Book of abstracts

24-28 July 2023

Poznań 2023

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MAGIC+ WORKSHOP
Magnetism, Interactions and Complexity

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The Workshop is supported by four projects:

- NCN GRIEG: Spin and charge transport in low-dimensional novel quantum materials (2Dtronics) (No. 2019/34/H/ST3/00515), coordinated by prof. Anna Dyrdał (AMU, Poznań, Poland) in collaboration with Dr Alireza Qaiumzadeh (QuSpin/NTNU, Trondheim, Norway)
- NCN POLS: Statics and dynamics of 3d magnetization textures (3DMATEX) (No. 2020/37/K/ST3/02450), coordinated by prof. Olena Tartakivska (AMU, Poznań, Poland and IMAG, Kyiv, Ukraine) in collaboration with prof. Konstantin Guslienko (UPV/EHU, San Sebastian, Spain) and Maciej Krawczyk (AMU, Poznań, Poland).
- NCN SHENG: Spin waves in magnetic skyrmion crystals (SPINSKY) (No. 2018/30/Q/ST3/00416), coordinated by prof. Maciej Krawczyk (AMU, Poznań, Poland) jointly with prof. Yan Zhou (The Chinese University of Hong Kong, Shenzhen, China).
- NCN OPUS: Magnetic domains without domain walls in magnetically patterned rare-earth-transition metal ferrimagnetic films (TWIST) (No. 2020/39/B/ST5/01915), coordinated by prof. Piotr Kuświk (IMP PAS, Poznań, Poland)

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Venue

The Będlewo Palace
Research and Conference Centre
Mathematical Institute Polish Academy of Sciences

Photo by Sławomir Malecha

History

The first mention of Będlewo comes from the end of 12th century when the village was owned by the Łodziów family, whose descendants were called Będlewscy. The situation changed in the following centuries. In the 17th century, Będlewo was ruled by Potoccy- the so-called Greater Poland branch of Potocki family. In 1851 Józefa Potocka funded a chapel in the parochial church in Łódź. Bolesław Potocki (1861-1898) was an outstanding owner of Będlewo. He ruled for 37 years and enlarged the properties, which consisted of Będlewo, Wronczyn, Dymaczewo, Zamysłowo, Srocko, Wojnowice, and Dakowe Mokre, totaling 4.728ha. Potocki was the founder of the KLIWECKI, POTOCKI I SKA Bank. He was also a member of the Theatrical Committee and dedicated the garden and palace to build a theatre. In 1866, the Palace in Będlewo was renovated. The manor house, with thatched roof, was built first. The palace is surrounded by the park which covers about 9ha. It is a park in an English style which joins the elements of the forest. There are unique trees protected by the law. The palace is surrounded by a marble fountain, two lakes and the terrace full of flowers. On one lake there is an island with a romantic grotto. It was believed that there was a chapel. Fifteen years ago there was also a pheasant farm. In 1939 Będlewo was ruled by Elżbieta from the Miączyńscy Ledóchowscy family. During the war the palace functioned as a residence to the Reich Commissioner, whose role was aimed at preserving the German nation. During that time, the polychromes in the Knightly hall were painted over and the portraits of Polish kings were destroyed with all the decorations. After the war, all the riches were inherited by the public treasury. A cinema and different schools were located in the palace. There were many reconstructions of the palace. In 1976 the

Polish Academy of Sciences from Poznań captured the palace and it was introduced as the Creative Work Centre. At the turn of the 70s and 80s the Palace was decorated by the Monuments Maintenance Studio. The polychromes were re-introduced, the dry rot was eliminated, and the roof was covered with the cupreous sheeting. In 1996 the Palace was inherited by the Mathematical Institute of the Polish Academy of Sciences. The conference centre was founded and it developed very fast. In 1997, the hotel part was built, then the lecture room, the farm entrance (the building with the reception and a tower with the bell), courtly outhouse and the stable appeared. The lakes and the ponds were cleaned. Now the Palace functions as a Mathematical, Research and Conference Centre in the Polish Academy of Sciences. There are only three such places in Europe of whichthe Będlewo centre is the biggest one- where 150 people can be seated. Our palace was visited by many well-known mathematicians, artists, politicians and contractors. Our guests' satisfaction is for us the biggest recommendation and allows us to organize following meetings.

24th July 2023

Registration at Faculty of Physics, Adam Mickiewicz University, Morasko

13:00-15:00

Opening Session, chairman: Piotr Kuświk, Maciej Krawczyk, Anna Dyrdał

15:00-16:00	Opening Ceremony
16:00-17:00	Invited Talk: Manipulating optical spin and polarization of localized light with metasurfaces Oleh Yermakov *V. N. Karazin Kharkiv National University, Ukraine*

Transport to Będlewo from Morasko Campus/Room Allocation

17:00-20:00

Welcome Dinner

20:00

25th July 2023

Breakfast

08:00-09:00	

Session 2, chairman: Anna Dyrdał

09:00-10:00	Invited Talk: First-principles design of magnetic topological insulators Arthur Ernst *Johannes Kepler University Linz, Austria*
10:00-11:00	Invited Talk: Van Hove singularities and charge density waves in transition metal dichalcogenides Marcin Mucha-Kruczyński *University of Bath, United Kingdom*
11:00-11:30	Coffee break

Session 3, chairman: GABRIEL DAVID CHAVES-O'FLYNN

11:30-12:00	In-plane magnetic skyrmion valve made of 90° pinned magnetic domain walls Pavel Baláž *FZU-Institute of Physics of the Czech Academy of Sciences, Czech Republic*
12:00-12:30	2D and 3D Topological solitons in chiral magnets Vladyslav M. Kuchkin *University of Iceland, Iceland*
12:30-13:00	Conference Photo

Lunch

13:00-14:30	

Session 4, chairman: Arthur Ernst

14:30-15:30	Invited Talk: Topological nodal-point superconductivity in a 2D-antiferromagnet/superconductor hybrid system Maciej Bazarnik *Institute of Physics, University of Münster, Germany*
15:30-15:50	Static and dynamic magnetic properties of two-dimensional vanadium-based transition-metal dichalcogenides, VX2 (X= S, Se,Te) Mirali Jafari *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*

15:50-16:10	Static and dynamic magnetic properties of single-molecule magnets separated on the surface Oleksander Pastukh *Institute of Nuclear Physics Polish Academy of Sciences, Poland*
16:10-16:30	Electronic and topological properties of a topological insulator thin film sandwiched between ferromagnetic insulators Piotr Pigoń *AGH University of Krakow, Poland*
16:30-17:00	Coffee break

SESSION 5, CHAIRMAN: MARCIN MUCHA-KRUCZYŃSKI

17:00-17:20	Nonlinear transport phenomena in 2D systems with *k*-cubed Rashba spin-orbit interaction Anna Krzyżewska *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*
17:20-17:40	Berry phase and transport properties of twisted graphene/semiconducting transition metal dichalcogenides heterostructure Izabella Wojciechowska *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*
17:40-18:00	Nonlinear longitudinal and transverse conductivity in topological insulators: effect of non-equilibrium spin polarization and scattering on spin-orbital impurities Kateryna Boboshko *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*

BARBECUE DINNER

19:00

26th July 2023

BREAKFAST

08:00-09:00

SESSION 6, CHAIRMAN: PIOTR KUŚWIK

09:00-10:00	Invited Talk: Lateral couplings for computation with magnetic domain walls and oscillators Aleš Hrabec *Laboratory for Mesoscopic Systems/Paul Scherrer Institute, Switzerland*
10:00-11:00	Invited Talk: Surface phenomena and defects in ferrimagnetic thin films and nanoparticles Michał Krupiński *The Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences, Poland*
11:00-11:30	Coffee Break

SESSION 7, CHAIRMAN: ALEŠ HRABEC

11:30-12:00	Magnetic properties of transition metal and rare-earth adatoms: An ab initio study Aleksander Wysocki *Department of Physics and Astronomy, University of Nebraska at Kearney, USA*
12:00-12:30	Topological Hall effect in antiferromagnetic skyrmions with non-collinear order Amir Nasser Zarezad *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*
12:30-13:00	Damping of magnetization precession in epitaxial and polycrystalline YIG thin films Adam Krysztofik *Institute of Molecular Physics Polish Academy of Sciences, Poland*

LUNCH

13:00-14:30

SESSION 8, CHAIRMAN: MICHAŁ KRUPIŃSKI

14:30-15:30	Invited Talk: Ultrafast and ultrasmall: all-optical switching of magnetization Clemens von Korff Schmising *Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Germany*
15:30-15:50	Magnetic domains without domain walls in Tb/Co layered films after patterning by Ga^{+} focused ion beam Daniel Kiphart *Institute of Molecular Physics Polish Academy of Sciences, Poland*

15:50-16:10	Focused-ion beam direct writing of the magnonic structures into the metastable iron thin layers Jakub Holobrádek *CEITEC BUT, Brno University of Technology, Czech Republic*
16:10-16:30	Influence of CoFeB layer thickness on elastic parameters in CoFeB/MgO heterostructures Shashank Shekhar *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*
16:30-17:00	Coffee break

FREE TIME

17:00-19:00

DINNER

19:00-20:00

POSTER SESSION

20:00

27th July 2023

Breakfast

08:00-09:00	

Session 9, chairman: Maciej Bazarnik

09:00-10:00	Invited Talk: New materials for all-optical control of spins Maciej Dąbrowski *University of Exeter, United Kingdom*
10:00-11:00	Invited Talk: Phase-resolved optical characterization of spin waves Michal Urbánek *CEITEC BUT, Brno University of Technology, Czech Republic*
11:00-11:30	Coffee Break

Session 10, chairman: Michal Urbánek

11:30-12:00	Magnonic Lieb lattices Jarosław Kłos *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*
12:00-12:30	Modeling dynamic, direct and inverse magnetoelectric effects Piotr Graczyk *Institute of Molecular Physics Polish Academy of Sciences, Poland*
12:30-12:50	Spin-wave scattering on localized modes: harnessing three magnon processes for frequency and trajectory control Krzysztof Sobucki *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*

Lunch

13:00-14:30	

Session 11, chairman: Maciej Dąbrowski

14:30-15:30	Invited Talk: Ultrafast and ultrasmall: all-optical switching of magnetization Aires Ferreira *York Centre for Quantum Technology, United Kingdom*
15:30-16:30	Invited Talk: Aspects of proximity induced effects in Van der Waals heterostructures Martin Gmitra *Institute of Experimental Physics, Slovak Academy of Sciences, Slovakia*

16:30-17:00	Coffee break

SESSION 12, CHAIRMAN: MARTIN GMITRA

17:00-17:30	Molecular engineering: inverted physics Łukasz Laskowski *Institute of Nuclear Physics Polish Academy of Sciences, Poland*
17:30-17:50	Nonreciprocal spin-wave devices Krzysztof Szulc *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*
17:50-18:10	Antidot lattice with perpendicular magnetic anisotropy: dynamics between edge modes and bulk modes Mathieu Moalic *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*

BANQUET

19:00

28th July 2023

Breakfast

08:00-09:00	

Session 13, chairman: Maciej Krawczyk

09:00-10:00	Invited Talk: Excitation of ferromagnetic resonance by microwave electric field: role of charge-current induced torques Bivas Rana *ISQI, Faculty of Physics, Adam Mickiewicz University, Poland*
10:00-11:00	Invited Talk: Thermal stability of micromagnetic systems beyond the Néel-Brown macrospin model Gabriel David Chaves-O'Flynn *Institute of Molecular Physics Polish Academy of Sciences, Poland*
11:00-11:30	Closing Ceremony
11:30-12:30	Check out

Lunch

12:30-13:30	

Transport to Poznań from Będlewo

13:30-15:00	

July 24th

Opening Session

Manipulating optical spin and polarization of localized light with metasurfaces

Oleh Yermakov [1]

[1] *V. N. Karazin Kharkiv National University, 4 Svobody Square, Kharkiv, Ukraine*

Polarization-dependent optical effects are widely used in microscopy, cryptography, ellipsometry and other areas of optics, while the polarizers are ubiquitous in our everyday life. Polarization plays also a role of optical "bit" for the information transferring and processing in the optical systems. One can easily control the polarization of plane waves in the far-field.

Miniaturization and planar technologies lead to the high localization of the electromagnetic signal in the plane of propagation. However, at the same time, the polarization degree of freedom is absent for the localized light, i.e. for surface and guided waves. In other words, the manipulation over the polarization and optical spin in the near-field is almost impossible and poorly studied to date. It significantly limits the functionality of flat optical and planar photonic devices.

