EVEN MAGNETOOPTICAL EFFECT IN COBALT THIN FILMS

FRANCISCO CARMONA GONZÁLEZ
Instituto de Física de Materiales. Serrano 144. Madrid-6. Spain

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ABSTRACT — In a study of cobalt thin films, hysteresis loops, magnetooptically determined, were displaced along the magnetization axis. This can be explained by assuming that an even magnetooptical effect is present. Use is made of observed displacements to evaluate this effect for different film thicknesses and deposition angles; it amounts to 30 % of Kerr effect for films of 150 Å obtained by normal incidence.

1 — EXPERIMENTAL

Cobalt thin films were vacuum deposited on Corning "7059" glass slides. Evaporation was achieved by electron bombardment, and vacuum during deposition was better than 10^{-6} Torr.

Several sets of films were obtained, with thicknesses ranging from 150 to 1000 Å, placing the substrates in such a way that, within each set, thickness was the same (± 25 Å) for all films, whilst θ , angle of incidence of the flux on the substrate (deposition angle), was different for each one.

Placing substrates at 50 cm, or nearer, to the emitting focus, gave as a result, especially for those films obtained under high incidence, non-uniformity in thickness. However magnetooptical measurements were made of areas uniform within 5 % or less.

Hysteresis loops were traced with the device sketched in Fig. 1. The film, located between the pole pieces of an electromagnet, with which fields up to ± 5000 Oersted are applied, is parallel to the applied field and can be rotated around an axis perpendicular to it; it is thus possible to determine hysteresis loops along different directions in the plane of the films. This was necessary because, due to oblique incidence, anisotropic properties were expected [1], [2], [3].

Reflectivity was measured at H = 5000 Oe and H = – 5000 Oe by noting voltage drop across resistance R of Fig. 1.

Some samples were also measured by means of a vibrating sample magnetometer.

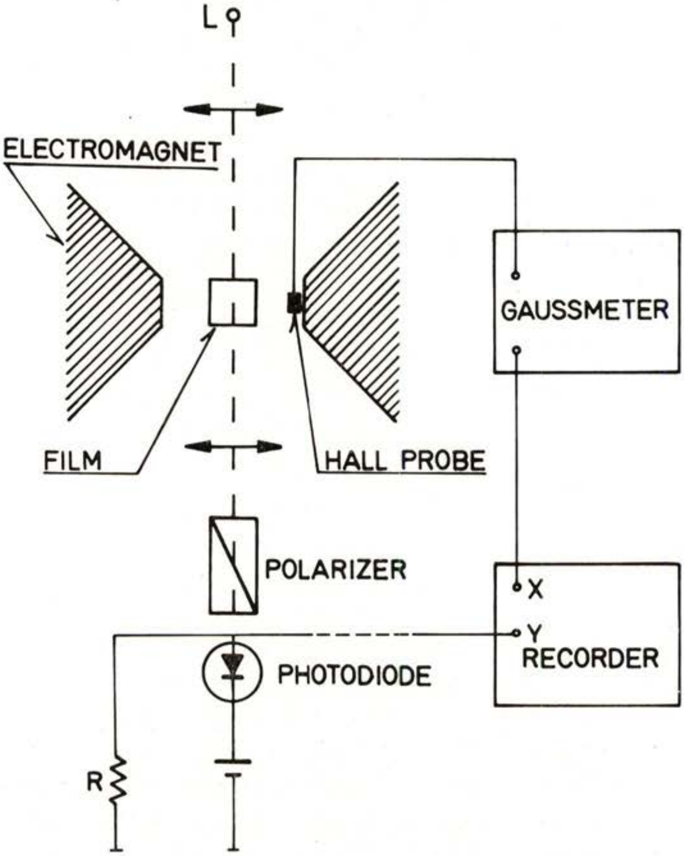

Fig. 1 — Kerr effect device for the measurement of thin films

White light from lamp L, reflected in the film under an angle of 60°, passes through calcite polarizer in P position and finally reaches a photodiode. Voltage across resistance R is thus proportional to the reflectivity of the film, and because of the equatorial Kerr affect, proportional to its magnetization. This voltage is adequately processed and applied to the vertical axis of an XY recorder.

2 — RESULTS AND DISCUSSION

Magnetooptic measurements gave hysteresis loops displaced along the magnetization axis. The magnitude of these displacements is direction dependent, and shows a variation with angle of measurement with the same periodicity as coercive force, remanence and reflectivity.

