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NEUTRON DEPOLARISATION IN ALUMITE IN REMANENT STATES AFTER IN-PLANE AND PERPENDICULAR MAGNETISATION

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Abstract. — An alumite film for perpendicular recording is studied by 3-D analysis of a polarised neutron beam transmitted through the film in different directions. Magnetic correlations between the Fe needles are shown to differ after applying an in-plane or a perpendicular magnetic field.

Introduction

In recent years perpendicular recording media have been proposed to replace longitudinal media because of their much higher obtainable bit density. One such medium, in addition to Co-Cr, is alumite consisting of an Al oxide film containing electro-deposited needle shaped Fe particles oriented highly perpendicular to the plane of the film [1].

Domain studies in Co-Cr films have contributed to understand their recording properties. The question whether Co-Cr behaves in its domain properties as a continuous or as a particulate medium has been given great attention and is by now settled in favour of the former. In alumite, on the other hand, the ferromagnetic Fe needles are geometrically isolated but magnetic correlations may occur.

In a previous paper [2] the influence of the Fe filling factor on these correlations was illustrated. The purpose of this paper is to show that one can influence these correlations by magnetic treatment and that 3-dimensional (3-D) neutron polarisation analysis is a technique to analyse them.

Experimental

The measuring technique is 3-D analysis of a polarised neutron beam transmitted through the sample, which yields a (3×3) depolarisation matrix D_{ij} ($i, j = x, y, z$; see Fig. 1 of Ref. [3] and insert of Fig. 1a). This matrix is measured as a function of transmission angle θ .

This technique has been applied to Alumite YS623 prepared at Yamaha R&D Laboratories, Hamamatsu, Japan. Preparation and magnetic properties are described by Tsuya e.a. [4, 5]; see also table I.

Table I. — properties of YS623.

thickness t	pore width δ	cell size p	cell area A	filling fr. f	H_c [4]	ϕ_s
[μm]	[\AA]	[\AA]	[μm^2]		[Oe]	[°]
4.3	425	618	1.65×10^{-3}	0.43	956	85

ϕ_s is the larmor precession angle for a neutron trajectory through the length of a Fe needle filling a

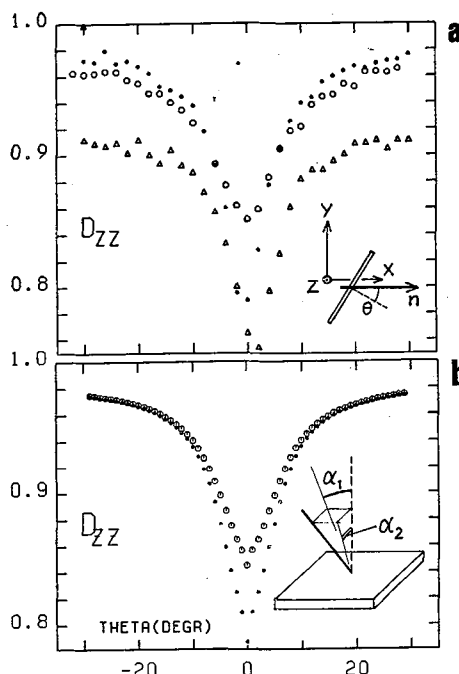


Fig. 1. — a) exper. results for D_{zz} in a stack of 8 layers: (●●●) "as received"; (○○○) after 8.6 kOe in plane; (△△△) idem perpend. b) Simulation for $D_{zz} = [D_{zz} \text{ Eq. (4a)}]^8$ with data from table I: (●●●) $\Delta W_{(\alpha_1, \alpha_2)} = 0.07 \text{ rad}$; corr; parameter $K = -0.45$; (○○○) idem; and 50 % of the needles magnetically "broken".

"pore". When the trajectory extends over a distance $\ell(\theta)$ through the needle, the precession angle is:

$$\phi(\theta) = 5.72 \times 10^8 (M_s \ell) \lambda = c\ell(\theta), \quad (1)$$

where M_s is the saturation magnetisation of Fe (A/m) and λ (nm) the neutron wavelength.

Measurements

We consider only the element D_{zz} which, for each θ , is equal to the average cosine of the total precession angle $\phi_t(\theta)$. In general $\phi_t(\theta)$ is small, so:

$$D_{zz}(\theta) = \langle \cos \phi_t(\theta) \rangle = 1 - \frac{\langle \phi_t^2(\theta) \rangle}{2}. \quad (2)$$

Measurements were taken in the magnetic states:

- (i) "as received" ;
 - (ii) the remanent state after 8.6 kOe in plane;
 - (iii) idem after 8.6 kOe perpendicular to the plane.
- Results of (i) were published earlier [2]. More recent results for D_{zz} are given in figure 1a as dots. The results corresponding to (ii) and (iii) are given in figure 1a as circles and triangles, respectively. The measurements have been corrected for the stray field due to the remanence of the sample.

