Excitation of High Frequency Spin Waves Using Metasurfaces: A Full Numerical Study

(Poster – Preliminary report)

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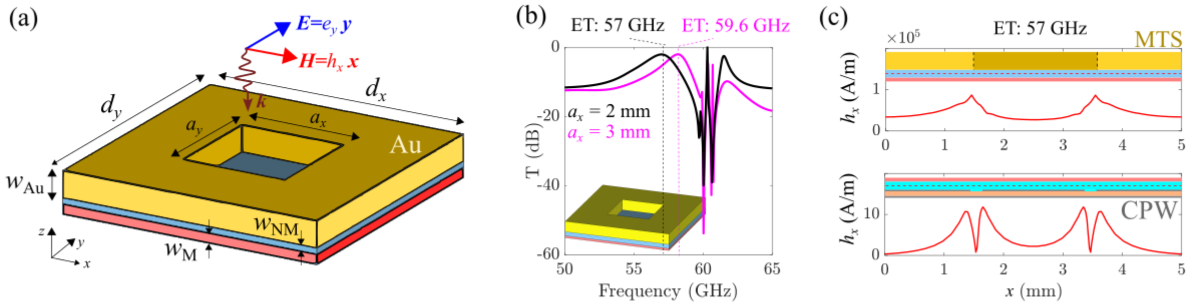
This research presents a novel methodology for the excitation of short-wavelength spin waves (SWs) using metasurfaces (MTSs), facilitated by a complete electromagnetic (EM)-micromagnetic simulator package (maxLLG™). SWs, crucial for emerging technologies like magnonics, offer unique opportunities for information processing at the nanoscale. However, achieving efficient and controlled excitation of short-wavelength SWs at high frequencies has posed a significant challenge given the electrical size of the EM transducers like coplanar waveguides (CPWs), fixed after manufacturing.

Our approach leverages MTSs, engineered surfaces with subwavelength structures, capable to allow Extraordinary Transmission (ET) in the millimetre-wave range and confine EM fields in very small regions depending on polarization, enabling a controlled technique over the local excitation of short-wavelength SWs using radiated EM fields. The results, integrating both EM and magnetisation dynamics, contribute to the understanding of the EM-SW interaction. In this work we will initially explore SW excitation in a multilayer system made by (from top to bottom) a metamaterial layer, made by periodic apertures in a non-magnetic (NM) conductive metal (Au), a thin NM dielectric layer, and a uniformly magnetised thin magnetic (M) film (Fig. 1a). When exposed to an EM field at the ET frequency (Fig. 1b) with the set polarisation, preliminary EM simulations reveal substantial field confinement in the NM layer under the aperture's edges in the x-direction (measured at half-thickness of the NM layer, see red dashed line in Fig. 1c), with a more uniform distribution beneath the aperture, compared to a similar configuration using a CPW (Fig. 1c). The stronger (x10^4) magnetic field is beneficial for non-linear excitation of SWs. This way, the propagation of high-frequency magnons in the magnetic layer can be explored. Preliminary results considering various shapes of the aperture and materials suggest that ET-MTSs placed over magnetic layers can serve as efficient, polarization-sensitive EM transducers for short-wavelength SW generation. This research provides further steps for designing metamaterial-based magnonic devices at high-frequency regimes.

Fig. 1. (a) Unit cell of a modelled slot array made of Gold (Au) on a thin magnetic Fe_3O_4 film (red layer), separated by a foam ($\varepsilon_r \sim 1$) layer (blue) in CST MWS™. (b) Simulated transmission (S_{21} parameter) through the MTS for two different a_x, with a Fe_3O_4 model bottom layer (see inset). Simulation parameters are: $a_x = a_y = 2$ mm, $w_{\mathrm{Au}} = 0.5$ mm, $w_{\mathrm{NM}} = 0.2$ mm, $w_{\mathrm{Fe3O4}} = 0.1$ mm. Note that if $a_x \neq a_y$ the MTS is sensitive to EM polarization. (c) Normalised in-plane (x-component) of the AC magnetic field (h_x) along the unit-cell width in x ($d_x = d_y = 5$ mm), 0.1 mm below the MTS (see red dashed line in schematic above) at the ET frequency (57 GHz). (Bottom panel) Equivalent result from a standard millimetre-wave CPW (adapted to 50 Ohms at the operating frequency of 57 GHz and $\varepsilon_r = 2.4$) with the Fe_3O_4 layer now on top of the NM layer.



1st Transnational Round Table on Magnonics, High-Frequency Spintronics, and Ultrafast Magnetism

Motivation letter

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Dear Organisers of TRTM 2024,

I, and on behalf of the rest of the co-authors, would like to introduce the work summarized here as a preliminary report, for presentation in poster form. The theme of the presented work fits into high-frequency magnonics and the generation of spin waves in a controlled manner using millimetre waves. As a novelty, not only is the proposed method itself, employing the phenomenon of Extraordinary Transmission, well known in the metamaterials research community, for excitation of spin waves at high frequencies, but also the complete study is carried out with a powerful and complete simulator package (maxLLG™) to solve the electromagnetic and magnonic phenomena in a coupled way. The nature of the problem to be treated, combining Extraordinary Transmission at high frequency (millimetre waves) and magnonics, is the perfect scenario to use it and explore the interaction mechanisms between millimetre electromagnetic waves and spin waves for high frequency magnonic devices. I deeply thank the organizers for the opportunity and I am looking forward to our work being of interest and being accepted as a poster to share and discuss more results on the day of the conference with the rest of the community.