Disentangling electric field effect on spin waves in ferromagnetic insulators

Vittorio Basso[1], Patrizio Ansalone[1], Adriano Di Pietro [1,2]

[1] *Istituto Nazionale di Ricerca Metrologica, Strada delle Cacce 91, 10135 Torino, Italy*

[2] *Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy*

The effect of an electric field on ferromagnets is currently an active topic of research because of the possibility to tune the phase of the magnetostatic spin waves [1] or to induce an additional, voltage-induced, anisotropy in magnetic memory elements [2]. By focusing on thin films made of ferromagnetic insulators, the effect of the electric field on the magnetization of the ferromagnet is twofold. The first effect is of relativistic nature and is due to the fact that the transport of magnetic moment in an electric field has an associated electromagnetic momentum $-(1/c^2)\mathbf{E} \times \boldsymbol{\mu}$ where c is the speed of light, $\mathbf{E}$ is the electric field and $\boldsymbol{\mu}$ is the transported magnetic moment. Like in the Ahronov-Casher effect [3] the spin wave acquires an additional phase which shifts the dispersion relation of $\gamma_L E/c^2$ where γ_L is the gyromagnetic ratio [4]. The second effect is associated to the energy terms emerging from the broken inversion symmetry caused by the electric field on the magnetic crystal [5]. It can be described by a DMI type energy term, with coefficient D (proportional to the electric field) plus an additional hard axis anisotropy along the direction of the electric field with coefficient D^2 [6]. Even if the spin wave dispersion relations with DMI are well known [7], to describe the spin waves in ferromagnetic insulators under electric field we have to consider both effects. In this paper we present the results of such a calculation for the surface magnetostatic waves. With respect to the standard calculations we have additionally considered: the role played by the metallic electrodes as boundary conditions for the magnetostatic field, the shift associated to the relativistic effect of the electromagnetic momentum and the additional anisotropy term. The results are compared with the experimental result of the magnetic field and electric field dependence of the phase acquired by magnetostatic spin waves on YIG thin films [1].

References

[1] X. Zhang et al. *Electric-field coupling to spin waves in a centrosymmetric ferrite*, Phys. Rev. Lett., 113, 037202 (2014).

[2] P. Khalili Amiri et al., *Electric-field-controlled magnetoelectric RAM: Progress, challenges, and scaling* IEEE Trans. Magn. 51, 3401507 (2015).

[3] Y. Aharonov and A. Casher, *Topological quantum effects for neutral particles*, Phys. Rev. Lett., 53, 319 (1984).

[4] V. Basso and P. Ansalone, *Electric field effect on spin waves: Role of magnetic moment current*, EPL 130, 17008 (2020).

[5] D. Mills and I. Dzyaloshinskii, *Influence of electric fields on spin waves in simple ferromagnets: Role of the flexoelectric interaction*, Phys. Rev. B 78, 184422 (2008);

[6] A. Di Pietro et al. *Gauge theory applied to magnetic lattices*, EPL 140, 46003 (2022)

[7] J. H. Moon et al. *Spin-wave propagation in the presence of interfacial Dzyaloshinskii-Moriya interaction*, Phys. Rev. B 88, 184404 (2013).