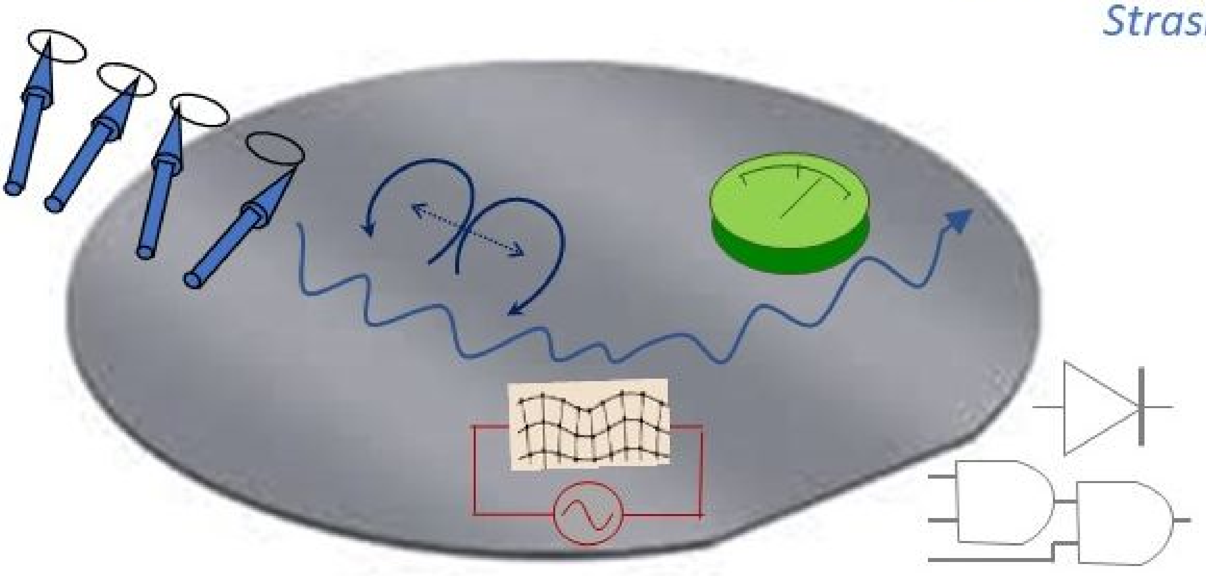
SWING: Spin waves for advanced signal processing

May 23 & 24 2024
Strasbourg



	Thursday 23/05	Friday 24/05
9h – 10h20		Thevenard 30' Chiroli 30' DeLoubens 20'
10h20 – 10h50		Coffee break
10h50 – 12h40		Bittencourt 20' Rovillain + Ngouagnia 30' Anane 30' Discussions 30'
12h40 – 14h00	Lunch CROUS restaurant Cronenbourg	Lunch CROUS restaurant Cronenbourg
14h00 – 15h50	Introduction 30' Schmool 30' Devolder + Thiancourt 30' Thonikkadavan 20'	Lab visits
15h50 – 16h20	Coffee break	
16h20 – 17h50	Vlaminck 30' Merbouche + Soares 30' Bailleul + Rossi 30'	
Evening	Dinner Restaurant Le Grand Tigre Strasbourg	

Reconfigurable magnonics

Hybrid magnonics

Nanomagnonics

Magnonic implementation

Table des matières

Programme

23 mai 2024

HEURE	TYPE	ÉVÉNEMENT
12:40 - 14:00	Logistique	Repas - CROUS Cronenbourg
14:00 - 14:30	Discours	Introduction - Matthieu Bailleul
14:30 - 15:50	Session	Jeudi 23 mai 14h30 - 15h50
14:30 - 15:00		› VNA-FMR in reconfigurable magnonic crystals - *Schmool David, Université Paris-Saclay, UVSQ-CNRS, GEMaC*
15:00 - 15:30		› Unidirectional spin waves measured using propagating spin wave spectroscopy - *Gaël Thiancourt, Centre de Nanosciences et de Nanotechnologies*
15:30 - 15:50		› Micromagnetic simulations of spin wave propagation in corrugated waveguides - *Ashfaque Thonikkadavan, Institut de Physique et Chimie des Matériaux de Strasbourg - Riccardo Hertel, Institut de Physique et Chimie des Matériaux de Strasbourg*
15:50 - 16:20	Pause	Pause café
16:20 - 17:50	Session	Jeudi 23 mai 16h20 - 17h50
16:20 - 16:50		› Shaping non-reciprocal spin wave beams in thin magnetic films - *Vincent Vlaminck, IMT Atlantique - Lab-STICC*
16:50 - 17:05		› Non-degenerate parametric excitation in YIG nanostructures for k-space neuromorphic computing - *Hugo Merbouche, SPEC*
17:05 - 17:20		› Mutual inhibition between parametrically excited spin-wave modes - *Gabriel Soares, Service de physique de l'état condensé*
17:20 - 17:50		› Magnetoresistive detection of spin-waves - *Quentin ROSSI, Institut de Physique et Chimie des Matériaux de Strasbourg*
20:00 - 23:00	Sortie	Dîner - Restaurant Le Grand Tigre Strasbourg

