FILTRATION OF SPIN WAVE SIGNALS AT TRANSMISSION OF DATA THROUGH A FERROMAGNETIC MEDIUM

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ABSTRACT

In this paper, we calculate the dependencies of spin wave reflection intensity on frequency and external magnetic field for a ferrogarnet structure in an exchange mode, for which the influence of the magnetostatic part of the energy is neglected as compared with the exchange part. A ferrogarnet structure is chosen because it has a very small damping parameter and provides high-quality transmission of data.

Keywords: Spin wave, Filtration of spin-wave signal, Ferromagnetic medium

1 INTRODUCTION

Spin waves are the super-high-frequency carriers of information in magnetic media. It is possible to use ferromagnetic materials as a conduit for spin wave propagation, where the information can be coded into the amplitude of the spin wave. Because of this property, the devices of spin-wave microelectronics and nanoelectronics have high potential for data exchange in magnetic media. Here we point out the possibilities of a filtration spin-wave signal. In the present work we calculate the intensity of a reflected spin wave and investigate wave behavior at the interface between two homogenous ferromagnetics.

2 BASIC EQUATIONS

Consider two half-infinite ferromagnetics with magnetizations of saturation M_{01}, M_{02}, parameters of exchange interaction α_1, α_2, and uniaxial anisotropy β_1, β_2, in contact along the yz plane. The material is placed in an external uniform permanent magnetic field H_0, directed along the easy axis and z axis of the coordinate system. For a material that consists of two homogeneous parts with the interface plane of *yz*, the energy density can be written as:

$$w = \sum_{j=1}^{2}\theta\left[(-1)^j x\right]w_j + A\delta(x)\mathbf{M}_1\mathbf{M}_2 , \tag{1}$$

where $w_j = \frac{\alpha_j}{2}\left(\frac{\partial m_j}{\partial x_k}\right)^2 + \frac{\beta_j}{2}\left(m_{jx}^2 + m_{jy}^2\right) - H_0 M_{jz}$ (j=1,2), (2)

A is the parameter characterizing the coupling interaction between homogenous parts, $\theta(x)$ is the Heaviside step function, $\mathbf{m}_j$ - unit vectors, along the magnetizations, $\mathbf{M}_j(\mathbf{r},t) = M_{0j}\mathbf{m}_j$. Further, we use the spin density formalism (Bar'yakhtar & Gorobets, 1988). Thus, the Lagrange equations have the form:

$$i\eta\frac{\partial\Psi_j(\mathbf{r},t)}{\partial t} = -\mu_0\mathbf{H}_{ej}(\mathbf{r},t)\,\sigma\Psi_j(\mathbf{r},t) , \tag{3}$$

where Ψ_j are quasi-classical wave functions playing the role of the order parameter of the spin density; $\mathbf{r}$ is the radius-vector of the Cartesian coordinate system; t is time, and $\boldsymbol{\sigma}$ the Pauli matrices, μ_0 the Bohr magneton, η the Plank constant, and $\mathbf{H}_{ej} = -\frac{\partial w_j}{\partial \mathbf{M}_j} + \frac{\partial}{\partial x_k}\frac{\partial w_j}{\partial\left(\partial \mathbf{M}_j / \partial x_k\right)}$. Then, using linear perturbation theory, the solution of Eq.(3) can be written as following (Gorobets , Zyubanov, Kuchko, & Shejuri, 1992):

$$\Psi_j(\mathbf{r},t) = \exp\left(i\,\mu_0 H_0 t/\eta\right)\cdot\begin{pmatrix}1\\ \chi_j(\mathbf{r},t)\end{pmatrix}, \qquad (4)$$

where $\chi_j(\mathbf{r},t)$ is a small function characterizing the deviation of magnetization from the ground state. Linearizing Eq.(3) and taking into account Eq.(2), we obtain:

$$\frac{i\eta}{2M_{0j}\mu_0}\frac{\partial}{\partial t}\chi_j(\mathbf{r},t) = \left[\tilde{H}_{oj} - \alpha_j\Delta + \beta_j\right]\chi_j(\mathbf{r},t), \qquad (5)$$

where $\tilde{H}_{0j} = H_0/M_{0j}$.

