Dispersion of spin magnetostatic surface waves in a medium with damping

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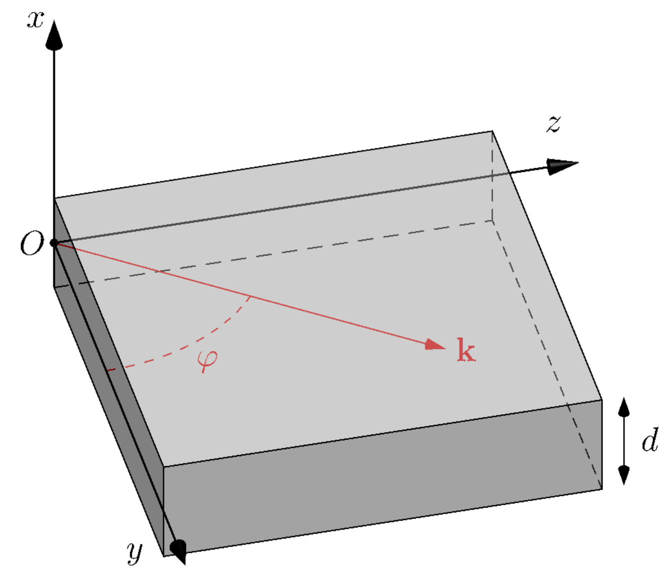
Introduction

Magnetostatic surface waves (MSSW) propagating in magnetic thin films are the basis for the construction of various microwave devices for analog and digital data processing, information transfer and control of GHz and THz dynamics. Minimization of wave losses is a prerequisite for its correct work, however the MSSW damping is understudied as the vast majority of research is performed without consider attenuation. Though, the damping may dramatically change the dispersion law. In particular, it limits the maximum value of the wave number, which results in increasing the minimum value of the signal delay time.
Therefore, the aim of this research is to study the impact of the damping effect on the dispersion of MSSW in general case when wave is transferred at arbitrary directions with respect to the permanent external magnetic field.

The modelling scheme

An unbounded ferrite film of thickness d is magnetized to saturation $4\pi\mathbf{M}$ by the DC field $\mathbf{H}$. The Cartesian coordinates $Oxyz$ are chosen so as the origin is at the middle of the slab thickness. The Oyz plane is parallel to the film plane and the axis Ox is perpendicular to latter. The Oz axis is oriented along the field $\mathbf{H}$. The wave vector $\mathbf{k}$ lies on the Oyz plane and is tilted by the angle φ with respect to the axis Oy.



It is assumed that the medium is homogeneous and isotropic. Waves are generated by a source with a predetermined frequency ω. Thus, the wave amplitude can only be reduced if the wave number is the complex value: $k = \eta - i\xi$.

Main equations

The dispersion equation for MSSW:

$$(\beta - 1)\tanh(kd\vartheta) - 2\mu\vartheta = 0. \qquad (1)$$

The equation (1) has been obtained by solving the LLG equation with the boundary conditions. The magnetic permeability of the medium:

$$\mu = 1 + \frac{\Omega_H + i\alpha\Omega}{\Omega_H^2 - (1+\alpha^2)\Omega^2 + i2\alpha\Omega\Omega_H}, \qquad (2)$$

The ancillary quantities ϑ and β are expressed by formulae

$$\vartheta = \sqrt{\cos^2\varphi - \frac{\sin^2\varphi}{\mu}}, \qquad \beta = (\nu^2 - \mu^2 + \mu)\cos^2\varphi - \mu, \qquad (3)$$

where ν is the magnetic susceptibility of the medium:

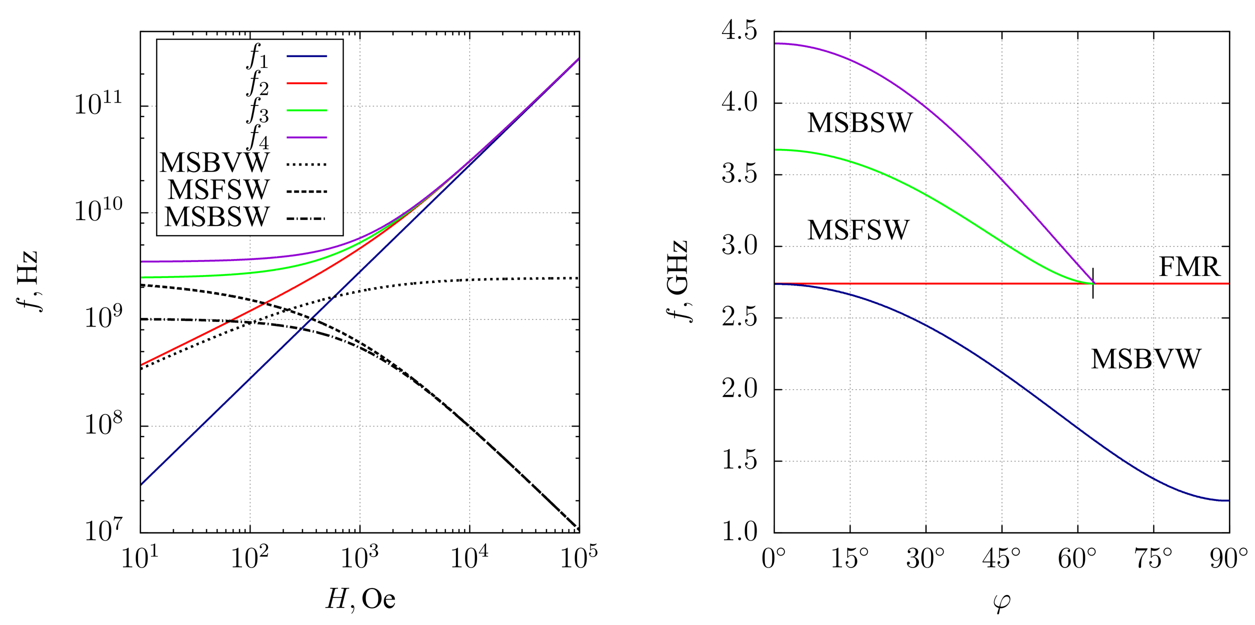
$$\nu = \frac{\Omega}{\Omega_H^2 - (1+\alpha^2)\Omega^2 + i2\alpha\Omega\Omega_H}. \qquad (4)$$

The quantities Ω and Ω_H given in equations (2) and (4) are the normalized wave frequency and the magnetic field respectively:

$$\Omega = \frac{\omega}{4\pi\gamma M}, \qquad \Omega_H = \frac{H}{4\pi M}, \qquad (5)$$

where γ is the gyromagnetic ratio.