Metasurface represents a periodic subwavelength array of scatterers enabling the efficient control of light. Plasmonic and all-dielectric metasurfaces can support surface and guided waves, respectively. This work aims to review the different approaches of controlling the optical spin and polarization of surface and guided waves propagating along the metasurfaces. First, we will consider the metasurfaces supporting the localized waves of various polarizations states: purely TE and TM, hybrid TE-TM [1,2] and degenerate TE-TM [3,4]. Then, based on the considered polarization states of the eigenmodes, we will analyze several phenomena and applications including the robust spin-directional coupling (spin-momentum locking) [5], the anisotropy-dependent optical spin [1] and the planar optical polarizer of localized light [3,6]. These results could potentially become a platform for new generation of planar photonic polarization devices.

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[4] O. Yermakov et al., Phys. Rev. X 11, 031038 (2021).
[5] K. Y. Bliokh, A. Y. Bekshaev, and F. Nori, Nat. Commun. 5, 3300 (2014).
[6] S. Polevoy, and O. Yermakov, IEEE Antenn. Wireless Propag. Lett., [Early Access] (2023).

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July 25th

Sessions 2-5

First-principles design of magnetic topological insulators

Arthur Ernst

Institute for Theoretical Physics, Johannes Kepler University Linz, Altenberger Straße 69 4040 Linz, Austria

It is a well-known fact that a magnetic field can break the time reversal symmetry and therewith can destroy a topologically protected surface state in topological insulators. However, the interplay between magnetism and topological order can yield a number of interesting phenomena such as the quantum anomalous Hall effect, a topological magneto-electric effect, and quantised Kerr- or Faraday rotation. This motivates researcher for a search of new magnetic topological insulators and for an intensive study on their electronic and magnetic properties. In my talk, I'll give an overview of our first-principles investigations on this class of materials focusing on the impact of disorder effects. In the first part, I'll present a method and approximations used in our simulations and then talk about several examples of magnetic topological insulators, studied in our group within the last three years. First of all, I'll discuss topological insulators doped with magnetic impurities, which can imply various magnetic order in these materials. A special attention will be devoted to the exchange interaction between magnetic impurities and to the impact of electron-magnon interaction on the electronic structure in some doped topological systems. As next, I'll demonstrate how some defects or impurities without magnetic moments can induce magnetism in topological insulators and discuss the main features of magnetic interactions in these systems.

Van Hove singularities and charge density waves in transition metal dichalcogenides

W. R. B. Luckin[1], Y. Li[2,3], J. Jiang[4], S. M. Gunasekera[1], C. Wen[3], Y. Zhang[3], D. Prabhakaran[5], F. Flicker[6], Y. Chen[5,3,7], M. Mucha-Kruczynski[1]

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[2]*Inst. for Advanced Studies, Wuhan University, Wuhan 430072, People's Republic of China*
[3]*ShanghaiTech University, Shanghai 201210, People's Republic of China*
[4]*University of Science and Technology of China, Hefei 230026, People's Republic of China*
[5]*Department of Physics, University of Oxford, Oxford OX1 3PU, UK*
[6]*School of Physics and Astronomy, Cardiff University, Cardiff CF24 3AA, UK*
[7]*CAS-Shanghai Science Research Center, Shanghai 201210, People's Republic of China*

The understanding and manipulation of correlated states of matter like superconductivity or ferromagnetism are amongst the principal challenges in condensed matter physics. From magnetic phases, high-temperature and topological Kagome superconductors to magic-angle twistronic graphene and other graphene materials, the correlated states often appear alongside a high density of electron states induced by van Hove singularities (vHs) [1-5]. Here, we focus on the interplay between a vHs and a charge density wave state in a layered metallic transition metal dichalcogenide 2H-$TaSe_2$. We use angle-resolved photoemission spectroscopy to investigate changes in the Fermi surface of this material under surface doping of a bulk crystal with potassium. At high doping, we observe modifications which imply the disappearance of the (3×3) charge density wave and formation of a different correlated state at the surface. We explain our observations as a consequence of coupling between the single-particle Lifshitz transition, during which the Fermi level passes through the vHs, and the charge density order. The high electronic density of states associated with the vHs induces a change in the periodicity of the charge density wave from the known (3×3) to a new (2×2) superlattice [6]. Our observation of the (2×2) phase validates a prediction from almost 50 years ago: we present the first spectral evidence of saddle-point nesting-driven charge density order in transition metal dichalcogenides as originally proposed [1]. Because presence of similar saddle points in the band structures of transition metal dichalcogenides is guaranteed by the nature of interatomic interactions, similar phenomenology might be expected in other materials from this family. Moreover, the tunability of our system opens a new avenue to explore the interrelationships between charge density waves, van Hove singularities and superconductivity.

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Acknowledgements: This work has been supported by the UK Engineering and Physical Sciences Research Council (EPSRC) through the Centre for Doctoral Training in Condensed Matter Physics (CDT-CMP), Grant No. EP/L015544/1. Y. L. acknowledges support from the National Natural Science Foundation of China (Grant No.~12104304). J. J. acknowledges support from the National Natural Science Foundation of China (Grant No.~12174362).

In-plane magnetic skyrmion valve made of 90° pinned magnetic domain walls

Pavel Baláž [1]

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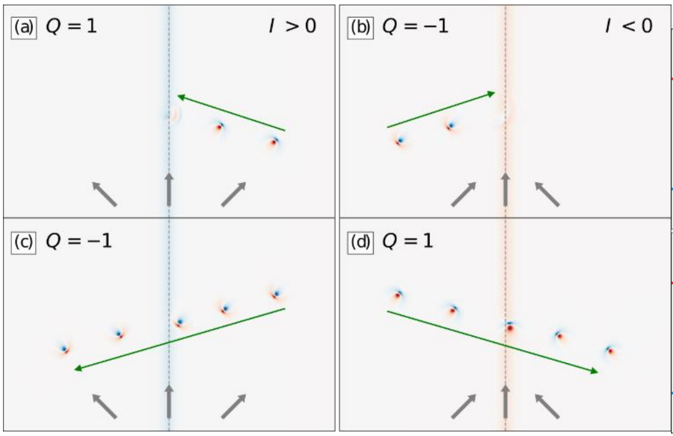
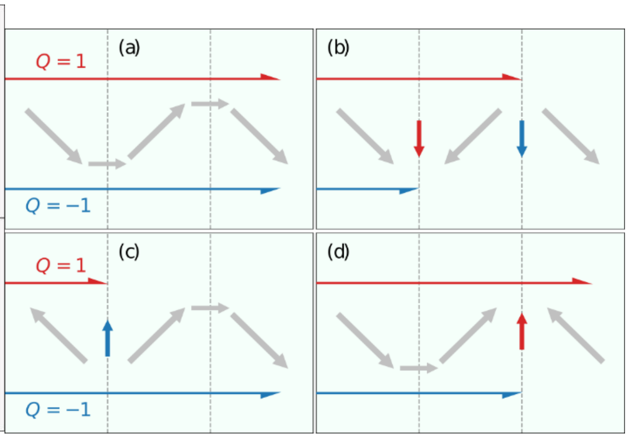
Magnetic skyrmions are small spherical whirls in the vector field of magnetization known for their hight stability. Typically, they can be found in thin films or magnetic multilayers featuring Dzyaloshinskii-Moriya interaction in combination with perpendicular magnetic anisotropy. Recently, number of theoretical studies and numerical simulations have shown a possibility of existence of in-plane skyrmions in magnetic thin layers with in-plane easy-axis magnetic anisotropy and interfacial DMI [1]. These topological defects known as in-plane skyrmions, or sometimes as asymmetric skyrmions [2], or bimerons substantially differ from their out-of-plane twins. Unlike skyrmions in systems with perpendicular magnetic anisotropy, the in-plane skyrmions of both topological charges (Q=±1) can simultaneously exist in the same magnetic domain.





Importantly, in-plane magnetic skyrmions can interact with planar magnetic textures, like 90° pinned magnetic domain walls (DWs), which are stable in hybrid multilayers consisted of ferromagnetic and ferroelectric layers [3,4]. Here, we show that a charged 90° DW can act as a topological-charge-selective filter of in-plane magnetic skyrmions. Namely, skyrmions crossing a 90° DW can pass or be annihilated according to their skyrmion charge (see left figure). This effect is caused by out-of-plane magnetization in the DW, which is induced by the presence of DMI. Combining two magnetic DWs, we suggest an in-plane skyrmion valve able to control the flow of skyrmion topological charge [5] (see right figure).

[1] K.-W. Moon, J. Yoon, C. Kim, and C. Hwang, Phys. Rev. Appl. **12**, 064054 (2019).
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2D and 3D Topological solitons in chiral magnets

Vladyslav M. Kuchkin[1]

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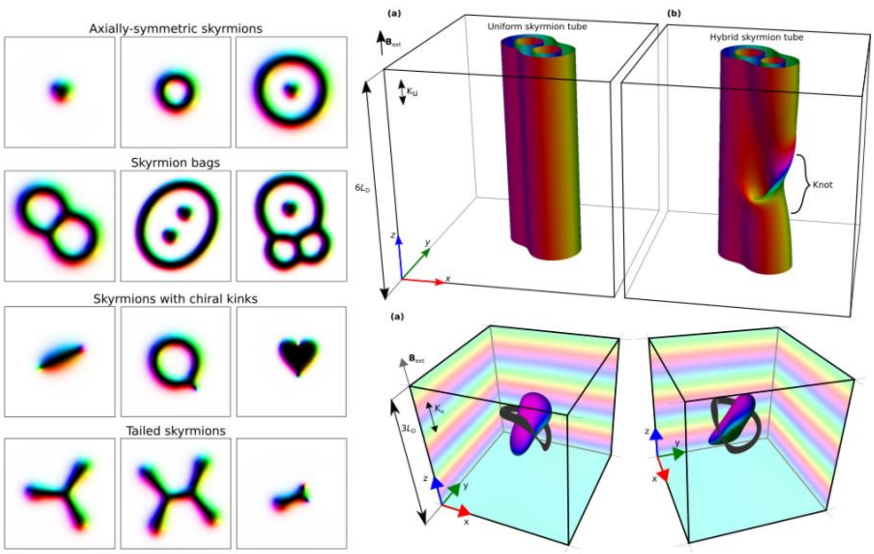
(24 May 2023)

Chiral magnets are a unique class of magnetic materials that exhibit a wide range of stabilized topological solitons (see Figure). Initially, only axially symmetric solutions known as k π -skyrmions were discovered. However, in recent years, there has been a significant increase in the diversity of both theoretically predicted and experimentally observed states. Notable examples of 2D solitons include skyrmion bags [1], skyrmions with chiral kinks [2], and tailed skyrmions [3]. I will comprehensively discuss these different states, focusing on their static and dynamic properties [4]. In the 3D case of chiral magnets, these solutions can be extended to skyrmion tubes, introducing a new degree of freedom and enabling the formation of skyrmion braids and hybrid skyrmions [5]. Moreover, in the thick films and bulk crystals of isotropic chiral magnets, the solitons fully localized in all three dimensions and known as hopfions can also be stabilized [6].



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Topological nodal-point superconductivity in a 2D-antiferromagnet/superconductor hybrid system

Maciej Bazarnik[1,2,3], Roberto Lo Conte[3], Eric Mascot[3,4], Dirk K. Morr[5], Kirsten von Bergmann[3], Roland Wiesendanger[3]

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In the recent years, pioneering studies have been carried out on magnet/superconductor hybrid systems [1-4], motivated by their potential to host emergent quantum phases such as topological superconductivity [5]. So far, the attention has been mainly focused on hybrid systems with a ferromagnetic order [1,3,4,6], which are understood as gapped topological superconductors with a finite Chern number [7,8] defining the amount of end states and propagating edge modes.

Here, we present the discovery of a topological nodal-point superconducting phase in a hybrid system consisting of antiferromagnetic manganese (Mn) monolayer islands on top of the *s*-wave superconductor niobium (Nb) [9]. The novel topological superconducting phase was discovered via a low-temperature spin-polarized scanning tunneling microscopy and spectroscopy investigation. Low-energy edge modes are observed at the boundaries of the magnetic islands, separating the topological phase from the trivial one. In accordance to tight-binding calculations, we find that the relative spectral weight of the edge modes depends on the edge's atomic configuration, which is a fingerprint of the discovered topological superconducting state. Our results establish the combination of antiferromagnetism and superconductivity as a novel route to design 2D topological quantum phases.

