IMPRS
for Science and Technology of Nano-Systems
INTERNATIONAL MAX PLANCK RESEARCH SCHOOL

IMPRS Retreat (September 22-25, 2024)

Venue

Elbresidenz Bad Schandau, Markt 1-11, 01814 Bad Schandau

Sunday, September 22

Time	Topic	Room
8.30	**Meet at platform 13!**	**Halle Hauptbahnhof**
8.40	Train departure from Halle	
12.00	Arrival in Bad Schandau	
12.30	Lunch	Restaurant
13.30	Welcome by organization committee Icebreaking	Canaletto
14-18	Outdoor discussion	
18-19.30	IMPRS meeting and dinner	Zum Ostrauer Hof Dorfstraße 1 Bad Schandau
19.30-20.00	Walk back to Bad Schandau	Via historic passenger lift
20.00-22.00	Discussion ar posters and informal get-together	

Monday, September 23

Time	Topic	Room
8-9	Breakfast	Restaurant
	Spintronics and beyond *chairs: Prajwal + Yung-Cheng*	Canaletto
9.00-9.30	**Stuart Parkin** – Welcome talk	

9.30-10.00	**Hyunsoo Yang** - Spin devices for nonvolatile memories and beyond	
10.00-10.30	**Andrea Migliorini** - Nanoscale control of chiral domain walls for energy-efficient spintronic applications	
10.30-11.00	Coffee break	Foyer
11.00-12.00	Round table discussion **Spintronics and beyond** Stuart Parkin, Hyunsoo Yang, Andrea Migliorini *moderators: Prajwal + Yung-Cheng*	Canaletto
12.00-13.00	lunch	Restaurant
13.00-15.30	Poster session 1 (pitches + 12 posters) Coffee from 15.00-15.30	Canaletto Foyer
15.30-18.00	Poster session 2 (pitches + 12 posters)	Canaletto
18.30	Dinner	Restaurant
20.00-22.00	Discussion at posters and informal get-together	

Tuesday, September 24

Time	**Topic**	**Room**
8-9	Breakfast	Restaurant
	Trends in spin dynamics *chairs: Chris + Lukas*	Canaletto
9.00-9.30	**Amir Capua** - Spin torque driven Skyrmion resonance technique in magnetic bulk crystal	
9.30-10.00	**Rouven Dreyer -** All-magnonic non-linear frequency conversion processes	
10.00-10.30	**Chi Fang** - Spintronic heterostructures based on yttrium iron garnet	
10.30-11.00	Coffee break	Foyer

11.00-12.00	Round table discussion **Trends in spin dynamics** Rouven Dreyer, Chi Fang, Amir Capua *moderators: Chris + Lukas*	Canaletto
12.00	Group picture	
12-13	lunch	Restaurant
14.00-15.30	Moderated discussion with speakers *chairs: Ismael + Ivan*	Canaletto
16-18	Outdoor session/hiking Q&A with invited speakers	
19.30	Dinner	Restaurant
20:00 – 21:30	Discussion at posters	Canaletto

Wednesday, September 25

Time	**Topic**	**Room**
8-9	breakfast	Restaurant
	Novel materials and devices for next generation computation techniques *chairs: Yishen + Simon*	Canaletto
9.00-9.30	**Jae-Chun Jeon** - Non-binary novel computational technologies from domain-based devices	
9.30-10.00	**Guanmin Li** - Novel computational element based on VO_2 oscillators: From material, beyond material	
10.00-10.30	**Wenjie Zhang** - Current-induced switching and domain wall motion in van der Waals ferromagnets	
10.30-11.00	Coffee break	Foyer

11.00-12.00	Round table discussion **Novel materials and devices for next generation computation techniques** Jaechun Jeon, Wenjie Zhang, Guanmin Li *moderators: Yishen + Simon*	Canaletto
12-13	lunch	Restaurant
13.00-13.30	Feedback and conclusion	Canaletto
13.30	Departure from hotel Train connection: 14.25 from Bad Schandau, arrival in Halle 17.01	

