COMPOSITION AND MAGNETIC PROPERTIES OF GdCo FILMS SPUTTERED FROM A SEGMENT TARGET*

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Domain structure, distribution of thickness and composition, as well as the Hall effect have been studied for GdCo films prepared by the bias-sputtering from a segment target. The target consisted of two sheets, cobalt and gadolinium, each of them being one half of the target area. The distribution of composition found in the obtained films agreed with those calculated from Hanak's model for the segment target. The concentration of Co varied across the sample from 61 to 91 at. %. Stripe domain structure was observed in the films with the Co concentration from 77 to 85 at. %, except for the compensation point. Bubble structure was found at about 81 at. % Co. Extraordinary Hall coefficient $R_1 = 5500 \times 10^{-12}$ Ωcm/Gs, saturation magnetization $4\pi M_s = 900$ Gs and uniaxal anisotropy constant $K_u = 0.55 \times 10^5$ erg/cm^3 were determined from the Hall and torque curves for the film containing about 81 at. % Co.

1. *Introduction*

The authors applied various conditions at deposition of amorphous GdCo films with sputtering technique [1–4]. Hanak et al. [5] reported a simple theory for calculating of the composition of the film sputtered from a segment target. The aim of our work was to examine the influence of Co content in GdCo films on the domain structure in a wide

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range of Co concentration and to verify Hanak's model for the GdCo segment target, using dc bias-sputtering. The saturation magnetization M_s and anisotropy constant K_u were determined for the composition giving bubble structure.

2. Theory

Starting from the model given in paper [5] we calculated the distribution of the film contents obtained by sputtering from a target consisting of two halves: gadolinium and cobalt.

The theory assumes the cosine law for the flux J of the atoms emitted from the target

$$d^2J = K d\sigma\, d\sigma' (\cos^2\theta / l^2) \tag{1}$$

where $d\sigma$ and $d\sigma'$ represent area elements of the target and of the substrate, respectively, the target and the substrate being mutually parallel, the angle θ specifies the direction of

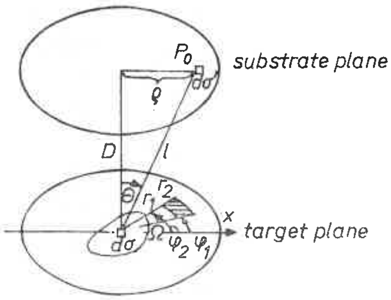

Fig. 1. Sputtering geometry consisting of two parallel planes [5]

the flux emitted from the target, l is the distance between the area elements (Fig. 1), the constant K is equal to the emission per unit area of the target divided by π. Integration of Eq. (1) over the target area Ω gives

$$G(P_0)_\Omega = \frac{1}{K}\,\frac{dJ}{d\sigma'} = \int_\Omega d\sigma (\cos^2\theta / l^2) \tag{2}$$

with $G(P_0)_\Omega$ called deposition profile at the point P_0.

The fundamental function of the integral (2) in polar coordinates reads

$$F(r, \varphi) = \tfrac{1}{2}\left\{\frac{r^2 - D^2 - \varrho^2}{(a^2 - b^2)^{1/2}} \arctan\left[\left(\frac{a-b}{a+b}\right)^{1/2} \tan \tfrac{1}{2}\varphi\right] + \frac{\varrho \sin\varphi}{(D^2 + \varrho^2 \sin^2\varphi)^{1/2}} \arctan \frac{r - \varrho\cos\varphi}{(D^2 + \varrho^2 \sin^2\varphi)^{1/2}}\right\} \tag{3}$$

where $a = r^2 + \varrho^2 + D^2$, $b = -2r\varrho$.

