurations. Afterwards, we implement the world line Monte Carlo using a Metropolis-like algorithm, where we attempt to maximize the configuration weight (instead of minimize the energy as the usual Metropolis) to reach the ground state and perform measurements of suitable observables.

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A Bosonization Approach to One-Dimensional Spin-1 Reticular Bosons

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Bosonization is an analytical technique for one-dimesional systems that takes advantage of the blurring of the difference between fermions and bosons due to the effect of dimensionality on quantum statistics. Although the method was developed and is most often used in the treatment of interacting fermions, we study the procedure to bosonize bosons, and apply it to a toy model of hard-core bosons. The aim of this gradual developement is to apply the technique to a gas of spin-1 interacting particles on an optical lattice described by the $S = 1$ Bose-Hubbard Hamiltonian, which is approached by developing an effective theory around the high-symmetry, $SU(3)$, point. Additionally, we study which areas of the phase space are suitable for analysis using this technique, and propose additional tools and approximations for further study of the system [1]–[5].

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Path Integral in Coherent States for the Study of Spin 1 Strongly Correlated Systems

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Ultra-cold atoms in optical lattices provide a novel opportunity to study strongly correlated systems,due to the high control of the relevant physical parameters [1] and the possibility of simulating phenomena with a controlled complexity [2]. This facilitates the study of the magnetic properties of the system, unlike the usual materials in which its study becomes more complex. Spin major systems ($> 1/2$) present novel phases, different from the ferromagnetic-antiferromagnetics usually studied in Heisenberg models for 1/2 spins. Furthermore, in recent years there have been different studies on the unconventional order in spin 1 magnets [3], hence the relevance of studying different techniques that allow us to delve further into this system. In the present work we study a strongly correlated spin 1 system in a one-dimensional periodic network described by the Bose-Hubbard Hamiltonian with the inclusion of the degree of freedom of spin. From this, the problem is limited to the generalized Heisenberg Hamiltonian, which describes the most relevant characteristics of the system at low energies in the Mott phase, for this, a quasi-perturbation theory generated up to the second order is used, taking the kinetic term as a disturbance. Subsequently, we proceed to analyze the system by constructing the partition function as a path integral on a basis of coherent states [4] and introducing the Matsubara formalism at finite temperature. The advantages of the base in spin coherent states and the base in a representation of bosonic coherent states are studied, to apply techniques usually used for the study of spin 1/2 systems, such as the Hubbard transformation [5] and Landau's theory [6] that allow the extraction of information on the characteristic scales of the system and the different.

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Simulations of FMR for Study the Shape Anisotropy in Square Hollow Nanopillars

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By means of micromagnetic simulation, the study of ferromagnetic resonance (FMR) in square hollow nanopillars was carried out [1]. The study was performed with the aim of analyzing the effects of geometry as the nanopillar (NP) cavity varies in size. NPs with L = 120 nm length and D = 30 nm external width were studied. By fitting the data from simulations and the FMR model for uniaxial symetry (for parallel field and using the Primary peak) the anisotropy field values were HA = 97.2, 116.4 and 144.5 kA/m for d = 0, 10 and 20 nm, respectively. For perpendicular field, HA = 175, 193 and 251 kA/m for d = 0, 10 and 20 nm, respectively. The variations were attributed to the increase in dipole interactions between the internal and external parts of the pillars, as the cavity size increases [2]–[4]. A secondary peak was also fitted to the FMR model for uniaxial anisotropy and HA values of 222.5, 220 and 226.9 kA/m were obtained for parallel configuration. Thus, this secondary peak, whose local effective field varies little with the dimensions of the cavity, were attributed to the effects of parallel edges.

