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THE EFFECT OF MAGNETOCRYSTALLINE ANISOTROPY
AND STRESS ON THE DOMAIN STRUCTURE
OF HIGH PERMEABILITY QUATERNARY ALLOYS

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Résumé. — L'effet magnéto-optique longitudinal a été utilisé pour étudier les domaines dans un alliage 77 Ni-14 Fe-5 Cu-4 Mo, avec $K_1$ voisin de zéro. La perméabilité initiale était $70 \times 10^3$. Des domaines de forme irrégulière, avec des parois bien définies, sont typiques. La taille des domaines était indépendante de $K_1$ dans un domaine de $-20$ à $+10$ J.m$^{-3}$. La tension produit des domaines en barres de largeur proportionnelle à $(\lambda_0 \sigma)^{-1}$. La perméabilité initiale décroît, et les pertes par courants de Foucault croissent avec la tension.

Abstract. — The longitudinal magneto-optic effect has been used to study domains in a 77 Ni-14 Fe-5 Cu-4 Mo alloy with $K_1$ close to zero. The initial permeability was $70 \times 10^3$. Irregularly shaped domains with well defined walls are typical. The domain size was independent of $K_1$ over a range from $-20$ to $+10$ J.m$^{-3}$. Tension produces bar domains of width proportional to $(\lambda_0 \sigma)^{-1}$. The initial permeability decreases and the eddy current loss increases with tension.

1. Introduction. — The first anisotropy constant $K_1$ of a quaternary alloy 77 Ni-14 Fe-5 Cu-4 Mo wt % varies from $-50$ J.m$^{-3}$ to $+25$ J.m$^{-3}$ depending on the cooling rate over a temperature range from 600°C to 300°C. At a cooling rate of about 90°C h$^{-1}$, $K_1$ is zero and initial permeabilities in excess of 10$^5$ are achieved in well annealed strain free specimens [1]. Infinite permeability is not achieved be cause of residual internal stresses which constitute an effective anisotropy $\simeq \lambda_1 \sigma_1$.

Almost nothing is known of the domain structure of low anisotropy material and it has been suggested that conventional structures do not exist.

Swindell [2] has measured the magneto-optic rotations for this alloy as a function of wavelength and angle of incidence. Domains should be observable provided surfaces of high optical quality can be prepared.

2. Experimental Work. — 2.1 Specimen Preparation. — High permeability material with a grain size of about 3 mm was prepared from the alloys described by Major and Martin [3]. Strip of 100 μ thickness was annealed at 1 100°C for 4 h in dry hydrogen. Rings or modified picture frames were etched from the strip and polished using standard lapping techniques. A single specimen was successively brought into varying states of order by variation of cooling rate from 10°C to 700°C per hour corresponding to $K_1 \simeq -20$ to $+10$ J.m$^{-3}$.

2.2 The Magneto-Optic Microscope. — The microscope was of standard design on the principles discussed by Treves [4] and Green [5]. Domain visibility was improved by coating the specimens with Zinc Sulphide and applying the double negative technique of Fowler and Fryer [6].

2.3 The Effect of External Stress. — Tension was applied to a double picture frame specimen, modified so that the clamped regions were not in the magnetic circuit. Assuming $\lambda_0 = 3 \times 10^{-7}$, the maximum tension produced an effective anisotropy of 8.2 J.m$^{-3}$ in 100 μ thick material.

2.4 Magnetic Measurements. — The initial permeability and loss of the single specimen being studied were measured at 400 Hz in a field of 50 μ Oe r. m. s. by an a. c. bridge method.

3. Estimation of Domain Sizes. — The magneto-static energy of the domain structure in figure 1 is

$$E_m = \frac{2}{1 + \mu^*} \times \frac{5.40 \times 10^8 L_0^2 a \sin^2 \theta}{d}$$

where $\mu^*$ is the permeability for rotation of the magnetic circuit out of an easy direction by a field normal to the surface. Thus $\mu^* \simeq L_0^2 \cos^2 \theta/2K$ and

$$E_m \propto Ka \tan^2 \theta$$

where $K$ is the total effective anisotropy. Since the wall energy is $\simeq 2(\lambda K)^{1/2}$ the optimum domain size is

$$a = \frac{0.27}{\tan \theta} \left(\frac{A}{K}\right)^{1/4}. \quad (1)$$

Enoch [1] estimates that $K$ is of the order 10 J.m$^{-3}$ whence $<a>$ is 450 μ for mean $\tan \theta$. The wall width is approximately $(A/K)^{1/2} = 0.9$ μ.

Fig. 1. — Model for estimation of domain sizes.
4. Results and Discussion. — Figure 2 shows typical domains in material cooled at 90 °C per hour and the probable ideal structure. The magnetostatic effects at the domain edges reduce the effect of the surface \( \mu^* \) and equation 1 will not hold. If \( \mu^* \) is completely discounted \( \langle a \rangle \approx K^{3/4} \). Thus the domain size tends to be independent of effective anisotropy.

The permeability is a maximum and the eddy current loss a minimum at \( K_1 = 0 \). The loss results indicate a minimum domain size at \( K_1 = 0 \), but the observations showed both increasing and decreasing domain size with variation of \( K_1 \). No correlation with grain orientation was observed.

Material for stress studies was cooled at 70 °C per hour to give an estimated value of \( K_1 = -2 \text{ J.m}^{-3} \). (Fig. 3) shows the effect of tension on the domain patterns. Well defined bars, closely aligned with the yaw angle of the nearest <100> direction are formed. The magnetization is parallel to the domain boundary. (Fig. 4) shows the variation of domain spacing with tension. The gradient of the line is \( (0.32 \pm 0.05) \) which supports the general validity of Equation 1. Thus when conventional bar type patterns exist in high permeability alloys the \( \mu^* \) effect is decisive in controlling domain sizes. The eddy current loss increases with decreasing domain size (Fig. 5) even though the structure is now similar to the theoretical models described by Lee [7].

References
[7] Lee (E.), IEE Monograph, 1960, No 371M.