Higher Harmonic Spin Wave Generation Using Out-of-Plane Magnetized Films with Localized In-Plane Magnetization

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Spin waves hold great promise for information transport in next-generation magnonic devices. However, the efficient excitation of exchange-dominated spin waves—characterized by inherently short wavelengths and high frequencies—remains a significant challenge. To overcome this, we introduce a hybrid magnetic structure composed of an in-plane magnetized region adjacent to a thin ferromagnetic film with out-of-plane magnetization. We investigate this system using micromagnetic simulations performed with Amumax[1], a customized fork of Mumax^3. The magnetic film is based on a Co/Pd multilayer stack[2], chosen for its strong perpendicular magnetic anisotropy (PMA) of 450 kJ/m³. In the initial configuration, a single antidot is positioned at the center of the waveguide. The antidot features 50 nm-wide rim regions where the anisotropy is removed, leading to an in-plane vortex-like magnetization. An external bias magnetic field B0, is applied perpendicular to the film to tune the resonance frequency.

Our simulations reveal that under microwave excitation, the in-plane magnetized rim efficiently emits high-frequency propagating spin waves into the surrounding out-of-plane magnetized strip (see Fig. 1). To quantify this mechanism, we perform simplified one-dimensional simulations in which the antidot is replaced by a 70 nm-wide anisotropy-free region at the edge of the strip, maintaining in-plane magnetization. We define the conversion efficiency as the ratio between the spin-wave amplitude at the driving frequency f_0, within the in-plane section and the amplitude of the resulting higher-harmonic spin waves in the strip. The simulations show that increasing the excitation field significantly boosts efficiency, reaching up to 42%. Additionally, tuning B_0 allows precise control over the generated frequency: for example, $2f_0$=14.27 GHz at 145 mT and 17.20 GHz at 360 mT.

Our results demonstrate that efficient higher-harmonic generation is driven by exchange interactions at the interface between the in-plane and out-of-plane magnetized regions. We show that, even under a spatially uniform out-of-plane polarized microwave magnetic field, spin waves can be excited locally in magnetically non-uniform regions and subsequently launched into the waveguide at integer multiples of the excitation frequency. This nonlinear magnonic effect could be beneficial for applications in signal synchronization and neuromorphic computing.

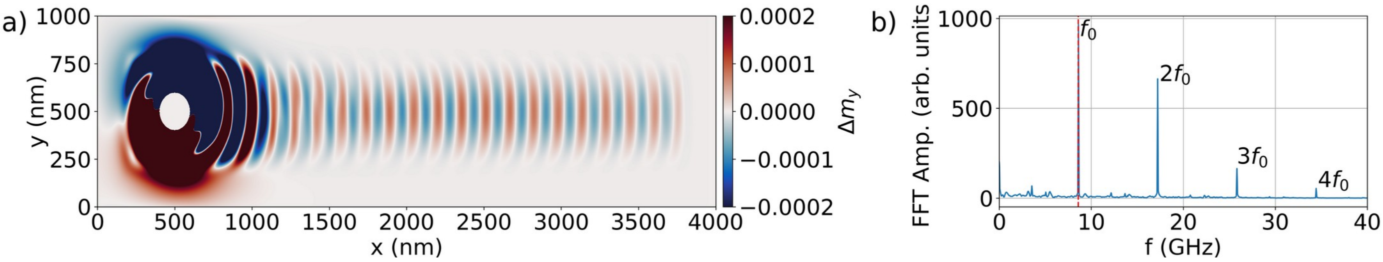

Figure 1: a) Dynamic y component of the magnetization in the waveguide with the antidot on the left and the propagating spin waves on the right (f_0 = 7.13 GHz at 145 mT). b) Fourier transform of the my magnetization in the strip over time.

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References

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