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Modulation of Quantum Coherence by Driven Non-Equilibrium Spin States in a Molecular Trimer: Ferromagnetic vs Anti-ferromagnetic Alignment

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The relationship between magnetism and phase coherence dates back to the Aharonov effect which has been successfully demonstrated and realized. Ever since, the quest for the connection between magnetism and quantum coherence has been intensified and it remains an open question. On the one hand, Quantum coherence which is an intriguing and fascinating phenomenon, has been observed in a variety of systems at the nanoscale [1], including single molecule junctions [2], where the ability to exhibit constructive or destructive interference and the emergence and nature of quantum decoherence has been accounted for in terms of the electronic transmission through the molecular junction [3]. On the other hand, molecular nanomagnets, have been realized as a cluster of magnetic molecules adsorbed on surface, and the atom by atom magnetic exchange interaction among them has been successfully engineered as well in the context of scanning tunneling microscopy [4], [5], hence yielding a fast growing interest in molecular spintronics and spin states preparation. From the theoretical side, quantum transport signatures of different spin states have been studied in [6]. Moreover, for the case of the ability to exhibit quantum interference at the nanoscale, predictions have established a strong connection between destructive quantum interference and entropy driven processes such as the Seebeck effect and the emergence of quantum decoherence [3], [6]. Here, inspired by the experiments in [4], [5], we considered a molecular junction, particularly, a molecular trimer, with the possibility exhibit both quantum interference and spin structure and therein, we study from a theoretical point of view, the non-equilibrium induced exchange interaction between the molecular spins and the corresponding magnetic ordering making particular emphasis in all ferromagnetic and all anti-ferromagnetic alignment. Furthermore, we considered the effect of this ordering on the ability of the molecule to exhibit quantum interference which can be determined from signatures in the electronic transmission function as detailed in [3], [6]. As a consequence we are able to show that: a) through external non-equilibrium drives one can switch between all ferromagnetic and all anti-ferromagnetic ordering in a spin molecular trimer, b) the spin structure of the molecule is a relevant characteristic to take into account when evaluating the degree to which quantum coherence is observed in quantum transport measurements

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RKKY Interaction Between Magnetic Impurities Indirectly Coupled to Local Vibrations Under Electro-Chemical and Thermal Non-Equilibrium Conditions

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One of the most rapidly growing fields in theoretical condensed matter physics is the magnetic impurity physics or the magnetism of dilute alloys [1]. Here, a low concentration of magnetic impurities is placed on a non-magnetic metal, and despite not interacting directly, the impurities become coupled effectively through the conduction electrons in the metal. This type of interaction is known as the RKKY interaction [2]–[4], and it has the property that, as the distance between the impurities (localized moments) varies, the nature of the coupling between them oscillates from ferromagnetic to anti-ferromagnetic and vice-versa. In recent years, the RKKY interaction has been engineered precisely at the atomic level in the context of scanning tunneling microscopy [5], where the coupling can be indeed switch between ferromagnetic and anti-ferromagnetic one. This very same effect has been been predicted in voltage biased metallic junctions [6], [7], where two magnetic impurities are considered and the coupling between them is modulated with varying the voltage of the junction, and it has shown a strong dependence with respect to the temperature gradient through the junction. Here, we consider the effect of local vibrations indirectly couple to each impurity on the non-equilibrium RKKY interaction between them, and in addition, we study the transmission of the molecular junction to establish a connection between quantum coherence and molecular magnetism.

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Non-Equilibrium Induced Chiral and Anti-Symmetric Exchange Interaction in Magnetic Field Free Molecular Junctions with Spin Structure

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From magnetism of dilute alloys and impurity physics, some of the most fascinating phenomena in condensed matter have emerged, for instance, the RKKY interaction and the Kondo Effect. The RKKY interaction emerges when magnetic impurities diluted in non-magnetic metals interact via conduction electrons, that is, an indirect exchange interaction [1]–[3]. This interaction resembles the Heisenberg interaction as it is a spin-spin symmetric and isotropic interaction though indirect. The latter, with the particularity that the interaction oscillates between ferromagnetic and anti-ferromagnetic in nature as a function of the separation distance between impurities. A different type of indirect exchange emerges in the presence of spin-orbit coupling [4], [5], which in nature resembles the Dzyaloshinskii-Moriya interaction, this is a chiral and anti-symmetric interaction. In the Nanoscale context, both the symmetric and isotropic interaction [6], and the chiral and anti-symmetric interaction [7] have been engineered in the framework of scanning tunneling microscopy, which motivated the work herein. In the present work, we report how the chiral and anti-symmetric effective exchange interaction between magnetic moments in molecular magnets adsorbed on a non-magnetic surface can be tuned by the action of a non-equilibrium drive. The origin of these drives could be a voltage bias induced by a scanning tunneling microscope tip or a temperature gradient between the microscope tip and the non-magnetic metallic substrate. We also report the different chiral regimes of the spin-spin behavior as a function of those non-equilibrium drives and how these affects the projection of the magnetic moments on the easy axis direction, looking forward to integrate the molecular spin structure with quantum transport measurements.

