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Dynamics of softened spin waves in thin films with perpendicular anisotropy at temporal interfaces

K. Sobucki,[a] N. Leśniewski,[b,a] and P. Gruszecki[a]
a: Adam Mickiewicz University, Poznań, Poland;
b: CNRS, Lab-STICC, UMR 6285, ENIB, Brest, France;

Perpendicular Magnetic Anisotropy (PMA) in thin ferromagnetic films at low magnetic fields can allow the formation of magnetic domain patterns with magnetization directed perpendicular to the surface. Examples of such domain structures are aligned stripe domain patterns with well-defined periodicity in the range of 100 nm. The presence of PMA not only modifies the magnetic configuration of the system, but also significantly affects the dynamics of the spin waves, i.e., the propagating collective precessional disturbances of the magnetic configuration. This effect on the spin waves is not only due to the PMA-induced inhomogeneity of the magnetitic texture, but also to the effect of PMA itself on the precession of the magnetic moments, which leads to surprising consequences that will be discussed in this paper. The effect of PMA on the dispersion is the most prominent for low fields near the phase transition to the strip domain pattern (see exemplary dispersion Fig. 1(left)) which leads to new effects that will be demonstrated. Then, after introducing Dzyaloshinskii-Moriya interaction into the system to get nonreciprocal dispersion, we will exploit the close connection between magnetic texture for fields below the critical field and softened spin wave modes in a uniformly magnetized system, leading to spin wave freezing[1]. Using step and gradient time interfaces by corresponding modulation of the bias magnetic field in time, we will demonstrate the reflection and refraction of the spin wave at temporal interfaces, the formation of space-time periodic magnetization patterns, and a new mechanism for spin wave amplification (e.g. see Fig. 1(right)). These effects may be useful in magnonic systems designed for neuromorphic computing.

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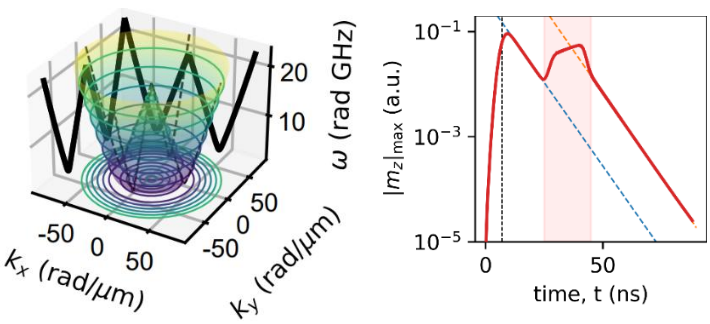

Fig. 1. (left) Dispersion relation of spin waves in 2-nm-thick Co film with reduced anisotropy constant $Q = 1.3$. The system is uniformly magnetized by the in-plane applied bias magnetic field of value 220 mT. (right) Time dependence of the spin wave amplitude in a 2-nm-thick Co layer with a damping constant of $\alpha = 0.002$. The wave packet of SWs is excited at $t \approx 7$ ns (black dashed vertical line), and amplification by temporal interfaces is obtained by modulating the value of the bias magnetic field for a time of about 20 ns. More than 22-fold amplification of the spin-wave amplitude is achieved.

[1] J. Kisielewski, P. Gruszecki, M. Krawczyk, V. Zablotskii, and A. Maziewski. *Between waves and patterns: freezing spin waves in films with Dzyaloshinskii-Moriya interaction*. Physical Revew B 107, 134416 (2023).