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Static and dynamic magnetic properties of two-dimensional vanadium-based transition-metal dichalcogenides, VX_2 (X= S, Se,Te)

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There is currently a great interest in two-dimensional (2D) Van der Waals magnetic materials, and many various groups of these materials have already been synthesized. In this presentation we will discuss basic magnetic properties of Vanadium-based transition-metal dichalcogenides, VX_2 (where X = S, Se, Te). These materials became interesting due to their potential application in future electronic and spintronic devices, such as atomically thin spin valves, non-volatile memory elements, or gates for information processing [1-3]. To determine the magnetic properties of these materials, we have employed two different methods; (i) the Density Functional Theory (DFT), and (ii) spin Wave theory in the case of magnetic excited states. More specifically, we calculated the spin-resolved band structures for both monolayers and bilayers of these materials (which were found to be in excellent agreement with previous results [4-6]), and then we utilized these results to determine important parameters describing magnetic properties, such as magnetic anisotropy constants and exchange parameters between Vanadium atoms. These parameters have been then used to calculate the Curie temperatures, hysteresis curves, and especially frequency (energy) of spin wave excitations. The latter has been determined from the numerical Quantum ATK code package [7] as well as from the spin wave theory based on the corresponding effective spin Hamiltonian. Results obtained from these two methods are in good agreement as shown in Figure below. Interestingly, we have found that the Curie temperature for VTe_2 monolayers and bilayers is below the room temperature, especially for bilayers, whereas for VSe_2 and VSe_2 it is close to or above the room temperature, which is consistent with available experimental data. This makes these class of materials (especially VTe_2) very useful for applications, including advanced spintronic devices.

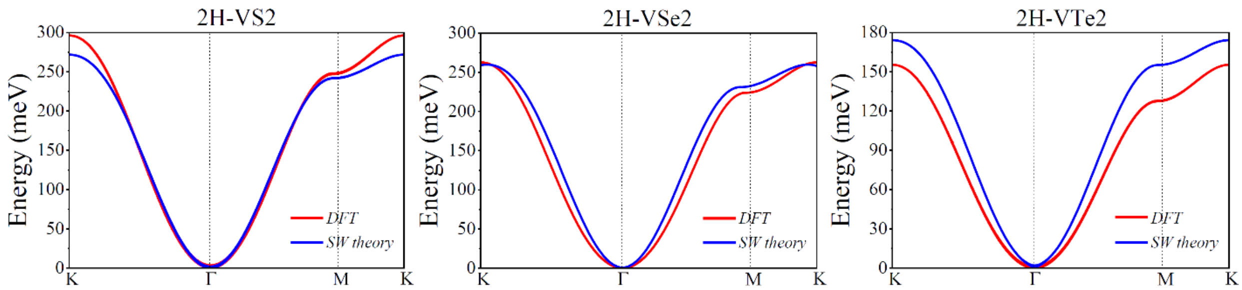

Figure 1: Spin waves obtained from numerical calculations within the ATK package (red line) and from spin wave theory based on the corresponding effective spin Hamiltonian (blue line).

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Static and dynamic magnetic properties of single-molecule magnets separated on the surface

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Nowadays, there is significant focus on developing new nanosized materials with specific magnetic properties. The single-molecule magnets (SMMs) exhibit unique magnetic properties at the molecular level and seems to be ideal candidates for applications in molecular spintronics, quantum computers, and dense magnetic memory devices [1]. However, in order to utilize individual molecules for nanoelectronic devices, it is necessary to deposit and separate SMMs on solid surfaces. A key challenge during this process is maintaining the original characteristics of the molecules, as any alterations to their internal structure can affect their magnetic properties. In current study the analysis of magnetic properties modification with the surface deposition were done for the Mn_{12} based SMMs. The molecules were separated on the spherical silica surface with controlled statistical distribution [2]. The magnetic measurements with the use of SQUID magnetometry confirmed the preservation of hysteretic behavior of SMMs in low temperature after surface immobilization. Possible alterations of the SMMs anisotropy can be attributed to the observed slight change in magnetic hysteresis shape relative to a bulk structure. In addition, the study of magnetic relaxations were performed using DC relaxation measurements as well as AC susceptibility studies. The both techniques confirm that molecular magnets exhibit considerable magnetic anisotropy and slow magnetic relaxations, which remain almost intact after the surface deposition. Obtained values of the effective energy barrier and relaxation time have shown to be similar to the corresponding values for analogous bulk compounds. The studies revealed the complex relaxation process in the deposited molecules and wide distribution of relaxation times.

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Electronic and topological properties of a topological insulator thin film sandwiched between ferromagnetic insulators

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We consider selected spin-orbit-driven effects in a thin film of a topological insulator sandwiched between two layers of a ferromagnetic insulator. The surface electron states in the topological insulator are magnetized due to the magnetic proximity effect to the ferromagnetic layers. Coupling between the ferromagnetic layers can be either ferromagnetic or antiferromagnetic and can be tuned with external magnetic field or by changing thickness of the topological insulator.

Using Green's function formalism, we will determine the transport and topological properties of the system. We will discuss, among others, how the change of magnetization of the ferromagnetic layers, hybridization between the surface states, and gating can affect the transport characteristics such as anomalous Hall effect, longitudinal conductivity, and current-induced spin polarization.

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Nonlinear transport phenomena in 2D systems with *k*-cubed Rashba spin-orbit interaction

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The transport phenomena beyond the linear response regime attract much attention mainly due to their unidirectional character that can be easily applied in spin-logic devices [1].

We consider theoretically selected nonlinear effects in a two-dimensional electron gas with *k*-cubed Rashba spin-orbit interaction under the external in-plane magnetic field. Our model can be applied to semiconductor heterostructures and interfaces of perovskite oxides, e.g., $LaAlO_3/SrTiO_3$ [2]. We will present our results on the intrinsic nonlinear Hall effect that can be tuned by an in-plane magnetic field [3], as well as on the behavior of bilinear magnetoresistance and planar Hall effect originating in non-equilibrium spin polarization in the system [4].

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Berry phase and transport properties of twisted graphene/ semiconducting transition metal dichalcogenides heterostructure

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The discovery of magic angles in twisted bilayer graphene and extraordinary phase transitions in such structures initiated enormous interest in twisted-angle-van-der-Waals structures. The possibility of exploring the dependence of proximity-induced spin-orbit coupling on a twisted angle in such heterostructures can lead to other interesting transport phenomena in which electric or spin signals can be tuned externally. Under particular interest are twisted structures containing graphene and semiconducting transition metal dichalcogenides (TMDCs), where the crucial role play proximity-induced effects.

We will present a theoretical study of selected spin-dependent transport properties of twisted graphene on selected TMDCs such as MoS_2, WS_2, $MoSe_2$, and WSe_2 modelled by an effective Hamiltonian derived based on symmetry considerations and DFT study [1]. We analyze, among others, the behaviour of Berry curvature as a function of twisted angle (from 0° to 60°) and parameters defining the Hamiltonian. We will focus on the behaviour of spin and valley intrinsic Hall effects and current-induced spin polarization and compare some of our results with those reported recently for graphene/WSe2 [2].

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Nonlinear longitudinal and transverse conductivity in topological insulators: effect of non-equilibrium spin polarization and scattering on spin-orbital impurities

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The nonlinear transport phenomena such as bilinear magnetoresistance (BMR) and nonlinear planar Hall effect (NPHE) reveal linear dependence on external electric and magnetic fields simultaneously. It has been shown that BMR and NPHE may have two different origins; (i) the nonzero second-order spin currents that can be induced in the systems with anisotropic Fermi contours, and (ii) the effective spin-orbital field (due to non-equilibrium spin polarization) and specific scattering mechanism, such as structural defects that lead to the spin-momentum locking inhomogeneity. The second mechanism also appears in systems with isotropic Fermi contours.

Based on the Green functions formalism, we have derived analytical and numerical results for the diagonal and transverse conductivity and determined nonlinear signals. We will present detailed characteristics of BMR and NPHE and compare our results with those obtained within other models.

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July 26th

Sessions 6-8

Lateral couplings for computation with magnetic domain walls and oscillators

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In order to go beyond the traditional CMOS logic technology, novel spin-based logic architectures are being developed to provide nonvolatile data retention, near-zero leakage, and scalability. Architectures based on magnetic domain walls take the advantage of the fast motion, high density, non-volatility and flexible design of domain walls to process and store information in three dimensions. Here we demonstrate a method for performing all-electric logic operations and their cascading using domain wall racetracks [1].

Our concept is based on the recently developed chiral coupling mechanism between adjacent magnets where the magnetic anisotropy competes with the interfacial Dzyaloshinskii–Moriya interaction (DMI) in Pt/Co/AlOx trilayers [2-5]. When a narrow in-plane (IP) magnetized region is incorporated into an out-of-plane (OOP) magnetized track, it couples to its surrounding, leading to the antiferromagnetic alignment of the OOP magnetization on the left and right of the IP region. The chiral OOP-IP-OOP structure then serves as a domain wall inverter, the essential building block for all implementations of Boolean logic. Based on this principle, we realized reconfigurable NAND and NOR logic gates, making our concept for current-driven DW logic functionally complete. We also cascaded several NAND gates to build XOR, full adder gates, domain wall diode based inverter [6] and proposed a network of chiral oscillators for dynamic computation [7].

I will also show a new, strong lateral coupling mechanism in a single ferrimagnetic layer based on the exchange interaction. This interaction arises from the compensation temperature patterning of the ferrimagnet. We also implemented this interaction into devices to show electrical switching of compensated ferrimagnetic domains utilizing spin-orbit torques [8]. This exchange-based interaction opens new avenues towards neuro-inspired computing.

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Surface phenomena and defects in ferrimagnetic thin films and nanoparticles

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Alterations of magnetic properties associated with a large surface-to-volume ratio or introduction of defects are of great importance for all magnetic nanosystems. In particular, amorphous rare earth-transition metal (RE-TM) thin films and nanoparticles can demonstrate modified magnetic characteristics and magnetization switching behavior in comparison with bulk counterparts caused by developed surface or by defects introduced e.g. by ion bombardment [1,2].

Understanding and experimental identification what fundamental processes are responsible for changes in the magnetism is, however, a challenge due to the variety of possible overlapping contributions and effects. In the talk, I will demonstrate how to study surface magnetism in amorphous ferrimagnetic RE-TM thin films and nanoparticles and how to determine the impact of defects. In particular, I will discuss the reduction of the average number of surface neighbors, preferential oxidation, and chemical segregation and show which of the processes plays a leading role in a given system. Because experimental separation of various surface and defect contributions is often impossible, a progress in exploring this issue may be achieved by employing computational tools. Therefore, part of the presentation will be devoted to building realistic atomistic spin models that can be validated by experimental results.

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Magnetic properties of transition metal and rare-earth adatoms: an ab initio study

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Individual magnetic adatoms on surfaces may exhibit long-lived spin quantum states and function as single atom magnets with significant remanent magnetization and coercivity at temperatures as high as several tens of kelvin [1]. Reading and writing [2] as well as coherent control [3] of the adatoms spin states have been demonstrated making such systems promising materials for ultrahigh-density magnetic information storage and quantum logic devices. Here, we study electronic structure and magnetic properties of different transition metal and rare earth adatoms on various surfaces using combination of density functional theory (DFT), *ab initio* multireference quantum chemistry methods, and effective spin Hamiltonian technique. Different surfaces are considered including insulating MgO and two-dimensional materials like graphene or ferroelectric In_2Se_3. Preferred adsorption sites and atomic coordinates are determined using DFT calculations in the supercell geometry. The resulting structures are used to build cluster models, and low-energy electronic spectra and magnetic interactions are calculated using quantum chemistry methods. *Ab initio* effective spin Hamiltonians are then constructed that include anisotropy, exchange, dipolar, and hyperfine interactions. The effects of external electric and magnetic fields on magnetic interaction parameters are investigated. Different mechanisms for magnetic relaxation and decoherence are analysed and potential applications of magnetic adatoms in quantum information science are discussed.

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Topological Hall effect in antiferromagnetic skyrmions with non-collinear order

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In this presentation we study the topological Hall effects in canted antiferromagnetic systems. Based on the Berry phase picture and using the adiabatic approximation [1,2,3], we obtain the effective emergent magnetic field by diagonalizing the local exchange Hamiltonian via a local unitary transformation. As in ferromagnets, the effective emergent magnetic field gives rise to the spin-dependent force which leads to an adiabatic contribution to the electron spin dynamics. In collinear antiferromagnets, the doubly degenerate bands ensure a continuous transverse pure spin current flow in the system [3,4]. However, the non-zero magnetization due to canting of the sublattice moments eliminates spin degeneracy. This gives rise to the polarization in the system which results in converting some part of the transverse spin current into transverse charge current [5]. Considering spin dependent emergent magnetic field and using the semi-classical Boltzmann approach, we obtain the diffusion equation for the spin accumulation in the presence of spin-flip scattering. According to the diffusion equation, the gradient of the emergent magnetic field acts as a source for spin accumulation, which may occur in the vicinity of Skyrmions. Finally, we find the corresponding THE conductivity/resistivity and analyze in detail its dependence on the total magnetization, spin-flip scattering, and skyrmion size.