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Antiferromagnetic Properties of Spin-1 Bosonic Gases in Optical Lattices

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In the present project, we study the magnetic properties of a system of spin-1 bosons loaded in an optical lattice with the presence of a quadratic magnetic Zeeman field. This system has been previously described denoting the presence of both ferromagnetic and antiferromagnetic phases when the system is under the presence of an external quadratic Zeeman field [1], [2]. In order to minimize the energy of the system we perform the imaginary time evolution using the Gutzwiller variational method which proposes an ansatz to approximate the ground state for a certain point in the phase space [3]. Both the ferromagnetic region has been treated with this method, as well as the antiferromagnetic properties. Paying special attention to the latter one. We use a set of observables as a tool set to characterize the phases of the system.

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Synthesis of Perovskites of the PZT(52/48) and PLZT(3/52/48) Systems by the Amorphous Citrate Method: Evaluation of their Structural, Morphological, and Optical Properties

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In this work, mixed oxides with perovskite structure type PZT(52/48) and PLZT(3/52/48) were synthesized by the amorphous citrate method. The solid precursors for these two systems were prepared at pH 8.5 and with a nitrate/citrate (n/c) ratio of 1 and 6. These precursors were characterized by Fourier transform infrared spectroscopy (FT-IR) and by thermogravimetry and differential thermal analysis (TGA-DTA). The precursors were calcined at $600°$C for 2 h to obtain PZT(52/48) and PLZT(3/52/48) type perovskites which were characterized by X-ray diffraction (DRX), scanning electron microscopy (SEM) and diffuse reflectance spectroscopy (DRS) to evaluate their structural, morphological and optical properties, respectively.

By FT-IR it was found that in the solid precursors for both systems prepared by the citrate method the formation of metal ion coordination compounds with citric acid occurs with good homogeneity. From the TGA-DTA results it was obtained that the solid precursors prepared with a ratio n/c = 1 are decomposed in stages, while the preparations with a ratio n/c = 6 their decomposition occurs in a single stage to form the perovskite structure. DRX analysis confirmed that PZT(52/48) and PLZT(3/52/48) type perovskites with single phase and tetragonal crystal system were obtained. Rietveld refinement treatment for the PZT(52/48) system reveals lattice parameters of a = b = 4.064655 Å and c = 4.104535 Å and a χ^2 = 4.677. The SEM images show that the morphology of both systems presents large clusters as a continuous phase with the presence of macropores and according to the results of DRS the band gap (E_g) for the PZT(52/48) system is equal to 3.41 eV, while for the PLZT(3/52/48) system it is of the order of 3.38 eV.

Contribute to the knowledge of the synthesis and characterization of materials of PZT and PLZT systems is of great importance, because these systems present several properties such as magnetic [1], piezoelectric [2], ferroelectric [3] and photovoltaic [4] that depending on their structure and stechemistry can be improved.

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A Comparative Study of the Stability of Magnetic Skyrmions in Elliptical and Rectangular-Shaped Cobalt Nanostructures

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Magnetic skyrmions are particle-like spin textures characterized by a non-trivial topology of the magnetic moments in a nanometer-size magnetic systems with broken inversion symmetry and spin-orbit coupling. Due to its unusual physical properties like high stability and mobility, magnetic skyrmions are suitable for spintronic applications including magnetic data carrier and logic devices [1]–[6]. In this work micromagnetic simulations have been used to study of the influence of the anisotropy (K_u) and Dzyaloshinskii-Moriya interaction (DMI) constant on the stability of magnetic skyrmions nucleated at the geometrical center of the cobalt nanostructures, for elliptical and rectangular-shaped structures . In order to compare the changes in the internal magnetic states for both types of nanostructures, the major and minor length sides of the rectangle are being considered to be the same that the x-axis and y-axis of the ellipse. For both types of nanostructures, micromagnetic simulations clearly demonstrate the influence of the Ku and DMI constants on the stability and size of the magnetic skyrmions . However, a plot of Ku versus DMI for a range between 1.10 and 1.40 MJ/m^3 for Ku, and 0.0 to 6.0 mJ/m^2 for the DMI, shows that the elliptical nanomagnet has a higher range of Ku and DMI values to stabilize the skyrmions. The analysis of the demagnetizing energy shows that the curved geometry of the ellipse produce a lower energy when compare with the rectangular nanostructures. For specific values of Ku and DMI of 1.30 MJ/m^3 and 2.0 mJ/m^2, respectively, the size of the magnetic skyrmions in elliptical nanostructures decreases with the ellipticity of the ellipse. Also, the stability for the topological charge, Sk, under externally applied magnetic field, increases with the diameter of the magnetic skyrmions. These results have been explained in terms of the interplay between the energies at that nanoscale.

