EFFECT OF BACKING ON TEMPERATURE DEPENDENCE
OF THIN-FILM MAGNETIC PROPERTIES

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Results are given from studies of temperature dependence of $H_e$ and $H_k$ for thin permalloy films. It is shown that the character of $H_e$ and $H_k$ temperature variation is to a significant degree determined by the difference in temperature-expansion coefficients of film and backing, and also by the magnitude and sign of magnetostriction $\lambda_S$.

Most temperature studies of magnetic parameters are conducted in films produced on backings made of various materials. The temperature-expansion coefficients for film and backing as a rule are unequal. Therefore, when the film temperature varies there will arise planar deformations ($\varepsilon$) proportional to the difference in temperature-expansion coefficients of the film ($\alpha_f$) and the backing ($\alpha_b$), and also to the temperature variation interval $\Delta T$:

$$\varepsilon = l_0 (\alpha_f - \alpha_b) \Delta T.$$  

Clearly, these deformations will act on the film in the entire temperature interval except for the precipitation temperature. If $\alpha_f > \alpha_b$, then when the temperature is decreased from the condensation point the film will expand ($\varepsilon$ positive), while, if the temperature is increased above the condensation point, the film will contract ($\varepsilon$ negative). For $\alpha_f < \alpha_b$, the picture will be reversed. Consequently, the temperature dependence of magnetic parameters for films condensed on backings, for which $\alpha_f \neq \alpha_b$, will be composed of two parts: a) purely temperature variations of parameters; b) variations due to planar deformations.

The effect of the second factor is determined by the backing material. Depending on the relationship between $\alpha_f$ and $\alpha_b$, different results may be obtained in temperature studies of the magnetic properties of films, even those having a single composition; as far as we know, this was not taken into account by other researchers.

In our work, we studied films having $\lambda_S$ which were various in magnitude and sign; these films were deposited on backing of material having various $\alpha_b$. This allowed us to evaluate qualitatively the backing's contribution to the temperature dependence of the film's magnetic properties.

EXPERIMENTAL METHOD AND RESULTS

Films composed of 25% Fe–75% Ni, 10% Fe–90% Ni, and 79 NMA were obtained by thermal vaporization in a vacuum $10^{-5}$ torr simultaneously onto backings of fused quartz ($\alpha = 4 \cdot 10^{-6}$ deg$^{-1}$), glass ($\alpha = 6 \cdot 10^{-6}$ deg$^{-1}$), and duraluminum ($\alpha = 31 \cdot 10^{-6}$ deg$^{-1}$) heated to 200°C.

The studies were conducted in a vacuum chamber using the Kerr magnetooptic effect. The chamber was equipped with water and nitrogen collectors. One of the nitrogen collectors was above the diffusion pump and the other was next to the sample. During the experiment a vacuum $\sim 10^{-6}$ torr was maintained in the chamber. The temperature was determined by a copper–constantan thermocouple.

The coercive force $H_c$ was measured from hysteresis loops and by the magnitude of the field corresponding to half magnetic reversal of the film. The anisotropy field $H_k$ was determined by squaring the 45-degree branches of the transverse hysteresis loop [1, 2].

Fig. 1. Temperature dependence of $H_c$ for films ~700 Å thick on glass backings with compositions: 1) 79NMA; 2) 25% Fe−75% Ni; 3) 10% Fe−90% Ni.

Fig. 2. Temperature dependence of $H_c$ for films ~700 Å thick produced on quartz backings, and having compositions: 1) 79NMA; 2) 25% Fe−75% Ni; 3) 10% Fe−90% Ni.

Figure 1 shows the temperature dependence of $H_c$ for films having compositions 25% Fe−75% Ni, 79 NMA, and 10% Fe−90% Ni, ~700 Å thick produced on glass backings. The ratios $H_c'/H_c$ are plotted on the ordinate axis; $H_c'$ is the value of the coercive force at the experimental temperature, while $H_c$ is the value at room temperature. Clearly, in proportion to cooling below 0°C, the coercive force $H_c$ increases for films of all compositions; the slope of the curve $H_c(t)$ is significantly greater for films having negative magnetostriction (curve 3) than for those with zero magnetostriction (curve 1). Curve 2, showing, for films having $\lambda_s > 0$, the variation of coercive force versus temperature, has the smallest slope. The difference in slope for curves 1 and 3 of films having the same composition but produced on quartz backing is even greater (see Fig. 2).

This relationship between coercive force and temperature can be explained as follows.

It was shown in [3, 4] that films produced by thermal vaporization, as a rule, possess perpendicular anisotropy, whose magnitude depends on the value of the magnetostriction constant and the preparation conditions. Under the influence of planar macrostresses, the magnitude of this anisotropy may vary significantly. For example, it was noted in [5] that when the film is removed from a glass backing the quantity $J_T/J_s$ increases and in some cases the film becomes clearly uniaxial. Huber and Smith [6] showed that when films having negative magnetostriction were removed from glass the hysteresis loops having specific form with high $H_c$ and $H_T$ and low $B_r/B_s$ become rectangular and the coercive force decreased from 40 to 4 Oe. Here, for films having positive magnetostriction, the perpendicular anisotropy arises if the macrostresses are compressive, while for films having $\lambda_s < 0$ it arises if there are tensile macrostresses [7]. In the case when only tensile stresses act, they either aid the appearance of anisotropy normal to the film surface or, on the contrary, impede it, depending on the sign of the magnetostriction [8].

The characteristics of $H_c$ behavior which are observed when the films are cooled (Figs. 1 and 2) can apparently be explained by the presence in the films of perpendicular anisotropy and its variation under the influence of isotropic macroscopic stresses arising due to the difference between $\alpha_T$ and $\alpha_B$. Films produced on glass and quartz backings will expand upon cooling ($e > 0$), which must lead to the magnetic vector leaving the plane, i.e., to increase in the paramagnetic anisotropy for films having $\lambda_s < 0$ and to a decrease for films with $\lambda_s > 0$. In fact, for films produced on glass and quartz backings which have negative magnetostriction and whose perpendicular anisotropy increases upon cooling, $H_c$ increases notably (Figs. 1 and 2), as we should expect. Here, the larger the difference between $\alpha_T$ and $\alpha_B$, the steeper $H_c(t)$. Compressive stress will arise in films produced on duraluminum backings when they are cooled; this must lead to the opposite effect, i.e., to large slope of $H_c(t)$ for films having positive magnetostriction and smaller slope for films with $\lambda_s < 0$. The behavior of curves showing the coercive force variation versus the temperature of films having positive, zero, and negative magnetostriction, and which were produced on duraluminum backings, confirms these assumptions (see Fig. 3).

A similar effect of thermal stress was observed in the temperature dependence for the anisotropy field $H_k$. Figures 4 and 5 show the temperature variation of $H_k$ for films having composition 79 NMA