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Damping of magnetization precession in epitaxial and polycrystalline YIG thin films

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Yttrium iron garnet ($Y_3Fe_5O_{12}$, YIG) is one of the compounds intensively investigated in terms of microwave and magnonic applications. This material is distinguished by its low damping of the magnetization precession, enabling the long-range propagation of spin waves. At the moment, it is predicted that information processing devices based on spin waves will have significantly lower energy consumption compared to those based solely on electronic transport. Potential applications are therefore the main motivation for the undertaken research. During the talk, the results of studies on the structural and magnetic properties of thin yttrium iron garnet films will be presented. Particular attention will be paid to the magnetization dynamics and its mutual relationship with the structural properties of the developed layers. More importantly, we will focus on the interpretation of the FMR linewidth in various systems. This includes the epitaxial YIG layers grown on lattice-matched and lattice-mismatched garnet substrates, films grown on naturally oxidized silicon, and YIG/metal bilayers, where the metallic films serve as a spacer separating YIG from the GGG substrate.

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Ultrafast and ultrasmall: all-optical switching of magnetization

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In order to establish all-optical techniques in future data processing technology, two aspects are of crucial importance: first, to achieve ultrafast read-write cycles and second to confine the magnetic information on the nanometre spatial scale. In this contribution, I will present two recent experiments where we used radiation in the visible as well as extreme ultraviolet spectral range to follow the ultrafast and nanoscale magnetization reversal in prototypical ferrimagnetic rare-earth transition metal alloys. In the first experiment, we visualized the ultrafast revolution of the magnetization using optical Faraday microscopy. Two strategies were explored to minimize the temporal separation of two consecutive femtosecond laser pulses toggling the out-of-plane direction of the magnetization: first, we systematically optimized the heat transfer rates using different substrates and second, we accelerated the magnetization recovery by replacing the transition metal iron by cobalt. As a result, we were able to demonstrate write/erase cycles with a minimum pulse-to-pulse separation of only 7 ps, approaching terahertz frequencies [1]. In a second experiment, performed at the free electron laser FERMI in Trieste, Italy, transient magnetic gratings were excited in a GdFe alloy with a periodicity of 87 nm by interfering two coherent femtosecond light pulses in the extreme ultraviolet spectral range. The subsequent ultrafast evolution of the magnetization pattern was then probed by diffraction of a third, time-delayed pulse tuned to the Gd N-edge at a wavelength of 8.3 nm. By examining the simultaneously recorded first and second order diffraction and by performing reference real-space measurements with a magneto-optical microscope, we conclusively demonstrated the ultrafast emergence of all-optical switching on the nanometre length scale.

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Magnetic domains without domain walls in Tb/Co layered films after patterning by Ga^{+} focused ion beam

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We have previously shown that 10 keV He^{+} ion bombardment (IB) through a photoresist mask can be used to locally modify the magnetic properties of rare earth (RE)-transition metal (TM) ferrimagnetic thin films. [1,2] This results from preferential oxidation of the RE species, leading to a reduced contribution of the RE sublattice to the effective magnetization. This allowed regions that where the TM species dominates the effective magnetization (TM+) to be fabricated in a matrix where RE species dominates the effective magnetization (RE+), in films that were RE+ prior to bombardment. The patterned structure could exhibit a unique magnetic structure - domains without domain walls. This may allow magnetic domains to be patterned on much smaller scale than is currently possible.

A promising method to follow this idea is to use a focused ion beam (FIB), because it can be focused below 10 nm. Therefore, in this work, we used 30 keV Ga^{+} FIB to investigate the magnetic properties of Tb/Co multilayers after IB. We found that compensation point and therefore, the coercive field and magnetization saturation can be tuned in the bombarded area by appropriate choices of fluence, similarly to He+ ions. A series of 2D square lattices consisting of TM+ areas (with size varying from 0.2-50 μm) embedded in the RE+ matrix were patterned with a range of different fluences from 1×10^{13}-2×10^{14} ions/cm^2. The magnetic properties were measured by P-MOKE magnetometry. The range of ion fluences which can change the sublattice domination while maintaining perpendicular magnetic anisotropy (PMA) were determined and we show that the magnetic stability of that spin texture depends not only on the size of the square but also on magnetization saturation inside the squares, which can be tailored by ion fluence. This range was also found to strongly depend on the protective capping layer (i.e. Au, Al).

Visualizing the smallest domains fabricated with FIB, however, is limited by the optical resolution. X-ray magnetic circular dichroism in photo-electron emission microscopy offers a resolution of up to 50 nm and can be tuned to provide element specific information. This allowed investigation of the magnetic texture at the interface between bombarded (TM+) and pristine (RE+) regions as well as the oxidation of the atomic species, the mechanism of which is still a matter of debate.

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Focused-ion beam direct writing of the magnonic structures into the metastable iron thin layers

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Iron, under normal conditions, occurs in the ferromagnetic phase with the body-centered cubic (bcc) crystallographic ordering. We are able to stabilize the high-temperature paramagnetic phase with the face-centered cubic (fcc) ordering by the evaporation under the ultra-high vacuum (UHV) conditions on the copper single crystal substrate. This is possible thanks to a low lattice mismatch between copper and fcc iron [1].

By the subsequent ion irradiation (for example by focused-ion beam (FIB) in a dual beam electron microscope) we can "write" ferromagnetic microstructures into paramagnetic surrounding. This fabrication technique allows us to avoid the use of nanolithography techniques like lift-off and etching.

We have shown that we can tune the magnetic and crystallographic properties of such structures by alternating FIB parameters as ion dose, number of scans, ion energy, and scanning direction [2]. We validated this by Kerr microscopy and Electron back-scattered diffraction (EBSD) measurements. An example of such structure consisting of different crystallographic domains is depicted in Fig 1a (the EBSD analysis of the structure is presented in Fig 1b). The possibility to create magnetic patterns with continuous magnetization transitions and at the same time to create patterns with periodical changes in magnetic anisotropy makes this system an ideal candidate for rapid prototyping of a large variety of nanostructured samples with applications in magnonics.

We have already published the first results on structures fabricated in metastable iron.

Local magnetic anisotropy direction control eliminates the need for external magnetic fields. Therefore, it is possible to propagate spin waves in these waveguides in the favourable Damon-Eshbach geometry without the presence of any external magnetic field [3]. To realize a spin-wave device, it is essential to manipulate the amplitude and the phase of spin waves. We achieved this by placing a domain wall inside the waveguides (see Figure 1c). The domain wall can work for example as a phase shifter [4].

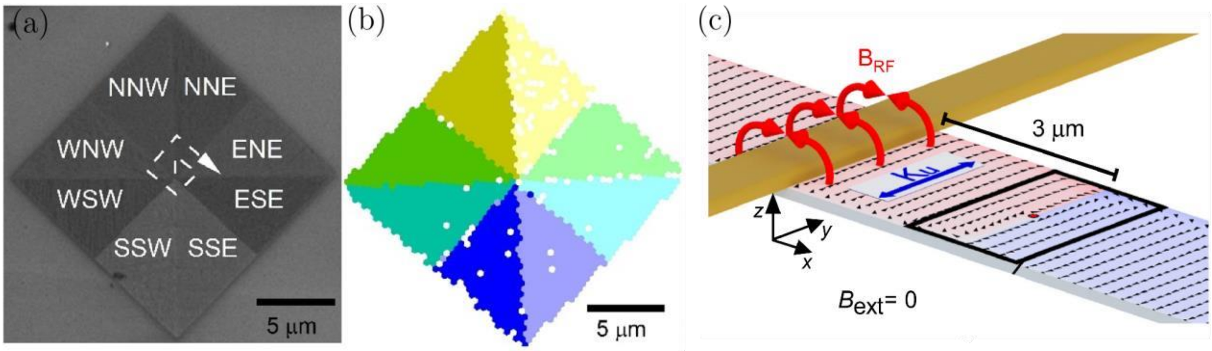

Figure 1: (a) SEM micrograph of magnetic structure fabricated by 30 keV single scan FIB. The dashed line represents the scanning strategy. (b) EBSD measurement on the structure. Each color represents the different crystallographic orientation. (c) Schematic representation of spin-wave propagation excited by the gold antenna in 2μm-wide waveguides in zero external magnetic field.

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Influence of CoFeB layer thickness on elastic parameters in CoFeB/MgO heterostructures

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Surface acoustic waves (SAWs), i.e., phonons (quasiparticles of SAWs) are acoustic waves propagating along the surface of an elastic material with decreasing amplitude with the depth of the material [1]. SAW-based devices have become an integral part of our daily lives [2]. They may also have potential applications in future spintronic devices if coupled with other waves (e.g., spin waves (SWs)) and/or quasiparticles. So, it is quite important to understand the coupling of phonons with other quasiparticles to enhance the coupling efficiency, especially in magnetic thin film heterostructures such as CoFeB/MgO, one of the most promising materials for future spintronics applications [3,4]. As a first step it is important to understand how elastic parameters of magnetic heterostructures and properties of acoustic phonons evolve with the CoFeB layer thickness.

Here, we have investigated SAWs in CoFeB/MgO multilayers by probing thermally generated acoustic phonons by Brillouin light scattering (BLS) spectroscopy to find out effective elastic parameters of the multilayers with varying CoFeB thickness. The multilayer structures: Ta(10)/$Co_{20}Fe_{60}B_{20}$(t=1 to 20)/MgO(2)/Al_2O_3(10) are deposited on Si[001]/SiO_2(700) substrates (the numbers in parentheses are the nominal thicknesses of layers in nm). We observe that the group velocity of Rayleigh type SAWs decreases with increasing CoFeB layer thickness and the phase velocity of Rayleigh waves is lower in studied multilayers as compared to Si/SiO_2 substrate. The experimental results are supported with Finite element method (FEM) based simulations, which helped us to estimate the elastic parameter of the CoFeB layer. Additionally, we estimate the effective elastic parameters (elastic tensors, Young's modulus, Poisson's ratio) of the whole stacks for varying CoFeB thickness. Interestingly, the simulated dispersion characters of SAWs with both types of parameters show very good agreement with the experimental results. These estimated elastic parameters will be quite useful to investigate magnon-phonon interaction in CoFeB/MgO heterostructures.

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July 27th

Sessions 9-12

New materials for all-optical control of spins

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Ultrafast laser pulses promise the fastest and most energy-efficient means of manipulating electron spin and storing information. Of particular interest is all-optical switching (AOS) of magnetization, in which optical excitation can write magnetic bits without an external magnetic field. Despite tremendous effort, so far all-optical toggle switching has been limited to a few ferrimagnetic materials such as GdFeCo, Mn_2Ru_xGa and YIG:Co. In this talk, I will discuss new types of materials exhibiting toggle switching. Firstly, I will focus on perpendicularly magnetized transition metal synthetic ferrimagnets, which are highly desirable due to the low cost and the unparalleled tunability of the constituent materials. Here, for two distinct ferromagnetic layers, Ni_3Pt and Co, multi-pulse all-optical toggle switching can be achieved independently of the optical polarization and across a broad temperature range [1]. Time-resolved measurements indicate that AOS is mediated by the transfer of spin angular momentum between the ferromagnetic layers, which promises a new arena for the exploration of ultrafast spintronic effects down to the nanoscale. Secondly, I will discuss the recently discovered two-dimensional (2D) van der Waals magnets CrI_3 [2] and $Cr_2Ge_2Te_6$ [3]. Most importantly, I will demonstrate that the incorporation of a thin CrI_3 flake into a heterostructure with a transition metal dichalcogenide WSe_2 monolayer allows for both helicity-dependent and helicity-independent AOS down to a single laser pulse [4]. The AOS can be explained by the spin-dependent charge transfer across the CrI_3/WSe_2, which is expected to begin within a few to hundreds of femtoseconds, and should allow for control of magnetic properties on unprecedented ultrafast timescales. Finally, I will demonstrate how optical pumping can also lead to formation of different spin textures with specific topology. In particular, in the case of 2D van der Waals magnet $Cr_2Ge_2Te_6$, laser pulses allow for reversible transformation between stripe and bubble/skyrmion phase [5].

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Phase-resolved optical characterization of spin waves

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When the spin wave wavelengths approach the exchange length of the magnetic material or when the dimensions of the magnonic system are reduced, new phenomena such as spin unpinning condition [1] arises. Nowadays, the only possibility to image nanoscale spin waves is X-ray microscopy, requiring synchrotron radiation and making investigation of nanoscale-related phenomena very time- and resource-demanding [2]. In our approach we show that the phase of spin waves can be characterized optically with sub-diffraction resolution and nanometer precision by using Mie resonance-enhanced Brillouin light scattering [3] with an array of nanoresonators. The spatial restriction of the subdiffractional regions allows the light to interact with the spin waves with much shorter wavelengths, than is the wavelength of free-space light. Our experiments show that it is possible to track spin-wave phase with spatial step of 70 nm and measure the spin-wave wavelength with precision down to few nanometers. We performed this experiment for multiple frequencies and retrieved dispersion relation in the broad range of wavenumbers (from 0 to 30 rad/μm).