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Micromagnetic Behavior of Iron Nanotubes as a Function of the Aspect Ratio

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We report the study of the magnetic properties and magnetization dynamics of Fe nanotubes with free boundary conditions as a function of aspect ratio (r/h), for which we use the finite difference method and Ubermag which is a utility level (Python) that ranks above ("über") existing micromagnetic simulation packages such as Object Oriented MicroMagnetic Framework (OOMMF) and mumax3 [1]. The hysteresis loops show a direct relationship between extrinsic properties such as coercive field (H_C) and remanent magnetization (M_r) with r/h, [2]; furthermore, the magnetization diagrams indicate the presence of vortex type magnetic states (V), accompanied by a centroid with displacement capability, and single domain (SD), [3]; the generation of nucleation (H_n) and annihilation (H_a) fields is also observed [4]. On the other hand, a direct competition was observed between the dipole energy (E_d) that tries to expand the magnetic domain walls and the exchange energy (E_{ex}) that tries to collapse them; on the contrary, the Zeeman energy (E_Z) and the anisotropy energy (E_k) do not compete with each other, since the external magnetic field is applied on one of the easy magnetization axes, [5].

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Probing anisotropy in epitaxial Fe/Pt bilayers by spin-orbit torque ferromagnetic resonance

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Studies on spin-orbit torques (SOTs) in novel material systems attracted enormous attention in the past decade. Investigation on SOTs improves our understanding of fundamental spin physics at interfaces and has the potential to revolutionize highly-energy efficient storage applications. From this end, spin-orbit torque ferromagnetic resonance (STFMR) is a prominent choice for studying spin-orbit torques in multilayers [1]–[6].

Here, we report the generation and detection of STFMR in micropatterned epitaxial Fe/Pt bilayers grown by molecular beam epitaxy. The biasing magnetic field was applied in an in-plane geometry at an angle of 45° with respect to the microwave-current direction. We observed the presence of two distinct resonance peaks. We compare our STFMR measurement with broadband ferromagnetic resonance spectroscopy of the unpatterned bilayer thin films. The experimental results are interpreted using an analytical formalism which indicates the presence of strong magnetic anisotropy. The formalism was further confirmed using micromagnetic modeling using MuMax3 [7], which reveals the field-dependent magnetization alignment in the microstructures. Our results demonstrate a simple and efficient method for determining magnetic anisotropies in microstructures by means of on-chip rf spectroscopy.

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Spin Transfer Torque Driven by Interfacial Roughness and Spin-orbital Scattering

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Spin transfer torques allow efficient electric control of magnetization dynamics in nanoscale heterostructures [1]–[4]. In this work, we theoretically investigate a spin-transfer torque effect in a ferromagnetic metal layer emanating from surface roughness and Rashba spin-orbit scattering in the presence of an in-plane charge current. A full quantum mechanical approach is used to evaluate the charge-current-spin-current response function, which allows us to analyze the effect of quantum interference between scattering states near the Rashba interface. In the ballistic regime, we find that while a field-like torque can be induced by applying an in-plane current regardless of the surface roughness, a damping-like torque only emerges from a Rashba interface together with magnetic impurities whereby the interference between scattering states is partially suppressed.

