Spintronics and Magnetism at the Nanoscale

Wednesday, 06.09.2023, Room 115

Time	ID	SPINTRONICS AND MAGNETISM AT THE NANOSCALE I *Chair: Aleksandr Kurenkov, ETH Zürich & PSI*
17:00	601	**High-Sensitivity and quantitative Magnetic Force Microscopy for the Analysis of Magnetic Multilayers supporting Skyrmions** *Hans J. Hug, EMPA, Swiss Federal Laboratories for Materials Science and Technology and Department of Physics, University of Basel* The development of magnetic thin film multilayers that support skyrmions through interfacial Dzyloshinskii-Moriya interaction can benefit greatly from high-resolution magnetic imaging techniques, such as magnetic force microscopy. Achieving highest sensitivity in MFM imaging requires operating in vacuum using cantilevers with quality factors of up to 1 million. However, this requires new operation modes to achieve a reproducible tip-sample distance control when the temperature is changed, or external magnetic fields are applied. Reproducible imaging conditions are essential for differential imaging techniques that can disentangle the contrast from the stray fields arising from the micromagnetic state of the sample from other contributions, such as signals arising from van der Waals force variations from the topography, local variations in the contact potential, or magnetic fields arising from spatial variations of the sample thickness and roughness. To obtain the stray field from the measured frequency shift contrast or to test the fidelity of MFM data simulated from the stray field of candidate micromagnetic model structures, a calibration of the MFM tip response to magnetic stray fields can be performed.
17:30	602	**Developing Metallic Multilayers Hosting Different Skyrmion Types Toward Local Control via Electric Fields** *Loghman Jamilpanah [1], Artur Braun [1], Hans Josef Hug [1,2], Andrada-Oana Mandru [1]* *[1] Empa, Swiss Federal Laboratories for Materials Science and Technology, CH-8600 Dübendorf* *[2] Department of Physics, University of Basel, CH-4056 Basel* The coexistence of two skyrmion types in a single system is highly relevant for future racetrack memory devices using such solitons. Here, we demonstrate a metallic ferromagnetic/ferrimagnetic (FM/FI) bi-layer system in which two skyrmion types are successfully stabilized at room temperature. This system has a simpler structure compared to the previous demonstration of the same observation in a FM/FI/FM trilayer. We show also how the two skyrmion types can be tuned by changing the magnetic properties of the FI. The simpler structure together with the FI control layer provide the opportunity for subsequent local control of the skyrmion type and pave the way for device implementation.
17:45	603	**Nanomagnets for manipulation of spin qubits** *Michele Aldeghi, Rolf Allenspach, Gian von Salis, IBM Research Zurich* The stray field of micro- and nanomagnets is exploited to manipulate the spin state of electrons confined in semiconductor quantum dots. Current devices use micromagnets that are uniformly magnetized along the direction of an external magnetic field. Here we introduce “U”-shaped Fe nanomagnets, where shape anisotropy sets a non-uniform magnetization pattern. We study the influence of size, shape and external applied magnetic field on such structures by micromagnetic simulations and spin-polarized scanning electron microscopy. We measure surface magnetization patterns for magnets down to 50 nm in width and discuss how nanomagnets are suitable for driving silicon spin qubits.