3 REFRACTION OF SPIN WAVES FROM THE INTERFACE BETWEEN TWO HOMOGENEOUS MEDIA

It is important to estimate the intensity of reflection and transmitted spin waves for using ferrogarnet structure as a high-sensitivity filter. We find the expressions for these intensities using boundary conditions, which follow from Eq. (1,2):

$$\begin{aligned}&\left[A\gamma(\chi_2-\chi_1)+\alpha_1\chi_1'\right]_{x=0} = 0,\\ &\left[A(\chi_2-\chi_1)+\gamma\alpha_2\chi_2'\right]_{x=0} = 0,\end{aligned} \qquad (6)$$

where $\gamma = M_{02}/M_{01}$.

We associate the functions $\chi_{fall} = \exp(i\mathbf{k}_1\mathbf{r})$, $\chi_{ref} = \mathrm{Re}\,xp(-i\mathbf{k}_1\mathbf{r})$, $\chi_{trans} = D\exp(i\mathbf{k}_2\mathbf{r})$ to the falling, reflected, and transmitted waves. Here *R* is the complex reflection amplitude, and *D* is the transmitted amplitude. The modulus of wave vectors $\mathbf{k}_j$ are determined by the expression $k_j^2 = \left(\Omega_j - \beta_j - \tilde{H}_{oj}\right)/\alpha_j$, where $\Omega_j = \omega\eta/2\mu_0 M_{0j}$, $\mathbf{k}_\perp = (0, k_y, k_z)$, ω - wave frequency.

Therefore:

$$R = \frac{k_1\alpha_1\alpha_2\gamma\cos\theta\cdot\sqrt{n^2-\sin^2\theta} - iA\left(\alpha_1\cos\theta - \alpha_2\gamma^2\sqrt{n^2-\sin^2\theta}\right)}{k_1\alpha_1\alpha_2\gamma\cos\theta\cdot\sqrt{n^2-\sin^2\theta} - iA\left(\alpha_1\cos\theta + \alpha_2\gamma^2\sqrt{n^2-\sin^2\theta}\right)}, \qquad (7)$$

$$D = \frac{-2Ai\alpha_1\cos\theta}{k_1\alpha_1\alpha_2\gamma\cos\theta\cdot\sqrt{n^2-\sin^2\theta} - iA\left(\alpha_1\cos\theta + \alpha_2\gamma^2\sqrt{n^2-\sin^2\theta}\right)}, \qquad (8)$$

where n is refractive index $n = \dfrac{k_2}{k_1}$ (Reshetnyak, 2004), and θ is the angle of incidence.

4 RESULTS

The intensity of reflected waves is defined as the ratio of flux densities of reflected waves to flux density of incident waves (Kravtsov & Orlov, 1980) and defined by $I_R = |R|^2$. As shown in Figure 1, there is a very narrow region of frequencies where the reflection coefficient changes its value practically from zero to one. Such a resonance value of the frequency can be changed by means of applying an external homogeneous permanent magnetic field. Therefore, the proposed system can carry out the role of a high-sensitive filter at a wide range of frequencies without changing the parameters of the medium. Moreover, as can be seen from Figure 2, the reflected intensity substantially depends on the strength of the external homogenous magnetic field. The intensity of a reflected wave can be controlled over a wide range by varying the strength of the external magnetic field for the constant materials parameters.

The reflection capacity of a structure involved not only has a strong dependence on the frequency and external field but also is determined mainly by the value of parameter *A*, which effect is pronounced especially strongly at small values of *A*, as shown in Figure 3.

