INFLUENCE OF TEXTURE ON THE SHAPE OF THE HYSTERESIS LOOP IN THIN MAGNETIC FILMS

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The calculations concerning the effect of thin magnetic film texture on the shape of the hysteresis loop are presented. This influence is expressed with the help of two parameters, namely, the degree and the direction of the texture. These factors influence both the value of the critical field and the rectangularity of the loop. The results of the calculations are presented graphically.

Introduction

Studies of thin magnetic films have hitherto been mainly performed with the assumption that there is no crystallographic texture. In 1959 Verderber found that there is some percentage of texture in many films. This percentage depends on the process of sample production. The largest texture was found in samples of the thickness exceeding 2000 Å which had been obtained at a temperature higher than 380°C. Verderber did not find the texture to influence coercive force, but he noted that the texture markedly affect the shape of the hysteresis loop. This work, following Verderber's suggestions, is a theoretical introduction to a series of structural studies of thin permalloy films connected with magnetic investigations, especially as regards the shape of the hysteresis loop.

Calculation of hysteresis loop with texture taken into account

The density of the total energy, including the energy of uniaxial anisotropy and the interaction with the magnetic field applied in an easy direction, is described by the formula

$$E_c = K_u \cdot \sin^2\varphi - MH \cdot \cos\varphi \tag{1}$$

If structural anisotropy for a plane case is taken into account we have

$$E_c = K_u \cdot \sin^2\varphi - MH \cdot \cos\varphi - \frac{1}{4} K_s \cdot \sin^2 2(\varphi - \beta) \tag{2}$$

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the particular direction and the angles between respective direction being shown in Fig. 1.

After transformation and the substitutions,

$$\frac{MH}{2K_u} = h \text{ and } \frac{K_s}{K_u} = S,$$

are performed, the formula (2) can be written in the form

$$\mathscr{E} = \frac{E}{2K_u} = \frac{1}{2}\sin^2\varphi - h\cdot\cos\varphi - \frac{1}{8}S\cdot\sin^2 2(\varphi-\beta) \tag{3}$$

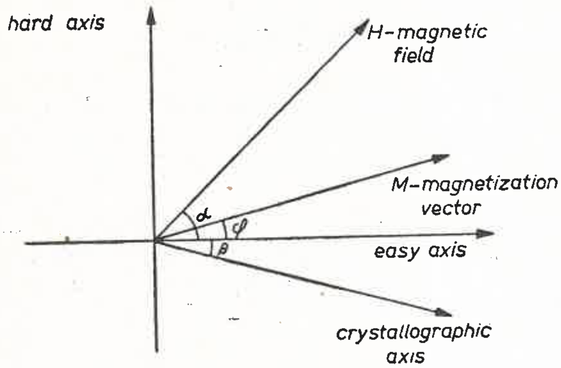

Fig. 1

where the quantity S in directly connected with the degree of texture in the sample.

From the equilibrium condition

$$\frac{d\mathscr{E}}{d\varphi} = \frac{1}{2}\sin 2\varphi - h\cdot\sin\varphi - \frac{1}{4}S\cdot\sin 4(\varphi-\beta) = 0 \tag{4}$$

