Letters to the Editor

SPONTANEOUS MAGNETIZATION OF THIN FERROMAGNETIC FILMS

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IT is known that when thin ferromagnetic films are deposited on an isotropic substrate, they acquire a uniaxial anisotropy, even in the case of perpendicular incidence of the metal ions (the anisotropy that occurs with angle of incidence less than 90° will not concern us here). Málek, Schüppel, et al.[1,2] conducted elegant experiments that demonstrated that this anisotropy occurs spontaneously, together with the appearance of ferromagnetism, at a certain film thickness, independently of whether or not an external magnetic field was applied to the film at the time of deposition. They studied certain properties of the spontaneous anisotropy, and they presented a hypothesis that attributes the occurrence of the anisotropy to a definite orientation of interacting pairs, formed by atoms of the ferromagnet and by defects.

In a thin film, in contrast to bulk polycrystals, the vector $\mathbf{I}_S$ upon appearance of ferromagnetism orients itself along a single direction throughout the whole film (the film either is magnetized to saturation or breaks up into domains with oppositely directed magnetizations). This direction is random when the film is deposited in the absence of an external field; when the deposition occurs in a magnetic field, the selected direction coincides with the direction of the field (or is close to it). Therefore the pairs of ferromagnet atoms and defects in any case are oriented by the internal field (from the requirement of minimum energy of the demagnetizing field) along a direction that is common to the whole polycrystalline film.

Another mechanism capable of leading to the occurrence of spontaneous anisotropy is proposed here; it is connected with magnetostriction. Upon appearance of spontaneous magnetization, magnetostrictive deformations of the film material occur. A circular region on the film surface elongates under the influence of magnetostriction (for $\lambda > 0$) to an ellipse in the direction of $\mathbf{J}_S$. It is such a deformed film that will adhere to the substrate. Magnetizing the film in the perpendicular direction entails doing work against the forces of adhesion of the film to the substrate (and of the individual "crystallites" to one another). The difference in magnetoelastic energy between the original and the perpendicular magnetizations of the film is

$$\Delta f_{me} = {}^3/_2 \lambda \sigma, \tag{1}$$

where σ is the stress produced by the magnetostrictive deformations. From the known relation of the stresses to the deformations, in the case of isotropic magnetostriction, we get

$$\sigma = E\lambda/(1+\nu)$$

(E = Young's modulus, ν = Poisson's ratio). Consequently the difference in magnetoelastic energy density, or the effective constant of spontaneous anisotropy, is

$$K_1' = 3E\lambda^2/2(1+\nu). \tag{2}$$

The values of E and ν for different materials do not differ greatly; and it may be assumed that the values measured on bulk specimens can be used for thin films. For the magnetostriction constant, such an assumption is appreciably further from correctness. But since the magnetostriction of thin films is not known, we shall use the bulk values for preliminary estimation. On taking[3] $\lambda = -7 \times 10^{-6}$ for iron and -34×10^{-6} for nickel, we get for the effective anisotropy constants 1.1×10^2 and 2.34×10^3 erg/cm^3, respectively.

Verification of this hypothesis can be accomplished either by direct measurement of the quantities that appear in formula (2) or by an indirect method. For example, the spontaneous anisotropy should diminish on separation of the film from the substrate; stronger adhesion of the film to the substrate should be associated with greater stability of the position of the anisotropy axis; etc.

The hypothesis presented here and the hypothesis advanced in references 1 and 2 appear not to be mutually exclusive.

[1] Z. Málek and W. Schüppel, Ann. Physik **6**, 252 (1960).

[2] Z. Málek, W. Schüppel, O. Stemme, and W. Andrä, Ann. Physik **5**, 211 (1960).

[3] C. Kittel, Revs. Modern Phys. **21**, 541 (1949).

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