INFLUENCE OF STRAIN ON SUSCEPTIBILITY AND STRUCTURE CONSTANT OF EVAPORATED NI-FE FILMS

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Résumé. — Des mesures de susceptibilité transversale ont été effectuées sur des couches minces de permalloy à anisotropie uniaxiale soumises à des contraintes appliquées soit suivant l'axe initial de facile aimantation, soit perpendiculairement. On en déduit la constante de structure S et l'anisotropie locale aléatoire K_s. La relation de K_s avec la contrainte a été étudiée sur plusieurs échantillons. Les résultats vérifient la théorie de Doyle et Finnegan [1].

Abstract. — Transverse susceptibility measurements were made on uniaxial permalloy films by changing the uniaxial strain applied parallel or perpendicular to the original easy axis. From this experiment, the structure constant S and the local random anisotropy K_s were estimated. The dependence of K_s on the strain was examined for several films having various values of K_s. The result in general coincides with the theoretical prediction of Doyle and Finnegan [1].

I. **Introduction.** — The magnetization ripple or the intrinsic part of the inhomogeneous anisotropy in uniaxial magnetic films is thought to originate from both the magnetocrystalline and the magnetoelastic anisotropies in the crystallites of the polycrystalline film. Recently Doyle and Finnegan [1] proposed a formula which combined these two anisotropies to the local effective anisotropy K_s,

$$K_s = \left[(K_1 + B_s \varepsilon_{33} + B_\sigma \sigma/4)^2 + (7/16)(B_\sigma \sigma)^2\right]^{1/2}, \quad (1)$$

where K_1 is the first magnetocrystalline anisotropy constant, ε_{33} is the uniaxial strain applied externally in the hard axis, σ is the intrinsic internal stress assumed to be homogeneous in the film plane, and B_s and B_σ are appropriate magnetoelastic coupling constants which are connected with the magnetostriction constants λ_{100} and λ_{111} as follows ;

$$\left.\begin{aligned} B_\sigma &= (3/2)(\lambda_{100} - \lambda_{111}), \\ B_s &= -3\, c_{44}\, \lambda_{111} + (3/2)(c_{11} - c_{12})\, \lambda_{100} \end{aligned}\right\} \quad (2)$$

In eq. (2), c_{11}, c_{12}, and c_{44} are the elastic constants.

The purpose of this work is to check this formula experimentally by applying the uniaxial strain to the film. A similar trial was made by Doyle and Finnegan themselves [1]. They investigated K_s by the measurement of the susceptibility which, after a theory of Hoffmann [2], is strongly influenced by K_s. Doyle and Finnegan found only a qualitative agreement between theory and experiment. The reasons for the quantitative failure are : i) the susceptibility theory [2] was applied outside of its range of validity (which was not known at the time of their investigations), ii) the skew and its influence on the susceptibility was not taken into account.

In the present experiment, great cares are paid on these points, and we succeeded in getting quantitative agreement between the theory and the experiment.

II. **Experimental method.** — According to the susceptibility theory [2], the transverse susceptibility χ_t, which is measured with a dc bias field H, applied in the hard direction, and a small tickle field, applied in the easy direction, is given by

$$\chi_t = \chi_0 / \{ h - 1 + B(h-1)^{-1/4} \} \qquad (\chi_0 = M_s/H_k, \quad h = H/H_k), \quad (3)$$

where M_s is the saturation magnetization, H_k is the anisotropy field, and B is the effective field which is given as

$$B = \{ d^{1/2}/\pi(2\, AH_k)^{4/5}\, M_s^{1/4} \}\, S^2, \quad (4)$$

$$S = D^{3/2}\, d^{-1/2}\, \sigma_1\, K_s, \sigma_1 = (8/105)^{1/2}. \quad (5)$$

In these equations, d is the film thickness, A is the exchange constant, S is the structure constant, and D is the mean diameter of the crystallites. The eq. 3 is valid only as long as the film area under investigation is free from any skew.

