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Spin–Wave Resonance as a Way of Studying the Constant of Surface Anisotropy, Using Films of Fe–Ni Alloy as an Example

I. G. Vazhenina[a, b], **L. A. Chekanova**[a], **and R. S. Iskhakov**[a, *]
[a]*Kirensky Institute of Physics, Siberian Branch, Russian Academy of Sciences,*
Krasnoyarsk, 660036 Russia
[b]*Siberian Federal University, Krasnoyarsk, 660041 Russia*
**e-mail: rauf@iph.krasn.ru*

Abstract—The effect the thickness and concentration composition of a ferromagnetic thin film have on surface anisotropy constant K_S is investigated. Spin–wave resonance is chosen as a way of detecting and measuring the K_S value. Fe–Ni thin films are synthesized via chemical deposition. Dependences of K_S on the content of Ni in the alloy and a film's thickness are established.

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INTRODUCTION

The spectrum of spin-wave modes in thin ferromagnetic films depends largely on the conditions of magnetic moment pinning on a film's surface. Much attention is therefore given to creating boundary conditions in films [1–5]. In the last decade, interest in the role of surface anisotropy in the propagation of magnetization waves and physical properties of nanoobjects has once again grown. The anisotropy in thin magnetic films fabricated in the form of multilayers with different spacers has traditionally been of interest [6–8]; in addition, new objects of study have appeared, including magnetic semiconductors [9], nanograined magnetic composites [10], and ferrihydrite nanoparticles [11]. The results from earlier intensive investigations of the effect boundary conditions have on the spin-wave resonance spectrum allow us to formulate the inverse problem of studying the dependences of the surface anisotropy constant on different parameters of a film using the spin-wave resonance (SWR) technique.

EXPERIMENTAL

The shape of excited magnetization oscillations (standing spin waves) is largely due to the boundary conditions on a film's surface. In the Kittel model [1], the magnetic inhomogeneity exciting the magnetic moment self-oscillation spectrum with a uniform RF field is introduced into the boundary conditions on a film's surface. When the boundary conditions are symmetrical relative to the film center, the SWR spectrum is a set of discrete peaks corresponding to the excitation of spin-wave modes with an odd number of half-waves (n = 1, 3, 5, ...).

Khlebopros et al. [3, 12] formulated and solved the problem of the artificial formation of specified boundary conditions on a sample's surface via the deposition of thin ferromagnetic layers with different magnetizations. Asymmetric boundary conditions $\beta^+ = -\beta^- = \beta$ awerere obtained on these structures. A surface mode with $k = i\beta$ and bulk trigonometric modes with $k = n(\pi/d)$ (n = 1, 3, 5 ...) were excited in the SWR spectrum, which is consistent with the Kittel spectrum. Upon deviating from the symmetric (antisymmetric) boundary conditions, low-intensity even modes (n = 2, 4, 6...) can occur.

Wave vectors $\vec{k}$ of the standing spin waves at arbitrary parameters β_1^S and β_2^S of magnetization pinning on the lower and upper film surfaces are determined using equations obtained from the exchange boundary conditions in [13]:

$$\tan(kL) = \frac{(\beta_1^S + \beta_2^S)k}{k^2 - \beta_1^S\beta_2^S}, \text{ if } k \text{ is real and}$$
$$\tanh(k_S L) = \frac{-(\beta_1^S + \beta_2^S)k_S}{k_S^2 + \beta_1^S\beta_2^S}, \text{ if } k = ik_S \text{ is imaginary.} \quad (1)$$

The validity of the boundary conditions (symmetric or antisymmetric) is established from the ratio between parameters β of surface pinning on different film surfaces (β^+ and β^-), determined as

