Journal of Magnetism and Magnetic Materials 385 (2015) 217–221

Contents lists available at ScienceDirect

Journal of Magnetism and Magnetic Materials

journal homepage: www.elsevier.com/locate/jmmm

Excitation of magnetic inhomogeneities in three-layer ferromagnetic structure with different parameters of the magnetic anisotropy and exchange

E.G. Ekomasov [a,*], R.R. Murtazin [a], V.N. Nazarov [b]

[a] Bashkir State University, 32, Validy Str., Ufa, 450076, Russia
[b] Institute of Molecule and Crystal Physics Ufa Research Centre of Russian Academy of Sciences, Prospekt Oktyabrya 151, Ufa, 450075, Russia

ARTICLE INFO

Article history:
Received 30 October 2014
Received in revised form
5 March 2015
Accepted 5 March 2015
Available online 7 March 2015

Keywords:
Three-layer ferromagnetic
Dynamics of localized magnetic inhomogeneities

ABSTRACT

The generation and evolution of magnetic inhomogeneities, emerging in a thin flat layer with the parameters of the magnetic anisotropy and exchange interaction, with the parameters different from other two thick layers of the three-layer ferromagnetic structure, were investigated. The parameters ranges that determine the possibility of their existence were found. The possibility of the external magnetic field influence on the structure and dynamic properties of localized magnetic inhomogeneities was shown.

© 2015 Elsevier B.V. All rights reserved.

1. Introduction

Multilayer magnetic structures have been widely studied recently in connection with the opportunity of their practical application [1].

Frequently, these are periodically alternating layers of two materials, including nanoscale, with different physical properties.

In studies of the dynamics of magnetic inhomogeneities, propagating in such systems along the layers interfaces, one often uses two-dimensional models (see, e.g., [2,3]). For the case of spin waves and magnetic inhomogeneities, propagating in such systems perpendicular to the layers interfaces, one-dimensional models are often used [4–6].

Note that, frequently, it is the study of one-dimensional models that makes it possible to understand the influence of various magnetic parameters on the process in question (see, e.g., [7–9]).

There are two approaches, used when studying the dynamics of linear and nonlinear waves of magnetization, which propagate perpendicularly to layers. In the first approach, often used to study the dynamics of spin waves, to describe the dynamics of magnetization in a layer, the Landau–Lifschitz equation is used with constant material parameters; in this case the fulfillment of certain boundary conditions is required at the layers interfaces [5]. In the second approach, the presence of layers that differ from each other in values of one or several magnetic parameters is taken into account via the spatial modulation of the magnetic parameters of the material (see, e.g., [4,6,10,11]).

The presence of local and periodic one-dimensional spatial modulation of the magnetic parameters of material (SMMP) influences on the propagation, spectrum, and damping of spin waves, and the high-frequency properties (see, e.g., [5,12]). Under certain conditions, the study of the one-dimensional dynamics of domain walls (DW) leads to the problem (interesting from a mathematical point of view) of finding a solution to an equation of the sine-Gordon type with variable coefficients, which is important for many fields of contemporary physics [13–17].

Due to the complexity of the problem, the researchers considered, as a rule, the modulation of only individual parameters of the magnetic system [18,19]. One often took into account, for example, the magnetic anisotropy modulations for the case of two- and three-layer magnetic, and the problems were studied both with analytical [16,20] and numerical methods [20–22]. There was shown that the presence of a thin layer with the parameters of the magnetic anisotropy, less than in neighboring layers, may lead, for example, to the appearance of the nucleus of a new magnetic phase, to new dynamic effects, such as moving DW reflection from an “attractive potential”. For the case of two-and three-layer magnetic there are works taking into account the modulation of the exchange parameter for both static and dynamic cases [5,7,12,23–25]. For instance, the dynamics of the DW and excitation of magnetic inhomogeneities of different types [4,23,25] was

* Corresponding author.
E-mail address: EkomasovEG@gmail.com (E.G. Ekomasov).

http://dx.doi.org/10.1016/j.jmmm.2015.03.019
0304-8853/© 2015 Elsevier B.V. All rights reserved.

studied in weak magnetic fields. In this paper we investigated the possibility of control by an external magnetic field of structure, parameters and excitation conditions of localized high-amplitude nonlinear magnetic waves of different types in three-layered ferromagnetic.