24 mai 2024

HEURE	TYPE	ÉVÉNEMENT
09:00 - 10:20	Session	Vendredi 24 mai 9h - 10h20
09:00 - 09:30		› Experimental determination of elastic constants and magnetic exchange in an epitaxial FeRh thin film - *Laura Thevenard, Institut des Nanosciences de Paris*
09:30 - 10:00		› Nanostructures périodiques soumises à des contraintes mécanique : Étude expérimentale et numérique des fréquences des modes magnétiques - *Stéphane Chiroli, Laboratoire des Sciences des Procédés et des Matériaux*
10:00 - 10:20		› Excitation of vortex core gyration by surface acoustic waves - *Grégoire de Loubens, Service de physique de l'état condensé*
10:20 - 10:50	Pause	Pause café
10:50 - 12:10	Session	Vendredi 24 mai 10h50 - 12h10
10:50 - 11:10		› Quantum backaction evasion in cavity magnomechanics - *Bittencourt Victor, University of Strasbourg*
11:10 - 11:25		› Surface Acoustic Waves and Spin Waves interaction - *Pauline Rovillain, Institut des Nanosciences de Paris*
11:25 - 11:40		› A micromagnetic study of Surface-Acoustic-Wave-Driven Excitation of Spin Waves in an Iron-based Conduit - *Igor Ngouagnia - IPCMS*
11:40 - 12:10		› Delay Line Utilizing Liquid Phase Epitaxy-Grown Films for Radio-Frequency Applications - *Madjid Anane, Laboratoire Albert Fert, Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France*
12:10 - 12:40	Discours	Discussions
12:40 - 14:00	Logistique	Repas - CROUS Cronenbourg

Jeudi 23 mai 14h30 - 15h50

VNA-FMR in reconfigurable magnonic crystals

Schmool David * [1], Daniel Marko [2], Luis Manuel Álvarez-Prado [3], Javier Díaz [3]

[1] Université Paris-Saclay, UVSQ-CNRS, GEMaC – UVSQ - CNRS – France
[2] Silicon Austria Laboratory – Autriche
[3] Universidad de Oviedo – Espagne

Periodic stripe domains that naturally occur in hard magnetic layers with weak perpendicular magnetic anisotropy have been shown to be suitable for controlling spin-wave dynamics. However, their intrinsically high damping limits their applicability towards magnonic devices. To circumvent this problem, while still benefiting from the advantages of periodic magnetization textures, we have studied hybrid magnetic systems based on hard magnetic NdCox films, which are dipolar coupled to a soft magnetic layer with in-plane magnetic anisotropy, such as permalloy and YIG, via a non-magnetic Al spacer. Using broadband ferromagnetic resonance, we have investigated the magnetization dynamics in this sample system, which, compared to an uncoupled permalloy reference film, exhibits a host of unique magnetic properties such as a frequency hysteresis and increased zero-field resonance frequencies. We provide an explanation for the origin of this hysteresis, which is intimately related to the regular magnetic hysteresis, by accounting for the switching of the modes between acoustic and optical resonances, that naturally occur in unsaturated systems with different magnetic domains. Our model is ultimately supported by a simple expression for the relation between the frequency difference at the applied field at which the mode shift occurs and the periodicity of the stripe domain pattern, that is imprinted into the permalloy film as a result of the coupling to the NdCo layer. Moreover, we show that these unique features in the FMR spectra can also be observed when substituting the ferromagnetic metal permalloy for a ferrimagnetic insulator such as yttrium iron garnet.

*Intervenant

Unidirectional spin waves measured using propagating spin wave spectroscopy

Gaël Thiancourt * [1], Thibaut Devolder [2]

[1] Centre de Nanosciences et de Nanotechnologies – Université Paris-Sud - Université Paris-Saclay, Université Paris Sud, Université Paris Saclay – France
[2] Centre de Nanosciences et de Nanotechnologies – Université Paris-Sud - Université Paris-Saclay, Université Paris Sud, Université Paris Saclay – France

The dispersion relation of spin waves can sometimes be monotonous around the center of the Brillouin zone. This feature leads to the unidirectional flow of zero-momentum wavepackets, of interest for applications. The standard way of analysing propagating spin wave spectroscopy experiments is inoperative to analyse near-zero-momentum magnons, thus also when encountering monotonous dispersion relations. We developed an exact analysis technique for this case and apply it by studying the acoustic spin waves propagating parallel to the applied fields in a synthetic antiferromagnet, in which we show that the spin waves are unidirectional within a large field interval. In contrast to the common thinking, we evidence that the phase accumulated by the spin waves upon their travels between two antenna is not strictly proportional to antenna spacing. In this work, we turn propagating spin waves spectroscopy data to a new way to measure spin waves dispersion relation. The synthetic antiferromagnet's acoustical SW dispersion relation is extremely non-reciprocal, and even monotonous near k = 0 which allow us to apply a formalism which to characterized this interesting state conducive for data processing application. We show that their is several characteristic lengths in the PSWS problem (antenna width, spacing between the antennas and spin attenuation length Latt) the phase accumulated by the spin wave upon its travel between the two antenna is not strictly proportional to r, which contrast to what is usually assumed.

