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Bulk Spin-Wave Filtration at the Interface of Two Uniaxial Ferromagnetic Media

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In this paper the dependencies are obtained of spin wave reflection coefficients on frequency and external magnetic field for ferromagnetic structure in the exchange mode, when the influence of magnetostatic part of energy is neglected as compared with exchange one. It is shown that ferrogarnet structure, having very small damping parameter, is good for high-quality filtration of spin waves because it gives large change of reflection coefficient in small intervals of frequencies and external magnetic fields.

Keywords: Spin wave, Filtration, Ferromagnetic medium, Magnetic field, Anisotropy.

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1. INTRODUCTION

Spin waves are the 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. Due to this property, the devices of spin-wave microelectronics and nanoelectronics are very perspective for data exchange in magnetic media. In the present work we point out the opportunity of filtration of spin-wave signal. We calculate intensity of 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, contacting along yz plane. The material is placed in external uniform permanent magnetic field H_0, directed along easy axis, and z axis of coordinate system.

For a material that consists of two homogeneous parts with interface plane of yz the density of energy can be written as [1]

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

where

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

A is the parameter characterizing the coupling interaction between homogenous parts, $\theta(x)$ is the Heaviside step function, $\mathbf{m}_j$ is the small deviations of magnetization from a ground state, $\mathbf{M}_j(\mathbf{r}, t) = M_{0j}\mathbf{e}_z + \mathbf{m}_j$. It is supposed, that $M_j^2 = const$.

Further, we will use the spin density formalism [1]. Thus, the Lagrange equations will have the form:

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

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 the time, and $\boldsymbol{\sigma}$ are Pauli matrices, μ_0 is the Bohr magneton, $\hbar$ is Plank constant,

$$\mathbf{H}_{ej} = -\frac{\partial w_j}{\partial \mathbf{M}_j} + \frac{\partial}{\partial x_k}\frac{\partial w_j}{\partial\left(\partial \mathbf{M}_j / \partial x_k\right)}\,.$$

Then, using the linear perturbation theory, the solution of Eq.(3) can be written as following [2]:

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

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

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

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

3. REFLECTION OF SPIN WAVES FROM THE INTERFACE BETWEEN TWO HOMOGENEOUS MEDIA

It is important to estimate the intensity of reflected and transmitted spin waves for using ferrogarnet structure as the high-sensitive filter. We will receive expressions for these intensities by means of boundary conditions, which follow from Eqs.(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 $\gamma = M_{02}/M_{02}$.

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We associate the functions $\chi_{fall} = \exp(i\mathbf{k}_1\mathbf{r})$, $\chi_{ref} = R\exp(-i\mathbf{k}_1\mathbf{r})$, $\chi_{trans} = D\exp(i\mathbf{k}_2\mathbf{r})$ to the incident, reflected, and transmitted waves correspondingly. Here R is the complex reflection amplitude, D is the transmitted amplitude. Modules 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 $\Omega_j = \omega\hbar/2\mu_0 M_{0j}$, ω is wave frequency.

Therefore

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

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

where n is refractive index $n = k_1/k_2$ [3], θ is angle of incidence.

4. RESULTS

Intensity of reflected wave is defined as ratio of flux density of reflected to flux density of incident wave [4] and defined by $I_R = |R|^2$. As shown in Fig. 1, for the parameters characteristic for ferrogarnets, there is a very narrow region of frequencies, where the reflection coefficient changes its value practically from zero to one. And such resonance value of the frequency can be changed by means of applying external homogeneous permanent magnetic field. Therefore, the proposed system can carry out the role of high-sensitive filter at wide diapason of frequencies without change of the parameters of medium. Moreover, as can be seen from Fig. 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 of the strength of the external magnetic field for the constant material's parameters.