18:00	**604**	**Domain wall qubits on magnetic racetracks** *Ji Zou [1], Stefano Bosco [1], Jelena Klinovaja [1], Daniel Loss [1], Banabir Pal [2], Stuart Parkin [2]* *[1] University of Basel, [2] Max Planck Institute of Microstructure Physics* We propose a scalable implementation of a quantum computer based on hardware-efficient mobile domain walls on magnetic racetracks. In our proposal, quantum information is encoded in the chirality of the spin structure of nanoscale domain walls. We estimate that these qubits are long-lived and could be operated at sweet spots reducing possible noise sources. Single-qubit gates are implemented by controlling the movement of the walls in magnetic nanowires, and two-qubit entangling gates take advantage of naturally emerging interactions between different walls. These gates are sufficient for universal quantum computing and are fully compatible with current state-of-the-art experiments on racetrack memories. Possible schemes for qubit readout and initialization are also discussed.
18:15	**605**	**Orbital-torque-induced switching of perpendicular magnetization** *Min-Gu Kang [1], Soogil Lee [2], Dongwook Go [3], Benjamin J. Jacot [1], Byong-Guk Park [2]* *[1] Department of Materials, ETH Zürich* *[2] Department of Materials Science and Engineering, KAIST* *[3] Peter Grünberg Institut & Institute for Advanced Simulation, Forschungszentrum Jülich & JARA* Spin-orbit torque (SOT) has been intensively studied to realize energy efficient magnetization switching in spintronic devices. Recently, proposed orbital torque (OT) suggested that the large SOT can be generated even in weakly spin-orbit-coupled light metals by the orbital current. It is a consequence of the orbital Hall and/or orbital-Rashba effect and subsequent orbital-to-spin conversion via spin-orbit coupling. In this talk, we present the current-induced switching of perpendicular magnetization via orbital torque, which is efficiently tailored by orbital-to-spin conversion engineering. Our study suggests that the orbital current can be utilized to further enhance the magnetization switching efficiency in spin-orbit-torque-based spintronic devices.
18:30	**606**	**Spin-orbit torques and thermal contributions to spin transport in CoFeB / $LaTiO_3$ / $SrTiO_3$** *Lauren Riddiford, Sauviz Alaei, Yuri Suzuki, Shan X Wang, Fen Xue, Xin Yu Zheng* *Stanford University* The Rashba-type spin orbit coupling found at the interface of two dimensional electron gases (2DEGs) is of great interest for spintronic applications. Here, we uncover the nature of spin transport from a 2DEG to magnetic metal via second harmonic Hall measurements, spin-torque ferromagnetic resonance, and temperature-dependent ferromagnetic resonance (FMR). While FMR indicates enhanced spin current absorption by the 2DEG, second harmonic Hall measurements reveal a large thermoelectric signal suggesting a strong in-plane thermal gradient generated by passing current through the $LaTiO_3$.
18:45	**607**	**Spin-orbit control of antiferromagnetic domains without a Zeeman coupling** *Marek Bartkowiak, Damaris Tartarotti Maimone, Michel Kenzelmann* *Laboratory for Neutron Scattering and Imaging, Paul Scherrer Institut* Encoding information in antiferromagnetic (AFM) domains is a promising solution for the ever growing demand in magnetic storage capacity as the vanishingly small stray fields eliminate cross-talk between different domain states. However, the absence of macroscopic magnetization is detrimental to the manipulation and detection of AFM domains. We report evidence for a new AFM domain selection mechanism where the charge transport response is controlled by the rotation of the magnetic field not affecting the Zeeman term. A pronounced new anisotropic magnetoresistance effect is found in the AFM phases of bulk materials $Nd_{1-x}Ce_xCoIn_5$. Our results indicate that this constitutes a universal effect across multiband materials, opening new perspectives for AFM spintronics.

19:00	**608**	**Interfacing antiferromagnets with different magnetic ordering** *Xanthe Verbeek, Mayan Si, Nicola Spaldin, ETH Zürich* We study the structural, electronic, and magnetic properties of interfaces between two easy-axis antiferromagnets, Cr_2O_3 and α-Fe_2O_3. Cr_2O_3 is the prototypical linear magnetoelectric, in which an applied magnetic field induces an electric polarization, whereas isostructural α-Fe_2O_3 has a different antiferromagnetic ordering that does not allow a linear magnetoelectric response. We use density functional theory to study crystallographically distinct interface environments and extract magnetic interaction parameters, which we input into Monto Carlo simulations to determine the finite-temperature magnetic properties. We find interfacial magnetizations and antiferromagnetic domain orderings that are strongly interface-structure dependent.
19:15	**609**	**Propagating Spin-Wave Spectroscopy Studies in a Millikelvin Temperature Environment** *David Schmoll [1], Sebastian Knauer [1], Rostyslav Serha [1], Roman Verba [2], Andrey Voronov [1], Carsten Dubs [3], Andrii Chumak [1]* *[1] University of Vienna, Faculty of Physics, Boltzmanngasse 5, Vienna, Austria.* *[2] Institute of Magnetism of NAS of Ukraine and MES of Ukraine* *[3] INNOVENT e. V. Technologieentwicklung, Prüssingstraße 27 B, Jena, Germany* Technological advancements in the access to millikelvin temperatures allow first steps towards the investigation of individual magnons in the field of quantum magnonics. Such experiments require millikelvin base temperatures, to ensure a thermal magnon-free system. Here, we measured spin-wave transmission at temperatures below 45 mK in a yttrium-iron-garnet (YIG) film on a 500 μm-thick gadolinium-gallium-garnet (GGG) substrate, using a cryogenic propagating spin-wave spectroscopy (PSWS) setup. These experiments revealed an increase of the spin-wave damping due to the paramagnetic GGG substrate, which was further investigated in temperature dependent ferromagnetic resonance (FMR) studies and k-dependent PSWS experiments. The obtained results consolidate the understanding of spin waves at cryogenic temperatures.
19:30		