*Intervenant

Micromagnetic simulations of spin wave propagation in corrugated waveguides

Ashfaque Thonikkadavan * [1], Riccardo Hertel *

2

[1] Institut de Physique et Chimie des Matériaux de Strasbourg – University of Strasbourg, CNRS – France

[2] Institut de Physique et Chimie des Matériaux de Strasbourg – Centre National de la Recherche Scientifique – France

Magnetic materials with periodic spatial patterning can act as magnonic crystals (MCs) with characteristic spin wave properties, such as band gaps at tunable GHz frequencies (1), thus displaying features comparable to their counterparts in photonic crystals. The possibility to control bands and band gaps by means of geometric or physical properties renders them interesting candidates for magnonic signal processing applications (2). Various types of magnonic crystals have been studied extensively over the past years, including, e.g., arrays of ferromagnetic stripes and antidot lattices. Such systems have specific structural variations, like periodic patterning, changes in the local material properties, or film thickness modulations. Recent progress in three-dimensional nanofabrication (3) has made it possible to generate MCs with purely geometrical – rather than structural – modulation. Here, we investigate systems in the form of micron-sized Permalloy thin-film elements with sinusoidally modulated surface (4). The study is conducted using finite-element micromagnetic simulations in the time- and frequency domain (5,6). In the corrugated magnetic film, the surface curvature varies with sub-micron periodicity, while the magnetic material properties and the film thickness (10 nm) are homogeneous throughout the sample. The curvature induces a local shape anisotropy sufficiently strong to align the magnetization perpendicular to the corrugation direction at zero field. We study the spin-wave propagation parallel and perpendicular to the corrugation direction and its dependence on the periodicity and amplitude of the modulation. We obtain dispersion relations with a band gap appearing only for backward-volume configuration, not in Damon-Eshbach geometry. Furthermore, we find that the width of the bandgap can be tuned by varying the sinusoidal modulation.

(1) H. Puszkarski and M. Krawczyk, *Solid State Phenomena* 94, 125 (2003)

(2) A V Chumak et al., *J. Phys. D: Appl. Phys.* 50, 244001 (2017)

(3) A. Fernández-Pacheco et al., Nat. Commun. 8, 15756, 10.1038/ncomms15756 (2017)
(4) I. Turcan et al., *Appl. Phys. Lett.* 118, 092405 (2021)
(5) R. Hertel, *tetmag*, https://github.com/R-Hertel/tetmag (2023)
(6) M. d'Aquino and R. Hertel, *J. Appl. Phys.* 133, 033902 (2023)

*Intervenant

Jeudi 23 mai 16h20 - 17h50

Shaping non-reciprocal spin wave beams in thin magnetic films

Vincent Vlaminck * [1]

[1] IMT Atlantique - Lab-STICC – IMT Atlantique Bretagne-Pays de la Loire : UMR6285 – Technopôle Brest-Iroise CS 83818 29238 Brest cedex 03 France, France

Magnonic devices, which take advantage of the versatility of spin waves, are anticipated to be a propitious alternative for efficient signal processing. Spin waves constitute the building blocks of novel wave computing methods such as spectral analysis (1), and neuromorphic computing (2), which are all interference based techniques. Recently, basics concepts of optics applied to spin waves demonstrated the possibility to shape and stir spin wave beams, suggesting prominent performance in particular tasks such as image processing and speech recognition (3). Along these ideas, we demonstrated that the beamforming in ferromagnetic thin films follows directly the near-field interference pattern of the excitation geometry (4-7).

Here, we present several approaches that allows exciting non-reciprocal spin wave beams in thin magnetic films such as curvilinear antennas, grating of nanomagnets, and sharp constrictions. We first present a near-field diffraction model that benchmarks spin wave beamforming in thin films for any geometry. Then, we experimentally test our predictions using both spin wave spectroscopy and micro-focused Brillouin light spectroscopy to map diffraction patterns in the 2D plane. We will show in particular how a sharp constriction in an antenna can directly excite non-reciprocal caustic beams in an extended film when the suitable conditions of field and frequency meets an inflection point in the dispersion relation. These findings have important implications for the development of switchable spin wave splitters, passive spin-wave frequency-division demultiplexers, and magnonic interferometry.

This work was supported by the French ANR project MagFunc, the Département du Finistère through the project "SOSMAG", and the Transatlantic Research Partnership, a program of FACE Foundation and the French Embassy.