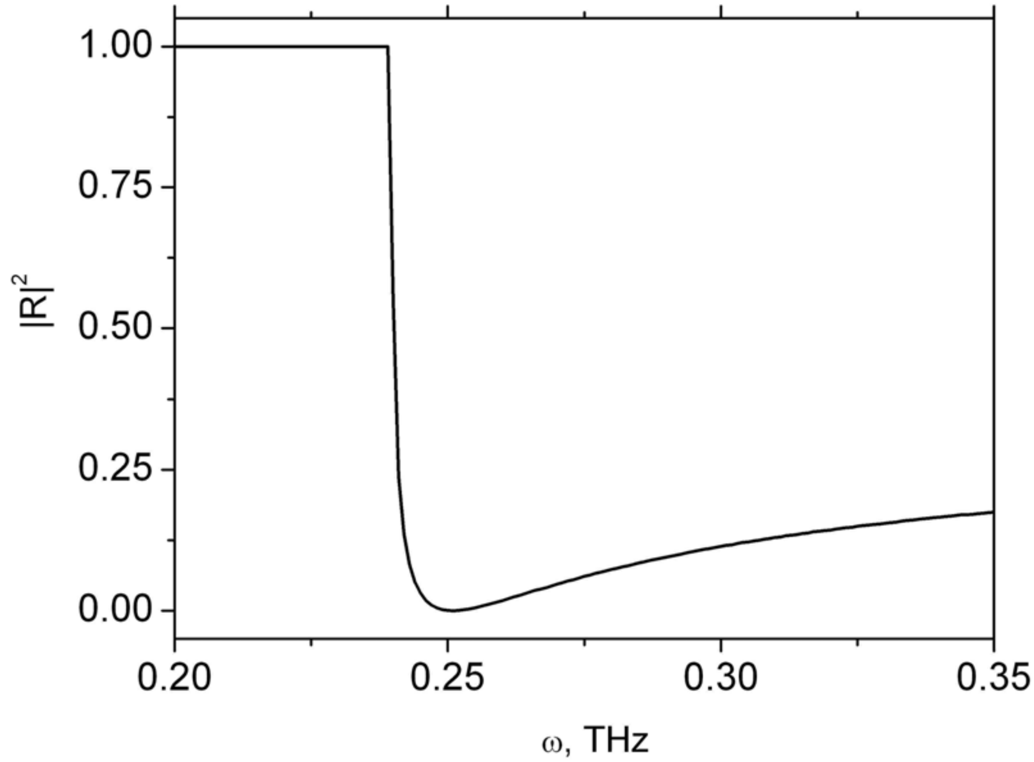

Figure 1. Variation reflection intensity with wave frequency at $\alpha_2/\alpha_1 = 5$, $\beta_1 = 40$, $\beta_2 = 90$, $H_0 = 2{,}3$ kOe, $M_{01} = 90$ Gs, $M_{02} = 125$ Gs, $A = 10$ mm, $\theta = \pi/80$.