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Magnonic Lieb lattices

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Lieb lattice is one of the simplest bipartite lattices, where compact localized states (CLS) are observed. This type of localization is induced by the peculiar topology of the unit cell, where the modes are localized only on selected sublattices due to the destructive interference of partial waves. We demonstrate the possibility of magnonic Lieb lattice realization, where flat bands and CLS can be observed in the planar structure of sub-micron in-plane sizes. Using forward volume configuration, the Ga-doped YIG layer with cylindrical inclusions (without Ga content) arranged in a Lieb lattice with 250 nm period was investigated numerically (finite--element method). The structure was tailored to observe, for a lowest magnonic bands, the oscillatory and evanescent spin waves in inclusions and matrix, respectively. The presented design reproduces the Lieb lattice of nodes (inclusions) coupled to each other by the matrix with the CLS in flat bands. The magnonic platform for the Lieb lattices seems to be attractive due to the larger flexibility in designing magnonic systems and the steering of its magnetic configuration by external biases. The idea of the magnonic Lieb lattices allows considering many problems related to dynamics, localization, and interactions in flat-band systems taking the advantage of the magnonic systems: presence and possibility of tailoring of long-range interactions, intrinsic non-linearity, etc.

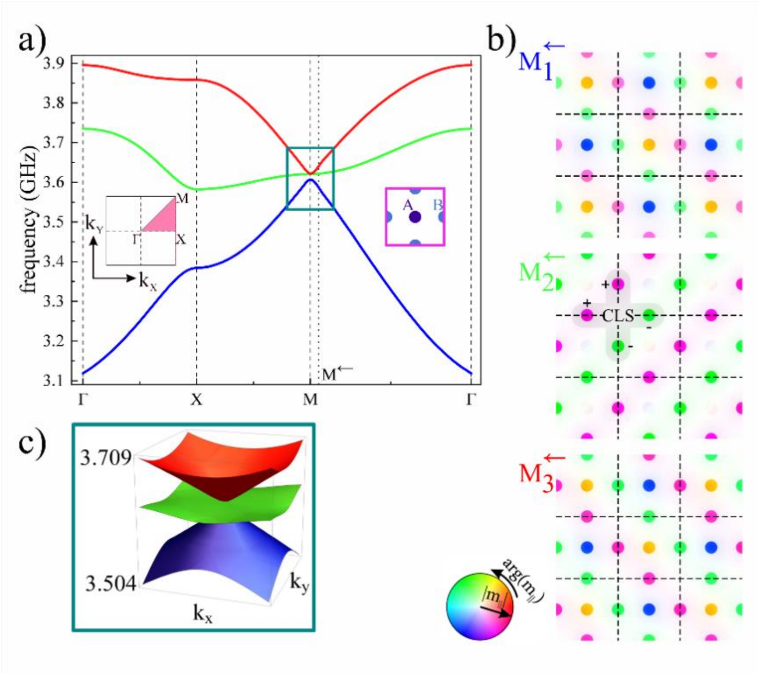

Fig.1. (a) Dispersion relation for magnonic Lieb lattice discussed in [4]. (b) The compact localized state M_2, observed for weakly dispersive band, close to (c) the high symmetry point M in the first Brillouin zone.

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Modeling dynamic, direct and inverse magnetoelectric effects

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I will present the numerical model that solves Landau-Lifshitz-Gilbert equation coupled with the charge-spin transport equations in Comsol Multiphysics in the s-d approximation. The model takes into account the effects of: spin-transfer torque, spin dephasing, spin pumping, spin-dependent conductivity, spin-dependent potential and voltage-controlled magnetic anisotropy. Time-dependent as well as eigenfrequency studies are possible.
The model is especially useful to simulate the magnetoelectric effects (spin-dependent potential, voltage-controlled magnetic anisotropy) in the presence of the spin or charge accumulation at ferromagnetic metal – normal metal or ferromagnetic metal – dielectric interfaces. In the presentation I will show that the time-varying charge accumulation in the ferromagnetic metal produces spin current while, conversely, the time-varying spin accumulation in the ferromagnetic metal (generated by the inverse spin Hall effect or spin pumping) produces charge current via the dynamic magnetoelectric effects.
In particular, we show by numeric simulations that spin-dependent screening at dielectric-ferromagnetic metal interface contributes to the spin-polarized current generation in the system subjected to the ac voltage [1]. Then, we show that spin current driven by spin-dependent screening may be used to modulate spin-wave amplitude in bilayer ferromagnetic system [2]. Finally, we combine *ab initio* calculations of electronic density of states at MgO/Fe interface with continuous model for charge transport. We show that the voltage-driven electron charge accumulation at MgO/Fe interface leads to the Stoner instability because of the electronic interface resonant states. This instability manifests itself in the spin-current and spin accumulation femtosecond pulses which are present because of the contribution of the dynamic spin-dependent potential to the spin-polarized current.

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Acknowledgements: The study has received financial support from the National Science Centre of Poland under grant 2018/28/C/ST3/00052.

Spin-wave scattering on localized modes: harnessing three magnon processes for frequency and trajectory control

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Spin waves (SWs) have attracted significant interest as a research topic due to their potential as an information carrier. One of the advantages of using SWs is their easily achievable non-linearity, which allows for confluence and splitting processes. In this study, we investigate the interaction between an incident SW beam and SW modes localized at the edge of a ferromagnetic film. The nonlinear interaction between the incident beam and the localized mode at the edge results in the creation of new beams with shifted frequencies due to inelastic scattering. Two approaches for localizing the edge modes are considered: the demagnetizing field [1] and placing a ferromagnetic strip directly over the film's edge, which is a realization of the magnonic Gires-Tournois interferometer [2,3]. The efficiency of the nonlinear processes for both systems is compared, and the inelastically scattered SW beams' lateral displacement along the interface with respect to the incident beam point is investigated. This spatial shift of new beams is the SW analog of the known in optics Goos-Hanchen effect that here can be observed in inelastically scattered beams [4]. It is demonstrated that the splitting process is more efficient than the confluence process for both methods of mode localization and that the lateral shift of inelastically scattered beams depends on the edge mode frequency. This research improves our understanding of the inelastic scattering of SWs, which can be used in magnonic circuits to modulate SW frequency and redirect SW beams by changing the localized mode frequency.

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Spin-orbit coupling phenomena in two-dimensional layered materials

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Spin-orbit coupling (SOC)—a relativistic interaction which entangles a particle's motion with its quantum mechanical spin—is fundamental to a wide range of physics phenomena, spanning from the formation of topological insulators to the spin Hall effect of light. The last decade has seen remarkable progress in the probing, enhancing and tailoring of SOC in artificial materials, specifically heterostructures, made of two or more individual flakes of graphene-like crystals arranged in a stack. From robust extrinsic spin Hall effect enabled by the interplay of Rashba effect and spin-valley coupling [1] to gate-tuneable spin-charge interconversion in graphene placed on atomically thin semiconductors [2], these discoveries challenge our previous notions on the possible behaviour of spin-orbit coupled electrons at interfaces. In this talk, I will focus on recent proposals for probing and exploiting the rich interplay of spin and lattice-pseudospin degrees of freedom afforded by two-dimensional layered materials, including a current-induced spin polarization tuneable by means of a simple interlayer rotation angle [3]. Theoretical developments in the microscopic description of coupled spin-charge transport in realistic disordered systems will be briefly reviewed.

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Aspects of proximity induced effects in Van der Waals heterostructures

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Proximity effects in atomically thin layers forming van der Waals heterostructures become paradigmatic materials of extensive interest. The proximity termed as borrowing of certain physical properties between the layers has recently been progressing towards the layer twisting. By a twist of the layers within the vertical heterostructures one can control emergence of extraordinary physical properties originally not possessed by the involved layers. In this talk we discuss several aspects of the proximity induced effects from first-principles and tight-binding approaches. We describe spin physics in proximitized graphene on transition metal dichalcogenides relevant for spintronics and opto-spintronics [1], emergence of topological edge states [2,3], and spin-valley locking due to field-effect in bilayer graphene as a platform for spin transistor [4]. Spintronics applications often relay on conventional electrodes made of 3d ferromagnets. In this case a strong hybridization with the graphene Dirac bands can be suppressed by separation of the graphene using a hexagonal boron-nitride. A giant exchange proximity effect on graphene bands is found when resonant 3d-level of the transition metal is close to the Dirac point [5]. Proximity induced exchange splitting can be efficiently controlled by the transverse electric field leading to fully polarized electronic states controlled by the exchange valve effect in bilayer graphene proximitized by the semiconducting two-dimensional ferromagnet [6]. Ising antiferromagnet can induce staggered spin-orbit and exchange coupling and turn graphene to the quantum anomalous Hall regime [7]. By means of the Chern number calculations we demonstrate that the anomalous Hall regime in graphene with induced superconductivity proximitized by the s-wave superconductor leads to emergence of chiral topological superconducting phases [8]. Field effect in bilayer graphene sandwiched between ferromagnet and strong spin-orbit coupling transition metal dichalcogenide can lead to swapping between the spin-orbit and exchange coupling splitting of the carbon states at the Fermi level creating a device whose properties are controlled by an interaction on demand [9]. We discuss also boosting of the spin-orbit coupling effects by the vertical strain relevant in the field of straintronics [10]. From calculational point of view the field effect can be used to compensate for the artificial energy offset effects of the Dirac point due to lateral strain in supercell calculations in twisted graphene on transition metal dichalcogenide [11]. Correlated electronic states with charge density waves in transition metal dichalcogenides and spontaneous in-plane magnetism provide all-in-one platform in which both spin-orbit coupling and exchange proximity effects can be transferred into graphene and can be utilized for spin-to-charge conversion and spin-orbit torque generation in graphene [12].

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Molecular engineering: inverted physics

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Within a framework of this presentation, the audience will be guided through the methods of molecular engineering. The key to the bottom-up approach for molecular engineering is to design synthesis in such a way that atoms create assumed molecular structure by themselves through the self-organization process. This concept can be applied to operate a position of individual atoms and molecules, preserving assumed distribution of the building blocks (atoms) and control distance between them. Then, we can observe them as separate objects, investigate the interaction between them as a function of intermolecular distance and utilize the properties of individual molecules, which often differs tremendously from their bulk characteristics.

All this above sounds promising but how to achieve this in practice? Let us imagine a solid material with regularly distributed anchoring units separated by a specific distance, which can catch particular atoms or molecules and keep them separated. One association which comes to mind is some kind of a solvent since the last one is able to coordinate the molecules in such a way that they are separated and to create a solvation complex. In the case of a liquid, nevertheless, dissolved molecules are difficult to investigate since they are not immobilized. The compound we are searching for should have such a form that allows for rigid immobilization of nano-objects. This way the objects could be used for specific purposes at specific time and place. It should be some kind of a „solid solvent".

In this lecture, the concept of 2D solid solvent will be presented. Such materials can be fabricated based on functionalized nanostructured materials, such as silica or alumina. A few examples of functional materials being in fact 2D solid solvents will be shown, along with an explanation of their structure, functionality, description the fabrication route and justification the purposefulness of their production. Also, the role of molecular engineering in the fabrication process will be clarified here.

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Nonreciprocal spin-wave devices

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Spin waves are emerging as good candidate for the signal processing thanks to their advantageous properties which include significantly lower energy consumption than comparable electronic processes, broad possibilities to control the spin-wave propagation, and the possibility to induce the nonreciprocity with ease in many ways. These properties raise a possibility to make well-functioning and efficient logic and signal-processing devices.

I want to focus on the last property which is the spin-wave nonreciprocity. In the last decade, the nonreciprocal spin-wave devices have found the interest in the magnonics community [1,2]. Our propositions base on various spin-wave properties. First, we use Dzyaloshinskii-Moriya interaction (DMI) to introduce nonreciprocity in the spin-wave propagation. By dipolarly-coupling DMI and non-DMI materials, we design a spin-wave diode and circulator [3]. Another way is to use the nonreciprocity of the dipolar coupling itself between the materials. In this way, with the use of chiral magnetic resonator to couple two spin-wave conduits, we proposed a multifunctional device [4]. The last proposition bases on the asymmetrical boundary conditions. Introducing the surface anisotropy of different strength on the boundaries of a thin film allows not only the nonreciprocal spin-wave propagation but also asymmetry in the band-gap size. It can be used then to design a spin-wave diode.