References

A. Papp, et al., Scientific Reports **7**, 9245, (2017).

A. Papp, et al. Nature Communications **12**, 6422, (2021).

E. Albisetti, et al., Advanced Materials **32**, 1906439, (2020).

*Intervenant

N. Loayza, et al., Physical Review B **98**, 144430, (2018).

V. Vlaminck, et al., Journal of Applied Physics **133**, 053903, (2023).

L. Temdie, et al., AIP Advances, **13**, 2, 025207, (2023).

V. Vlaminck et.al, Phys. Rev. Appl. **21**, 014032 (2024).

Mutual inhibition between parametrically excited spin-wave modes

Gabriel Soares * [1], Amel Kolli [1], Rafael Lopes Seeger [2], Titiksha Srivastava [2], Hugo Merbouche [1], Grégoire De Loubens [1]

[1] Service de physique de l'état condensé – Commissariat à l'énergie atomique et aux énergies alternatives, Université Paris-Saclay, Centre National de la Recherche Scientifique – France
[2] Centre de Nanosciences et de Nanotechnologies – CNRS, Université Paris Sud, Université Paris Saclay – France

Leveraging on nonlinear magnetization dynamics is promising for neuromorphic computing (1)(2). Recently, pattern recognition has been achieved using a magnon-scattering reservoir (3). To proceed further from reservoir computing, one should be able to characterize the connectivity and to program the neural network. In magnetic microstructures, spin-wave eigenmodes are defined in the k-space and are interpreted as neurons. Mutual nonlinear couplings between the modes are predominantly determined by their amplitudes and are interpreted as synaptic weights. We have previously demonstrated that parallel parametric pumping allows the selective excitation of a large number of eigenmodes in YIG microdisks (4). Here, we parametrically excite pairs and trios of modes to study their mutual interactions. Two-tone MRFM and BLS spectroscopy demonstrate that modes can inhibit each other, the strength of this nonlinear interaction being governed by the power of the rf pulses and the time delay between them. We observe similar inhibition of modes as a function of the delays between three different rf pulses. Full micromagnetic simulations and a description of the nonlinear magnetization dynamics in terms of normal modes (5) provide some insights into these nonlinear processes, which could be used to demonstrate basic neuromorphic functions. This work has received financial support from the Horizon 2020 Framework Program of the European Commission under FET-Open grant agreement no. 899646 (k-NET).

(1) A. Papp, W. Porod, and G. Csaba, Nature Commun. 12, 6422 (2021)
(2) A. Allwood, et al., Appl. Phys. Lett. 122, 040501 (2023)
(3) T. Srivastava, et al., Phys. Rev. Appl. 19, 064078 (2023)
(4) S. Perna et al., J. Magn. Magn. Mater. 546, 168683 (2022

*Intervenant

Non-degenerate parametric excitation in YIG nanostructures for k-space neuromorphic computing

Hugo Merbouche * [1]

[1] SPEC – CEA-DRF-IRAMIS – France

Magnonic neuromorphic computing schemes require the excitation and manipulation of many modes in small magnetic structures. This task can be fulfilled by parametric processes, where a photon or a magnon at frequency f splits in two magnons at frequencies $f + df$ and f - df (1). The splitting can be degenerate ($df = 0$) or non-degenerate ($df \neq 0$). Recently, the non-degeneracy was shown to open the possibility to cross-stimulate a mode using multiple parametric excitations, effectively implementing an interconnected recurrent neural network capable of classifying rf signals (2). While exciting degenerate magnon pairs is simple, the observation of non-degenerate pairs has been limited to μm-thick YIG films (3) and metallic microstructures with a vortex ground state (2).
In this study, we demonstrate that by varying the direction of the parametric excitation field one can efficiently excite degenerate or non-degenerate magnon-pairs in a 500 nm diameter 50nm thin YIG disk. When the rf field is applied parallel to the static magnetization, a photon splits into a degenerate magnon-pair at half the pump frequency. However, when the rf field is applied transverse to the static magnetization, it non-resonantly excites a magnon which splits into a magnon-pair that is typically non-degenerate.

This non-resonant transverse parametric pumping technique in YIG is flexible in terms of external field and sample shape. These findings represents a new paradigm for non-degenerate parametric processes that have been underutilized in thin ferromagnetic films such as YIG. The properties of non-degenerate parametric processes are of decisive importance to implement novel hardware platforms for non-conventional computing and data processing relying on modes interacting in the reciprocal space.
(1) G A Melkov and A.G. Gurevich. *Magnetization Oscillations and Waves.* CRC Press. New York, 1996.
(2) L. Körber, C. Heins, T. Hula, J.-V. Kim, H. Schultheiss, J. Fassbender, and K. Schultheiss, *Pattern recognition in reciprocal space with a magnon-scattering reservoir,* Nat. Commun. **14**, 3954 (2023).
(3) A Melkov and S V Sholom. *Parametric excitation of spin waves by a surface magnetostatic wave.* Journal of Experimental and Theoretical Physics 96, 712–719 (1989).