TABLE I

β \ S	0	1	2	4
0°	$h_{kr} = -1$ $\varphi_1 = 0°$ $\varphi_2 = 180°$	$h_{kr} = -2$ $\varphi_1 = 0°$ $\varphi_2 = 180°$	$h_{kr} = -3$ $\varphi_1 = 0°$ $\varphi_2 = 180°$	$h_{kr} = -5$ $\varphi_1 = 0°$ $\varphi_2 = 180°$
22°30′	$h_{kr} = -1$ $\varphi_1 = 0°$ $\varphi_2 = 180°$	$h_{kr} = -1.15338$ $\varphi_1 = 35°33'$ $\varphi_2 = 186°06'$ $h = \frac{\frac{1}{2}\cos 4\varphi - \sin 2\varphi}{2\sin\varphi}$	$h_{kr} = -1.50509$ $\varphi_1 = 37°58'$ $\varphi_2 = 189°14'$ $h = \frac{\cos 4\varphi - \sin 2\varphi}{2\sin\varphi}$	$h_{kr} = -2.22898$ $\varphi_1 = 39°24'$ $\varphi_2 = 192°05'$ $h = \frac{\cos 4\varphi - \frac{1}{2}\sin 2\varphi}{\sin\varphi}$
40°	$h_{kr} = -1$ $\varphi_1 = 0°$ $\varphi_2 = 180°$	$h_{kr} = -0.85098$ $\varphi_1 = 50°40'$ $\varphi_2 = 185°00'$ $h = \frac{\frac{1}{2}\sin(4\varphi+20°) - \sin 2\varphi}{2\sin\varphi}$	$h_{kr} = -1.10087$ $\varphi_1 = 56°09'$ $\varphi_2 = 193°57'$ $h = \frac{\sin(4\varphi+20°) - \sin 2\varphi}{2\sin\varphi}$	$h_{kr} = -1.65162$ $\varphi_1 = 57°44'$ $\varphi_2 = 201°02'$ $h = \frac{\sin(4\varphi+20°) - \frac{1}{2}\sin 2\varphi}{\sin\varphi}$