Hyunsoo Yang - Spin devices for nonvolatile memories and beyond

Spin-based magnetic random access memory is emerging as a key enabling technologies, which have already spread over markets from embedded memories to the IoT. In addition, spin devices can offer alternative solutions for unconventional computing and energy harvesting. We present an Ising computer based on MTJs, which successfully solves a 70-city travelling salesman problem. By integrating the electrically connected 10 spin-torque oscillators (STOs), we demonstrate the battery-free energy-harvesting system to power electronic devices. We also present our perspective on spin device applications using emerging 2D materials. Previous proposals for spin-orbit torque (SOT) switching of perpendicular magnetic anisotropy (PMA) require an additional magnetic field. Exploiting the out-of-plane spins could be a solution to this challenge. We show field-free switching of PMA CoFeB at room temperature utilizing out-of-plane spins from Weyl semimetals, $TaIrTe_4$ and $PtTe_2/WTe_2$. Finally, we discuss magnon-mediated spin torques, which could minimize Joule heating and corresponding energy dissipation. We finally demonstrate magnon-driven field-free switching of PMA at room temperature.

Andrea Migliorini - Nanoscale control of chiral domain walls for energy-efficient spintronic applications

The exponential growth of global data traffic and the increasing gap between processors and memories in terms of performance and scalability, have dramatically boosted the demands for advanced, non-volatile memories with larger data capacity, higher operation speed and lower energy consumption. Spintronic devices based on current-induced manipulation of chiral domain walls in magnetic nanowires are

promising candidates for the development of fast and energy-efficient memory and logic applications, with advanced functionality and improved scalability.

In this seminar, I will discuss the prospects and challenges of nanosized domain-wall-based devices, with a particular focus on the practical realization of such nanodevices, which requires efficient and reliable methods for nucleating, controlling and detecting magnetic domain walls at the nanoscale.

Amir Capua - Spin torque driven Skyrmion resonance technique in magnetic bulk crystal

Skyrmions are attractive candidates for ultra-dense magnetic data storage and distribution applications. Conventionally, Dzyaloshinskii-Moriya interaction (DMI) is responsible for the Skyrmion's topological protection. Recently, frustration in ferromagnetic (FM) crystals was predicted of also being capable of providing the topological protection without relying on the DMI and the effect was immediately discovered in Fe_3Sn_2 crystals. Surprisingly, these Skyrmions survive at extremely high temperatures and are controllable by electrical currents illustrating the exceptional technological potential of the Fe_3Sn_2.

Here, were present a new technique for studying the Skyrmion ferromagnetic resonance (FMR) in a bulk Fe_3Sn_2 crystal where the dynamical response is excited by an AC spin-torque in a fashion that is reminiscent of the spin-torque FMR experiment. Using this technique, we identify the magnetic phase transitions form a disordered phase to an ordered lattice phase.

The generality of the presented technique paves way towards resolving the spin dynamics in nonconventional magnetic crystals.

Rouven Dreyer - All-magnonic non-linear frequency conversion processes

In magnonics, the phase state of the collective excitation of the spin system in magnetically ordered materials - a so-called spin wave or magnon - can be exploited as a carrier of information for spin-based devices. Over the last decade, non-linear processes, such as three and four magnon scattering, have pushed magnonics towards the next level by demonstrating magnonic counterparts of electronic devices, such as magnon transistors, diodes, amplifiers, etc. However, the possibility of frequency up-conversion as a basic functionality for all-magnonic circuits was missing. To understand the potential use of higher-order non-linear processes, we investigated microstructured Ni80Fe20 elements by using the phase-sensitive SNS-MOKE approach [1]. By employing this technique, we demonstrated the existence of phase-stable non-linear spin waves oscillating at odd half-integer multiples of the driving frequency and

applied a phase-locking scheme [2]. Moreover, we found that for low-frequency excitations an all-magnonic frequency comb emerges spanning over six octaves, allowing to link MHz frequencies from CMOS devices to high-frequency spin-wave excitations in magnonic circuits [3].

[1] R. Dreyer, et al., Phys. Rev. Mat. 5, 064411 (2021).
[2] R. Dreyer, et al., Nat. Commun. 13, 4939 (2022).
[3] C. Koerner, et al., Science 375, 1165-1169 (2022).