*Intervenant

Magnetoresistive detection of spin-waves

Quentin Rossi * [1], Daniel Stoeffler [2], Hicham Majjad [3], Romain Bernard [4], Ulrich Noumbe [5], Grégoire De Loubens [6], Aurélie Solignac [7], Matthieu Bailleul [8]

[1] Institut de Physique et Chimie des Matériaux de Strasbourg – CNRS - Unistra – France
[2] IPCMS – CNRS, Université de Strasbourg, université de Strasbourg – France
[3] Institut de Physique et Chimie des Matériaux de Strasbourg – IPCMS, Université de Strasbourg – France
[4] Institut de Physique et Chimie des Matériaux de Strasbourg – université de Strasbourg, Centre National de la Recherche Scientifique, Matériaux et Nanosciences Grand-Est, Réseau nanophotonique et optique, Réseau nanophotonique et optique – France
[5] Institut de Physique et Chimie des matériaux de Strasbourg – Institut de Physique et Chimie des Matériaux de Strasbourg (IPCMS), UMR 7504 du CNRS, Université de Strasbourg, 23 rue du Loess, 67037 Strasbourg Cedex 08, France – France
[6] Service de physique de l'état condensé – Commissariat à l'énergie atomique et aux énergies alternatives, Université Paris-Saclay, Centre National de la Recherche Scientifique – France
[7] Service de physique de l'état condense (SPEC), CEA, CNRS, Université Paris-Saclay, CEA Saclay – Université Paris-Saclay, CEA-DRF-IRAMIS – France
[8] Institut de Physique et Chimie des Matériaux de Strasbourg (IPCMS) – université de Strasbourg, CNRS : UMR7504 – 23 rue du Loess - BP 43 - 67034 Strasbourg Cedex 2, France

The development of more energy-efficient information technologies has become a key focus of scientific research. This is especially true in the fields of magnonics, which has been expanding rapidly in the last decades. Indeed, the use of spin-waves (or "magnons") as an information vector seems particularly promising, as it enables one to combine the key advantages of wave-based systems (massively parallel architectures enabled by wave propagation) with those of magnetic systems (non-volatility and large tunability). This led, for example, to the development of all-electrical inductive methods for detecting spin-waves at the micrometer and sub-micrometer scales. However, inductive detection methods are now reaching their limits in terms of miniaturisation, and the very small signals extracted at the nanometer scale are hardly compatible with an implementation in micro-electronics.
In this communication we propose a new method for detecting spin waves based on the giant magneto-resistance (GMR) effect, which enables one to obtain high-sensitivity devices on sub-micrometre scales.

*Intervenant

Vendredi 24 mai 9h - 10h20

Nanostructures périodiques soumises à des contraintes mécanique : Étude expérimentale et numérique des fréquences des modes magnétiques

Stéphane Chiroli * [1], Damien Faurie [1], Mohamed Haboussi [2], Adekunle O. Adeyeye [3,4], Fatih Zighem [5]

[1] Laboratoire des Sciences des Procédés et des Matériaux – Centre National de la Recherche Scientifique, Université Sorbonne Paris nord – France
[2] Laboratoire des Sciences des Procédés et des Matériaux (LSPM) – Université Sorbonne Paris nord – Université Sorbonne Paris Nord, UPR 3407 CNRS, F-93430, Villetaneuse, France
[3] Durham University – Royaume-Uni
[4] National University of Singapore – Singapour
[5] Université Sorbonne Paris Nord – Université Sorbonne Paris Cité (USPC) – France

Les travaux que nous souhaitons présenter s'articulent autour de la magnonique et des couplages magnéto-élastiques. Nous nous intéressons au contrôle des fréquences des ondes de spin dans des films nanostructurés par application de contraintes mécaniques. Une partie de ce travail est concentrée à la simulation par éléments finis de tels phénomènes sous Comsol Multiphysics®. Ces simulations qui couplent les effets des déformations mécaniques sur les propriétés magnétiques (couplage indirect) ainsi que l'effet de l'aimantation sur les propriétés mécaniques (effet direct) permettent de rendre compte de l'évolution temporelle des propriétés magnétiques, des propriétés dispersives des ondes de spin et permettent même de prédire les coulages entre magnons et phonons pouvant apparaître dans certains systèmes.

*Intervenant

Experimental determination of elastic constants and magnetic exchange in an epitaxial FeRh thin film

Djoudi Ourdani [1,2], Ashwin Kavilen Vythelingum [3], Yves Roussigné [4], Mohamed Belmeguenai [5], Catherine Gourdon [2], Jon Arregi [6], Bernard Perrin [2], Vojtech Ulhir [6], Laura Thevenard * [3]

[1] Laboratoire des Sciences des Procédés et des Matériaux – Institut Galilée, Université Sorbonne Paris Cité, Centre National de la Recherche Scientifique, Université Sorbonne Paris nord – France
[2] Sorbonne Université, CNRS, Institut des NanoSciences de Paris – Sorbonne Université, CNRS, Institut des NanoSciences de Paris, INSP, F-75005 Paris, France – France
[3] Institut des Nanosciences de Paris (INSP) – Sorbonne Universite, Centre National de la Recherche Scientifique – Sorbonne-Université, Case 840 4 place Jussieu 75252 Paris Cedex 05, France
[4] Laboratoire des Sciences des Procédés et des Matériaux – Institut Galilée, Centre National de la Recherche Scientifique, Université Sorbonne Paris nord, Université Sorbonne Paris nord : UPR3407 – France
[5] Laboratoire des Sciences des Procédés et des Matériaux, Univ. Paris 13 Nord, Villetaneuse – LSPM, Univ Paris 13 – France
[6] Central European Institute of Technology [Brno] – République tchèque