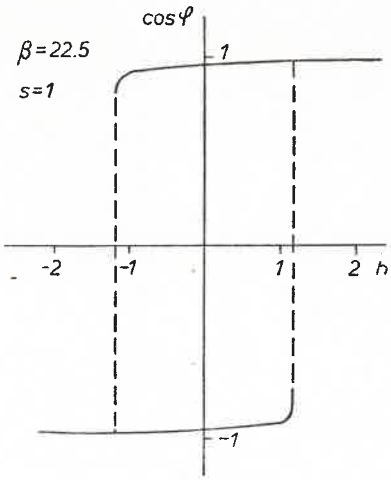

Fig. 2a

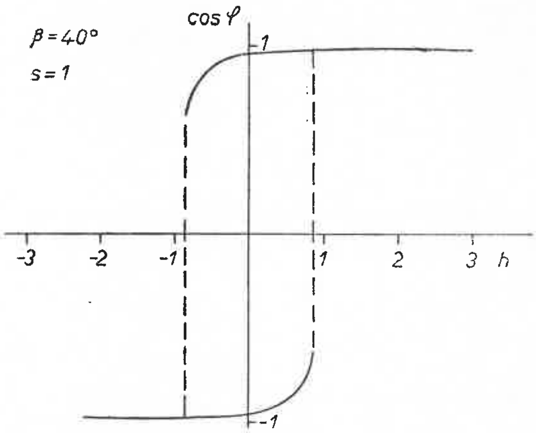

Fig. 2b

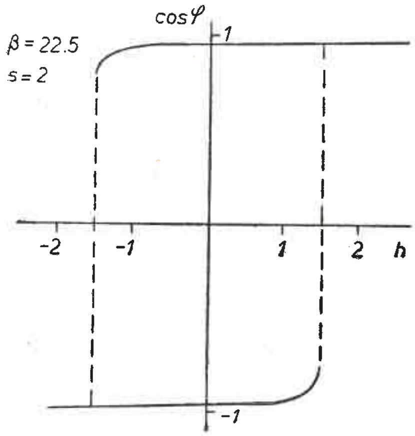

Fig. 2c

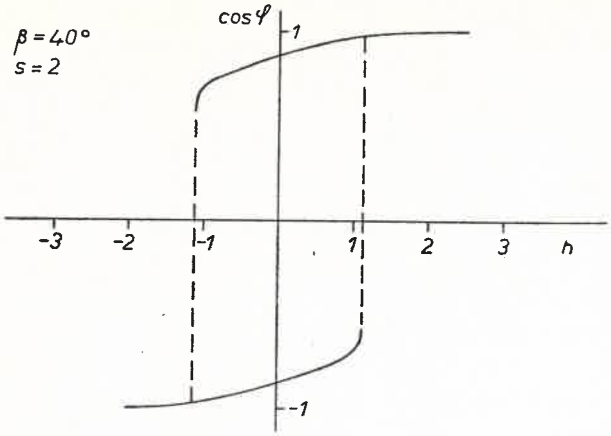

Fig. 2d

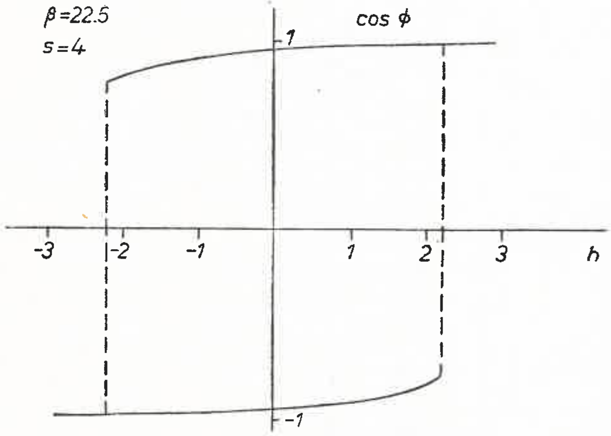

Fig. 2e

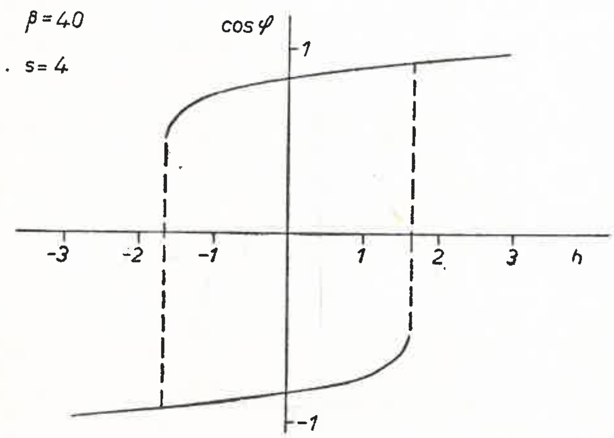

Fig. 2f

and from minimum-energy condition

$$\frac{d^2\mathscr{E}}{d\varphi^2} \geqslant \cos 2\varphi - h \cdot \cos \varphi - S \cdot \cos 4(\varphi - \beta) \tag{5}$$

one can find for given β and S the position of the magnetization vector depending on the value of the magnetic field h in normalized units.

On the basis of Eq. (4) the shape of the hysteresis loop in easy direction can be presented graphically. Likewise the value of the critical field can be found from Eq. (5).

The results are presented in Table I.

For $S = 0$, but for arbitrary β, there is no texture, what is equivalent to uniaxial anisotropy with a rectangular shape of the hysteresis loop. For $\beta = 0$, but for arbitrary S, there is a similar rectangular shape of the loop; in this case, however, the critical field h_{cr} depends on the degree of texture S, and is given by the formula

$$h_{cr} = -1 - S \tag{6}$$

For the other values of β and S given in the table the shapes of the calculated hysteresis loops are shown in Figs 2 *a–f*.

Conclusions

The method presented here may be used for investigating the texture of thin magnetic films on the basis of the shape of the hysteresis loop. The above considerations are valid as long as the magnetization vector remains in the plane of the thin film. This is so for films of thickness not larger than about 5000 Å, since for the thicker films a new type of domain structure, *i.e.* strip domains, may appear in which the magnetization vector is no longer in the film plane. Moreover the values of the critical fields obtained here are valid only for uniaxial single domains undergoing rotational flux reversal and not subject to wall motion. In other words, the critical field H_{cr} ought to be reached earlier than the coercive force H_c at which movement of walls occurs. Thus, some care should be taken during interpretation of the experimental results.

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