$$\beta = \frac{K_S}{A}, \quad (2)$$

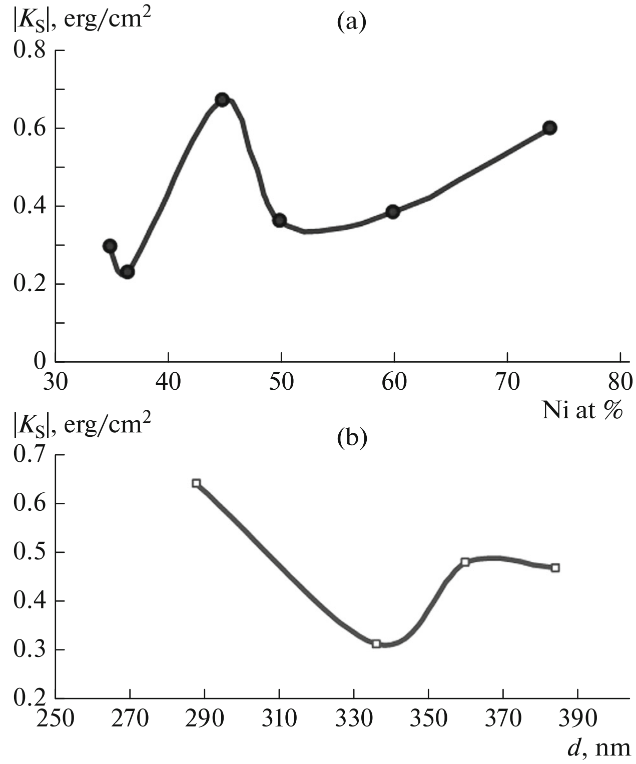

Fig. 1. Dependences of the surface anisotropy constant on (a) Ni content and (b) sample thickness for the Fe–Ni ferromagnetic films.

where A is the exchange coupling constant associated with $\eta = 2A/M_S$.

The case of $\beta > 0$ corresponds to easy-axis anisotropy; that of $\beta < 0$, to easy-plane anisotropy. The symmetric boundary conditions correspond to the equality $\beta^+ = \beta^-$.

Surface spins pinning by the easy-plane anisotropy field ($\beta < 0$) leads to surface mode $k^2 < 0$ appearing in the spectrum; this corresponds to magnetization oscillation damping over the thickness. In the case of thick films with the symmetric boundary conditions, the SWR spectrum can contain two surface modes when $d > 1/|\beta|$ and $\beta < 0$.

In this work, we investigated the effect the thickness of a thin ferromagnetic film and its concentration composition has on K_S using the SWR technique. Our measurements were performed on thin Fe–Ni films synthesized via chemical deposition from a solution of corresponding salts. Two sample series of varying composition and thickness were fabricated. The second sample series was investigated using the $Fe_{25}Ni_{75}$ composition. The synthesis technique allowed us to detect the SWR spectrum in the surface and bulk modes.

The resonance characteristics were measured on a standard ESR spectrometer at a pumping frequency of 9.2 GHz. The films were magnetized both parallel and perpendicular to the sample surface in fields of up to 20 kOe.

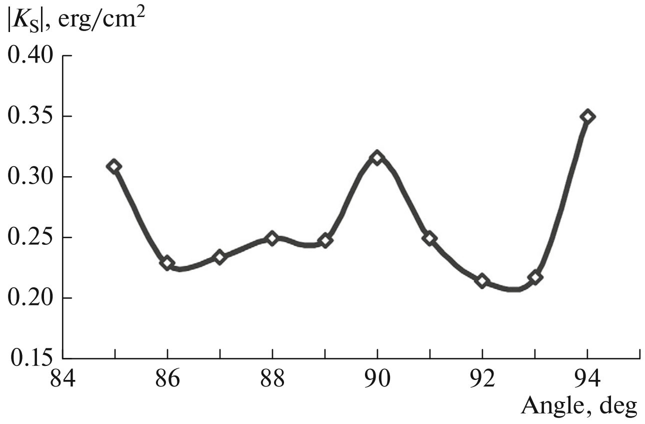

Fig. 2. Dependence of the surface anisotropy constant on the angle of rotation.

RESULTS AND DISCUSSION

The detected SWR spectra of the investigated samples allowed us to determine the exchange coupling constant, which can be calculated using the expression

$$A = M_{\text{eff}}\left(\frac{d}{2\pi}\right)^2 \frac{H_n - H_{n+1}}{(n+1)^2 - n^2}. \qquad (3)$$

This parameter was calculated for long-wavelength values of the wave vector.

In addition, the SWR spectra allowed us to determine the parameter of magnetic moment pinning on the surface. The surface anisotropy constant was described by the expression

$$|K_S| = \sqrt{\frac{1}{2}(H_S - H_1)\,M_{\text{eff}}A}. \qquad (4)$$

Substituting the experimental H_S, H_1, M_{eff}, and A values for the Fe–Ni film system into Eq. (4), we obtain $K_S < 0$, where the absolute K_S value depends on the content of Ni in the film and on the sample thickness. Figure 1 shows the concentration dependences of the uniaxial surface anisotropy constant and the dependence of this parameter on the sample thickness. The obtained $K_S(d)$ dependence agrees with the data reported in [7]. Using one of the samples in the series, we measured angular dependences of K_S (Fig. 2).

CONCLUSIONS

Our synthesis technique yielded film samples with easily identified surface and bulk spin–wave modes in the SWR spectra. The dependences of surface anisotropy constant K_S on the Fe–Ni film thickness and composition, and on the angle of rotation, were established.

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