Thursday, 07.09.2023, Room 115

Time	**ID**	**Spintronics and Magnetism at the Nanoscale II** *Chair: Jeffrey Brock, ETH Zürich & PSI*
14:00	**611**	**The Spin-wave Asymmetry in Confined Rectangular $Ni_{80}Fe_{20}$ Microstrips** *Santa Pile [1], Andreas Ney [1], Kilian Lenz [2], Ryszard Narkowicz [2], Jürgen Lindner [2], Sebastian Wintz [3], Johannes Förster [3], Sina Mayr [4], Markus Weigand [5]* *[1] Johannes Kepler University Linz, [2] Helmholtz-Zentrum Dresden-Rossendorf* *[3] Max Planck Institute for Intelligent Systems, [4] Paul Scherrer Institut, Villigen PSI* *[5] Helmholtz-Zentrum Berlin für Materialien und Energie* The design of a microstructure can affect the internal field distribution and, therefore, the spin-wave (SW) behaviour. Under the uniform excitation only symmetric SW interference pattern is expected. Changes in the geometry of the structure can cause breaking of the symmetry. In this work the asymmetry parameter (AP) of SW dynamics in confined rectangular permalloy microstrips is suggested and applied to the TR-STXM results and micromagnetic simulations. In this work profiles of the out-of-plane component of the dynamic magnetization are analyzed. The results show a higher asymmetry for a strip when a second perpendicular microstrip is placed at the distance of 2 μm.

14:30 **612**

Propagating spin-wave spectroscopy in a liquid-phase epitaxial nanometer-thick YIG film at millikelvin temperatures

Sebastian Knauer [1], Kristýna Davídková [2], David Schmoll [1], Rostyslav Serha [1], Andrey Voronov [1], Qi Wang [3], Roman Verba [4], Oleksandr Dobrovolskiy [1], Morris Lindner [5], Timmy Reimann [5], Carsten Dubs [5], Michal Urbánek [2], Andrii Chumak [1]
[1] Faculty of Physics, University of Vienna, Boltzmanngasse 5, Vienna
[2] CEITEC BUT, Brno University of Technology, Purkyňova 123, Brno, Czech Republic
[3] Huazhong University of Science and Technology
[4] Institute of Magnetism, Kyiv
[5] INNOVENT e.V. Technologieentwicklung, Prüssingstraße 27 B, Jena, Germany

To realise large-scale integrated magnonic circuits for quantum applications it is required to perform propagating spin-wave spectroscopy in nanostructures at low temperatures. In this work, we demonstrate all-electrical spin-wave propagation in a 100 nm-thick yttrium-iron-garnet (YIG) film at temperatures down to 45 mK. The extracted spin-wave group velocity and the YIG saturation magnetisation agree well with the theoretical values. We show that the gadolinium-gallium-garnet (GGG) substrate influences the spin-wave propagation characteristics only for the applied magnetic fields beyond 75 mT, originating from a GGG magnetisation up to 62 kA/m (45 mK). Our results demonstrate that the developed fabrication and measurement methodologies enable the realisation of integrated magnonic quantum nanotechnologies at millikelvin temperatures.

14:45 **613**

Fast isotropic exchange spin waves in Ga:YIG for future magnonic networks

Khrystyna Levchenko [1], Tobias Böttcher [2,3], Moritz Ruhwedel [2], Qi Wang [1,4], Hryhorii Chumak [5], Maksym Popov [5], Igor Zavislyak [5], Carsten Dubs [6], Oleksii Surzhenko [6], Burkard Hillebrands [2], Andrii Chumak [1], Philipp Pirro [2]
[1] NanoMag research group, Faculty of Physics, University of Vienna
[2] Fachbereich Physik and Landesforschungszentrum OPTIMAS, Technische Universität Kaiserslautern
[3] MAINZ Graduate School of Excellence, Mainz
[4] Huazhong University of Science and Technology (China)
[5] Faculty of Radiophysics, Electronics and Computer Systems, Taras Shevchenko National University of Kyiv (Ukraine)
[6] INNOVENT e.V. Technologieentwicklung, Jena

To facilitate magnonics technology, the delay time in nanostructures should be improved. Hence, single-crystalline sub-100 nm thick films of Ga:YIG and reference YIG were fabricated and characterised via VSM, FMR and BLS. Ga:YIG demonstrates a perpendicular magnetic anisotropy, reduced magnetisation, good Gilbert damping, and an enhanced exchange stiffness, which results in improved (~ 3.4 times) group velocities for $k > 30$ rad/µm. The spin waves soon (from $k \approx 4$ rad/µm) start to exhibit an exchange nature and their dispersion is more isotropic compared to pure YIG. Therefore, Ga:YIG opens access to the operation with fast isotropic exchange spin waves in future magnonic applications.