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

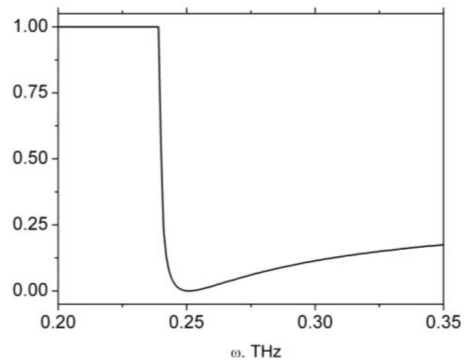

Fig. 1 – Variation of reflection intensity with wave frequency at $\alpha_1/\alpha_2 = 1{,}25$, $\beta_1 = 40$, $\beta_1 = 90$, $H_0 = 2{,}3$ kOe, $M_{01} = 90$ G, $M_{02} = 125$ G, $A = 10$ mm, $\theta = \pi/80$

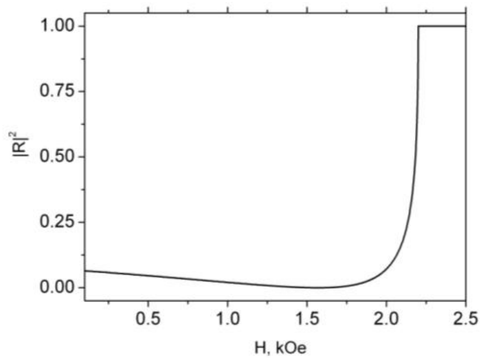

Fig. 2 – Variation of reflection intensity with external magnetic field at $\alpha_1/\alpha_2 = 1{,}25$, $\beta_1 = 40$, $\beta_1 = 90$, $H_0 = 2{,}3$ kOe, $\omega = 0{,}235$ THz, $M_{01} = 90$ G, $M_{02} = 125$ G, $A = 10$ mm, $\theta = \pi/80$

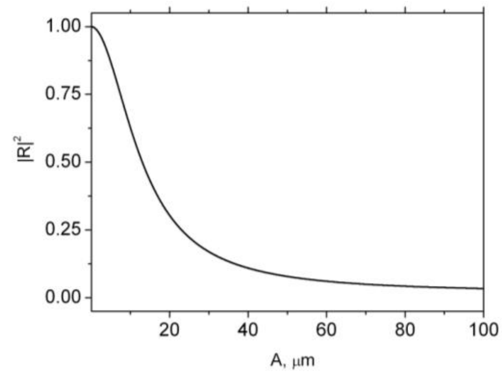

Fig. 3 – Variation of reflection intensity with the parameter A, characterizing the coupling interaction at $\alpha_1/\alpha_2 = 1{,}25$, $\beta_1 = 40$, $\beta_1 = 90$, $H_0 = 2{,}3$ kOe, $\omega = 0{,}238$ THz, $M_{01} = 90$ G, $M_{02} = 125$ G, $A = 10$ mm, $\theta = \pi/80$

5. CONCLUSIONS

Thus, we propose to use the 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. It is possible because of the revealed specific frequency dependence of reflection coefficient of spin waves, when they fall on the interface of such media. So, the proposed system can fulfil the role of high-sensitive wide-range resonance filter of spin-wave signal at transmission of data in ferromagnetic media.

Фильтрация объемных спиновых волн на границе двух одноосных ферромагнитных сред

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В работе получены зависимости коэффициента отражения спиновых волн от частоты и внешнего магнитного поля для ферромагнитной структуры в обменном приближении, когда магнитостатической частью энергии можно пренебречь по сравнению с обменной. Показано, что структура из феррит-граната, имеющая очень малый параметр затухания, дает высококачественную фильтрацию спиновых волн в малых интервалах частот и магнитных полей.

Ключевые слова: спиновая волна, фильтрация, ферромагнитная среда, магнитное поле, анизотропия.

Фильтрація об’ємних спінових хвиль на межі двох одновісних феромагнітних середовищ

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В роботі отримані залежності коефіцієнта відбиття спінових хвиль від частоти та зовнішнього магнітного поля для феромагнітної структури в обмінному наближенні, коли магнітостатичною частиною енергії можна знехтувати у порівнянні з обмінною. Показано, що структура з ферит-гранату, яка має дуже малий параметр згасання, дає високоякісну фільтрацію спінових хвиль в малих інтервалах частот і магнітних полів.

Ключові слова: спінова хвиля, фільтрація, феромагнітне середовище, магнітне поле, анізотропія.

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