Now, if we measure the dependence of χ_t on h, we can determine the value of B from eq. 3 followed by the determination of S and K_s through the eq. 4 and 5. In actual experiment, however, some attentions have to be paid in comparing the experimental dependence with eq. 3. The most important point is that the comparison should be made above the blocking field h_a, namely $h > h_a = 1 + B^{4/5}$, which usually is somewhat larger than the field for the peak susceptibility. Other points are in the determination of zero level and in that of the proportional constant between the output signal and χ_t. For these purposes, three points fitting method [3] was used.

In order to remove the effect of the skew, the susceptibility was measured either on a small region in a film by the use of Kerr magneto-optic apparatus or measured for films having small over all fall back angle ($\alpha_{90} < 1.5$ degrees).

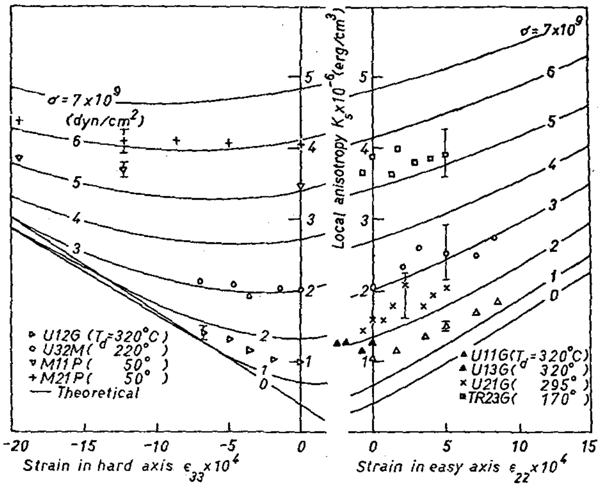
Precise determination of H_k was requested to have correct value of B, and the modified Kobelev method [4] was used.

Films were deposited on thin glass substrate or on some flexible materials such as mica or polycarbonate resin. (They are designated by the final character of the film number as G, M, and P respectively as seen in the figure.) Deposition temperature was changed from room temperature to 320 °C in order to have various values of K_s. Film composition was forced to be around 81.5 % Ni. Otherwise, the value of H_k changes so greatly by the application of the strain that this made the determination of B very difficult.

Uniaxial strain was applied either in the hard axis (ε_{33}) or in the easy axis (ε_{22}) by bending the substrate in an appropriate way.

III. Result and conclusion. — The final result is summarized in the figure where the dependence of the local anisotropy K_s on the uniaxial strain is shown. In this figure, the solid curves give the theoretical dependences calculated from Doyle Finnegan formula for 81.5 % Ni ($K_1 = -4 \times 10^3$, $B_\sigma = 10^{-5}$, $B_s = 1.3 \times 10^7$ all in c. g. s. unit) taking the internal stress σ as a parameter. Of course, eq. 1 says only about the hard axis strain ε_{33}, so we extend their theory to the case of the easy axis strain ε_{22}. The result is as follows ;

$$K_s = [(K_1 + B_\sigma \sigma/4 - 3 B_s \varepsilon_{22}/4)^2 + (7/16)(B_\sigma \sigma + B_s \varepsilon_{22})^2]^{1/2} . \quad (6)$$



The dependences of the local anisotropy K_s on the uniaxial strain applied in the hard axis (ε_{33}) and in the easy axis (ε_{22}). Solid curves are calculated from the Doyle-Finnegan formulae eq. 1 and 6 taking $K_1 = -4 \times 10^3$, $B = 10^3$, and $B_s = 1.3 \times 10^7$ in c. g. s. unit. For some experimental points, the limits of the experimental error are shown which are estimated from the five independent experiments.

It is seen from this figure that the quantitative agreement between the experiment and the theory is good as a whole for the alloy composition under investigation. Former measurements of Schmitt [5] gave the following homogeneous strains for 81-19 Ni-Fe films evaporated on to glass substrates :

$T_d = 320$ °C $\sigma = 1 \times 10^9$ dyn. cm^{-2},

$T_d = 295$ °C $\sigma = 1 \times 10^9$,

$T_d = 220$ °C $\sigma = 1.8 \times 10^9$,

$T_d = 170$ °C $\sigma = 3 \times 10^9$.

These are just the values which are needed for the quantitative agreement between theory and experiment. In this way, it may be safe to conclude that the theory of Doyle and Finnegan is correct.

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