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Abstract. – A stack of Co-Cr layers sputtered on polyester is magnetised in plane. After reducing the magnetising field to zero, the presence of stripe domains parallel to the former field direction is demonstrated in a transmission experiment with polarised neutrons, using 3D polarisation analysis.

Introduction

Co-Cr layers evaporated or sputtered on various substrates (e.g. polyester, polyimide, Si) continue to be a subject of study because of their perpendicular magnetic anisotropy which makes such layers a promising high density recording medium. In Co-Cr layers with low coercivity ($\sim$ 20 kA/m) stripe domains are observed [1]. These give rise to additional noise in recording experiments [2, 3]. The size of the stripe domains can be influenced by a magnetic field [1]. The aim of the present paper is to investigate by means of 3-D neutron polarisation analysis the domain structure in a Co-Cr layer treated by an in-plane magnetic field.

Sample and measuring technique

The $Co_{79}Cr_{21}$ layers were prepared by RF sputtering on polyester substrates (14.5 μm) at an initial substrate temperature of 30 °C [2]. This study deals with a stack of 50 samples taken from one layer with characteristics given in table I.

Table I. – *Sample characteristics.*

Thickness	T_{substr}	$H_{c\perp}$	$H_{c\parallel}$	K_u
0.8 μm	30 °C	17 kA/m	13 kA/m	120 kJ/m^3

A concise description of the 3D neutron depolarisation technique and the setup is given in [5]. Figure 1 contains a schematic view of the experiment. If we suppose that the cross section through the domain structure in Co-Cr corresponds to the section given in figure 1 (i.e. perpendicular domains extend trough the thickness h of the film), the average $\langle\cos\phi\rangle_\theta$ of the cosine of the Larmor precession angle ϕ can be calculated for each value of the transmission angle θ. It can be shown from geometry that the diagonal elements of the depolarisation matrix D_{ij} for one film are equal to:

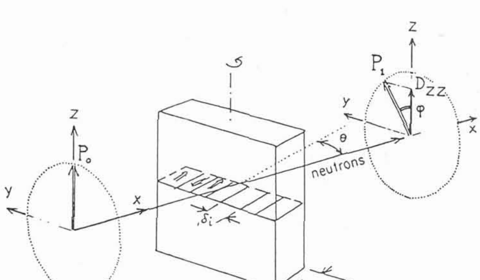

Fig. 1. – Schematic view of the neutron depolarisation experiment.

$$D_{xx} = 1 - \sin^2\theta\left(1 - \langle\cos\phi\rangle_\theta\right) \approx 1 \qquad (1a)$$

$$D_{yy} = 1 - \cos^2\theta\left(1 - \langle\cos\phi\rangle_\theta\right) \approx \langle\cos\phi\rangle_\theta \qquad (1b)$$

$$D_{zz} = \langle\cos\phi\rangle_\theta\,. \qquad (1c)$$

The angle ϕ [radian] is connected with the path length ℓ [m] and the saturation induction B_s [T] by

$$\phi = 4.55\times10^5\lambda\,(B_s\ell) \quad (\lambda \text{ in nm})\,. \qquad (2)$$

For a stack of N films expr. (1a, c) should be raised to the Nth power. Measurement of D_{yy} or D_{zz} as a function of θ yields the domain dimensions:

$$\text{height}: \quad h_{\text{eff}} = \cos^{-1}\left[\sqrt[N]{D_{zz}}\,(\theta=0)\right]; \qquad (3a)$$

$$\text{width}: \quad \delta = \frac{2}{3}\theta_0 h_{\text{eff}}\cdot(\theta_0\text{: see Fig. 2a})\,. \qquad (3b)$$

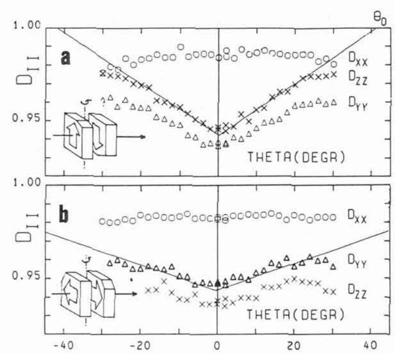

Fig. 2. – The elements D_{ii} ($i = x,\ y,\ z$; see Fig. 1) as a function of transmission angle θ measured with the remanence of the films parallel to $\pm\,z$ (a) and $\pm y$ (b).