FeRh is a fascinating material that undergoes a first-order phase transition, changing from an antiferromagnetic (AF) to a ferromagnetic (FM) state upon heating. The phase transition temperature in FeRh strongly depends on the stoichiometry of Fe and Rh, the deformation state (1), and the applied magnetic field (2). FeRh has shown significant potential for thermally assisted magnetic recording in thermal information storage (3). Moreover, it has been observed that the AF-FM transition can be triggered by ultrafast laser pulses inducing a heating effect (4), which could be valuable for optical information recording.
FeRh is also characterized by a large magnetostriction coefficient, making it interesting for straintronics applications. To take full advantage of this feature, a knowledge of the elastic constants that determine the propagation velocities of acoustic waves and the magnetic properties that govern those of spin waves is necessary. In this respect, we need an experimental tool that can probe both types of waves simultaneously.

Therefore, in this study, Brillouin light scattering, combined with a picosecond acousto-optic interferometry technique have been used to investigate the evolution of C11, C12 and C44 with temperature, together with the magnetic exchange constant and the effective magnetization in an epitaxial FeRh (110) film deposited on MgO (100).

Picosecond measurements of the longitudinal velocity VL=sqrt(C11/ρ) revealed a decrease in the C11 constant when FeRh goes from its FM to AF phase. Brillouin light scattering measurements evidenced the presence of three different acoustic modes, with frequencies changing with

*Intervenant

temperature. Subsequently, we derived the frequency versus wave vector dispersion, extracting the C12 and C44 constants, which are lower in the FM phase. Furthermore, the appearance of magnetic modes (Damon Eshbach and Perpendicular Standing Spin Waves) in the uniform FM phase allowed us to estimate the magnetic exchange constant.

This work constitutes the initial step in the study of the phonon-magnon coupling in FeRh, which will be further employed in a device to excite spin waves with acoustic waves.

(1) Cherifi R O et al *Nat. Mater.* 2014, (2) Maat S et al *Phys. Rev. B* 2005, (3) J.U. Thiele, et al, *J Appl. Phys.* 2003, (4) Thiele J-U, et al *Appl. Phys. Lett.* 2004

Excitation of vortex core gyration by surface acoustic waves

Rafael Lopes Seeger [1], Florian Millo [1], Gabriel Soares [2], Joo-Von Kim [1], Aurélie Solignac [2], Thibaut Devolder [1], Grégoire De Loubens * [2]

[1] Centre de Nanosciences et de Nanotechnologies – Centre National de la Recherche Scientifique - CNRS – France

[2] Service de physique de l'état condensé – Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) - Saclay – France

The standard way to excite spin-wave dynamics in magnetic materials is through microwave magnetic fields, produced by the injection of currents in rf antennas. Although well established for many years, it would be highly desirable to excite magnetization dynamics by non-inductive means. Magneto-elastic effects offer such an alternative: in certain conditions, rf strains produced by applying voltages on a piezo-electric substrate can couple to spin-waves in a magnetic film deposited on top (1). Recently it has been proposed that a surface acoustic wave (SAW) can excite the gyrotropic mode of the vortex state in a magnetic disk (2). In this presentation, we report on recent experiments where we use a magnetic resonance force microscope to probe the magnetization dynamics in CoFeB sub-micrometer disks sustaining the vortex state at equilibrium, grown on a Z-cut LiNbO3 substrate. A specific design allows us to excite the gyrotropic mode either by inductive means, using an rf antenna deposited on top of the disks, or by launching SAWs from an IDT deposited 100 μm away. It allows us to demonstrate the unambiguous excitation of the vortex gyrotropic mode by an rf mechanical strain.

This work is supported by public grants overseen by the ANR as part of the "Investissements d'Avenir" program (Labex NanoSaclay, reference: ANR-10-LABX-0035, project SPICY) and by contract No. ANR-20-CE24-0025 (MAXSAW).

(1) M. Weiler et al. Phys. Rev. Lett. 106, 117601 (2011)

(2) A. Koujok et al., Appl. Phys. Lett. 123, 132403 (2023)

*Intervenant

Vendredi 24 mai 10h50 - 12h10

Quantum backaction evasion in cavity magnomechanics

Bittencourt Victor * [1], Clinton A. Potts [2,3], John P. Davis [4], Anja Metelmann [1,5,6]

[1] University of Strasbourg – Université de Strasbourg, CNRS, Université de Strasbourg, CNRS : LBP, UMR 7021 – France
[2] Kavli Institute of NanoSciences – Pays-Bas
[3] Niels Bohr Institute – Danemark
[4] Department of Physics, University of Alberta – Canada
[5] Institute of Condensed Matter, Karlsruhe Institute of Technology – Allemagne
[6] Institute for Quantum Materials and Technology, Karlsruhe Institute of Technology – Allemagne

Magnons hosted in a solid can couple to mechanical vibrations of the material (phonons) via a radiation-pressure like interaction due to magneto-elastic effects. When the magnet is loaded on a microwave cavity, phonons can be driven and measured via the microwave while having the tunability of the magnetic excitations. Nevertheless, the noise added to mechanics can hinders both potential applications of the system at the quantum level and measurements of the phonon mode. Here, we propose a scheme to evade quantum backaction on a phonon mode of a cavity magnomechanical system by using a two-tone microwave drive. We study the robustness of the different possible backaction evading schemes, and show that measurements of the phonon mode can be performed with added noise below the standard quantum limit.

