

Non-reciprocal spin wave beams in thin magnetic films

V. Vlaminck^{1,2}, L. Temdie^{1,2}, V. Castel^{1,2}, D. Wagle³, B. Jungfleisch³, C. Dubs⁴, G. Pradan⁵, J. Solano⁵, H. Majjad⁵, R. Bernard⁵, Y. Henry⁵, D. Stoeffler⁵, M. Bailleul⁵

¹ IMT Atlantique, Institut Mines Telecom Atlantique, Microwave Dpt., CS 83818, 29238 Brest, France

² Lab-STICC (UMR 6285), CNRS, Technopole Brest-Iroise, CS 83818, 29238 Brest Cedex 3, France

³ University of Delaware, Dept. of Physics and Astronomy, Newark, Delaware, USA

⁴ INNOVENT e.V. Technologieentwicklung, Prussingstrasse 27B, 07745 Jena, Germany

⁵ IPCMS – Institut de Physique et Chimie des matériaux de Strasbourg, France

*corresponding author: vincent.vlaminck@imt-atlantique.fr

Abstract: We present several approaches that allows exciting non-reciprocal spin wave beams in thin magnetic films. Using primarily the spin wave spectroscopy techniques performed in both in- and out-of-plane geometries, we show that the spin wave beamforming can be tailored using concepts inspired from optics. We also developed a near-field diffraction model that benchmarks spin wave diffraction in thin films for any geometry, and is readily applicable for future designs of magnon interferometric devices.

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 [4-6].

In this communication, we focus on the beam shaping of spin wave using different methods such as curvilinear antennas, grating of nanomagnets, and sharp constrictions. Firstly, we will introduce our near-field diffraction model, which is applicable for all spin wave modes in thin magnetic films, and serves as a decisive tool to identify proper designs of spin wave beam antennas. Secondly, we will present measurements done via spin wave spectroscopy on various pairs of antenna whose designs allows characterizing the propagation properties in the 2D plane as shown in Fig. 1. Thirdly, using spatially resolved micro-focused Brillouin light spectroscopy, we will show how a sharp constriction in an antenna can directly excite 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”, the U.S. Department of Energy, Office of Basic Energy Sciences, Division of Materials Sciences and Engineering under Award DE-SC0020308, and the Transatlantic Research Partnership, a program

of FACE Foundation and the French Embassy.

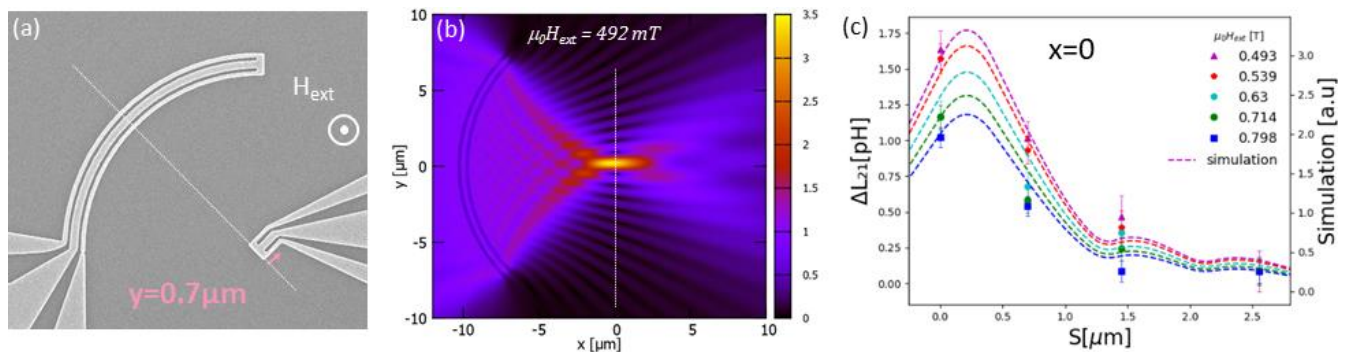


Figure 1: (a) SEM image of a spin wave concentrator. (b) Near-field diffraction simulation for an out-of plane field of 492mT, and a frequency of 8.5 GHz. (c) Discrete mapping of the spin wave intensity in the vicinity of the focal point.

References

1. Papp, A. and Porod, W. and Csurgay, A. I. and Csaba, G. “Nanoscale spectrum analyzer based on spin-wave interference”, Scientific Reports 7, 9245, 2017.
2. Papp, A. and Porod, W. and Csaba, G. “Nanoscale neural network using non-linear spin-wave interference”, Nature Communications 12, 6422, 2021.
3. Albisetti, E and Tacchi, S. and Silvani, R. and Scaramuzzi, G. and Finizio, S. and Wintz, S. and Rinaldi, C. and Cantoni, M. and Raabe, J. and Carlotti, G. and Bertacco, R. and Riedo, E. and Petti, D., “Optically inspired nanomagnonics with nonreciprocal spin waves in synthetic antiferromagnets”, Advanced Materials 32, 1906439, 2020.
4. Loayza, N. and Jungfleisch, M. B. and Hoffmann, A. and Bailleul, M. and Vlaminck, V., “Fresnel diffraction of spin waves”, Physical Review B 98, 144430, 2018.
5. Vlaminck, V. and Temdie, L. and Castel, V. and Jungfleisch, M. B. and Stoeffler, D. and Henry, Y. and Bailleul, M., “Spin wave diffraction model for perpendicularly magnetized films”, Journal of Applied Physics 133, 053903, 2023.
6. Temdie, L. and Castel, V. and Dubs, C. and Pradhan, G. and Solano, J. and Majjad, H. and Bernard, R. and Henry, Y. and Bailleul, M. and Vlaminck, V., “High wave vector non-reciprocal spin wave beams”, AIP Advances, 13, 2, 025207, 2023.