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Antidot lattice with perpendicular magnetic anisotropy: dynamics between edge modes and bulk modes

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Magnonic crystals (MCs) have demonstrated a lot of potential as a way to control the propagation of spin waves (SWs). Having the ability to create and control SWs could lead to the creation of magnonic devices that are more space efficient than optical devices and more energy efficient than current electronics. In this research, we study a MC created in a thin film made up of 8 repetitions of Co (0.75nm) and Pd (0.9nm) bilayers for a total thickness of 13.2 nm [1]. This particular combination of a ferromagnetic layer and a heavy metal layer results in a strong perpendicular magnetic anisotropy (PMA) which is interesting as it makes the SW dispersion isotropic. Periodically throughout this thin-plane film, nanodots were etched out using a 10nm wide focused ion beam producing a pattern of antidots. This process not only removed some material, but also damaged the area around each antidot, creating a ring around the antidots where the magnetic properties, notably the PMA have been modified. Due to this, the magnetization at the antidot's edges is almost in-plane. As shown in Fig.1, the ground state of a circular antidot is magnetized in its edge ring in a vortex-like configuration. Through micromagnetic simulations, we analyse the dynamic coupling between edge localised and bulk modes in the film. At first, we limit our analysis to non-propagating SWs and we modify the exciting field as well as the strength of the global external static magnetic field which is oriented out-of-plane and we analyze the SW modes that exist in the rim or in the bulk as shown in Fig.2. Next we show the dynamic coupling between rims and bulk, demonstrating collective behavior on the lattice and promising magnonic applications.

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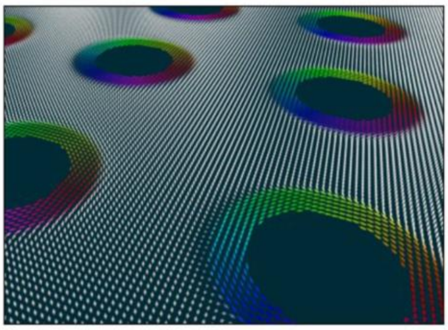

Figure 1: Magnetization in the magnonic crystal.

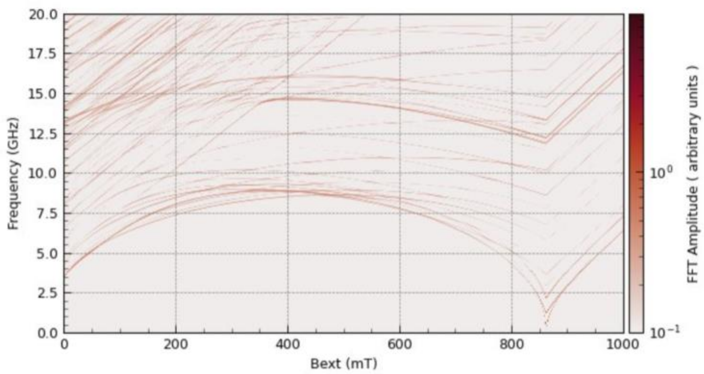

Figure 2: Resonnance spectra of spin waves in the MC depending on the external field.

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July 28th

Sessions 13-14

Excitation of ferromagnetic resonance by microwave electric field: role of charge-current induced torques

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Excitation of magnetization dynamics in magnetic materials, especially, in ultrathin ferromagnetic films, is of utmost importance for developing various ultrafast spintronics devices. Recently, the excitation of magnetization dynamics, i.e. ferromagnetic resonance (FMR) via electric field-induced modulation of interfacial magnetic anisotropies, has received particular attention due to several advantages, including lower power consumption [1]. When an electric field is applied at ferromagnet/oxide interfaces, the relative change in the electron population of out-of-plane 3d orbitals of ferromagnets with respect to the in-plane orbitals at the interface modulates both perpendicular magnetic anisotropy (PMA) [2] and induced in-plane magnetic anisotropy (IMA) [3], if any. This phenomena enables us to generate FMR in an in-plane magnetized ultrathin ferromagnetic film through the electric field induced modulation of IMA [4], even though the torque originated from the electric field induced modulation of PMA becomes zero for this magnetization orientation. During the excitation of FMR by electric field, several additional torques generated by unavoidable microwave current induced because of the capacitive nature of the junctions may also contribute to the excitation of FMR [5].

In this work, we study the FMR signals excited by applying microwave signal across the metal-oxide junction in CoFeB/MgO heterostructures with Pt and Ta buffer layers [6]. Analysis of the resonance line shape and in-plane magnetization orientation dependent behavior of resonance amplitude revealed that apart from voltage-controlled in-plane magnetic anisotropy (VC-IMA) torque a significant contribution also arise from spin-torques and Oersted field torques originating from the flow of microwave current through metal-oxide junction. Surprisingly, the overall contribution from spin-torques and Oersted field torques are comparable to the VC-IMA torque contribution, even for a device with negligible defects. Notably, the contribution from the spin-torques and Oersted field torques further increases in the presence of a small junction current in the device This study will be beneficial for designing future electric field-controlled spintronics devices.

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Thermal stability of micromagnetic systems beyond the Néel-Brown macrospin model

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Magnetic systems are among the most used technologies for long term information storage. Certain magnetic textures, such as vortices or skyrmions, may also serve as fast information carriers. More recently, magnetic devices are being proposed for random number generation devices. A key consideration for these applications is a proper estimation of thermal stability of magnetic textures being used to encode information bits [1].

The stability of a chosen magnetic configuration (state) against thermal fluctuations is obtained by calculating the rate of escape from its basin of attraction once noise has been added to the equations of motion. Early work by Néel and Brown in uniformly magnetized bodies (macrospin) predicted that the escape rate f follows an Arrhenius type law:

$$f = f_0 e^{-\frac{\Delta E}{k_B T}},$$

where f_0 is an attempt rate, T is the temperature and ΔE is the height of the minimum energy barrier around the state. In most cases, the problem reduces to determining the height of the minimum energy barrier around the state in question. To do this, one necessary step is the proper identification of the transition state which must be a saddle point of the equations of motion.

Two key assumptions of Néel and Brown prevent its application to many systems of technological interest. The first is that the condition of uniform magnetization is violated for systems considerably larger than the exchange length; the second assumption is that the dynamics can be expressed as the gradient of a potential however, there are physically relevant excitations that do not satisfy this condition. After introducing the Néel and Brown model and its successes, we present analytical and numerical results of thermally activated switching in systems that are either not uniformly magnetized or have non-gradient dynamical terms.

Analytical identifications of the saddle point are difficult to obtain in non-uniformly magnetized systems. The greatest challenge is caused by the non-locality of the magnetostatic energy, which is not amenable to variational analysis; nevertheless, in important cases this term can be approximated by a local term associated with the system's geometry. The thermal activated switching of nanorings is a rare instance in which energy barriers and attempt rates can be analytically obtained. I will be discussed in detail [2].

The String Method is one of several computational techniques available for cases in which the saddle state cannot be analytically obtained. As an example of its use, we identify transition states for annihilation of magnetic skyrmions in nanodisks as a function of strength of the Dzialoshinskii-Moriya interaction. Our results show that topological objects are mediators in thermally activated transitions [3].

For non-gradient dynamical systems, the energy difference must be substituted by a path dependent action functional. We discuss how this theory can be used for systems excited by spin polarized currents, such as in magnetic droplet solitons [4].

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July 26th

Poster Session

Effect of electric Dzyaloshinskii-Moriya interaction on stability of ferroelectric skyrmions

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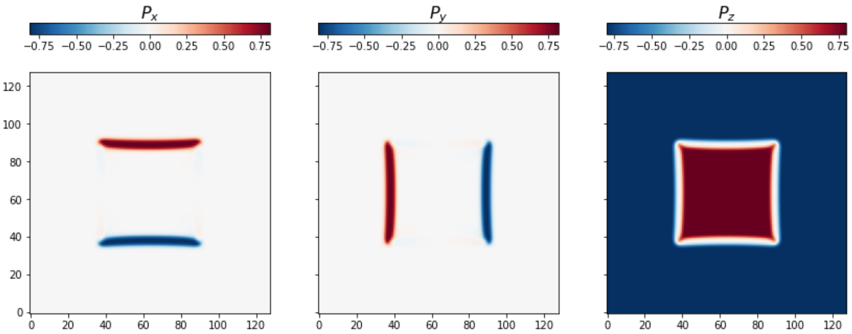
In magnetic materials, bubbles or skyrmions can be stabilized by means of long-range dipolar interactions or magnetic Dzyaloshinskii-Moriya interaction (DMI). The latter is an asymmetric exchange originating from spin-orbital coupling in materials with broken inversion symmetry. In turn, skyrmions in ferroelectric materials seems to be stabilized purely by the dipolar interaction. Nevertheless, recent first principles calculations have shown evidence of ferroelectric DMI in the class of ABO_3 perovskites with direct correspondence between ferroelectric and ferromagnetic DMI energy terms [1].



Here, we study how ferroelectric DMI can stabilize topological defects in $PbTiO_3$ layer. Namely, using phase-field simulations based on the Ginzburg-Landau-Devonshire model [2, 3] we analysed possibility of stabilizing ferroelectric skyrmions and their robustness with respect to other interactions. Apart from ferroelectric DMI, in the Gibbs free-energy functional we have assumed Landau, Ginzburg (gradient), elastic and electrostriction free-energy densities [4]. In addition, effect of long-range electrostatic energy has been considered. Our simulations have shown, that for sufficiently strong DMI, ferroelectric skyrmions can be indeed stabilized at electric field perpendicular to the layers plane. Figure shows three components of polarization (P_x, P_y, P_z) of a Bloch skyrmion stabilized in $PbTiO_3$ layer assuming also dipolar interaction. We shall present our analysis on how the stability of such skyrmions depends on further material parameters and external conditions.

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Cavity-mediated coupling of terahertz antiferromagnetic resonances in distant crystals

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In the regime of strong light-matter coupling, polariton modes are formed that are hybrid light-matter excitations sharing properties of both, an electrodynamic cavity mode and a matter mode. In the recent decade, magnon-polaritons were intensively researched using ferromagnetic materials in the microwave range, with potential applications for quantum technology and sensors. Exploring antiferromagnetic resonance (AFMR) rises magnon-polariton frequencies into the terahertz (THz) range. Here, we are investigating AFMR in hematite (α-Fe_2O_3) owing to its very low spin damping and temperature-dependent frequency above room temperature. We report on coupling of AFMR in two parallel-plane crystal slabs placed next to each other at a well-controlled gap, forming a tunable Fabry-Perot type cavity. Frequency of AFMR in each crystal was independently controlled by changing its temperature. Thus, as a function of temperature difference between the slabs, one expects to observe a crossing of AFMRs from both crystals. We used a continuous-wave spectrometer operating in the range of 0.2-0.35 THz, which is based on a frequency extender to a vector network analyzer. In reflection spectra, collected as a function of temperature difference between the two crystals, we observed avoided crossings of cavity modes and AFMRs from both slabs. Frequencies of cavity modes can be controlled by changing the gap between the crystals. For distances such that one of cavity modes has a frequency close to the crossing point between the AFMRs from both slabs, we observe that they hybridize by showing avoided crossings. This cavity-mediated coupling softens with rising gap between the crystals and is observable up to almost 9 mm, that is 10 times the sum of crystal slabs thicknesses (0.9 mm). We explain our results using classical electrodynamics and a model based on the input-output theory.

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Spin-wave interference control for self-imaging based logic operations

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There are many applications of the Talbot effect, or wave self-imaging, in linear optics, particularly in computational scenarios. Our recent work has demonstrated this phenomenon also for spin waves [1,2]. Through micromagnetic simulations of interference systems propagating in thin ferromagnetic multimode waveguides, we propose the application of spin-wave self-imaging functionality in computing operations [3]. The high programmability and scalability of these devices allows us to design lookup tables and logic gates that are particularly suitable for field-programmable gate arrays, which allow multiple logic realizations simultaneously. Based on the threshold detection technique, the proposed system consists of a wide waveguide with 8 single-mode inputs and 5 outputs (see Fig. 1). After determining the phase shift of the input signal, we measure the spin-wave intensity at the output and define its logic state based on the assumed threshold value. Fig. 1 shows simulation results for a thin film of yttrium-iron-garnet and a spin-wave frequency of 40 GHz. A wide range of static and dynamic parameters can influence the Talbot effect, which is particularly useful for the design of reconfigurable magnonic logic systems. This presentation draws the magnonic community's attention to the self-imaging effect and logic function processing caused by spin-wave diffraction and interference. Since the proposed layouts are feasible for experimental implementation, we believe that our numerical demonstration will attract researchers to pursue further development. Therefore, we have developed a physical basis for applying the magnonic Talbot effect to signal processing technology.