Hysteresis loops traced with a vibrating sample magnetometer were *not* displaced. Observed displacements would thus have to be ascribed to the magnetooptic method that was used.

The simplest explanation of these displacements is to assume that we have, superposed on the equatorial Kerr effect, an even magnetooptical effect; that is, to assume that the *apparent*, or as measured, magnetization, μ, is given by

$$\mu = A m^2 + B m + C \tag{1}$$

where m is the *actual* magnetization.

A, B and C are easily determined: Let $\mu = \pm 1$ for $m = \pm 1$ and $\mu = (\mu_r)_\pm$ for $m = \pm m_r$, where $(\mu_r)_+$ and $(\mu_r)_-$ are (reduced) apparent remanences and m_r is the actual (reduced) remanence. It follows that

$$\begin{gathered} A = -C = -[(\mu_r)_+ + (\mu_r)_-] / 2(1 - m_r^2) \ , \ B = 1 \\ m_r = [(\mu_r)_+ - (\mu_r)_-] / 2 \end{gathered} \tag{2}$$

It is thus possible to correct displaced hysteresis loops. But the point is that the first of eqs. (2) allows us to evaluate the magnitude of the even magnetooptical effect that causes the displacement.

In Fig. 2 we have mean values of *A* against deposition angle for different thicknesses. Straight lines are least squares fits in order to show tendencies: an increase of A with θ, except for the thinner films group (125-175 Å).

It is to be noted that *A* values are relative, and that *B* is, as the second of eqs. (2) shows, arbitrarily made equal to unity. In order to arrive at "absolute" values, let us recall that *Bm* , the second term of eq. (1), is the equatorial Kerr effect. Values for this are given in Fig. 3, in which δ, reduced reflectivity difference, is represented against thickness with θ as a parameter. Curves are best fit approximations to experimental values. Orders of