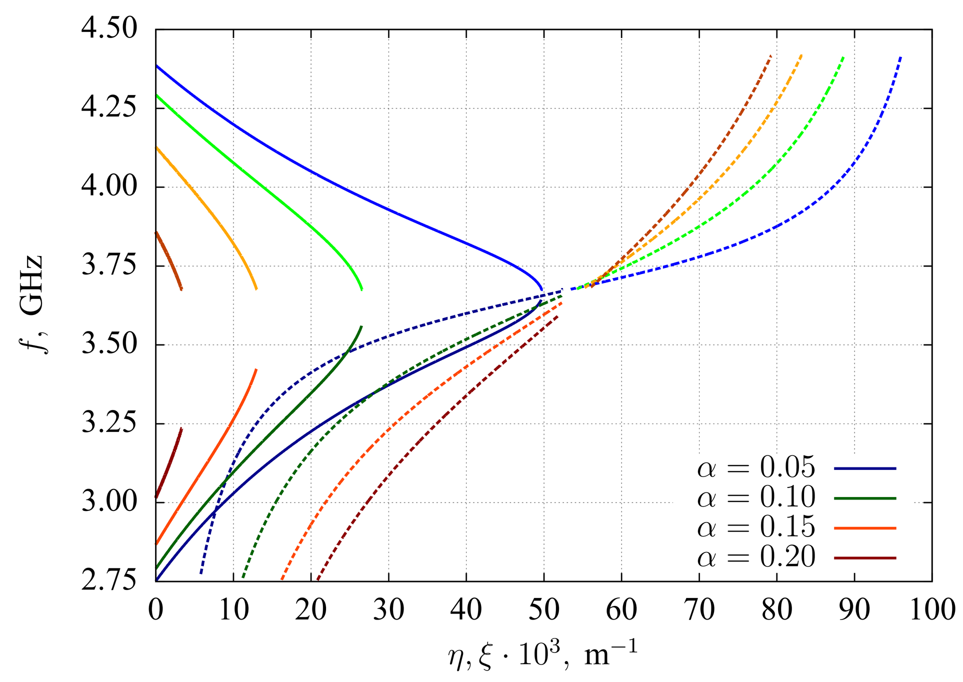
Frequency spectrum



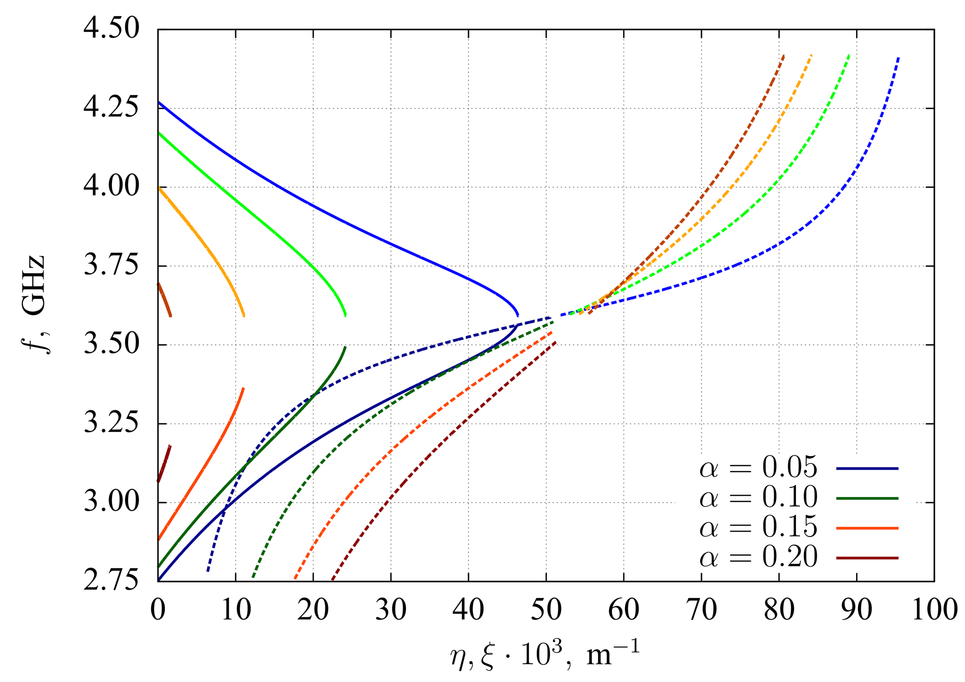
This figures are represents the field and angular dependencies of MSBVW ($f_1 \leqslant f \leqslant f_2$), MSFSW ($f_2 \leqslant f \leqslant f_3$) and MSBSW ($f_3 \leqslant f \leqslant f_4$) boundary frequencies in case $\alpha = 0$. $4\pi M = 1750$ Gs, $\gamma = 1.76\cdot 10^7$ rad/(s · Gs), $H = 437.5$ Oe.

Dispersion curves

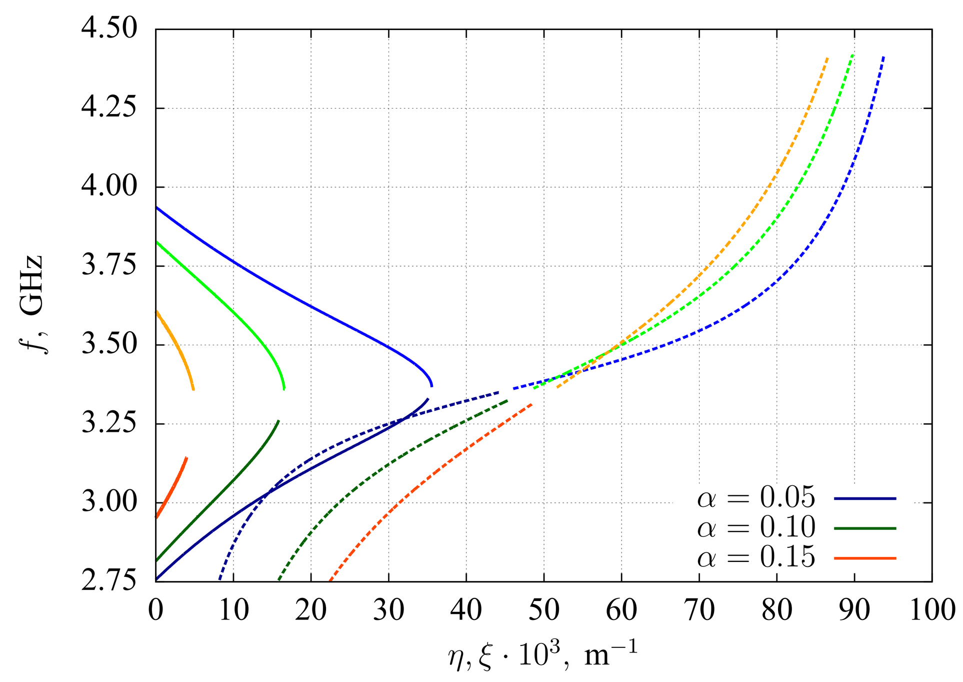
This figures demonstrates the assemblage of dispersion curves obtained by the numerical solution of equation (1). A set of solid curves represents the dependence of the wave frequency from the real part of the wave number $f(\eta)$; the family of dashed curves displays the dependence of the frequency from the imaginary part of the wave number $f(\xi)$. Each of the four lines in the set is constructed for different values of the damping parameter α.