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Approximate Model Describing Stability and Dynamic Properties of Room-Temperature Bose-Einstein Condensate of Magnons

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Formation of Bose-Einstein condensate of magnons (mBEC) at room temperature has been observed under microwave parametric pumping in in-plane magnetized ferrite films of a micron thickness [1], and in nanometer-thick ferrite films undergoing rapid cooling after heating by a DC current pulse [2]. It is also known that mBEC has non-trivial nonlinear properties with the sign of the nonlinear frequency shift coefficient g determining the mBEC stability [3]–[5].

Assuming that mBEC is formed in spectral minima $\omega = \omega_{BEC}$ of the dipole-exchange magnon spectrum of an in-plane magnetized magnetic film corresponding to wavenumbers $k = \pm k_{BEC}$, we developed a simple approximate model of mBEC , where the magnon spectrum near the BEC point is parabolic and nonlinear: $\omega(k) \approx \omega_{BEC} + (\hbar/2)(\mathbf{k} - \mathbf{k}_{BEC}) \cdot \hat{\mathbf{M}}_{eff} \cdot (\mathbf{k} - \mathbf{k}_{BEC}) + (g/\hbar)\rho + (2g_{\pm}/\hbar)\rho$, where $\hbar$ is the reduced Planck constant, $\mathbf{k}$ and $\mathbf{k}_{BEC}$ are wavevectors, $\hat{\mathbf{M}}_{eff}$ is the tensor of the effective mass of a magnon as a quasi-particle, $\left[\hat{\mathbf{M}}_{eff}\right]_{ij} = \hbar/(d^2\omega(\mathbf{k})/dk_i dk_j)$, ρ is the effective magnon density, g is the coefficient of the nonlinear magnon self-interaction in one of the spectral minima, while $g_{\pm}$ is the coefficient of the nonlinear cross-interaction of magnons belonging to two different spectral minima (see [3] for details). The magnon effective mass turns out to be anisotropic, i.e. strongly dependent on the direction of the magnon propagation in the film plane, which strongly affects the dynamic properties of mBEC, for example, the speed of Bogolyubov waves [6]. It was also found that the cross-interaction nonlinear coefficient $g_{\pm} \gg g$ is positive, and does not depend on the mBEC in-plane localization. In contrast, the self-interaction nonlinear coefficient g depends on the in-plane localization of mBEC [4], and, when the demagnetization factor N, determined by the ratio of the mBEC localization length in the direction of magnon propagation to the film thickness d exceeds a critical value $N_{cr} = (3\pi/2\sqrt{2})(\lambda_{ex}/d)$ (where λ_{ex} is the exchange length in the film material) the coefficient g can change its sign from negative to positive, thus guaranteeing the mBEC stability against the collapse [3]–[5].

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Unbounded FEM Formulation for 2D Static Fields

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Poisson's equation can describe electromagnetic potentials in 2D, with suitable boundary conditions. This equation is generalized as:

$$\nabla \cdot \mathrm{k}\nabla\Theta + \mathrm{Q} = 0 \tag{1}$$

The parameter Θ assumes V, electric potential, for electrostatic and electrokinetic studies. Such a value is A, magnetic vector potential normal component, for magnetostatic studies [1]. The parameter k is permittivity ε for electrostatic studies, conductivity σ for electrokinetics, reluctivity $\nu = 1/\mu$ for magnetostatic or a tensor reluctivity for permanent magnets and anisotropic materials studies. The parameter Q is charge density ρ for electrostatic or null for electrokinetics. It also assumes the current density J for magnetostatics.

The integral equation of the Weighted Residual Method, being W_0 a weight function and D the Del operator, for the mapped elements at the limits of the domain in a u, v transformed coordinate system is then

$$\int\limits_{\Omega'^e} D_{uv}^T W_0^e \left[k'\right] D_{uv} \Theta^e \, \mathrm{d}u\mathrm{d}v = 0 \tag{2}$$

where

$$\left[k'\right] = \boldsymbol{J}^T k \boldsymbol{J} |\boldsymbol{J}^{-1}| \tag{3}$$

Therefore, the FEM modeling for the mapped domain is equivalent to the solving of Poisson's equation (1) in an anisotropic material $[k']$ described as a tensor. We solve the mapped problem with the usual boundary conditions, being the Del operator expressed for the transformed coordinates and $\boldsymbol{J}$ the Jacobian matrix of the transformation.