15:00 **614**

Influence of paramagnetic GGG substrate on YIG films at millikelvin temperatures

Rostyslav Serha [1], Andrey Voronov [1], David Schmoll [1], Roman Verba [2], Sabri Koraltan [1], Kristýna Davídková [3], Barbora Budinská [1], Qi Wang [4], Oleksandr Dobrovolskiy [1], Michal Urbánek [3], Morris Lindner [5], Timmy Reimann [5], Carsten Dubs [5], Claas Abert [1], Dieter Suess [1], Sebastian Knauer [1], Andrii Chumak [1]
[1] University of Vienna, Faculty of Physics, Boltzmanngasse 5, 1090 Vienna
[2] Institute of Magnetism, Kyiv
[3] CEITEC BUT, Brno University of Technology, Purkyňova 123, Brno, Czech Republic
[4] Huazhong University of Science and Technology
[5] INNOVENT e. V. Technologieentwicklung, Prüssingstraße 27 B, Jena, Germany

It is known that YIG films on GGG substrates worsen their magnetic properties important for magnonics at low temperatures. We present experimental results, simulations, and an analytical theory to clarify the influence of the GGG substrate on a 97 nm-thick YIG film at ultralow temperatures. At low temperatures, the paramagnetic GGG substrate can be magnetized by an external magnetic field. The GGG magnetization creates a stray field in the YIG film that affects its magnetization

		dynamics. In the case of in-plane magnetization of YIG/GGG the FMR frequency is shifted to lower values. Simultaneously, the magnetic damping of YIG increases by more than eight times compared to measurements at room temperature.
15:15	**615**	**Non-reciprocal magnonic directional coupler** *Noura Zenbaa [1], Qi Wang [2], Kristýna Davídková [3], Sebastian Knauer [1], Moritz Ruhwedel [4], Oleksandr Dobrovolskiy [1], Sabri Koraltan [1], Claas Abert [1], Carsten Dubs [5], Michal Urbánek [3], Philipp Pirro [4], Dieter Suess [1], Andrii Chumak [1]* *[1] Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna* *[2] Huazhong University of Science and Technology* *[3] CEITEC BUT, Brno University of Technology, Purkyňova 123, Brno, Czech Republic* *[4] Fachbereich Physik and Landesforschungszentrum OPTIMAS, TU Kaiserslautern* *[5] INNOVENT e. V. Technologieentwicklung, Prüssingstraße 27 B, Jena, Germany.* We use a bilayer of YIG/CoFeB to construct waveguides of the directional coupler to induce non-reciprocity in the spin-wave propagation and add new functionalities to the directional coupler. The non-reciprocity due to the symmetry breaking leads to Δk being different in the two propagation directions when magnetized in the Damon-Eschbach configuration (+*k* –*k*). Therefore, the coupling length differs in the two directions. At a frequency, where $L_{-k} = 2L_{+k}$, the directional coupler operates as a Y-circulator. The spin-wave dispersion curves are numerically investigated in nm-thick bilayers of YIG(100)/CoFeB(40) and YIG(100)/SiO_2(5)/CoFeB(40) plane films as well as in nano-scale waveguides and measured using Ferromagnetic Resonance (FMR) spectroscopy and k-resolved Brillouin Light Scattering (BLS) spectroscopy.
15:30	**616**	**Probing magnetic coupling of spins on surfaces using EPR-STM** *Aishwarya Vishwakarma, S. Kovarik, R. Schlitz, D. Ruckert, Pietro Gambardella, S. Stepanow* *Department of Materials, ETH Zürich, CH-8093 Zürich* Manipulating spins and magnetic interactions for quantum computing encounters challenges due to invasive measurements. We employ spin-polarized scanning tunnelling microscopy (STM) to conduct electron paramagnetic resonance (EPR) experiment which probes magnetic interaction between spins delocalized into molecular orbitals of pentacene dimers. Spins in these organic molecules couple through overlapping orbitals within µeV regime, sensitive to exceptional energy resolution of EPR-STM. The dominant exchange coupling is investigated for different dimer configurations on MgO/Ag(100). Despite the anticipated antiferromagnetic coupling, we report ferromagnetic coupling due to current-induced pumping effect. This study aims to offer a non-invasive approach to intrinsic properties of remotely-driven spin.
15:45	**617**	**Modelling the dynamics and consequences of frustrated magnetism in the hexagonal manganites** *Tara Tosic, Nicola Spaldin, ETH Zürich* Using symmetry analysis, first-principles density functional theory and spin dynamics, we pinpoint the origin of the diffuse neutron scattering observed in hexagonal yttrium manganite (h-$YMnO_3$). h-$YMnO_3$ is a prototype system for studying frustrated magnetism, due to its dominant first nearest-neighbor anti-ferromagnetic coupling on a triangular lattice. We argue that thermal fluctuations departing from the ground state 120° spin configuration - a scenario ruled out in previous modelling attempts - give rise to short-range correlations. Though a hierarchy of nearest-neighbor exchanges and magnetic anisotropy terms, clusters of ordered spins form and interact with each other, creating excitations. Moreover, we simulate the formation of planar and vertical magnetic domains.
16:00	**618**	**X-ray Linear Dichroic Tomography** *Andreas Apseros [1], Christian Appel [2], Claire Donnelly [3], Zirui Gao [1], Manuel Guizar-Sicairos [2], Mirko Holler [4], Johannes Ihli [5], Valerio Scagnoli [1]* *[1] ETH Zürich, [2] EPFL, [3] Max Planch Institute for Chemical Physics of Solids,* *[4] Paul Scherrer Institut, [5] University of Oxford* Functional materials, from catalysts to energy storage and load-bearing materials, are hierarchical polycrystalline composites. Their functionality derives from their composition, the 3D arrangement of components and their microstructure; the distribution of crystalline grains and the defects within them. Techniques providing this combination of information are currently either limited to planar