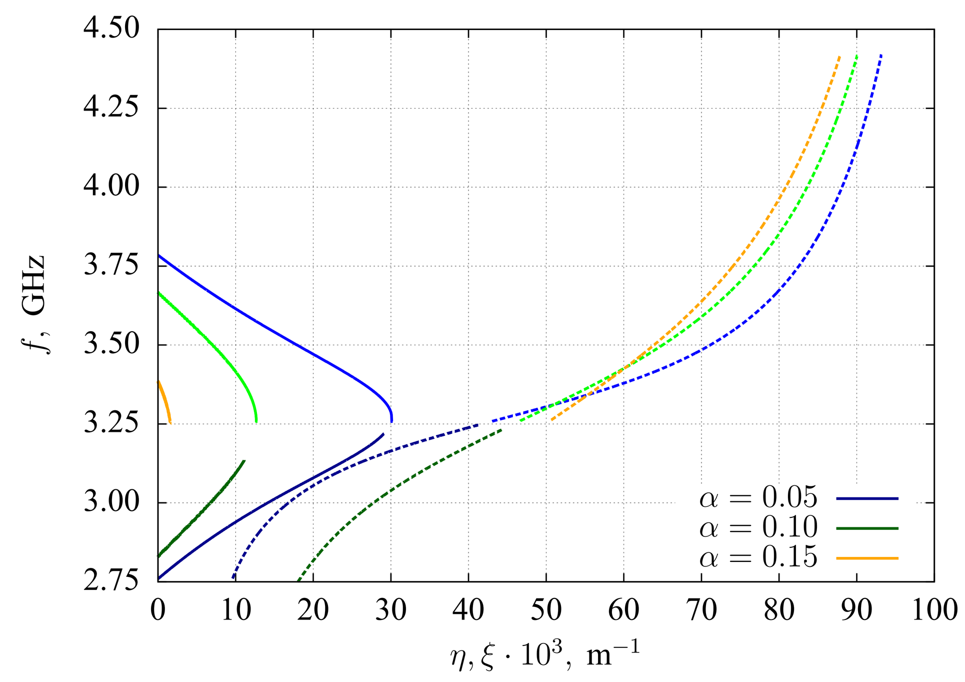
$\varphi = 0°$



$\varphi = 15°$



$\varphi = 30°$



$\varphi = 35°$

$4\pi M = 1750$ Gs, $\gamma = 1.76\cdot 10^7$ rad/(s · Gs), $H = 437.5$ Oe, $d = 15$ mkm.

Conclusion

In this study dispersion relation for the wave number of magnetostatic surface spin waves was obtained. It was shown that dispersion curves are limited both by the wave number and frequency, and these restrictions tighten with an increase in the damping parameter and angle.
The frequency spectrum dependence on the magnitude of the constant magnetic field and the direction of the wave vector of surface (MSSW) and backward volume (MSBVW) magnetostatic waves is analyzed.
A new branch of the magnetostatic backward surface waves (MSBSW) was discovered. Between the MSFSW and MSBSW branches of the dispersion curves $f(\eta)$ there is a bandgap of width Δf that is the increasing function of the damping coefficient. Therewith, the frequency range of MSFSW and MSBSW significantly narrows with the increase of α. Furthermore, there is a limitation to the maximum of η for a given α.
MSSW are characterised by existence of a critical value of the damping parameter and propagation angle, beyond which it does not exist. With the increase of the angle φ, limitation of dispersion curves tightens, the branches of the dispersion curves are shifted towards lower wave numbers and the damping parameter limits them from below and above.

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