Chi Fang - Spintronic heterostructures based on yttrium iron garnet

Yttrium iron garnet (YIG, $Y_3Fe_5O_{12}$) is a cornerstone material in the field of spintronics due to its exceptional properties, such as a low damping factor and its ability to support pure magnon transport without the need for electrical current. In this talk, I will discuss the preparation of YIG films using techniques like sputtering and pulsed laser deposition (PLD), as well as their integration into heterostructures with magnetic and non-magnetic layers. In this talk, YIG plays a dual role: it magnetically proximities the adjacent layer, and it facilitates the conversion of spin current into magnon current within the YIG region. These two functionalities underscore the critical importance of YIG films in the development of advanced spintronic devices.

Jae-Chun Jeon - Non-binary novel computational technologies from domain-based devices

The manipulation of mobile domain walls in nanoscopic magnetic wires through current and their electrical detection are crucial for advancing domain-wall-based memory and logic devices beyond traditional binary technologies. A racetrack device with a single domain wall functions similarly to a memristor, where the output signal corresponds to the position of the domain wall. This allows for analogue-like output through current-induced domain wall motion, offering a promising platform for neuromorphic computing. The capacity to store and synchronously move multiple domain walls within these devices can generate highly complex time-signal outputs. We explore device structures and methods to effectively trace and control multiple mobile domain walls in racetrack devices, demonstrating that domain wall dynamics and stochasticity can be precisely managed in sub-micron-scale racetracks. Finally, we discuss how one can further improve such non-binary, domain-wall-based devices by refining their structure, operational method, architecture, and materials.

Guanmin Li - Novel computational element based on VO_2 oscillators: From material, beyond material

Computational technologies based on coupled oscillators are of great interest for energy efficient computing. A key to the development of such technologies is the tunable control of the interaction strength between the oscillators. Thus far, such coupled oscillators have been accomplished by additional external electronic components.

We show that the synchronization of closely spaced vanadium dioxide (VO2) oscillators can be controlled via a thermal triggering element that itself is formed from VO2. This tuning process allows the control of the amplitude, frequency of the coupled VO2 oscillators. 3 Boolean logic gates AND, NAND and NOR are realized by these oscillators. Biological plausibility and functionality of two spiking neuron models (Hodgkin-Huxley model and leaky-integrate-and-fire model) directly implemented by VO2 oscillators are demonstrated. Simulation of network based on 150 VO2 LIF neurons shows 90% accuracy for recognizing hand-written digits from MNIST data set. Our findings demonstrate that the networks of thermally coupled oscillators can be readily applicable to novel bio-inspired computational schemes.

Wenjie Zhang – Current-induced switching and domain wall motion in van der Waals ferromagnets

The manipulation of spin textures in magnetic systems by spin currents derived from charge currents is of fundamental and technological interest. A particularly interesting system like 2D van der Waals ferromagnets have recently been studied intensively. Defects in the structure lower their symmetries and allow for a bulk vector Dzyaloshinsky-Moriya interaction, so that chiral spin textures can been observed and tuned.

This talk will introduce some basic knowledge about van der Waals materials and spin textures, followed by a detailed report of our recent published work, focusing on current-induced domain wall motion in a van der Waals ferromagnet Fe3GeTe2 and its heterostructures. These attempts in van der Waals ferromagnets and their heterostructures bring more possibilities to the development of functional spintronic devices based on van der Waals materials.

Poster session 1

Ajin Joy, Banabir Pal, Jiho Yoon, Ajesh K. Gopi, Jae-Chun Jeon, Tatiana Gurieva, Benjamin Lilienthal-Uhlig, P. S. Anil Kumar, Stuart Parkin. *Gate controlled superconductivity*

Matthias Rohmer, Wolfgang H. Binder. *Photo-switchable helical chirality to modulate the CISS effect*

Ivan Kindiak, Swapna Sindhu Mishra, Andrea Migliorini, Banabir Pal, Stuart Parkin. *Reduced decay in Josephson coupling across ferromagnetic junctions with spin-orbit coupling layers*