		investigations, provide insufficient spatial resolution, are destructive or don't allow the examination of system-representative volumes, hampering the rational-driven optimization of current and design of next-generation materials. Here, we introduce ptychographic X-ray linear dichroic vector tomography, facilitating a quantitative, non-invasive, and simultaneous intra- and inter-granular characterisation of extended polycrystalline and amorphous samples in 3D with nanometre spatial resolution.
16:15	**619**	**Three-Dimensional Characterization of the Metamagnetic Phase Transition in B2-Ordered FeRh** *Jamie Robert Massey [1,2], Andreas Apseros [1], Peter Derlet [1,2], Claire Donnelly [3], Simone Finizio [2], Michael Grimes [2], Laura Heyderman [1,2], Jörg; Raabe [2], Joakim Reuteler [1], Valerio Scagnoli [1,2], Thomas Thomson [4], Samuel Treves [2,5]* *[1] ETH Zürich, [2] Paul Scherrer Institut, [3] Max Planck Institute, [4] University of Manchester, [5] University of Basel* We use soft x-ray magnetic laminography to characterize the three-dimensional spatial evolution of both the ferromagnetic and antiferromagnetic domains through the FeRh first-order phase transition. We observe different distributions of the nucleating magnetic domains in three-dimensions on heating and cooling. Monte Carlo simulations reveal different sample properties – namely, the sample surface and local variations in the exchange energy - are responsible for the nucleation of domains of differing magnetic order. This asymmetry suggests the microscopic mechanism responsible for the transition differs on heating and cooling, which affects the systems' macroscopic thermodynamic properties.
16:30		***Coffee Break; END***
19:30		***Conference Dinner***

ID	Spintronics and Magnetism at the Nanoscale Poster
631	**Controlling interactions in a kagome artificial spin ice coupled to a cobalt underlayer** *Tianyue Wang, Luca Berchialla, Peter Derlet, Laura Heyderman, Gavin Macauley* *ETH Zürich & Paul Scherrer Institute* Artificial spin ices are arrays of nanomagnets, which are coupled through dipolar interactions. The kagome artificial spin ice is the archetypal, highly frustrated example. It is predicated to exhibit a rich phase diagram but the ground state proves difficult to reach. In this project, we investigate how the presence of a cobalt underlayer and a platinum spacer affects the interactions between nanomagnets, and whether it promotes the formation of a low energy state on thermal annealing. By using magnetic field microscopy and x-ray photoemission electron microscopy, we study how the position of magnetic domains in the thin film layer influences the effective interaction between nanomagnets.
632	**Nonlinear spin-wave transport in the YIG nano-waveguides** *Kristýna Davídková [1], Andrii Chumak [1], Carsten Dubs [2], Sebastian Knauer [1], Morris Lindner [2], Timmy Reimann [2], Michal Urbánek [3], Andrey Voronov [1], Qi Wang [1], Ondřej Wojewoda [3]* *[1] University of Vienna, Faculty of Physics, Boltzmanngasse 5, Vienna, Austria* *[2] INNOVENT e. V. Technologieentwicklung, Prüssingstraße 27 B, Jena, Germany* *[3] CEITEC BUT, Brno University of Technology, Purkyňova 123, Brno, Czech Republic.* We report the nonlinear spin-wave transport in the array of the ten and ninety 260 nm wide YIG nano-waveguides. A new method based on Ar^+ ion beam etching was developed for the nano-waveguide fabrication using a positive CSAR resist as a hard mask. For generating and detecting spin waves, 2 μm wide microwave antennas spaced 5 μm apart are used. The propagating spin-wave spectroscopy is measured in Damon-Eshbach and backward volume configurations for different microwave powers to evaluate the efficiency of the nonlinear multimagnon scattering processes and compare it with the reference case of a continuous YIG film.