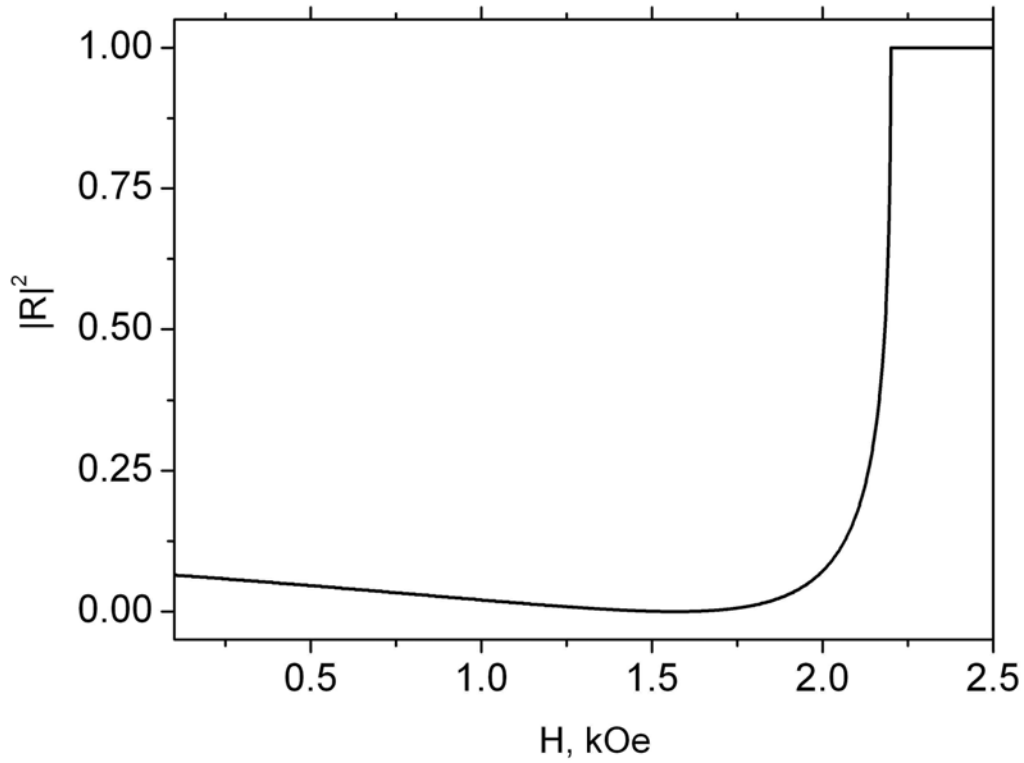

Figure 2. Variation reflection intensity with external magnetic field at $\alpha_2/\alpha_1 = 5$, $\beta_1 = 40$, $\beta_2 = 90$, $\omega = 0{,}238$ THz, $M_{01} = 90$ Gs, $M_{02} = 125$ Gs, $A = 10$ mm, $\theta = \pi/80$.

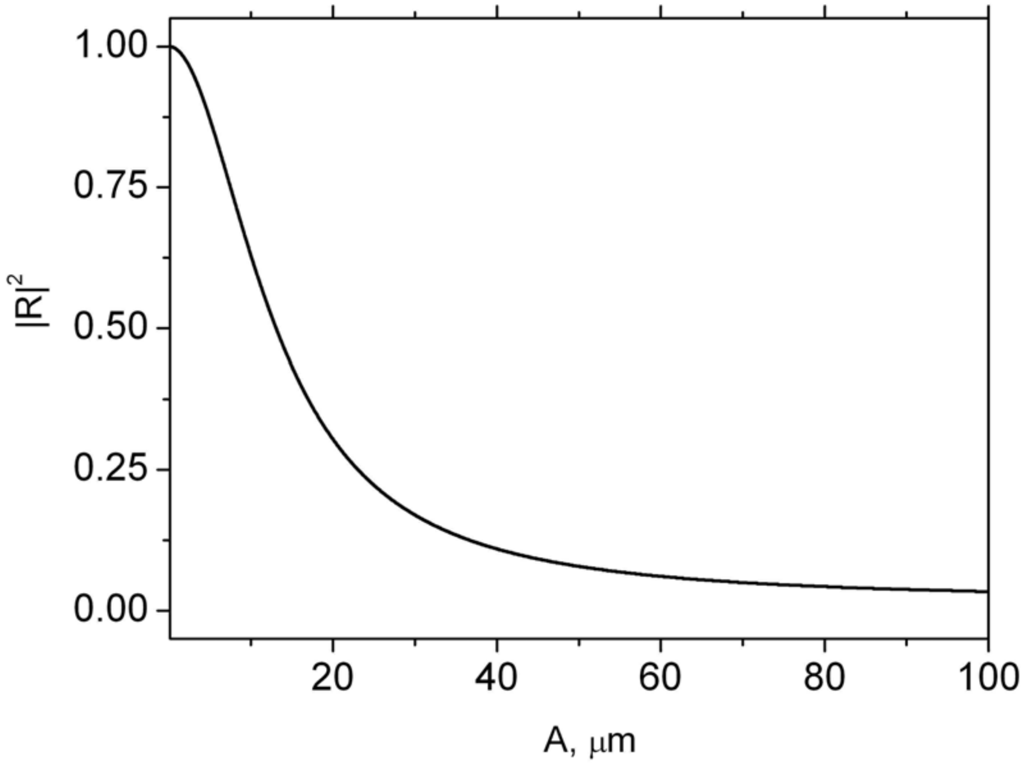

Figure 3. Variation reflection intensity with the parameter A , characterizing the coupling interaction at $\alpha_2/\alpha_1 = 5$, $\beta_1 = 40$, $\beta_2 = 90$, $\omega = 0{,}238$ THz, $M_{01} = 90$ Gs, $M_{02} = 125$ Gs, $H_0 = 2{,}3$ kOe, $\theta = \pi/80$.

5 CONCLUSION

Thus, we propose to use a chip of two homogeneous ferromagnetic media having different parameters of uniaxial magnetic anisotropy, exchange interaction, and saturation magnetization as a high-sensitive filter of spin-wave excitations. This approach is possible because of the revealed specific frequency dependence of reflection coefficient of spin waves when they fall on the interface of such media. Consequently, the proposed system can fulfill the role of a high-sensitive wide-range resonance filter of spin-wave signal at transmission of data in ferromagnetic media.

6 REFERENCES

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