This paper presents a domain mapping for the elements in the outer limits of a bidimensional domain, where the source term Q is supposed null for every study. We impose typical boundary conditions at boundary nodes. However, the mapped elements have an anisotropic behavior, and the material property has a spatial dependency.

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Negative Magnetoresistance Driven by Rashba Spin-Orbit Coupling and Paramagnetic Impurity

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Negative magnetoresistance (NMR) –which is rarely seen in normal metals –is often hosted by topological materials and linked to band topology. We show that, in metallic systems with strong spin-orbit coupling and inversion symmetry breaking, NMR may arise from the Rashba states as well. As a proof of concept, we consider a minimal model of a Rashba two-dimensional (2D) electron gas with paramagnetic impurities, and calculate the magnetoresistance by solving the semiclassical Boltzmann transport equation exactly. We find that the magnetoresistance relies not only on the strength of the magnetic field B but also on its orientation relative to the electric field E: the longitudinal resistance monotonically decreases with an increasing magnetic field – namely an NMR –when E and B are parallel, whereas it increases monotonically with the magnetic field –namely a positive magnetoresistance –when E and B are both in-plane and mutually perpendicular. We will also extend our discussion to (nontopological) 3D metallic systems such as Bismuth thin films [1].

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Effect of Structural Transformation (fcc to $L1_0$) on the Magnetic Properties of FePt, CoPt, and $PtFe_{0.5}Co_{0.5}$ Nanoparticles

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The magnetic properties of hard magnetic materials such as FePt and CoPt depend strongly on their structure. These binary alloys exhibit hard magnetic properties in the ordered face-centered tetragonal (fct/$L1_0$) structure. FePt nanoparticles attract a lot of interest because of their many potential applications such as high density recording media, biomedicine and catalysis [1]–[3]. In the fct state, FePt has a high magnetocrystalline anisotropy of about 70 Merg/cm^3 and high coercivity making it ideal for use in high density recording media [4]. Various chemical techniques have been used to enhance the coercivity of $L1_0$ FePt, particles such as using halide intermediary [5] or using Bi additive [6]. Usually, the as-made particles have the fcc structure and low coercivity. In most cases, the simplest way to obtain the L10 structure after synthesis is by performing heat treatment under an inert environment above $550°$C. The drawback of post annealing is the increase in grain size and sintering, leading to widening in size distribution and solubility of the nanoparticles, reducing their suitability in applications as catalysts. In the first part of this work, we study different stages of the $L1_0$ state transformation in FePt nanoparticles after annealing under various conditions, and apply a simplistic model to describe the temperature dependence of coercivity of selected FePt samples into different stages of the fcc to fct transformation.

In the second part, we study the properties of chemically synthesized CoPt nanoparticles. CoPt nanoparticles are chemically stable and have a high magnetocrystalline anisotropy of the order of 4×10^7 erg/cm^3, making them suitable as a stable permanent magnetic material [7] and for applications in ultrahigh density magnetic recording [8]. In our work, we mainly studied the magnetic properties of CoPt which were annealed at $700°$C for 4 hours and applied a model to describe its temperature dependence of coercivity. We also synthesized a ternary system of Pt-Fe-Co, $PtFe_{0.5}Co_{0.5}$, and studied the evolution of its structure from fcc to fct after heat treatment under different conditions, as well as its magnetic properties and compared its properties to those of FePt and CoPt.

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Emerging exotic phases due to RKKY interaction in magnetic spin systems

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We study the competition between the nearest neighbors exchange interaction and effective RKKY couplings, whose origin is the interaction with itinerant electrons, for Ising spins in a square lattice. The RKKY-type interaction is, in principle, long-ranged, and depends on the Fermi momentum of the itinerant electrons and the coupling constant of the RKKY interaction. Depending on the parameters chosen, this model may present magnetic frustration.

To focus on areas where the competition between interactions is stronger, we vary the parameters around the values for which all the effective exchange constants are of the same order of magnitude. We analyze the low temperature phases numerically, using the Monte Carlo Metropolis algorithm. We find that the frustration in combination with an external magnetic field gives rise to a plethora of exotic plateaux. This is a first step towards exploring the effect of RKKY interactions in more complex systems.

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Universal Time conversion table

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