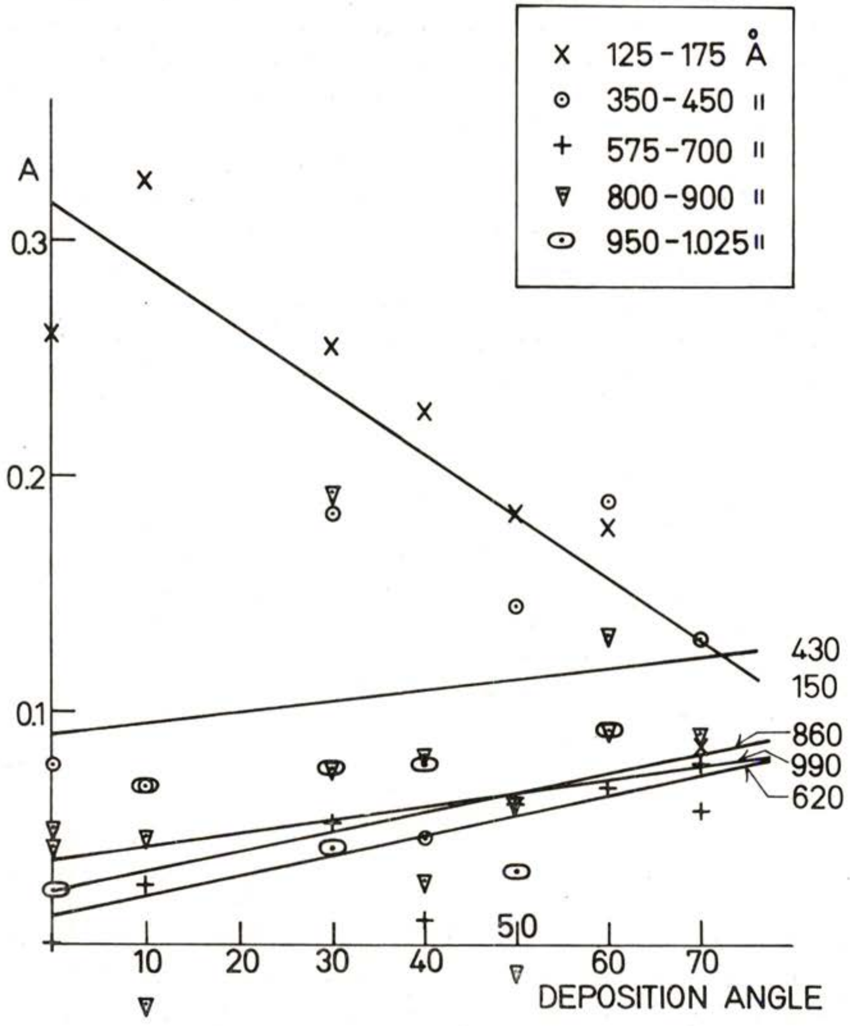

Fig. 2 — Mean values of *A* vs. deposition angle for different thicknesses

A is the magnitude of the even magnetooptical effect relative to the equatorial Kerr effect taken as unity. Films were measured along twelve different directions in their plane. The average over the twelve directions is here given for each film vs. deposition angle. Straight lines are least squares fits showing tendencies for groups of films of similar thickness.

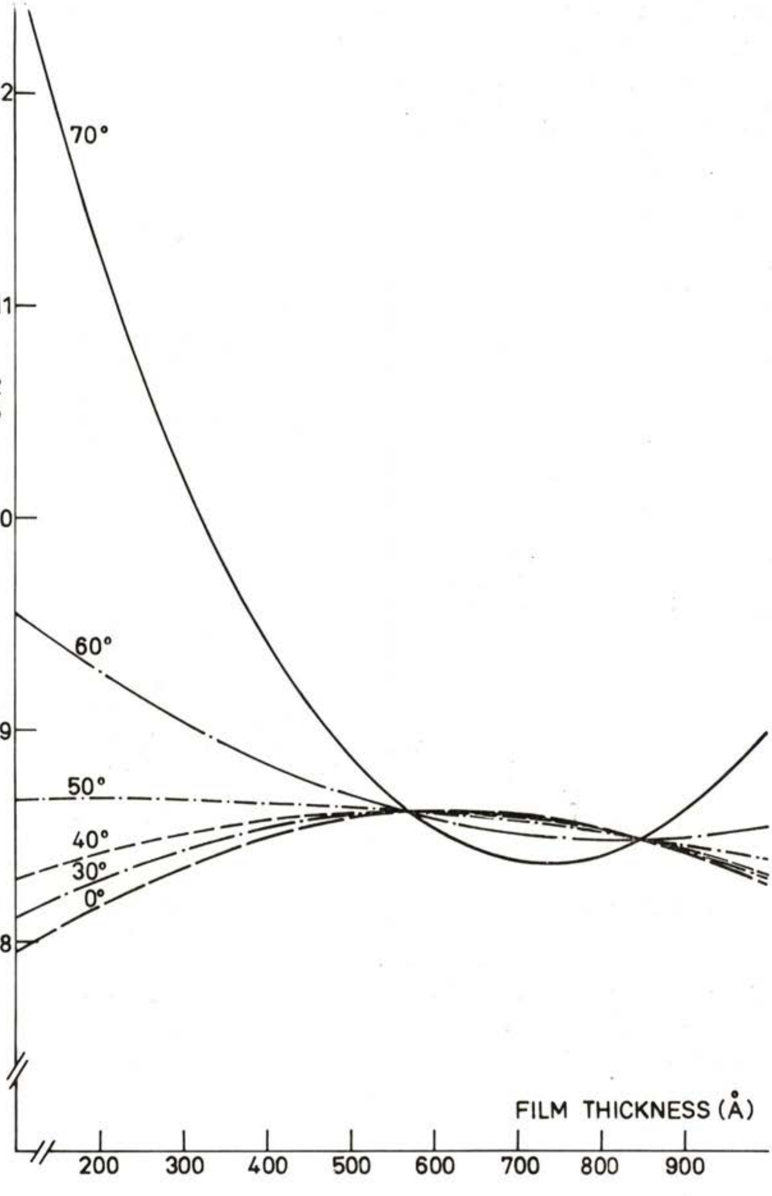

Fig. 3 — Reduced reflectivity difference vs. thickness for different values of θ. Reduced reflectivity difference is defined as $\delta = (I_1 - I_2)/I_0$, where I_1 and I_2 are reflected light intensities corresponding to saturation states, and I_0 reflected light intensity for zero magnetization [4]. Curves are best fit approximations to mean values of δ over 12 directions in the plane of the film.

magnitude and shape of curves are in agreement with the work or Carey et al. [4].