633	**Ultrafast Magnetization Dynamics in Arrays of Dipolar-Coupled Permalloy Nanostructures** *Davide Pecchio [1,2], Sergii Parchenko [3], Laura Heyderman [1,2], Kevin Hofhuis [2], Sourav Sahoo [1,2], Valerio Scagnoli [1,2]* *[1] ETH Zürich, [2] Paul Scherrer Institute, [3] European XFEL GmbH* Despite more than two decades of research, the proposed microscopic mechanisms underpinning laser-induced ultrafast demagnetization in magnetic thin films are not fully established. Little attention has been paid so far to nano-sized systems, where dipolar coupling and shape anisotropy may play an important role. We show that the optically-induced ultrafast magnetization suppression in arrays of parallel-oriented permalloy nanostructures can substantially differ from that of unpatterned thin films. In thin films, the Kerr signal increases before the material's demagnetization, suggesting an optically induced spin transfer (OISTR) between the sublattices of the alloy. In contrast, the efficiency of this mechanism is highly reduced in the nanostructures.
634	**Strong lateral exchange coupling and current-induced switching in single-layer ferrimagnetic films with patterned compensation temperature** *Ales Hrabec [1,2], Zhentao Liu [1,2], Zhaochu Luo [3], Ivan Shorubalko [4], Christof Vockenhuber [1], Laura Heyderman [1,2], Pietro Gambardella [1]* *[1] ETH Zürich, [2] Paul Scherrer Institute, [3] Peking University* *[4] Swiss Federal Laboratories for Materials Science and Technology* Magnetic interlayer couplings are widely explored in spintronic architectures, while the lateral couplings are rarely studied. Here we demonstrate a lateral interfacial exchange coupling based effect in ferrimagnetic thin film systems by patterning the device into regions with different compensation temperatures via oxidation and He^+ irradiation. We show that the coupling induced exchange bias can reach up to 2.5 T in nanoscale domain wall track devices. Furthermore, by combining with spin orbit torques, we demonstrate current induced switching of compensated ferrimagnet and lat- eral exchange bias structures. The discovery of lateral exchange coupling opens new possibilities in planar spintronic device designs.
635	**Spin Waves in a Three-Dimensional Artificial Spin Ice Structure** *Sourav Sahoo [1], Anjan Barman [1], Sam Ladak [2], Andrew May [2], Amrit Kumar Mondal [1], Arjen van den Berg [2]* *[1] Department of Condensed Matter and Materials Physics, S. N. Bose National Centre for Basic Sciences* *[2] School of Physics and Astronomy, Cardiff University* Exploration of high-frequency magnetization-dynamics in three-dimensional (3D) magnetic nanostructures may lead to paradigm-shifting in next-generation spintronic and magnonic devices. Despite remarkable progress in fabrication, the measurement and interpretation of magnetization-dynamics in 3D magnetic structures has remained challenging. Here we present the measurement of coherent spin-waves within a 3D artificial spin-ice (ASI) system, fabricated by using two-photon lithography and thermal evaporation. Two spin-wave modes were observed in the Brillouin light scattering (BLS) spectra whose frequencies showed nearly monotonic variation with the applied magnetic field strength. Numerical simulations revealed the collective nature of the modes extending throughout the complex network of nanowires while showing spatial quantization with varying mode quantization numbers.
636	**Full dipolar model for the Archimedean lattices of spin ices** *Aleksandra Pac [1], Gavin M. Macauley [1,2], Jamie R. Massey [1,2], Frédéric Mila [3], Peter M. Derlet [1,2], Laura Heyderman [1,2]* *[1] Paul Scherrer Institute, [2] ETH Zürich, [3] EPFL* Artificial spin ices are arrays of dipolar-coupled single domain nanomagnets, which exhibit rich behaviour. We study a family of artificial spin ices, formed by placing out-of-plane nanomagnets on the vertices of the Archimedean lattices. By demagnetising these arrays using field protocols and imaging their configuration using magnetic force microscopy, we observe different types of magnetic ordering. We use experimental results and the Metropolis Monte Carlo simulations to obtain the residual entropy, magnetic correlations and effective temperatures for various lattice types. This allows us to catalogue the behaviour for lattices with varying frustration in the framework of a full dipolar model.