*Intervenant

Surface Acoustic Waves and Spin Waves interaction

Pauline Rovillain * [1], Jean-Yves Duquesne [1], Louis Christienne [2], Maria Goria Pini [3], Angelo Rettori [4], Silvia Tacchi [5], Franck Fortuna [6], Anane Abdelmadjid [7], Catherine Gourdon [8], Laura Thevenard [8], Massimiliano Marangolo [9]

[1] Institut des Nanosciences de Paris – Sorbonne Universite, Sorbonne Universite : CNRS, UMR 7588 – France
[2] Acoustique pour les nanosciences – Institut des Nanosciences de Paris – France
[3] Istituto dei Sistemi Complessi del CNR (CNR-ISC), I-50019 Sesto Fiorentino, Italy – Italie
[4] Department of Physics and Astronomy, University of Firenze, INFN and INSTM RU – Italie
[5] : Istituto Officina dei Materiali del CNR (CNR-IOM), Sede Secondaria di Perugia, c/o, Department of Physics and Geology, Università di Perugia – Via Alessandro Pascoli, 06123 Perugia, Italie
[6] Centre de Sciences Nucléaires et de Sciences de la Matière (CSNSM) – Université Paris-Sud - Paris 11, Institut National de Physique Nucléaire et de Physique des Particules du CNRS, Centre National de la Recherche Scientifique : UMR8609 – Bâtiments 104 et 108 91405 Orsay Campus, France
[7] Unité Mixte de Physique – cnrs thales – France
[8] Institut des Nanosciences de Paris (INSP) – Sorbonne Universite, Centre National de la Recherche Scientifique – Sorbonne-Université, Case 840 4 place Jussieu 75252 Paris Cedex 05, France
[9] Institut des NanoSciences de Paris – Sorbonne Universités, UPMC, CNRS – France

The emerging field of magnon straintronics promises advancements in beyond-CMOS technology, allowing for the design of magnonic logic devices with voltage control over spin wave (SW) amplitude and phase, leveraging strain-induced magnon-phonon coupling. Resonant coupling between phonons and magnons in heterostructures of piezoelectric and magnetostrictive materials, conceptualized in the late 1950s (1), leads to Ferromagnetic Resonance and SW generation, either at magnetic remanence or with a moderate magnetic field. This induces mode hybridization due to magnetoelastic coupling.
Recently, coupling of surface acoustic waves (SAW) and SW has been observed in SAW-induced Ferromagnetic Resonance (SAW-FMR). We achieved SAW-FMR in Fe epitaxially grown on a GaAs(001) substrate, a spintronic and magnonic compatible magnetoelastic and piezoelectric heterostructure (2,3). SAW propagation in thin Fe film is influenced by SW mode dispersion in reciprocal space. Dependence of acoustic attenuation and sound velocity on **Bext** is critical, particularly in the backward configuration when **Bext** is parallel to the Fe hard axis (110). A phenomenological approach, derived from LLG equations, interprets this dependence with calculated SW dispersion curves. Our model describes the non-reciprocity effect observed when inverting **kSAW** at SAW-FMR resonance, suggesting potential creation of non-reciprocal acoustic elements.

To modify the magnetic anisotropy and then the magnetoelastic coupling in SAW-FMR, we implanted N atoms into Fe thin films at low doses, preserving epitaxial character and manipulating SW spectra. N atom implantation impacts in-plane and out-of-plane magnetic anisotropy

*Intervenant

in a Fe thin film.

Our study envisions SAW-based magnonic devices where a single IDT provides energy to activate magnetization dynamics and SW propagation in numerous waveguides. Tailoring SW propagation and magnetic anisotropy through ion implantation opens avenues for energy efficient advanced magnonic devices with enhanced functionalities.

(1) C. Kittel, Phys. Review 110 (1958) 836

(2) P. Rovillain, et al., Phys. Rev. Applied 18 (2022) 064043
(3) J-Y Duquesne, et al., Phys. Rev Applied Phys. Rev. Applied 12 (2019) 024042

A micromagnetic study of Surface-Acoustic-Wave-Driven Excitation of Spin Waves in an Iron-based Conduit

Igor Ngouagnia * [1], Louis Christienne [2], Jean-Yves Duquesne [3], Pauline Rovillain [4], Massimiliano Marangolo [5], Abdelmadjid Anane [6], Daniel Stoeffler [7]