A should be multiplied by the corresponding value of δ in order to have a measure of the even magnetooptical effect allowing comparison between samples. In Fig. 4 we have $\delta \cdot A$ against thickness for different θ's. Experimental results can be seen to be somewhat dispersed, but the overall picture for the magnetooptical effect under consideration is clear: a) it is bigger for thinner films; b) it depends on the deposition angle under which the film was formed (higher for normal incidence for small

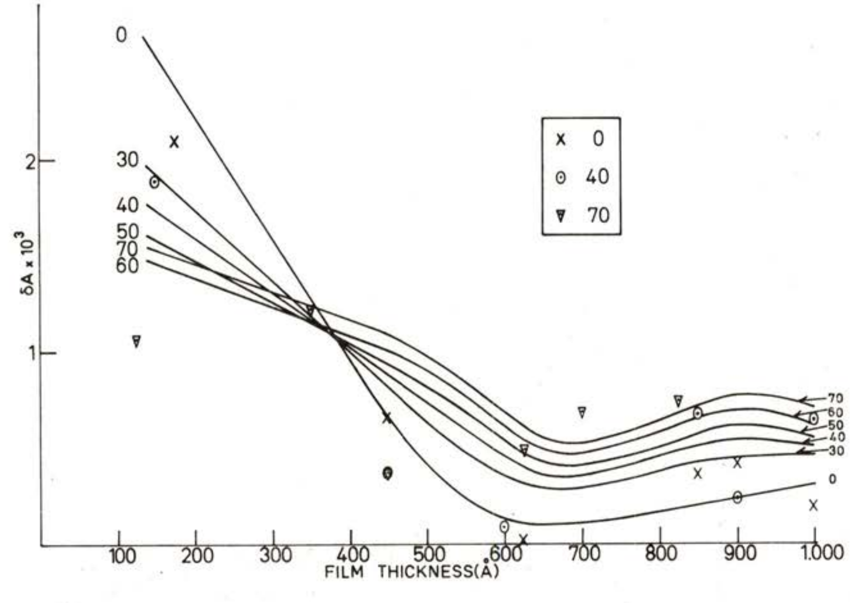

Fig. 4 — Even magnetooptical effect vs. thickness for different values of θ

A is just a measure of the even magnetooptical effect relative to the equatorial Kerr effect taken as unity. If each value of *A* is multiplied by the corresponding value of δ, we have a measure of the effect that allows comparison between samples. $A \cdot \delta$ is represented vs. film thickness for different deposition angles. Curves are best fit approximations.

thicknesses, in the range 100-300 Å, and higher for oblique incidence in the range 500-1000 Å).

The nature of even magnetooptical effects has been thoroughly studied by Krinchik et al. [5], [6], [7] and by Afonso [8]. A striking feature of these effects, pointed out as a "paradox" in Ref. [6], is that their maximum value should correspond to zero magnetization, whilst their minimum value (zero) corresponds to saturation. There is no such paradox. A term proportional to the magnetization squared has the same value for $m = m_s$ and for $m = -m_s$; which amounts to no relative effect at all. On the other hand, it is necessary to add a constant to the term in m^2 (otherwise, it would not be possible to have symmetry for $m = \pm m_s$ unless $A = B = 0$). The effect is thus given by $Am^2 + C = A\,[(M/M_s)^2 - 1]$ with its maximum (absolute) value for $M = 0$.

REFERENCES

[1] D. O. SMITH, M. S. COHEN, G. P. WEISS, *J. Appl. Phys.*, **31**, 1755-1762 (1960).

[2] D. E. SPELIOTIS, G. BATE, J. K. ALSTAD, J. R. MORRISON, *J. Appl. Phys.*, **36**, 972-974 (1965).

[3] E. MÜNSTER, *IEEE Trans. Mag.*, **7**, 263-267 (1971).

[4] R. CAREY, D. M. NEWMAN, B. W. J. THOMAS, *J. Phys. D: Appl. Phys.* **10**, L131-L134 (1977).

[5] G. S. KRINCHIK, V. S. GUSHCHIN, *JETP Letters*, **10**, 24-26 (1969).

[6] G. S. KRINCHIK, E. E. CHEPUROVA, *JETP Letters*, **11**, 64-66 (1970).

[7] G. S. KRINCHIK, E. A. GAN'SHINA, *Sov. Phys. JETP*, **38**, 983-987 (1974).

[8] C. N. AFONSO, «*Efectos magnetoópticos de simetría par en metales ferromagnéticos*», Tesis, Universidad Complutense de Madrid, 1979.