637	**Remarkable robustness of metastable skyrmion lattice in $NdMn_2Ge_2$ at room temperature** *Samuel Treves [1], Andreas Apseros [2], Simone Finizio [3], Naoya Kanazawa [4], Aki Kitaori [4], Patrick Maletinsky [1], Jamie Robert Massey [2,3], Valerio Scagnoli [2,3], Yoshinori Tokura [4], Victor Ukleev* *[1] Department of Physics, University of Basel, 4056 Basel, [2] ETH Zürich,* *[3] Paul Scherrer Institut, [4] University of Tokyo* Metastable magnetic topological textures are of high interest to the spintronics community, in part because may find applications in future magnetic data storage technologies. $NdMn_2Ge_2$ is a rare-earth complex non-collinear ferromagnet, which has been shown to host metastable skyrmions at room temperature with no applied magnetic field. Here we, present a scanning transmission x-ray microscopy study on a skyrmion lattice within a single crystal $NdMn_2Ge_2$ lamella. We demonstrate the robustness of this lattice to temperature and magnetic field variations, and thereby the potential of this material for future spintronics applications.
638	**Magnetic phase transition in Molybdenum disulfide detected with AFM** *Akash Gupta, Alexina Ollier, Marcin Kisiel, Mehdi Ramezai, Andreas Baumgartner, Urs Gysin, Christian Schönenberger, Ernst Meyer, University of Basel* Low doping electron-electron interactions in monolayer MoS_2 lead to a ferromagnetic spin order,whereas larger occupation of spin-polarized energy bands results in paramagnetism. The electron density of MoS_2 might be tuned with gate voltage, thus providing the switch ability of the ferromagnetic to paramagnetic first-order phase transition. An abrupt phase transition in two-dimensional semiconductor gated MoS_2 monolayer is detected by magnetic force spectroscopy. Spontaneous reproducible changes of the magnetic force were observed at doping concentration equal to $n = 3.0 \times 10^{12}$ cm^{-2} and are attributed to first order ferromagnetic to paramagnetic phase change. Linear dependence of force versus external magnetic field was noted in the paramagnetic state, whereas no dependence was found in ferromagnetic state.
639	**High frequency antennas for all-electrical excitation and detection of propagating spin waves** *Andreas Höfinger, David Schmoll, Andrey Voronov, Sabri Koraltan, Claas Abert, Dieter Suess, Andrii Chumak, Sebastian Knauer* *University of Vienna, Faculty of Physics, Boltzmanngasse 5, Vienna, Austria.* A requirement for the realisation of large-scale magnon-based circuits is the low-loss excitation and detection of spin-waves. To minimise radiation losses and to approach single magnon level, an efficient coupling of high frequency microwave signals to propagating spin waves is required. In particular, large-area impedance-matched and on-chip lithographed nanoantennas are necessary. Here we demonstrate an efficient coupling between electromagnetic waves and spin waves with different nanoantenna designs, using finite element and finite difference micromagnetic simulations. Specifically, radiation and reflection losses are investigated. Further, we fabricate and measure the characteristics of the nanoantennas deposited on yttrium-iron-garnet films using vector network analyser.
640	**Phase Transitions and Magnetic Order in a Ruby Lattice Artificial Spin Ice** *Luca Berchialla [1], Peter Derlet [1,2], Laura Heyderman [1,2], Gavin Macauley [1,2], Valerio Scagnoli [1,2], Tianyue Wang [1,2]* *[1] Paul Scherrer Institute, [2] ETH Zürich* Artificial spin ice are arrangements of dipolar coupled nanomagnets, which exhibit a range of interesting behaviour. Here, we study an artificial spin ice based on the ruby lattice. This pattern has a complex unit cell with 12 nanomagnets and two lattice constants that define it. By varying the two lattice constants independently, we can change the interaction between nanomagnets. Using x-ray photoemission electron microscopy we observed different ordering mechanisms depending on the lattice constants. Moreover, the system can order in one or two steps as shown by Monte Carlo simulations.