2. Origin and evolution of one-dimensional magnetic inhomogeneities

Let us consider a three-layer ferromagnetic structure that consists of two thick identical layers separated by a thin layer with a different value of the exchange and anisotropy parameters, which we assume to be functions of the coordinate x oriented perpendicular to the interface between the layers. We will further study the dynamics of a DW lying in the plane yz under the action of an external magnetic field H_z. Usually, when solving dynamic problems, it is suitable to go to spherical coordinates of the magnetization vector $\mathbf{M}(\cos\varphi\sin\theta,\ \sin\varphi,\ \cos\varphi\cos\theta)$, where $0 \le \theta \le 2\pi$ – is the angle in the plane xz between the direction of the vector of the magnetic moment and easy axis (axis Oz); $-\pi/2 < \varphi < \pi/2$ – is the angle that describes the deviation of M from the DW plane. Taking into account in the energy density the exchange interaction $A(x)$, the anisotropy $K_1(x)$, the Zeeman energy, damping, and assuming that the damping parameter$\sigma_0 < < 1$, $\varphi < < 1$, $K_1 < < 2\pi M_s^2$, $H_z < < 4\pi M_s$ [1], one-dimensional equation of motion for the magnetization in the angular variables can be represented in the following dimensionless form [24]:

$$\frac{\partial}{\partial x}\left(A(x)\cdot\frac{\partial\theta}{\partial x}\right) - \frac{\partial^2\theta}{\partial t^2} - \frac{1}{2}K(x)sin2\theta = h\sin\theta + \sigma\frac{\partial\theta}{\partial t} \tag{1}$$

where, $A(\mathrm{x}) = A_1(x)/A_1^0$, $K(\mathrm{x}) = K_1(x)/K_1^0$ are the functions that define the spatial modulation of the exchange interaction parameter and anisotropy constant; A_1^0, K_1^0 are the parameters of exchange and anisotropy in thick layers; $h = H_Z/(4\pi M_S Q)$ – the normalized external magnetic field; and $\sigma = \sigma_0/\sqrt{Q}$ – is the normalized damping constant, where $Q = K_1^0/(2\pi M_S^2)$ – is the quality factor of the material; M_S – is the saturation magnetization of magnetic sublattices. The time t is normalized to $4\pi M_S\gamma\sqrt{Q}$, the coordinate x is normalized to δ_0, (where δ_0 – the width of a static Bloch DW). Note that to fulfill our approximations the presence of the limiting Walker velocity of a DW stationary motion ($V^* = 2\pi\gamma\delta_0 M_S$) and of the limiting DW advancing field ($H^* = 2\pi\sigma M_S$) [1] imposes serious limitations on the selection of the magnitude of the advancing field:

$$H_z \le \frac{\sigma}{2}\pi M_S \tag{2}$$

while investigating the DW dynamics [26]. This restriction is not essential for the study of localized magnetic inhomogeneities.

Eq. (1) with a zero right-hand side and $A(x) = K(x) = 1$ passes into the well-known sine-Gordon equation [13]. At present, the sine-Gordon equation with variable coefficients is studied quite intensively. There is a well-developed perturbation theory for this equation and exact solutions for separate special cases [13,26–28]. However, in the case of arbitrarily changing parameters K and A, numerical methods should be used [24,25].

To further investigate the problem we use the following form of the function $K(x)$ and $A(x)$ – function of Gaussian type [19,25]:

$$K(x) = 1 + (K-1)\cdot\cosh^{-2}(4(x-x_0)/W), \tag{3a}$$

$$A(x) = 1 + (A-1)\cdot\cosh^{-2}(4(x-x_0)/W), \tag{3b}$$

where W – parameter characterizing the width of the defect, x_0 – position of the defect center, $K(x_0)$ – normalized magnetic anisotropy constant at point x_0, A – exchange interaction normalized parameter at point x_0. Next we consider the case of a thin layer with low anisotropy and exchange, which is a potential well for the DW [23].

