Thin Ferromagnetic Films with Out-of-Plane Magnetization and In-plane Magnetized Insets for High Harmonic Spin Wave Generation

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Spin waves are attractive candidates for information transport, however, efficiently exciting exchange-dominated spin waves, which inherently exhibit short wavelengths and high frequencies, remains a challenge. To address this limitation, we propose a hybrid structure comprising an in-plane magnetized region coupled with an out-of-plane magnetized ferromagnetic strip. To thoroughly investigate the dynamic interactions governing this process, we conduct micromagnetic simulations using Amumax, a fork of Mumax3. The material used is a Co/Pd multilayer[1], forming a thin film with strong perpendicular magnetic anisotropy (450e3 J/m³). Initially, a single antidot is introduced at the center of the waveguide, featuring 50 nm rims where magnetic anisotropy is removed, stabilizing magnetization in in-plane vortex state. A bias magnetic field, B_0, is applied along the out-of-plane direction to adjust the resonance frequency. We found that the rim under the action of the microwave magnetic field emits the propagating spin waves of high frequency to the strip (Fig. 1).To quantify the efficiency of this process, simplified one-dimensional simulations are performed by replacing the antidot with a 70 nm wide anisotropy-free strip at one end of the strip, where magnetization stabilizes in-plane. Efficiency is determined as the ratio of the spin-wave amplitude in the strip, oscillating at the driving frequency f_0, to the generated spin waves in the stripe at $2f_0$. Higher excitation fields enhance efficiency, reaching up to 42%. Tuning B_0 enables precise control over the generated frequencies, with $2f_0$ = 14.27 GHz at 145 mT and increasing to 17.20 GHz at 360 mT. We show that this highly efficient process of 2nd-harmonic generation is driven by exchange interactions at the interface between the in-plane and out-of-plane magnetized regions. This shows that under a homogeneous out-of-plane polarised microwave magnetic field, spin waves can be excited in regions of non-uniform magnetisation and transferred to the propagating waves at integer multiples of the fundamental frequency. This nonlinear magnonic effect may be useful for applications such as synchronisation or neural computing.We demonstrate that under a homogeneous microwave magnetic field polarized out-of-plane, spin waves can be excited in regions of non-uniform magnetization and transferred into the waveguide as propagating waves at integral multiples of the base frequency, as illustrated in Fig. 1.

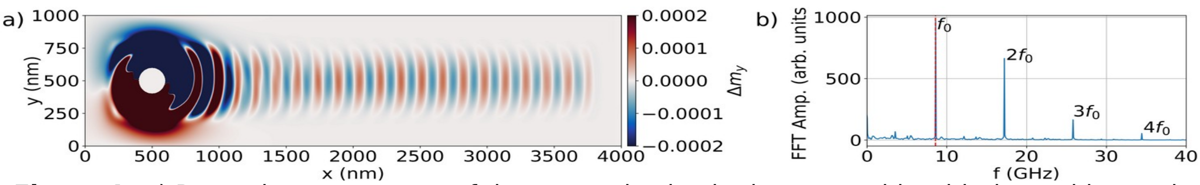

Figure 1: a) Dynamic y component of the magnetization in the waveguide with the antidot on the left and the propagating spin waves on the right (f_0 = 7.13 GHz at 145 mT). b) Fourier transform of the my magnetization in the strip over time.

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References

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