Experiments and results

The stack of Co-Cr samples was saturated in an in-plane field of 650 kA/m (8.3 kOe) prior to the experiments. To avoid excessive rotation of the polarisation vector in the remanent field, the stack was split into 2 stacks of 25 which were joined in the configuration shown in the inserts of figure 2. A first run as a function of θ was performed with the remanence parallel to z (Fig. 2a). In this geometry the element D_{zz} (thick symbols) is unaffected by the rotation of the polarisation vector in the stray field. Application of equations (3a) and (3b) yields: $h_{\text{eff}} = 0.58\ \mu\text{m}$; $\delta = 0.30\,(\pm\ 0.03)\ \mu\text{m}$.

A second run was performed after rotating the stack 90° around x (Fig. 2b). In this geometry the element D_{yy} is unaffected. From the experimental points the angle θ_0 cannot be determined with great precision; the lines drawn give an estimation of $\delta = 0.6\ \mu\text{m}$.

Discussion

It appears from the results that the domain width δ in the direction of remanence is about twice the width perpendicular to the remanence; this indicates the presence of stripe domains parallel to the remanence. The formation of this kind of stripes may be qualitatively understood as follows.

When the magnetising field **H** drops below the saturating value, in first instance the angle ψ between the magnetisation and **H** is small. The decrease of the parallel component of the magnetisation is $\delta M_{\text{p}} = M_{\text{s}}\,(1 - \cos\psi)$; the increase of a perpendicular component is $\delta M_{\text{n}} = M_{\text{s}} \sin\psi$, so $\delta M_{\text{p}} \ll \delta M_{\text{n}}$. The latter gives rise to magnetic poles on the surfaces of the layer which will be avoided by creating a flux closure configuration, provided the corresponding increase in anisotropy energy density is less than the decrease of the free pole energy density. In view of the ratio $K_{\text{u}}/M_{\text{s}}^2$ it is not certain that this condition is fulfilled. However, it is surely fulfilled on the substrate side of the CoCr, where K_{u} is known to be substantially lower than the bulk value given in table I. In figure 3 two configurations are sketched schematically: "bulk" domain walls parallel (3a) and perpendicular (3b) to the applied field. The vectors drawn are deviations of the magnetisation from the mean magnetisation. In figure 3a the component δM_{n} perpendicular to **H** is the one which acts as a flux closure between bulk domains. Due to the direction of δM_{n}, these domains (which at zero field become the stripe domains) must have their boundaries parallel to **H.** On the other hand, in the configuration of figure 3b the component $\delta M_{\text{p}}(\ll \delta M_{\text{n}})$ cannot act effectively as a flux closure.

A second argument in favour of the configuration of figure 3a is connected with the rotation of the magnetisation inside the domain (Bloch) wall. In the case of figure 3a the sense of rotation may be such that a component δM_{p} parallel to **H** occurs. Although $\delta M_{\text{p}} \ll \delta M_{\text{n}}$, this leads to a slightly smaller wall energy than in the model of figure 3b where a component δM_{n} exists perpendicular to the field.

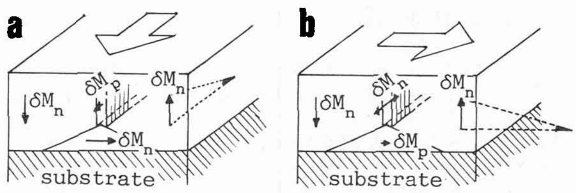

Fig. 3. – Models to show flux closure at large in-plane field (arrow). The vectors in the models are the deviations of the magnetisation from the field direction.

The height of the domains is noticed to be about 70 % of the film thickness. The present data are not precise enough to give an analysis of the domain structure which make up the remaining part of the film thickness.

In conclusion, we have seen that we can characterise with the 3-D depolarisation technique lateral domain sizes as well as domain heights of perpendicular domains. Application of this technique to Co-Cr layers which are treated by an in-plane field, has shown that an anisotropic domain size distribution exists in plane, with the largest size in the direction of the applied field, which indicates the presence of stripe domains.

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