Model description

The measured data are interpreted using a model consisting of Fe cylinders (needles) of length t and diameter δ with their axes perpendicular to the plane of the film, arranged in a hexagonal lattice of period p . In absence of magnetic correlation between needles, the total precession angle $\phi_t(\theta)$ due to the precession in the $N(\theta)$ needles along the neutron trajectory increases as $\phi_t(\theta) = \sqrt{N(\theta)} \cdot \phi(\theta)$ with θ . When we also introduce the parameter $K = \langle \mathbf{n}_i, \mathbf{n}_{i+1} \rangle - m^2$ to express the excess magnetic correlation between neighbouring needles (i and $i+1$) above the mean magnetisation m [6], equation (2) becomes:

$$D_{zz}(\theta) = 1 - N(\theta) \frac{\phi^2(\theta)}{2} \left(\frac{1+K}{1-K} \right). \quad (3a)$$

From the geometry of the model we find:

$$N(\theta) = P(\theta) / A \cos \theta; \quad (3b)$$

$$\phi(\theta) = cV / P(\theta) \quad (V = \text{volume of a cylinder}) \quad (3c)$$

where

$$P(\theta) = \delta \cos \theta (t \tan \theta + \pi \delta / 4). \quad (3d)$$

As shown in [2], equations (3) describe the observations for $|\theta| > 15^\circ$. For smaller θ , a normalised gaussian distribution $W(\alpha_1, \alpha_2)$ with half width Δ was introduced to describe the orientation variation of the needles around the normal in two orthogonal directions. An average of equation (3a) was taken over α_1 and α_2 (insert of Fig. 1b) with $W(\alpha_1, \alpha_2)$ as a weight factor:

$$D_{zz}(\theta) = \int \int d\alpha_1 d\alpha_2 W(\alpha_1, \alpha_2) \cos \phi(\theta, \alpha_1, \alpha_2) \quad (4a)$$

with

$$\cos \phi(\theta, \alpha_1, \alpha_2) = 1 - \frac{\phi^2(\theta)}{2} \frac{f}{\cos^2 \theta} \frac{1}{1+Q} \left(\frac{1+K}{1-K} \right) \quad (4b)$$

and

$$Q = \frac{4t}{\pi\delta} \tan [(\theta - \alpha_1)^2 + \alpha_2^2]^{1/2}. \quad (4c)$$

Interpretation and discussion

The observations of state (i) are satisfactorily described by the model with $\Delta = 0.07$ rad and $K = -0.4$, as seen by comparing the dots in figures 1a and b.

For state (ii), K should be less negative to fit the observations for $|\theta| > 15^\circ$. However, then the model fails to describe the observations around $\theta = 0$. This is explained as follows. The definite magnetic configuration of the needles is imposed by the stray fields around their ends (film surface). After inplane magnetisation, this configuration arises in both surfaces independently, giving a mismatch of polarity in 50 % of the needles. These are broken in two antiparallel domains with a Neel wall halfway the length of the needle. This is expressed in the model by supposing

$$V = \frac{\pi}{4} \delta^2 t \left(1 - \frac{h(\theta)}{t} \right), \quad [h(\theta) = \min(t, \delta / \sin \theta)] \quad (5)$$

instead of the geometrical volume. The result is given as circles in figure 1b. The outcome for $|\theta| > 15^\circ$ is hardly affected, but the observations of state (ii) in figure 1a are explained.

In state (iii), in first instance an excess correlation $K = 0$ is expected. However, in saturation a demagnetising field in the order of 10 kOe should be formed. Since H_c is only 1 kOe, we assume that the sample is divided in regions of parallel magnetic alignment of the needles, interlaced with opposite regions. This reduction of m results in $K > 0$ by definition. This is in qualitative agreement with the observations in figure 1a (triangles) which for $|\theta| > 15^\circ$ correspond to $K = 0.07$.

In summary, using the 3-D Polarization Analysis it appears possible to analyse the magnetisation distribution in Alumites on a microscopic scale after different magnetic histories. In the state "as received" correlations between the magnetisations of neighbouring needles explain the observations. The analysis after in-plane magnetisation indicates that the needles are magnetically "broken". After perpendicular magnetisation the excess correlation between neighbouring needles appears to vanish, as expected.

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