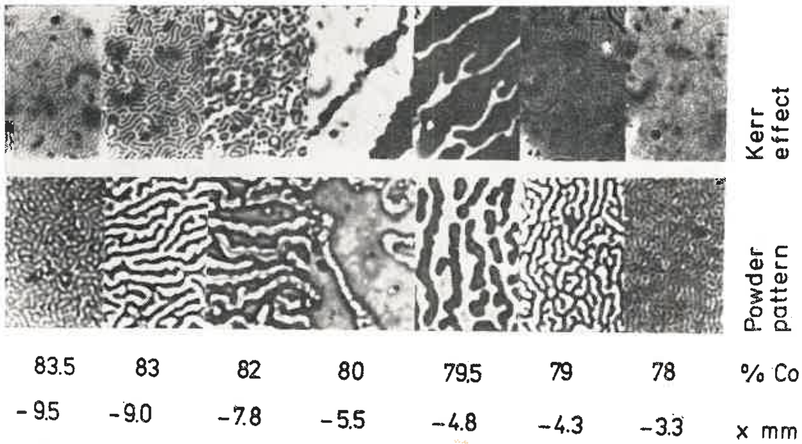

Fig. 3. Zero-field stripe domain patterns for various compositions

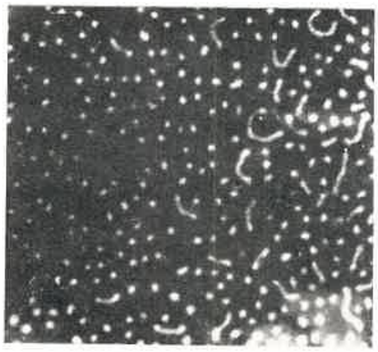

Fig. 4. Bubble domains observed by the polar Kerr magnetooptic effect (magnification 1000×)

Deposition profile $G(P_0)_\Omega$ due to the target area Ω bounded by coordinates (r_1, r_2) and (φ_1, φ_2) is expressed by the boundary values of the function (3):

$$G(P_0)_\Omega = F(r_2, \varphi_2) - F(r_2, \varphi_1) - F(r_1, \varphi_2) + F(r_1, \varphi_1). \quad (4)$$

The composition $C_{at}(P_0)$ at any point P_0 of the film can be calculated using our profiles determined from Eq. (4).

$$C_{atCo}(P_0) = G_{Co}(P_0)/[G_{Co}(P_0) + G_{Gd}(P_0)K_{Gd}/K_{Co}]. \quad (5)$$

The ratio of the emission coefficients for both deposited materials K_{Gd}/K_{Co} must be fitted from experimental data.

3. *Preparation of films*

The GdCo films were prepared by the dc bias-sputtering technique. The applied system for film preparation consisted of a water cooled cathode and a substrate table 5 cm in diameter. The distance between the cathode and the table was 33 mm. The target consisted of two sheets of Co 99.99% and Gd 99.9% each of them forming a semicircle. Those sheets were fixed to the cathode with a narrow molybdenum ring. Corning glass substrate of dimension $20 \times 30 \times 0.8$ mm^3 covered with chromium was placed at the centre of the table; the longer edge being perpendicular to the joint-line of the sheets forming the target.

The substrate with predeposited electrodes for the Hall effect measurement, masked with a metallic shutter, was placed on the substrate table at a distance of 8 mm from its centre.

The system was evacuated to about 2×10^{-6} Torr and then filled with argon to the operations pressure of 2×10^{-2} Torr. Prior to the film deposition the target was cleaned by sputtering for 30 minutes. The deposition rate was about 50 Å/min with the cathode potential -1400 V, the plate current 10 mA and the bias potential -100 V.

The thickness of the films obtained varied from 0.6 to 2 μm.

4. *Measurements*

The distribution of thickness across the deposited film was measured by a multi-beam interference technique, whereas the distribution of the concentration of Gd and Co in the film was determined with an electron micro-probe. The thickness varied from about 1.5 μm at the sample edge richer in gadolinium to about 0.6 μm at the other one (Fig. 2). The concentration of cobalt varied across the sample from 61 at.% at the one side to 91 at.% at the other. The sample for the Hall effect measurements was a rectangle of dimensions 3×10 mm^2. The concentration of Co varied across the sample from 81 to 82 at.%, being Co-richer at the edge lying outside the centre of the substrate table. The ratio of the emission coefficients $K_{Co}/K_{Gd} = 3$ for the point $\varrho = 0$ was taken for fitting the theoretical curve following from Eq. (4). Hence, the calculated curve agrees with the experimental one over the entire sample (Fig. 2). The content of Mo in these films was undetectable by the microprobe used, hence it was less than 0.05 at.%.

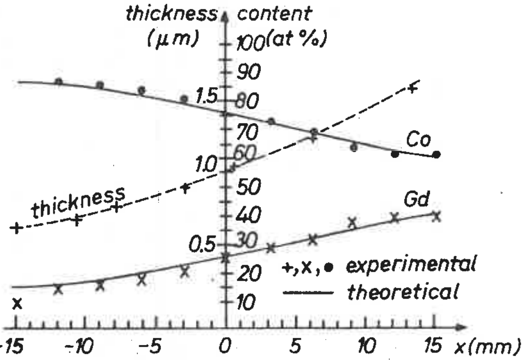

Fig. 2. Theoretical and experimental concentrations of Gd and Co, and thickness *versus* distance from the centre of the film

The domain structure of the GdCo films was observed both by the method of the powder pattern and Kerr effect with a magnification of 500×. Remnant structure occurs in the content range from 77 to 85 at.% Co. The variation of the domain structure with