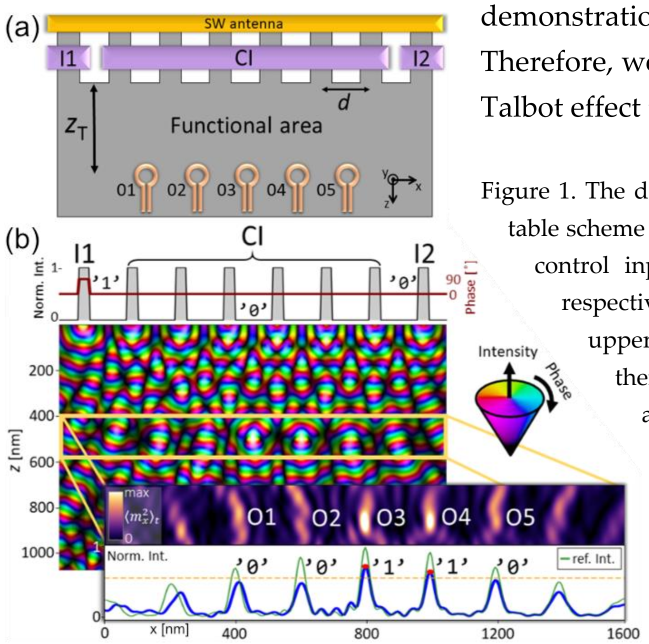

Figure 1. The design of a 2-in-5-out lookup table. In (a), a symmetric spin-wave lookup table scheme is presented with Talbot length z_T and input period *d* marked. **CI** denotes control input, and the numbered labels **I** and **O** denote inputs and outputs, respectively. Simulation results for lookup table operation are shown in (b). The upper part displays the intensity distribution of the inputs (gray columns) and their phase shift (maroon line). Below is a phase map of the functional domain, and the inset zooms-in on the region where self-imaging occurs. The plot includes the normalized dynamic magnetization intensity in 2D and its averaging in 1D. The orange dashed line indicates the predefined threshold.

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Coupling analysis of the surface states in periodic microwave transmission line

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The spectrum of electromagnetic waves in periodic linear structures, such as periodic waveguides or chains of microelements i.e. spheres, cavities, exhibit the sequence of stop bands for propagating waves. Breaking the translational symmetry of the periodic microstrip can also lead to the localization of the microwaves at the microstrip edge. In this work, we investigated periodic microstrip transmission line represented as 1D photonic crystal operating at the GHz frequencies. On the ground of topology, we explain the condition of surface state existence. The transmission measurements and numerical calculations support our theoretical predictions. Moreover, we show that in the symmetric microstrip the surface states split into symmetric and antisymmetric modes due to evanescent wave coupling between the modes localized on the opposite sides of the microstrip. Interestingly, both modes offer significant microwave transmission inside the frequency gap, which is promising for applications

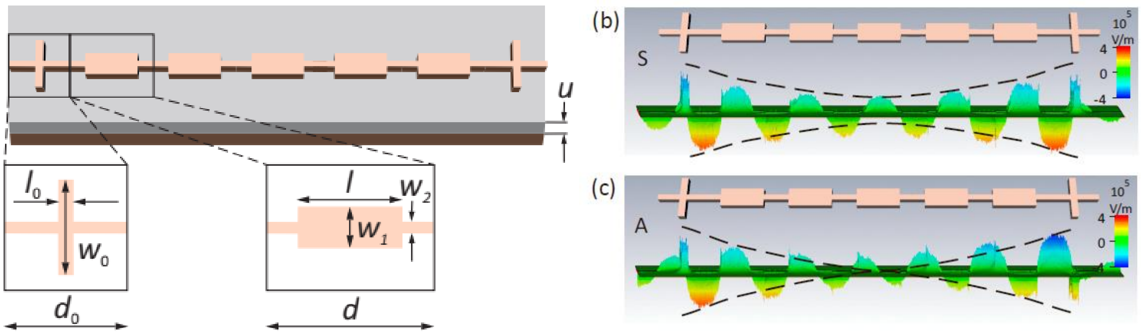

Fig.1. (a) MSTL composed of 5 bulk cells and defect cell; The spatial profiles of: (b) symmetric surface mode (S) and (c) antisymmetric surface mode (A) calculated numerically, which correspond to the double peak visible in (a). The hand-drawn black dashed lines in (b) and (c) show the exponential decay of the amplitude for S and A modes, respectively.

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Spin wave analysis of ultra-thin CoFeB films & anomalous dispersion relation

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Magnonics is an emerging field of research and technology, that has been established to meet the requirements of future signal processing devices by application of spin waves (SWs), which minimizes the energy cost of logic operations [1]. This investigation explores the interaction between spin waves, based on CoFeB/Au multilayers with Perpendicular Magnetic Anisotropy (PMA). The composition we examine here exhibits a small pumping effect, hence low damping together with the PMA effect will be promising for future applications in magnonics [2]. Brillouin Light Scattering (BLS) method was implemented here, to quantify the magnon energy. A detailed comparison of this result is made through FMR and P-MOKE to ensure the accurate illustration of magnetic characterization.

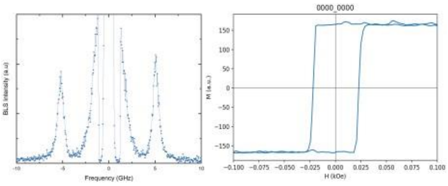

Figure 1. Shows the BLS spectra and hysteresis loop of sample with CoFeB thickness 0.9nm.

We observed Dzyaloshinskii-Moriya Interaction (DMI) and described its strength in terms of DMI coefficients. The structure possessing synergy of PMA and DMI can be considered as an interesting thing here, due to their necessity in creating energetically favourable chiral structures. Moreover, we have emphasized field and thickness-dependent studies. Spin wave dispersion relations were extracted and studied the nonlinear effect as well as system behaviour. Opposed to the conventional dispersion relations of magnetic multilayers, it shows anomalous characteristics [3,4]. These unusual profiles lead to further wide and extensive experimental as well as theoretical analysis of this composition.

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Spin waves localization induced by stray field of superconducting stripe

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Investigation of spin waves (SWs) in ferromagnetic films is of great importance because knowledge of these phenomena is crucial for the designing of magnonic devices [1]. One of the current problems in this research area is how to control SW propagation and localization. Here we propose to localize SWs in a ferromagnetic film using electromagnetic coupling with a superconducting (SC) stripe. We present the theoretical description and micromagnetic simulation for SW dynamics in the system, which consists of a ferromagnetic thin film and infinite SC stripe that is placed above the film – see Fig.1.

We assumed that the external magnetic field is directed perpendicularly to the film's plane. The infinitely extended ferromagnetic film creates a magnetic field that is uniform in its plane, whereas the SC stripe provides the non-homogenous magnetic field distribution in the plane of the film, which can be controlled by an external field (Fig.2). So, the presence of SC stripe and its static coupling to ferromagnetic layer provides the consolable landscape of internal field for SWs.

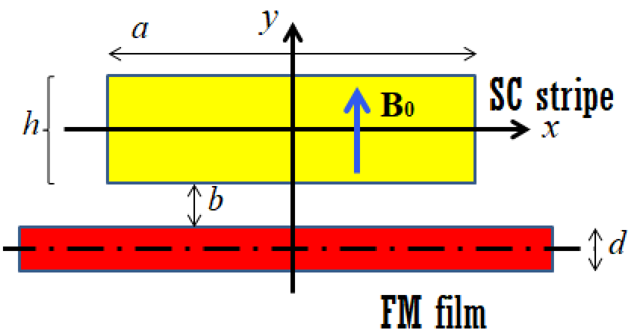

Figure 1. The sketch of the system, where *d* is film thickness, *b* is the distance between the film and SC stripe, *a* and *h* are stripe weight and thickness respectively, and B_0 is an external magnetic field.

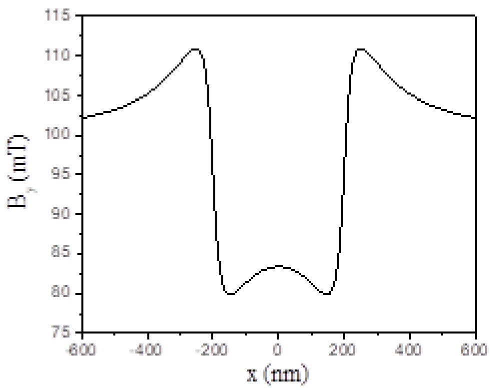

Figure 2. The distribution of the magnetic field created by the SC stripe of a small London penetration depth, taken in the middle of the film (dashed-dot line in Fig.1).

The ferromagnetic resonance conditions in the film area under the stripe will differ from the ones in other film parts. As a result, propagating SWs could be localized in the area under SC. Moreover, since the resonance conditions could be changed by variation of the external magnetic field, it opens the possibility to control the frequency and the strength of SWs' localization.

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Modulation of higher-order spin wave modes to excite skyrmion dynamics

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Spin waves can be controlled through the manipulation of magnetic fields, geometrical confinement, or by interactions with other magnetic elements, thus the study of the interaction between spin waves and magnetization structures such as skyrmions is an interesting area of research [1-3]. This area of research could lead to the control of spin wave propagation. However, the research on skyrmion-spin-wave systems mainly focuses on the motion and dynamics of the skyrmion inside the waveguide, with the potential use of these systems as track memories motivating this research [4].

In our research, micromagnetic simulations were used to investigate a three-layer hybrid system with zero magnetic field. This system consists of (i) a permalloy waveguide, (ii) a thin circular nanodot with a stable Néel-type skyrmion made of a material with perpendicular magnetic anisotropy, and (iii) a non-magnetic separation layer. The purpose of the study was to investigate (i) the static coupling between the nanodot and the waveguide [5], (ii) the use of propagating spin waves to induce skyrmion dynamics, and (iii) the effect of skyrmion in the nanodot on the transmission of spin waves through the waveguide. Due to shape anisotropy, magnetic saturation along the long axis of the waveguide was maintained, and magnetic interactions between the nanodot and the waveguide result in the formation of a skyrmion imprint upon the nanodot. The interaction caused also deformation of the skyrmion in the nanodot. The interaction of the waveguide and the nanoresonator, the presence of the skyrmion in the nanodot and the imprint in the waveguide, all these components affect the spin-wave flow. We conducted studies on the transmission of spin waves over a wide range of frequencies using broadband excitation. We found that the skyrmion and its imprint affect the transmission spectrum in different ways. In particular, the imprint shows oscillations of significant amplitude at low frequencies, and skyrmion excitations dominate around 10 GHz. The propagating spin-wave results in skyrmion excitation, and leads to the appearance of azimuthal modes at the edge and standing waves in the skyrmion core, and stimulates very low-frequency modes due to coupling to higher-frequency modes. The spectra of these excitations are also visible in the imprint spectrum due to their coupling to the nanodot. We have found that coupling propagating spin waves to the resonant modes of the skyrmion-imprint hybrid system is a viable approach, making it a promising technique for various applications.

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Magnetic properties of Ir/Co/Pt films tuned by Ga^+ ion bombardment

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In ultrathin thin magnetic films, interfaces play an important role in inducing, for example, the perpendicular magnetic anisotropy (PMA), the Dzyaloshinskii-Moriya interaction, and the exchange bias effect. These properties can be controlled by selecting the appropriate surroundings of ferromagnetic layers or by interfaces modification. Interface modification during deposition is challenging. Therefore, the post-modification (e.g. ion bombardment (IB)) is often performed.

In this study influence of Ga^+ IB on the magnetic properties of Ir(30nm)/Co(0.8nm)/Pt(5nm) films was investigated. The IB was performed for the ion energy E_{ion} = 5, 8, and 30 keV and dose $10^{12} \leq D \leq 10^{15}$ Ga^+/cm^2. The magnetic properties were determined from the hysteresis loops measured using the polar magneto-optical Kerr effect before and after IB. The hysteresis loop evolution caused by IB shows a reduction of H_C and gradual transformation from PMA to easy-plane anisotropy with increasing D. However, the dose range where the spin reorientation transition (SRT) occurs strongly depends on the E_{ion}. For higher E_{ion} SRT appears for lower D, which is in contrast to the results for Co/Pt multilayers bombarded by 30keV Ga^+, 20 keV and 2 MeV Ar^+, and 20 keV and 2 MeV He^+, in which SRT appears for higher D with increasing E_{ion} [1]. To understand this difference, we conducted a Monte-Carlo simulation using the SRIM. This code allows computing so-called ion stopping power (S), which can be separated into the interactions with atom nucleus (S_n) and electron (S_e). These parameters were calculated for the Co layer bombarded with Ar^+ and Ga^+ in a wide E_{ion} range (1keV-10MeV). Our results show that for Ga^+ in the E_{ion} range of several tens of keV, the interaction between the ion and atomic nuclei dominates ($S_n > S_e$) and S_n increases with increasing E_{ion}. This means that the ballistic mixing increases with E_{ion} increases. The situation is different for Ar^+. For 20 keV the S_n is larger than for 2 MeV, which means that for higher energy higher D is required to modify magnetic properties. This analysis explains the observed changes in magnetic properties of Ir/Co/Pt system vs the energy of Ga^+. However, additionally, we have to take into account that in the case of lower E_{ion} of Ga^+ (5 and 8 keV), as was shown by a Monte-Carlo TRIDYN simulations, the interface ballistic mixing is less effective on the bottom Ir/Co interface than on the top Co/Pt interface. Taking into account that the surface anisotropy from the Ir/Co interface is greater than that from the Pt/Co interface [2], bombardment with low E_{ion} will require higher D to reduce PMA.