For the case of a weak magnetic field excitation in the thin layer (or defect) of localized high-amplitude nonlinear magnetic waves of soliton and breather types, we investigated after a domain wall passing through it [21], the magnetization distribution at the initial time was set as 180° Bloch DW – $\theta_0(x) = 2\arctan(e^x)$, located outside of a thin layer. The chosen scheme of numerical experiment for the case of a strong magnetic field is different: at the initial time the domain wall is localized in the center of a thin layer, which is a potential well for the DW.

Eq. (1) was solved numerically using the explicit integration scheme [24]. The discretization of the equation was carried out according to the standard five-point scheme of the “cross” type. The boundary conditions had the following form: $\theta(\pm\infty) = 0, \pi$; $\theta'(\pm\infty) = 0$.. For our calculations, we use a uniform grid with a step ξ in the coordinate x: $\{x_i = \xi\cdot i,\ i = 0, \pm 1, \ldots, \pm N_x\}$, and with a step τ in the time t: $\{t_n = \tau\cdot n,\ n = 0, 1, \ldots, N_t\}$ where N_x, N_t – are the numbers of grid points. By satisfying the convergence condition of the explicit scheme $\tau/\xi \le 0.25$, we calculated the angle θ at the subsequent instants of time. Then, for the domain wall structure, at each instant of time we calculated the main dynamic characteristics of the domain wall.

For different parameter values of $A - 1$, $K - 1$ and W were performed numerical calculations. The value of external magnetic field used $h = 0.35$ – the minimum field at which there will be a breakdown of the DW from a thin layer of $\sigma = 0.01$.

When considering the dynamics of the DW output from the thin layer, similar to the case of weak magnetic fields, it was found that there appear magnetic inhomogeneities in this area. In Fig. 1a we can see, that a high-amplitude localized nonlinear wave appears in a thin layer after the departure of DW (the magnetic inhomogeneities of the first type). Its amplitude is at maximum in the thin layer center. In Fig. 2 (curve 1), for the case considered in Fig. 1a, the dependence of the function $\theta^*(t)$ in the center of the thin layer from time is shown. It can be seen that this function is periodic and varies from θ^*_{max} to $-\theta^*_{max}$. The amplitude of the excited magnetic inhomogeneities of the first type decreases with time, and its oscillations are accompanied by the radiation of the volume spin waves. The damping decrement, resulting from the approximation depending on time, was almost equal to a predetermined one, i.e. the radiation, in this case, is one of the major channels for the magnetic inhomogeneities of the first type energy dissipation.

With the increase of the parameters$(1-A)$, $(1-K)$ and W after the DW leaving, a magnetic inhomogeneity of the second type is excited in the thin layer (Fig. 1b). If the amplitude of the magnetic inhomogeneities of the first type tends to zero with time, the amplitude of the magnetic inhomogeneities of the second type periodically tends to a constant value – θ^* (Fig. 2 curve 2). Note that after the extinction of oscillations the magnetic inhomogeneity of the second type is similar to the zero-degree DW discussed earlier for the static case [29,30]

Fig. 3a shows the dependence of the magnetic inhomogeneities of the first type maximum amplitude (at the initial time) – θ^*_{max} from the parameter W for different values of A. The figure suggests that this dependence is analogous to the case $A = 1$, previously discussed in [22]. With decreasing value W for all considered values of parameter A, θ^*_{max} decreases and tends to zero. Contrary to the dependence on parameter K, an increase of parameter A in comparison with 1 leads to a decrease in the maximum value θ^*_{max}, and the decrease of the parameter A in comparison with 1 leads to an increase in the maximum value θ^*_{max}.

Fig. 3b shows the dependence of W on angle oscillation frequency θ^* – ω_{br} for magnetic inhomogeneities of the first type for

Download English Version:

https://daneshyari.com/en/article/1799143

Download Persian Version:

https://daneshyari.com/article/1799143

Daneshyari.com