641	**Phase Transitions and Magnetic Order in a Twisted Form of the Kagome Artificial Spin Ice** *Gavin Macauley [1,2], Luca Berchialla [1], Aleksandra Pac [1], Tianyue Wang [1,2], Rhea Stewart [1,2], Armin Kleibert [1], Valerio Scagnoli [1,2], Peter Derlet [1,2], Laura Heyderman [1,2]* *[1] Paul Scherrer Institute, [2] ETH Zürich* Artificial spin ices are arrays of strongly-correlated nanomagnets, which provide a valuable platform to study phase transitions. The kagome artificial spin ice is a highly frustrated example that undergoes two separate ordering transitions. We show how rotating each nanomagnet in the kagome lattice about its centre allows us to access a rich phase diagram. Using a combination of magnetic force microscopy to characterise the as-grown states and x-ray photoemission electron microscopy to observe the thermally-active states, we determine how ordering proceeds in the different arrays. We find that the rotation maps from a spin ice sector near hexagonal geometries to a ferromagnetic phase, and then to a flux closed state.
642	**2D curved nano-conduits for magnonic transport made of GaYIG** *Andrey Voronov [1], Ondřej Wojewoda [2], Kristýna Davídková [2], Qi Wang [3], Carsten Dubs [4], Michal Urbánek [2], Andrii Chumak [1]* *[1] University of Vienna, Faculty of Physics, Boltzmanngasse 5, Vienna, Austria* *[2] CEITEC BUT, Brno University of Technology, Purkyňova 123, Brno, Czech Republic* *[3] Huazhong University of Science and Technology* *[4] INNOVENT e. V. Technologieentwicklung, Prüssingstraße 27 B, Jena, Germany* We present a study on the effective propagation of spin waves in curved nano-conduits made of Gallium-substituted Yttrium Iron Garnet (GaYIG) using micro-focused Brillouin Light Scattering spectroscopy. The investigation was carried out in the Forward Volume geometry to ensure an isotropic in-plane medium for spin-wave propagation. The curved nano-conduits have a thickness of 69 nm and a minimum width of 170 nm. Due to the pronounced uniaxial anisotropy of GaYIG, an external magnetic field of 50 mT is sufficient to magnetise it. Long-range propagation of spin waves was observed because GaYIG has a high exchange stiffness. Our results pave a promising way for efficient information transport in 2D magnonic networks.
643	**Anisotropic Spin Orbit Torque in Epitaxial Pt (110) Thin Films** *Ryan Thompson, University of Fribourg* Over the past decade of spintronics research, spin-orbit torque (SOT) has emerged as an ultrafast and energy efficient method for electrically switching magnetizations. Ultrathin heavy metal/ferromagnetic bilayers have been the subject of particular interest, due to the strong spin-orbit coupling in heavy metals, as well as having many materials engineering opportunities to tune the SOT. One promising path forward for this has been epitaxial growth, which has been shown to enhance spin Hall angles and lower critical currents. In this work, we show that the SOT and spin Hall angle exhibit anisotropy with regards to crystallographic direction in epitaxial Pt (110) thin films, providing another avenue for tuning the SOT.
644	**From randomly distributed to short range ordered spins: Dy/HOPG** *Alexis Rary-Zinque, Marina Pivetta, Maria Alfonso Moro, Stefano Rusponi, Harald Brune, François Patthey, EPFL* Magnetization curves recorded with X-ray magnetic circular dichroism on samples with a few % of a monolayer (ML) of Dy atoms on highly oriented pyrolytic graphite (HOPG) indicate two distinct magnetic species with mutual antiferromagnetic interactions. To understand the origin and magnetic interactions of the species, spatial distributions of Dy atoms and small clusters were studied using scanning tunneling microscopy. While deposition at 10 K gave statistical growth, deposition at 40 – 60 K with possible thermal diffusion led to equally spaced atoms suggesting repulsive dipolar interactions caused by charge transfer between the adatom and substrate. The atoms have a direct capture area of a 3-sites radius; atoms landing inside that area form dimers.

645

Nanoscale imaging of materials for memories and quantum bits with Scanning NV Magnetometry

Liza Žaper [1,2], Vicent Borras [2], Robert Carpenter [3], Sebastien Couet [3], Boris Gross [1], Marcus Wyss [4], Patrick Maletinsky [1], Martino Poggio [1,4], Floris Braakman [1], Peter Rickhaus [2]
[1] Department of Physics, University of Basel, [2] Qnami AG, Muttenz, Switzerland
[3] IMEC, Loewen, Belgium, [4] Swiss Nanoscience Institute, University of Basel

Storing information in magnetic bits requires excellent control over their nanoscale magnetic properties. A prime example of this challenge are STT-MRAM (spin transfer torque magnetic random access memory) devices - which have rather high failure rates. In order to investigate the sources of potential failure, a technique that can resolve small magnetic fields with high spatial resolution is required. The request is even more urgent for next-generation magnetic memory materials, such as antiferromagnets, which generate even smaller magnetic signals. Scanning NV magnetometry (SNVM) is an emerging quantum sensing technique that offers the required sensitivity. Here, we will look at the local magnetic properties of bits in state-of-the-art STT-MRAM devices using SNVM, as well as the SNVM results of Co – nanomagnets for spin qubit control.