[1] IPCMS – CNRS, Université de Strasbourg, université de Strasbourg – France
[2] Acoustique pour les nanosciences – Institut des Nanosciences de Paris – France
[3] Institut des Nanosciences de Paris (INSP) – Université Pierre et Marie Curie - Paris 6, Centre National de la Recherche Scientifique : UMR7588 – Université Pierre et Marie Curie Case 840 4 place Jussieu 75252 Paris Cedex 05, France
[4] Institut des Nanosciences de Paris (INSP) – Université Pierre et Marie Curie - Paris VI, CNRS : UMR7588 – France
[5] Institut des Nanosciences de Paris – Sorbonne Universite, Centre National de la Recherche Scientifique, Centre National de la Recherche Scientifique : UMR7588 – France
[6] Unité Mixte de Physique, CNRS/Thales – CNRS : UMR137 – France
[7] IPCMS – CNRS, Université de Strasbourg, université de Strasbourg – France

Recently, a number of basic building blocks of the magnonic paradigm have been experimentally demonstrated such as the spin-torque-induced amplification of spin waves (SWs) (1) and the magnonic diode (2). But, up to now, those building blocks intrinsically consume much more energy per logic-gate than their CMOS counterparts as they still rely on Ampere fields for signal transduction and amplification. An innovative approach based on elastic strain can be used to overcome this issue, allowing an energy efficient and large scale integration of voltage controlled magnonic circuits. Indeed, taking advantage of the resonant MagnetoElastic Coupling (MEC), Surface Acoustic Waves (SAWs) can be used to excite Ferromagnetic Resonance (FMR) of Fe films epitaxially grown on top of a piezoelectric substrate, even at low frequencies ($\leq$ 1 GHz) (3).
The goal of this study is to use SAW and resonant MEC to trigger magnetization precession in a small Fe pad (few hundreds of nm long), in order to excite a propagating SW in a waveguide connected to the pad. Thus, the traditional inductive antennas found in magnonic devices are replaced here by SAW-induced SW emission. To prevent the waveguide from being affected by the travelling SAW, one uses N-atoms implantation in the pristine Fe structure. Such implantation indeed leads to a high level of tunability of the Fe film magnetic anisotropy, allowing the desired control of the SW dispersion (4).
As expected, we observe the propagation of spin waves within the FeN waveguide. But in the case where the Fe pad is in the middle of the guide, we have an unexpected result with an asymmetric signal, the spin waves propagating essentially on one side of the pad. Additional simulations show that this asymmetry can be reversed by adjusting either the direction of SAW propagation or by changing the value of the SAW wave vector. These results suggest that the

*Intervenant

propagation ultimately depends on the sign of the spin waves group velocities.

The authors acknowledge support from the Agence Nationale de la Recherche Grant No. ANR-22-CE24-0015 SACOUMAD.
(1) Applied Physics Letters 108, 172406 (2016)
(2) Phys. Rev. Appl. 14, 024047 (2 2020)
(3) Phys. Rev. Appl. 12, 024042 (2 2019)
(4) Journal of Applied Physics 121, 243903 (2017)

Delay Line Utilizing Liquid Phase Epitaxy-Grown Films for Radio-Frequency Applications

Madjid Anane * [1]

[1] Laboratoire Albert Fert, Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France – CNRS, UMR137 – France

Sarah Mantion, Hugo Merbouche, Romain Lebrun, Dedalo Sanz Hernandez, Vincent Cros, Paolo Bortolloti, Abdelmadjid Anane
Laboratoire Albert Fert, Unité Mixte de Physique, CNRS, Thales, Université Paris-Saclay, Palaiseau, France

Jamal Ben Youssef

LabSTICC, UMR 6285 CNRS, Université de Bretagne Occidentale, Brest, France

Developing magnonic-radiofrequency components based on propagating spin waves holds significant potential for advancing signal processing technologies in radiocommunication frequencies. These concepts are optimally implemented on sub-micrometer yttrium iron garnet (YIG) films with extremely low damping, which are best achieved using liquid phase epitaxy. To minimize insertion losses, it is crucial to optimize the S-parameters of the device, necessitating comprehensive multiphysics simulations. This paper reports on the fabrication, characterization, simulation, and modeling of delay lines utilizing these principles. We also discuss the prospects and potential applications of these devices in the field of radiofrequency signal processing.

*Intervenant

Liste des auteurs

Liste des participants

- Anane Madjid
- Bailleul Matthieu
- Chiroli Stéphane
- David Schmool
- De Loubens Grégoire
- Devolder Thibaut
- Doddi Greeshmani
- Fenoy Quentin
- Gloppe Arnaud
- Henry Yves
- Hertel Riccardo
- Kundys Bohdan
- Lefevre Christophe
- Leuga Kankam Ulrich Karles
- Manfredi Giovanni
- Mantion Sarah
- Merbouche Hugo
- Monvoisin Margaux
- Ngouagnia Igor
- Pradhan Gyandeep
- Rossi Quentin
- Roussigne Yves
- Rovillain Pauline
- Soares Gabriel
- Stoeffler Daniel

- Thevenard Laura
- Thiancourt Gaël
- Thonikkadavan Ashfaque
- Vazquez Bernardez Maria Jose
- Viart Nathalie
- Victor Bittencourt
- Vlaminck Vincent
- Zafar Talha
- Zighem Fatih