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Abstract

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PHYSICS

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ON THE INFLUENCE OF UNIAXIAL STRESSES ON THE GALVANOMAGNETIC EFFECT IN THIN FERROMAGNETIC FILMS

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In paper ⁽¹⁾ it was experimentally established that, for single-domain nickel films, the change in resistance in a magnetic field is well described by a relation that can be represented in the form

$$\rho_{\varphi} = \rho_{\parallel} - (\rho_{\parallel} - \rho_{\perp}) \sin^2 \varphi$$

or

$$\rho_{\varphi} = \rho_{\perp} + (\rho_{\parallel} - \rho_{\perp}) \cos^2 \varphi,$$

where φ is the angle between the directions of magnetization and electric current in the film; ρ_{\parallel} and ρ_{\perp} are the resistivities of the film at $\varphi = 0$ and $\varphi = \pi/2$, respectively. The quantity $\Delta\rho = \rho_{\parallel} - \rho_{\perp}$ is a characteristic of the material.

Study of the galvanomagnetic effect in permalloy films ^(2,3) showed the applicability of this relation in the region of saturating magnetic fields for films of different compositions and thicknesses. In the region of smaller fields, the observed deviations from this dependence may be due to the magnetic anisotropy of the films, macrodispersion anisotropy, and the fine structure of magnetization. Studying the change in the resistance of a film in a magnetic field with allowance for the indicated relation makes it possible to judge the course of the film remagnetization process.

In the present work we investigated the influence of elastic uniaxial stresses on the change in the resistance of films in a magnetic field.

Permalloy films were studied, obtained by thermal evaporation of an alloy of 75% Ni, 25% Fe in a vacuum of $\sim 10^{-5}$ mm Hg. The alloy was evaporated from tungsten crucibles. Microscope cover glasses heated to 200° were used as substrates. The films were obtained in the presence of a constant magnetic field of 50 and 1000 Oe. The thickness of the films was measured by the method of

Fig. 1

Figure 1: Fig. 1

lines of equal chromatic order. Electrical contact with the film was made by soldering wires with Wood's alloy. Electrical measurements were carried out by the bridge method. To oscillographically record the process of resistance change in a magnetic field, a direct current was passed through the film, and the film was remagnetized by an alternating magnetic field with a frequency of 50 Hz. The signal from the film was fed to the vertical input of the oscilloscope, while the sweep signal was taken from an active resistance connected in series with the Helmholtz coils. Deformation of the films was effected by producing pure bending of the substrates with two pairs of parallel knife edges.

Figure 1 presents the change in the hysteresis loops of the galvanomagnetic effect under the action of tensile deformations of different magnitude and direction. The hysteresis loop of the galvanomagnetic effect is the curve of the change in film resistance over a full period of the remagnetizing field and reflects the course of the film remagnetization process. The oscillograms of series *a* illustrate the change

hysteresis loops when the film is magnetized in the direction of the easy axis under the action of tensile stresses along this same axis. The minima of the curves of the change in resistance in a magnetic field, as simultaneous observations of the domain structure show, correspond to those values of the field at which magnetization reversal of the films begins through displacement of the boundaries. Up to this moment the change in resistance

Fig. 1. Change in the hysteresis loops of the galvanomagnetic effect under the action of stresses.

a $-\alpha = 0^\circ, \beta = 0^\circ, \gamma = 0^\circ$, scale unchanged;

$-\alpha = 0^\circ, \beta = -15^\circ, \gamma = 75^\circ$;

$-\alpha = 0^\circ, \beta = 90^\circ, \gamma = 0^\circ$

(α is the angle between the easy axis and the electric current; β is the angle between the magnetizing field and the easy axis; γ is the angle between the applied stress and the easy axis). ε is the magnitude of the relative deformation: 1 -0 ; 2 $-2 \cdot 10^{-4}$; 3 $-3.5 \cdot 10^{-4}$; 4 $-7 \cdot 10^{-4}$; 5 -0 ; 6 $-1 \cdot 10^{-4}$; 7 $-5 \cdot 10^{-4}$; 8 $-9 \cdot 10^{-4}$; 9 -0 ; 10 $-2.8 \cdot 10^{-4}$; 11 $-6.5 \cdot 10^{-4}$; 12 $-9.7 \cdot 10^{-4}$.

reflects the magnetization-reversal process consisting in nonuniform rotation of the magnetization of individual regions of the film. This corresponds to those values of the magnetizing fields at which the appearance of subdomains is observed in the films ⁽⁴⁾.

