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CONDITIONS FOR STRESS-INDUCED UNIAXIAL ANISOTROPY IN MAGNETIC MATERIALS OF CUBIC SYMMETRY*

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ABSTRACT

Uniaxial magnetic anisotropy may be induced in materials of cubic symmetry by the application of either planar stress or uniaxial stress normal to the plane. It is proven theoretically that either situation will produce the same result provided that the stress is of the same magnitude but opposite sign. From theory, the conditions for effective uniaxial anisotropy are derived for the {001}, {110}, and {111} families of planes, and possible applications are discussed from this standpoint. Of the three families, the {001} is the simplest and most desirable for this effect, while uniaxial anisotropy can be achieved for {111} planes only when the stress effects overwhelm the cubic magnetic anisotropy.

Introduction

The effect of external stress on magnetic anisotropy has been a subject of renewed interest in recent years. Remanent magnetization is affected by uniaxial stress in both microwave ferrites (1) and ferromagnetic metal tapes (2). A theoretical analysis of this effect has revealed that the hard-axis magnetostriction constant controls the changes in remanence properties (3). Another area where stress effects have received attention is in ferrimagnetic films for cylindrical domain device applications. In this case, the stress is biaxial and in the plane of the film. A partial analysis of this situation has been reported (4), and cylindrical domains have been observed in epitaxial films grown on substrates with different thermal expansion coefficients to create the planar stresses necessary for stress-induced uniaxial anisotropy (5).

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Since the uniaxial anisotropy induced by stress is produced by movement of the easy and hard axes of magnetization, the conditions for uniaxial anisotropy may be readily derived from the theory previously outlined (3). The purpose of this paper is to set up the general solution by proving that the planar stress situation may be simplified by treating it as a uniaxial stress along the normal to the plane, and to determine the conditions for stress-induced uniaxial anisotropy with the easy axis perpendicular to the three major families of planes, i.e., {001}, {110}, and {111}.

Theory

The total magnetic anisotropy energy E of a single crystal may be expressed as the sum of three terms which combine the effects of magnetocrystalline anisotropy (E_K), stress anisotropy (E_σ), and shape anisotropy (E_S), such that

$$E = E_K + E_\sigma + E_S \ . \tag{1}$$

For a material of cubic symmetry with magnetocrystalline anisotropy constant K_1, the associated energy is given by (6)

$$E_K = K_1(\alpha_1^2\alpha_2^2 + \alpha_2^2\alpha_3^2 + \alpha_3^2\alpha_1^2) \tag{2}$$

where α_i represent the direction cosines of the magnetization vector with reference to the $\langle 001\rangle$ cubic axes. In spherical polar coordinates, Eq. (2) becomes

$$E_K = K_1(\sin^4\theta\sin^2\phi\cos^2\phi + \sin^2\theta\cos^2\theta) \ . \tag{3}$$

If a uniaxial compressive stress σ is applied to the same material with magnetostriction constants λ_{100} and λ_{111}, the stress anisotropy term in given by (6)

$$E_\sigma = \frac{3}{2}\sigma\lambda_{100}(\alpha_1^2\gamma_1^2 + \alpha_2^2\gamma_2^2 + \alpha_3^2\gamma_3^2) + 3\sigma\lambda_{100}(\alpha_1\alpha_2\gamma_1\gamma_2 + \alpha_2\alpha_3\gamma_2\gamma_3 + \alpha_3\alpha_1\gamma_3\gamma_1) \ , \tag{4}$$

where γ_i represent the direction cosines of σ relative to the cubic axes. A biaxial or planar stress may be represented by two orthogonal components of equal magnitude σ having cosines γ_i and γ_i' (7), so that Eq. (4) becomes

$$E_\sigma = \frac{3}{2}\sigma\lambda_{100}\sum_i \alpha_i^2(\gamma_i^2 + \gamma_i'^2) + 3\sigma\lambda_{111}\sum_{i<j}\alpha_i\alpha_j(\gamma_i\gamma_j + \gamma_i'\gamma_j') \ . \tag{5}$$