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Abstract

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PHYSICS

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MEASUREMENT OF THE MAGNETOSTRICTION OF THIN NICKEL FILMS

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The study of the magnetostriction of ferromagnetic films is of both scientific and practical importance. Magnetostriction substantially affects the processes of technical magnetization and is very sensitive to any disturbance in the distribution of the magnetization vectors of domains.

The nature of the remagnetization processes of ferromagnetic specimens that are in a stressed state depends in many respects on the sign and magnitude of the magnetostriction constant. In ferromagnetic films, magnetostriction is one of the causes of internal stresses, which affect anisotropy ⁽¹⁾ and other magnetic characteristics. It is especially important to know the magnetostriction of ferromagnetic films that may be used as memory elements in high-speed computing machines.

In recent years an intensive study of the physical properties of ferromagnetic films has been carried out, but the magnetostriction of films, owing to considerable experimental difficulties, was discussed only in works ^(2,3) and was approximately measured in work ⁽⁴⁾ for a nickel film 3000 Å thick. As the authors of work ⁽⁴⁾ themselves indicate, the value $\lambda_s = 41 \cdot 10^{-6}$ was obtained with an error, a large part of which is introduced because of averaging of the Young's modulus of the mica substrate, whose crystallographic orientation is unknown, and also of the Young's modulus of the film, assumed to be the same as that of massive nickel. Meanwhile, there are works ⁽⁵⁾ indicating a difference between these constants.

In the present article a new method is described, making it possible to measure the magnetostriction of films 200 Å thick and above, and quantitative data are given for the magnetostriction of nickel films 600 Å thick.

Theory of the problem. In Fig. 1a are shown a substrate of thickness h_2 and two identical ferromagnetic films, each of thickness $h_1/2$. It is assumed that the film is not in contact with the substrate, that no external forces act on them, and that there are no internal stresses in them. The films and the substrate have the same length l_0 .

Figure 1

Figure 1: Figure 1

If this system is placed in a magnetic field H_1 , directed along l_0 , then the films, as a result of the phenomenon of magnetostriction, change their length by Δl_1 (Fig. 1b), and in this case no internal stresses arise.

If, however, the films and the substrate have reliable adhesion along their entire length (Fig. 1c), then when they are placed in the same magnetic field H_1 , the whole

Fig. 1. Change in length of ferromagnetic films and the substrate in a magnetic field. $h_1/2$ –film thickness; h_2 –substrate thickness; l_0 –initial length of the films with the substrate; Δl_1 –magnetostrictive change in the length of the films; Δl_0 –effective magnetostrictive change in the length of the entire system; H_1 –external magnetic field directed along l_0 .

the system will change its length by Δl_0 . The films will be stretched by $\Delta l = \Delta l_1 - \Delta l_0$ with the stress

$$\sigma_1 = E_1(\varepsilon_0 - \varepsilon_1), \quad (1)$$

and the substrate compressed by Δl_0 with the stress

$$\sigma_2 = E_2\varepsilon_0, \quad (2)$$

where E_1 is the Young' s modulus of the film; E_2 is the Young' s modulus of the substrate; $\varepsilon_0 = \Delta l_0/l_0$ is the effective relative magnetostrictive change in length of the whole system; $\varepsilon_1 = \Delta l_1/l_0$ is the relative magnetostrictive change of the ferromagnetic films themselves. In this case an equilibrium state will be established, when, according to ^(6,7), the following must hold:

$$\sigma_1 h_1 + \sigma_2 h_2 = 0. \quad (3)$$

Solving the system of equations (1), (2), (3) with respect to ε_0 , we obtained:

$$\varepsilon_0 = \frac{\varepsilon_1}{1 + E_2 h_2 / E_1 h_1}. \quad (4)$$

Equality (4) can be written as:

$$\frac{1}{\varepsilon_0} = \frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_1} \frac{E_2}{E_1 h_1} h_2. \quad (5)$$