The height of the hysteresis loop when magnetizing in the easy direction corresponds to the fraction of the contribution of rotation processes to the magnetization reversal of the film by the moment at which boundary displacement begins. It should be noted that the magnitude of this rotation depends substantially on

Fig. 2

Figure 2: Fig. 2

Fig. 3

Figure 3: Fig. 3

the technology used to obtain the films. In Fig. 2, for comparison, two curves are given for the change in the magnitude of the angle of the mean deviation of the magnetization from the easy axis by the beginning of boundary displacement as a function of the magnitude of the tensile stresses. The magnitude of this angle was calculated by the formula given above. Films 1 and 2 were obtained in magnetic fields of 50 and 1000 oersted, respectively, with all other conditions identical. The sharp difference in the behavior of these films can be explained by the fact that the larger magnetic field applied in the plane of the film during its preparation reduces the magnitude of the dispersion of the local anisotropy axes and, quite possibly, affects the fine structure of the magnetization of the films.

When the films are stretched along the easy magnetization axis, an increase in the coercive force H_c is usually observed. This is expressed in a change in the distance between the extrema of the hysteresis loop recorded when the film is magnetized along the easy axis. Measurements carried out by means of the galvanomagnetic effect show that the character of the change in H_c with increasing deformation depends on the thickness of the films.

In work ⁽⁵⁾ it was found that the character of the dependence of H_c on the magnitude of uniaxial stress is also substantially affected by the degree of steepness of the film edge. Investigation of the effect of stresses on hysteresis loops

hysteresis of the galvanomagnetic effect of films having different edge fall-off zones through the thickness showed that, in the case where the coercive force of the films is determined by the nucleation field (the nucleation field is greater than the field for displacement of interdomain boundaries), H_c ceases to be a single-valued function of the strain. In this case the given dependence does not characterize the film as a whole, but to a greater extent characterizes the edge effect. The edge effect is manifested most clearly in thick films ($d > 1000 \text{ \AA}$).

Fig. 2. Dependence of the average angle of deviation of the magnetization from the easy axis at the onset of boundary displacement on the magnitude of the strain. 1 —film obtained in a field of 50 oersteds; 2 —in a field of 1000 oersteds. Film thickness $\sim 500 \text{ \AA}$.

Fig. 3. Dependence of the anisotropy field H_k and the coercive force H_c on the magnitude of the relative strain ε for films of thickness 930 \AA . The steepness of the film edges increases from 1 to 3.

Figure 3 shows three dependences of the coercive force on the magnitude of

Fig. 4

Figure 4: Fig. 4

the relative strain for films of thickness 930 Å, obtained simultaneously but having different edge zones, produced by different degrees of fitting of the glass substrates to the masks. As is seen from the graphs, H_c increases with increasing strain the faster the more gently sloping the film edges are. This is explained by the fact that, as observations of the domain structure show, under the action of stresses, owing to the growth of anisotropy, the nucleation process is hindered to a greater degree in films with less steep edges.

Fig. 4. Dependence of the magnitude of the galvanomagnetic effect on the magnitude of the magnetic field and strain. Solid curves are theoretical, points are experimental results. $a - \varepsilon = 0$; $b - 2.3 \cdot 10^{-4}$; $c - 4.8 \cdot 10^{-4}$. $R_0 = R_{\parallel}$ at $\varepsilon = 0$.

The growth of the anisotropy field leads to broadening of the hysteresis loop of the galvanomagnetic effect when the film is remagnetized in the hard direction (Fig. 1b).

At the same time, the hysteresis decreases, and at a certain strain the loop becomes hysteresis-free. The decrease in hysteresis is due to the fact that stretching the film along the easy magnetization axis reduces the anisotropy dispersion. The magnitude of the anisotropy field grows linearly with increasing strain, and the slope of the straight line does not depend on the film thickness. Figure 3 gives the dependence of the anisotropy field on the magnitude of strain. The anisotropy field—

or was measured from the hysteresis loop of the galvanomagnetic effect by the method of V. V. Kobelev (6).

Stresses applied at an angle to the axis of easy magnetization change the direction of this axis and increase the magnitude of the anisotropy field. This corresponds to a change in the hysteresis loop of the galvanomagnetic effect (Fig. 1b).

A study of the influence of uniaxial stresses on the magnitude of the galvanomagnetic effect showed that, in the region of fields smaller than the anisotropy field, this quantity changes with the field, since the magnetization of the film is not oriented along the field. In the region of fields larger than the anisotropy field and sufficient to saturate the film, the magnitude of the galvanomagnetic effect does not depend on the magnitude of the deformation ($\varepsilon = 0 \div 16 \cdot 10^{-4}$).

Figure 4 presents theoretical dependences, calculated on the basis of the coherent-rotation model, of the magnitude of the galvanomagnetic effect on the applied magnetic field for three values of the stresses, and gives the corresponding experimental values. As can be seen from the figure, the best agreement between the theoretical and experimental data is observed with

increasing deformation. The discrepancy in the region of fields close to the anisotropy field, in the absence of deformation, is apparently due to anisotropy dispersion. A decrease in anisotropy dispersion with increasing deformation leads to better agreement.

Thus, the influence of external elastic uniaxial stresses on the galvanomagnetic effect in permalloy films is due to changes in the anisotropy and in the anisotropy dispersion of the films.

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