This all shows that the proper selection of the IB parameters is significant for precisely changing the magnetic parameter and structure of the magnetic films.

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Single-molecule magnet systems on silica nanostructures

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Silica nanostructures are widely used in microelectronics, catalysis, and drug delivery systems. The physicochemical properties of silica nanostructures, like large specific surface area, high thermal and hydrothermal stability, chemical inertness, transparency, and non-toxicity, predispose them to be used as a support for molecules in various investigations. The research presented here is intended to show that silica can be a convenient tool for studying complex molecular systems [1]. The use of silica nanostructures as substrates to separate and control the distribution of single-molecule magnets (SMMs) will be discussed using the example of Mn12-stearate molecules [2-4]. The approach presented here provides an opportunity to investigate magnetism at the nanoscale level.

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Spin-wave dynamics in ferromagnetic nanorods with crescent-shaped cross sections

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Experimental evidence shows that crescent-shaped nanorods (CSNs) are capable of forming 3D ferromagnetic networks that can be used in various magnonic applications [1], [2]. Recently, a single CSN has also been extracted, offering the possibility to design planar magnonic systems based on CSNs. In our study we make focus on curvilinear magnetism [3], and in particular the propagation of SWs in CSN. The influence of the magnetization chirality, forced by the geometry, on the dispersion relation of SWs, obtaining different frequency values with the same wavenumber but propagating in opposite directions. By analogy with the cylindrical cross section of a nanotube, we can assume that the magnetization in the CS nanorods spreads along their curvature at low magnetic fields, giving rise to SWs with chiral properties. In Fig. 1 we show the dispersion relations for a wavevector directed along the z-axis for two values of the external magnetic field, 1 T and 3 T, and its two orientations, $\varphi = 0$ and 90◦ perpendicular to waveguide. The results for the field directed along the x-axis (Fig. 9 (a, b)) show a clear, field-value dependent non- reciprocity for the bulk mode, represented by the inset plots $\delta f\,(|k_z|) = f\,(k_z) - f\,(-k_z)$. The highest value of this function for the bulk mode at 1 and 3 T along the x-axis is max(δf) ≈ 1.35 GHz, and 1.03 GHz correspondingly. A novelty of the presented systems is the wide operating frequency range and the dynamic tunability using an external magnetic field. Another interesting step may be to test their operation in small fields (or even remanence), where the chirality and thus the nonreciprocity should be stronger and the SW frequencies lower. In addition, it is worth noting that the fabrication of structures with a CS cross section is less expensive than that of nanotubes, which is also an invaluable parameter for future applications.

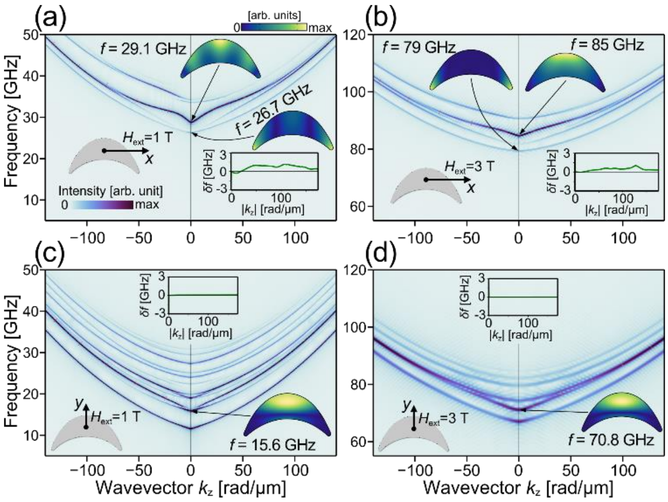

Fig.1 Dispersion relations of CS nanorods for (a, c) 1 T and (b, d) 3 T external magnetic field directed along the x- axis (a, b) and the y-axis (c, d) for 1 T and (d) for 3 T. The wave vector is directed along the z-axis. Nonreciprocity is shown in insets as the frequency differences δf between the most in- tense branches for positive (yellow dots) and negative (red dots) wavevectors. The plots also include visualizations of volumetric and edge modes (where they occur) for $k_z = 0$

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Spin chirality in Co/Ni layered system before and after plasma oxidation

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Nowadays, spintronics and magnonics research is focused on finding materials that offer tunable perpendicular magnetic anisotropy (PMA) together with low Gilbert damping and high spin polarization. Co/Ni films satisfy all of these requirements [1]. Moreover, new applications are expected because the Dzyaloshinskii-Moriya interaction (DMI) is observed in Co/Ni films surrounded by heavy metal or oxide layers. The interest in this interaction is related to their prospective application in memories based on skyrmion motion. The latest research results show the important role of an antiferromagnetic (AFM) layer in the stabilization of skyrmions at room temperature (RT). This layer, through exchange bias (EB) coupling, induces a unidirectional anisotropy in the ferromagnetic (FM) layer. Due to the presence of both EB and DM interactions, it is possible to obtain skyrmions at RT even in the absence of external magnetic fields. For this reason, we focused on the EB, DMI, and magnetic anisotropy of Co/Ni bilayers before and after plasma oxidation (PO). The oxidation process was controlled using different oxidation times ($t_{Ox.}$). We show that the magnetic anisotropy of these bilayers can be tuned by the thickness of Co (t_{Co}) and Ni (t_{Ni}) and exposure times, t_{Ox}, between 15 and 220 seconds [2]. We attribute this effect not only to the reduction of ferromagnetic Ni layer thickness after oxidation but also to the EB coupling between AFM (NiO) and FM (Co/Ni) sublayers, which induces a surface contribution to the effective anisotropy favoring perpendicular spin alignment of the Co/Ni. The presence of a NiO layer was confirmed by X-ray photoelectron spectroscopy [3]. It is known that NiO is a source of DMI when it is in contact with Co [4,5], therefore we measured magnetic domain structure before and after PO using PEEM-XMCD. PEEM-XMCD images shows that Co1/Ni1.5 nm before oxidation shows micrometers size domains with mixed Bloch and Néel domain walls. After oxidation with 110 s, a larger domain (few tens of microns) appears that can be correlated with higher anisotropy, however, the domain walls were not visible and spin chirality cannot be detected. Therefore, we measured magnetic domain structure at different magnetic fields, which allows us to determine the chirality of the domain walls after PO. These measurements reveal that the NiO formation supports DMI with right-handed chirality, the same as was found for Au/Co/NiO [5].

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Applying machine learning techniques to the interpretation of ferromagnetic resonance spectra using an old Kittel approach

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One of the primary purposes of making ferromagnetic resonance (FMR) experiments is to determine the spatial distribution of the free magnetic energy of the ferromagnetic sample placed in a magnetic field. Historically, the oldest approach to FMR experiments interpretation is Kittel's method [1]. Here the resonance condition is derived from the classical equation of motion, which describes the precession of the magnetization vector in a strong magnetic field. We report the analysis, within this method, of Bickford's FMR experimental results[2] for magnetite. We check, how many anisotropy constants are needed to correctly describe the dependence of the resonance field on the angle of a constant magnetic field with the crystallographic axes of the sample. In his paper, Bickford uses a single anisotropy constant to find the spatial distribution of free energy for magnetite. We check using Machine Learning (ML) techniques whether taking into account higher-order anisotropy terms lead to a description closer to experimental results. This approach allows us to find not only the anisotropy constants but also the components of the demagnetization tensor (only their differences were found in the original paper). The results of our analysis indicate that the use of ML has a significant advantage over the older approach: 1) it is possible to obtain additional model parameters (demagnetization tensor components) from the same experimental data, 2) to determine the best model of magnetocrystalline anisotropy for a given material, 3) to obtain higher accuracy results from analyzing the same experimental data.

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Study of the hopfion gyrovector in magnetic cylindrical dots

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Hopfions have been garnering increasing attention lately due to their unique properties as topological, three-dimensional, localized magnetic structures. These structures may have useful applications in information technology, as they have been observed in magnetic multilayer systems and proposed as information carriers in 3D racetrack memories [1]. Unlike skyrmions and vortices, hopfions have a Gz component of gyrovector is equal to zero, which eliminates the unwanted Hall effect and makes their current-induced motion straightforward, rendering hopfions ideal information carriers [2]. However, this characteristic of hopfions has only been demonstrated in infinite magnetic films. Our study focuses on hopfions confined to ferromagnetic cylindrical nanodots, where we derived a formula for the hopfion gyrovector and found its dependence on the radius and thickness of the nanodot. We discovered that when the dot radius is comparable to the hopfion size, Gz component of gyrovector may not be zero. These findings are significant for the analysis of the dynamics of hopfions in racetracks and their interactions with elementary magnetic excitations such as spin waves.

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Magnetic resonance in single-oriented sol-gel-based spin-coated yttrium iron garnet on GGG(111) substrate

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Magnonics has drawn the great attention of researchers in basic sciences and applied physics [1]. Various fundamentals of magnons are understood by exploring the yttrium iron garnet (YIG), making it one of the longest-explored materials [2]. YIG was synthesized in the 1950s for the first time and explored very well in past decades [3]. Its potential application in magnon spintronics has made it relevant in the current scenario [1]. Currently, thin films of YIG are proving them in spin pumping and spin-transfer-torque oscillators [1,4]. YIG thin films are usually deposited using pulsed laser deposition, liquid phase epitaxy, and RF-sputtering. This abstract proposes to present the magnetic resonance study of the sol-gel-based spin-coated YIG on gadolinium gallium garnet (GGG). The sol-gel-based spin-coating is the cost-effective way to deposit these films without many resources using the complete solution method [5]. The proposed poster deals with the single-oriented growth thin film of YIG on GGG (111) substrate. Surface roughness is less than a nm. Ferromagnetic resonance is used to study the quantification of the magnetic dissipation in the YIG/GGG. Figure 1 shows an angel-dependent resonance magnetic field at different microwave frequencies 2GHz to 16 GHz. Complete results and analysis will be presented in the poster.

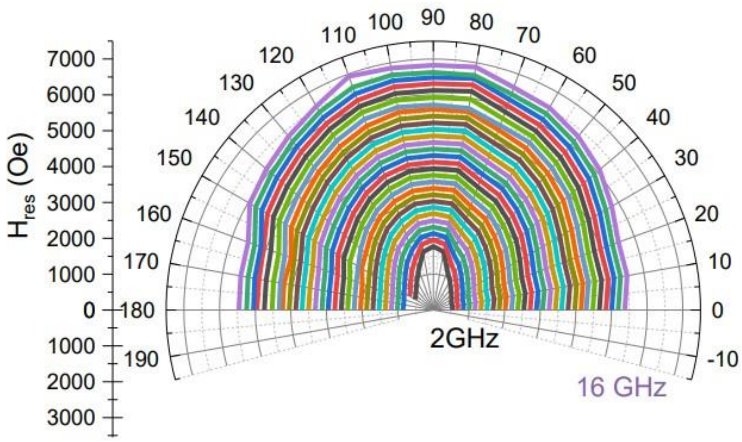

Figure 1: Angular dependence of the resonance magnetic field for 2 GHz to 16 GHz.

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Magnetic properties of monolayers and bilayers of chromium trihalides

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The weakly coupled two-dimensional Van-der-Waals materials are promising candidates for various applications in two-dimensional nanoelectronics and spintronics. Significant progress has been made recently in the characterization and manipulation of static magnetic texture and dynamic properties of these fascinating materials.

Our considerations are limited to monolayers and bilayers of CrI_3. The ground state of this material is known to be ferromagnetic (FM) in the case of monolayers and antiferromagnetic (AFM) for bilayers (antiferromagnetically coupled ferromagnetic monolayers). However, it is also possible to achieve FM ground state of bilayers due to strain, different stacking, and crystal anisotropy which can be modulated by the underlying substrate, non-magnetic separation layer, etc.

Our main objective is to study basic properties of CrI_3, like coercivity fields in hysteresis loops, Curie temperatures, and stable non-collinear magnetic textures formed usually in non-zero magnetic fields (i.e., skyrmions or stripe domains).

We will focus on the impact of stacking and Dzyaloshinskii-Moryia interaction (DMI) on magnetic properties. In the case of CrI_3, the effective Heisenberg model can be defined for chromium atoms which form the hexagonal lattice. We will present a detailed analysis of various origins of DMI, including the nearest-neighbour DMI induced by an electric field and next-nearest-neighbours DMI obtained from first principles calculations.

In this work, the atomistic spin dynamic method is applied to the numerical study of the magnetic properties of the system. The static properties of the system are simulated using the Monte Carlo method and Heisenberg model. In turn, the dynamic properties are studied using the atomistic Landau–Lifshitz–Gilbert equation.

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