Ricardo Barbosa, Dijana Milosavljevic, Stuart Parkin, Annika Johansson. *Nonlinear anomalous transport in multiple Weyl points*

Anshuman Padhi, Prajwal Rigvedi, Ajin Joy, Ajesh K. Gopi, Jae-Chun Jeon, Jiho Yoon, Jae-Chun Jeon, Banabir Pal, Stuart Parkin. *Proximity induced superconductivity in non-collinear antiferromagnets (NCAFs)*

Ge He, Jiahao Yan, Siyuan Wan, Huiyu Zhao, Jonathan Ward, Jack Murphy, **Jenny Davern**, Catherine Dawson, J.C. Séamus Davis. *Stripe Phase Pair Density Wave Visualisation in NbSe2*

Sergio Leiva, Börge Göbel, Igor Maznichenko, Jürgen Henk, Ingrid Mertig, Annika Johansson. *Spin and orbital Edelstein effect in SrTiO3-based two-dimensional electron gases.*

Christoph Durner, Andrea Migliorini, Jae-Chun Jeon, Stuart Parkin. *Reconfigurable magnetic inhibitor for domain-wall logic and neuron devices*

Anagha Mathew, Berthold Rimmler, Banabir Pal, Stuart Parkin. *Structural and magnetic properties of Mn_3GeN thin films*

Prajwal Rigvedi, Binoy Hazra, Andrea Migliorini, Banabir Pal, Jae-Chun Jeon, Stuart Parkin. *Current induced domain wall motion in non-collinear antiferromagnet*

Konstantin Holst, Ihsan Çaha, Leonard Francis, Jagannath Jena, Stuart Parkin. *4D-STEM measurements in NMC particles*

Anvesh Dixit, Stuart Parkin. *Is electron chiral? – Electronic vs. Geometric chirality*

Poster session 2

Ismael Ribeiro de Assis, Ingrid Mertig, Börge Göbel. *RC-circuit analogue based on skyrmions*

Guanmin Li, Zhong Wang, Yuliang Chen, Jae-Chun Jeon, Stuart Parkin. *Spiking neurons based on coupled VO2 oscillators via tunable thermal triggering*

Torje Orlamünde, Anja Marinow, Wolfgang Binder. *Micro-Segregated Polymers as Gating Materials*

Sagar Gambhira, Swapna Sindhu Mishra, Peng Wang, Prajwal Rigvedi, Banabir Pal, Ilya Kostanovskiy, Jae-Chun Jeon, Stuart Parkin. *Novel Spintronic Materials for Advanced Cryogenic Memory Applications*

Yishen Xie, Pranava K. Sivakumar, Yufeng Wu, Ke Gu, Jitul Deka, Ron Naaman, Stuart Parkin. *Chiral molecules Josephson Junction*

Zihan Yin, Peng Wang, Ke Gu, Tingting Jiang, Holger Meyerheim, Abhay Kant Srivastava, Stuart Parkin. *Strain Effects of Néel-type Skyrmions in Novel Freestanding Heterostructures*

Lukas Fischer, Rouven Dreyer, Jae-Chun Jeon, Georg Woltersdorf, Stuart Parkin. *Resonant Domain Wall Excitation for Self-Sustained Propulsion*

Dongchang Kim, Hyeon Han, Stuart Parkin. *Control superconductivity in infinite layer nickelate with Ionic diffusion*

Chris Körner, Rouven Dreyer, Hans Bauer, Niklas Liebing, Georg Woltersdorf. *Frequency multiplication by collective nanoscale spin wave dynamics*

Yung-Cheng Li, Jae-Chun Jeon, Andrea Migliorini, Yicheng Guan, Stuart Parkin. *Oscillators Synchronisation in Chiral Magnetic Domains*

Tiange Dong, Haojie Zhang, Yicheng Guan, Jitul Deka, Chi Fang, Stuart Parkin. *Domain wall motion in 3-Dimensions*

Simon Arnold, Jaechun Jeon, Kerem Y. Camsari, Stuart Parkin. *Toward analog probalistic computing with stochastic spintronic devices*