If it is taken into account that $E_1, E_2, h_1, \varepsilon_1$ are constant quantities for a group of ferromagnetic films of the same thickness, prepared under identical conditions and differing from one another only in the thickness of the substrates, then equality (5) represents the equation of a straight line which, at $h_2 = 0$, cuts off on the ordinate axis a segment equal to $1/\varepsilon_1$. Thus, ε_1 can be found directly from the graph $1/\varepsilon_0 = f(h_2)$. In the case when the film is magnetized from the direction of the easy magnetization axis along the hard axis, $\varepsilon_1 = 3/2\lambda_s$, or

$$\lambda_s = 2/3\varepsilon_1. \quad (6)$$

Fig. 2. Schematic diagram of the setup for determining the magnetostriction of ferromagnetic films by the interferometric method. P –films with substrate; Z –mirror; C –solenoid with cooling; O –MII-4 objective.

Experiment and results. The films were obtained by thermal evaporation of nickel in a vacuum of $\sim 10^{-5}$ mm Hg onto four rotating organic substrates made of polyethylene terephthalate, at room temperature. The length of the films with substrates was 100 mm, and the width 8 mm. Films of identical thickness were deposited on the substrates on both sides so that, when they were introduced into a magnetic field, the substrates would not bend. After the films had been obtained, they were annealed for 4 h in a magnetic field of 100 Oe at a temperature of 70° in such a way that the easy magnetization axis was established perpendicular to the length of the films. The film thickness was measured by the multiple-beam interference method.

The layout of the setup for determining the magnetostriction of the films is shown in Fig. 2. The sensitivity of the method for measuring magnetostriction for films 100 mm long is $2.7 \cdot 10^{-7}$.

The effective magnetostrictive change in length Δl_0 was determined from the displacement of the interference fringes

$$\Delta l_0 = n\lambda/2, \quad (7)$$

where n is the number of interference fringes, and λ is the wavelength of monochromatic light, equal to 5300 Å.

The effective relative change in length is

$$\varepsilon_0 = \frac{\Delta l_0}{l_0} = \frac{n\lambda/2}{l_0}, \quad \text{i.e., } \varepsilon \sim n. \quad (8)$$

Thus, it is possible to construct the dependence of n on H . Figure 3 shows a typical magnetostrictive loop of a nickel film 600 Å thick. Films 600 Å thick, deposited on substrates of thickness 50; 30; 20; 7.5 μ , caused, at saturation in a magnetic field, respectively, shifts in the number of interference lines of 5; 7; 9; 15.

Fig. 3. Magnetostrictive loop of a nickel film 600 Å thick. The ordinate axis gives the number of interference lines, and the abscissa axis gives the external magnetic field directed along the axis of hard magnetization of the film

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Fig. 4. Dependence of $1/n$ on the substrate thickness h_2 (n is the number of interference lines). $Oa = 0.052$

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Fig. 4. Dependence of $1/n$ on the substrate thickness h_2 (n is the number of interference lines). $Oa = 0.052$.

The dependence between the substrate thickness h_2 and the quantity reciprocal to the number of shifted interference lines is shown in Fig. 4, where the intercept $Oa = 1/n_1$ is proportional to $1/\varepsilon_1$.

From (8), taking into account that $h_2 = 0$, $1/\varepsilon_0 = 1/\varepsilon_1$, one can find

$$\lambda_s = 2/3\varepsilon_1 = 2\frac{\lambda n_1}{2 \cdot 3l_0} = \frac{\lambda n_1}{3l_0}. \quad (9)$$

Substituting into (9) $n_1 = 19$, $\lambda = 5300 \text{ Å}$, $l_0 = 10^9 \text{ Å}$, we obtain for a nickel film 600 Å thick $\lambda_s = 35.6 \cdot 10^{-6}$, i.e., the saturation magnetostriction of nickel films 600 Å thick is approximately equal to the magnetostriction of bulk nickel.

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