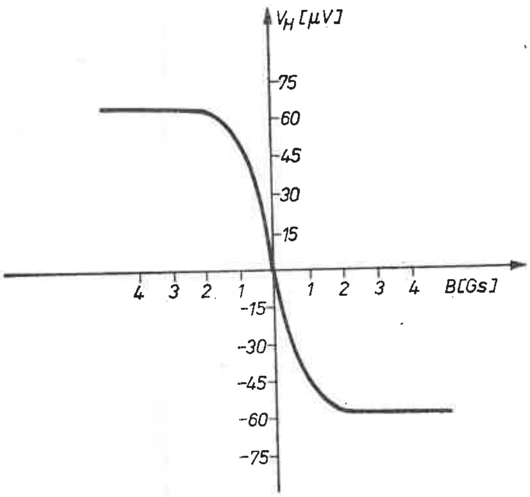

Fig. 5. Hall effect loop of the GdCo film

the concentration of Co is shown in Fig. 3. At 80 at.% Co we observed domains similar to those in permalloy films. Such large domains are characteristic for the composition near the compensation point [2]. The width of stripe domains decreases with a rise of

Co concentration; a similar change in the domain width occurs with an increase of Gd concentration relative to the compensation point.

No domain structure could be detected outside the concentration range of 77 to 85 at.% Co, because of a very fine stripe domain pattern.

At about 81 at. % Co a bubble structure was found in a perpendicular field ranging from 160 to 20 Gs (Fig. 4).

The Hall effect was measured by an ac-method [2, 6] in a five terminals system. In Fig. 5 a characteristic Hall loop is shown, and in Fig. 6 the torque curve characteristic

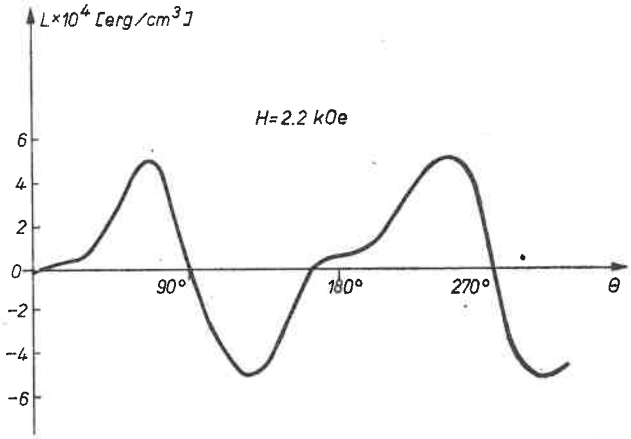

Fig. 6. Torque curve characteristic for the GdCo film with perpendicular anisotropy

for the same film which exhibited perpendicular anisotropy. The saturation magnetization $4\pi M_s = 900$ Gs, the extraordinary Hall coefficient $R_1 = 5500\times10^{-12}$ Ωcm/Gs, and the perpendicular anisotropy constant $K_u = 0.55\times10^5$ erg/cm³ were determined from those curves.

5. *Conclusions*

One can conclude from the presented results: (1) the distribution of the film composition calculated from the model of Hanak et al. agrees well with that of GdCo films prepared by dc bias-sputtering from a segment target; (2) domain structure of a film with continuous change in the Gd–Co content varies in a similar way to that of GdFe films deposited onto separate substrates [7] (3) the values of M_s, K_u and R_1 are in basic agreement with the other authors results.

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REFERENCES

[1] P. Chaudhari, J. J. Cuomo, R. J. Gambino, *IBM J. Res. Develop.* **17**, 66 (1973).
[2] K. Okamoto, T. Shirakawa, S. Matsushita, Y. Sakurai, *IEEE Trans. Magn.* **MAG-10**, 799 (1974).
[3] H. C. Bourne, R. B. Goldfarb, W. L. Wilson, R. Zwingman, *IEEE Trans. Magn.* **MAG-11**, 1332 (1975).
[4] M. B. Bystra, A. Jahn, B. Knappe, G. R. Müller, *Fiz. Tver. Tela* **18**, 851 (1976).
[5] J. J. Hanak, H. W. Lehmann, R. K. Wehner, *J. Appl. Phys.* **43**, 1666 (1972).
[6] R. J. Gambino, T. R. McGuire, Proc. 7th Intern. Coll. Magn. Thin Films, Regensburg 1975, 6A-4.
[7] Y. Mimura, N. Imamura, T. Kobayashi, *J. Appl. Phys.* **47**, 368 (1976).