

# Generation of Second-Harmonic Propagating Spin Waves in Out-of-Plane-Magnetized Ferromagnetic Film

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Spin waves are attractive information carriers due to their gigahertz-to-terahertz frequencies, nanometer-scale wavelengths, negligible Joule heating, and nonlinearity related to magnetization dynamics. However, exciting short-wavelength, high-frequency spin waves locally and exploiting nonlinear effects at these frequencies remains challenging. To overcome these limitations, we propose the use of a thin ferromagnetic film with strong perpendicular magnetic anisotropy containing an in-plane magnetized nanosized area (a magnonic nanocavity), which is exchange-coupled to an out-of-plane magnetized film or stripe [1, 2]. Micromagnetic simulations demonstrate that a spatially uniform, out-of-plane microwave magnetic field excites only the nanocavity's fundamental mode. Due to the nanocavity's confinement and nonuniform magnetization texture, the second harmonic is effectively generated and coherently launched into the extended part of the ferromagnet, yielding propagating spin waves. This process can be achieved with stripe or extended film geometries, which excite plane waves or radial spin waves, respectively. Because degrading the anisotropy of a ferromagnetic layer with perpendicular magnetic anisotropy is a simple fabrication process, e.g., using a focused ion beam, the spin-wave wavefront can be extensively shaped by adjusting the nanocavity geometry. The emission frequency can be tuned via the bias magnetic field or the nanocavity width, which can enhance the second-harmonic generation process when resonant conditions are met. These findings suggest a compact route toward on-chip, short-wavelength, high-frequency nonlinear spin-wave sources for artificial neural networks.

## References:

- [1] M. Moalic, et al., arXiv:2509.07705v1 (2025)
- [2] M. Moalic, et al. Sci. Rep. 14 (2024) 11501

*The study has received financial support from the National Science Centre of Poland, Grant No. UMO2020/37/B/ST3/03936. The simulations were partially performed at the Poznan Supercomputing and Networking Center (Grant No. PL0095-01).*