Localized Spin Wave Modes in the Fishnet Metamaterial

(Poster– Preliminary report)

D. Osuna Ruiz,[a] F. Y. Ogrin,[b,c] and M. Beruete[a,d]
a: Antennas Group, Public University of Navarra, Spain;
b: University of Exeter, Exeter, United Kingdom;
c: maxLLG Ltd., Exeter, United Kingdom;
d: Institute of Smart Cities, Pamplona, Spain;

This research presents a novel methodology for the excitation of short-wavelength spin waves (SWs) based on metasurfaces (MTSs), using micromagnetic simulations (maxLLG™, OOMMF™). 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 **[1]**.

Our approach leverages engineered surfaces with subwavelength structures, capable to allow narrow-band Extraordinary Transmission (ET) in the millimetre-wave range and confine EM fields in very small regions **[2]**. The proposed multilayer system is made by (from top to bottom) a metamaterial layer of periodic apertures in a non-magnetic (NM) conductive metal (Au), a thin NM dielectric layer, and a patterned, uniformly magnetised thin magnetic (M) film (Fig. 1a). Substantial field confinement ***near*** the aperture's edges occurs at the ET frequency, as a superposition of evanescent and propagating modes (see Fig. 1b).

The magnetic (h) field distribution from EM simulations (CST MWS™) is replicated in micromagnetic simulations providing insight on the SW's anisotropic propagation as a function of the aperture's shape and magnetisation orientation. As an alternative to CPWs or current lines, we explore the suitability of the fishnet metamaterial for exciting characteristic SW modes in the 2D magnonic crystal, particularly **edge modes** in a narrow frequency band. This research provides further steps for designing metamaterial-based magnonic devices at high-frequency regimes.

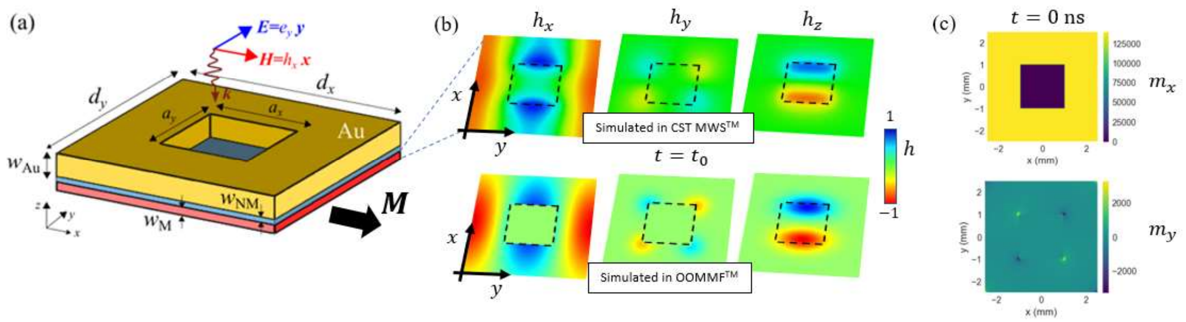

Fig. 1. (a) Unit cell of a modelled slot array made of Gold (Au) on a thin magnetic Fe_3O_4 film (red layer), in-plane magnetized, separated by a foam ($\varepsilon_r \sim 1$) layer (blue) in CST MWS™. (b) Simulated AC magnetic field components (h_x, h_y, h_z) for two different a_x, with a Fe_3O_4 model for the M layer, using CST MWS™ (top panels) and OOMMF™ (bottom panels). Simulation parameters are: $d_x = d_y = 5\ \mathrm{mm}, a_x = a_y = 2\ \mathrm{mm}, w_{\mathrm{Au}} = 0.5\ \mathrm{mm}, w_{\mathrm{NM}} = 0.005\ \mathrm{mm}, w_{\mathrm{Fe3O4}} = 0.01\ \mathrm{mm}$. Note that if $a_x \neq a_y$ the MTS is sensitive to EM polarization. (c) Equilibrium state of magnetisation $\boldsymbol{M}$ at the mid-plane of the M layer ($\boldsymbol{m_z} \sim 0$) with in-plane bias field of 159 kA/m.

References:

[1] N. Kumar *et al.*, Adv Quantum Techno, **7**, 2400015 (2024)

[2] T. W. Ebbesen *et al.*, Nature, **391**, 667–669 (1998)