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SURFACE ACOUSTIC WAVE ATTENUATION IN THIN FERROMAGNETIC FILMS*

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Abstract - Experimental results on the thickness and composition dependence of surface acoustic wave attenuation in thin films of nickel and nickel-iron alloys are discussed.

Introduction

The phenomenon of magnetic field dependent high frequency surface acoustic wave (SAW) attenuation in thin films of Ni and Ni-Fe films /1,2,3,4/ provides a method for characterizing the magnetic parameters of such films and offers the possibility of important technological applications. In single domain magnetic films which may be characterized by an in-plane magnetization M related to a uniaxial anisotropy field H_A ; i.e. films in which the Stoner-Wohlfarth model /5/ for coherent magnetization reversal is applicable, the SAW-film attenuation mechanism may be modeled as being essentially due to a variation in M via a SAW-induced (through inverse magnetostriction) variation ΔH_A of the films anisotropy field H_A . Solution of a linearized form of the Gilbert damping equation for small variations of M about its equilibrium position as determined by a free energy equation appropriate for a single-magnetic-domain uniaxially anisotropic film leads to an imaginary component of magnetic susceptibility and hence provides a mechanism for SAW energy dissipation, $E_d(H_A, H, M, G)$, where H is an externally applied in-plane magnetic bias field and G is the Gilbert damping parameter /2/. For the case of either $H \parallel k$ or $H \perp k$ where k is the SAW propagation vector, E_d the energy dissipation per unit volume per cycle is given

$$E_d = \frac{\pi \left(\frac{\Delta H_A}{2} \sin 2\theta_0 \right)^2 [B^2 + H_s^2 (1 + G^2)] H_s M}{[AB - H_s^2 (1 + G^2)]^2 + [GH_s(A+B)]^2} \quad (1)$$

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$$\text{where } A = H_A \cos 2(\theta_0 - \phi) + H \sin \theta_0$$

$$B = H \sin \theta_0 + 4\pi M$$

θ_0 = equilibrium position angle of M with respect to k

ϕ = Angle of the film's uniaxial anisotropy axis with respect to k

$H_S = \omega/\gamma$ where ω is the angular frequency of SAW, and γ the magneto-mechanical ratio

$\Delta H_A = \eta_e$ where η = magnetoelastic coupling coefficient and e = strain due to SAW

Then the SAW attenuation per centimeter is given by

$$\alpha = 8.686 \frac{fE_d}{VE} \text{ dB/cm}$$

where E , F , and V are, respectively, the total energy density, frequency and velocity of the SAW.

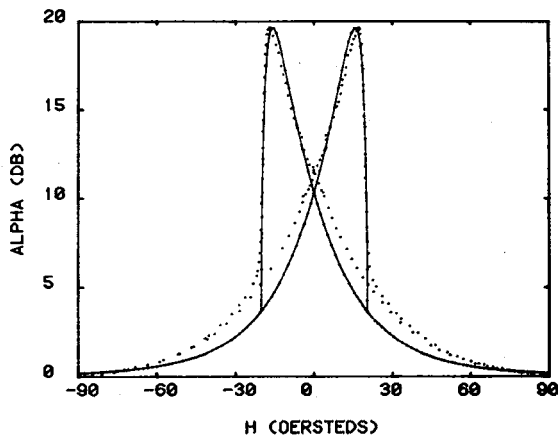


Fig. 1 - Typical $\alpha(H)$ curve for a 250\AA nickel film at 618 MHz. The solid curve is the theoretical fit, in arbitrary attenuation units, to the experimental curve (dots) generated by using $H_A = 40$ Oe, $\phi = 53.3^\circ$, and $G = 0.11$ in Eq. 1.

As shown in Figure 1, it is possible to qualitatively fit many experimental data by using reasonable values for the important film parameters H_A , G , and ϕ (and the bulk value of M) in Eq. 1. Experimentally it has been found that α is strongly dependent on film thickness /2,3,4/, composition /3/, temperature /2,6/ and in-plane static tensile strain /6/ which in the context of Eq. 1 may imply corresponding dependencies of H_A , G , and ϕ on these external variables. Departures from the idealized single domain structure i.e., the occurrence of magnetization ripple and even multiple domain structure may be responsible for the behavior of those samples whose response can only poorly be fit by Eq. 1.

In this paper we will discuss the experimentally observed thickness dependence of the SAW attenuation response of nickel and nickel-iron alloy films. However for these thickness dependence curves, it appears that neither magnetization ripple nor magnetic domain wall transitions provide an adequate model for explaining our observations.

Experimental Details

Thin films of Ni or Ni-Fe alloys were deposited between SAW interdigital transducers on quartz substrates by evaporation from tungsten sources in a vacuum of 5×10^{-7} torr. A Matec ultrasonic attenuation system was used to perform in situ attenuation measurements during the process of film deposition while film thickness was registered on a digital thickness monitor. Thus $\alpha(H = 0)$ vs thickness, T , curves such as that of figure 2 were generated during formation of the samples.

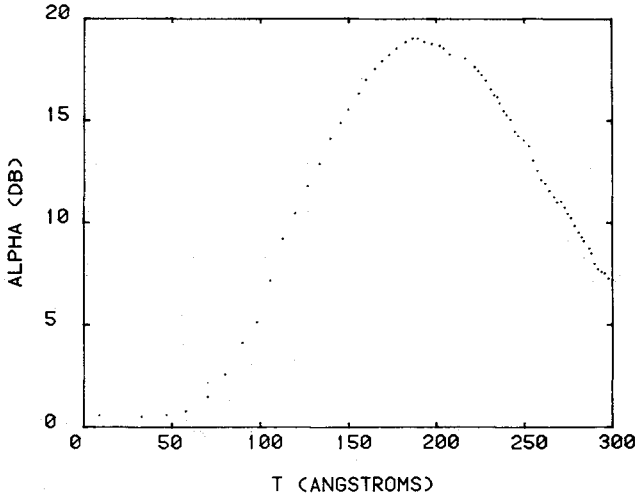


Fig. 2 - Typical α vs T curve for Ni at 700 MHz.

Results and Discussion

Figure 2 shows a typical α vs T curve for a 100% Ni film at 700 MHz. The initial sharp peak in α at about 20Å thickness are thought to be due to coupling of the SAW to the film through piezoelectrically induced film currents *77*. For each film a broad peak in the α vs T curve is observed; for 100% Ni the maximum

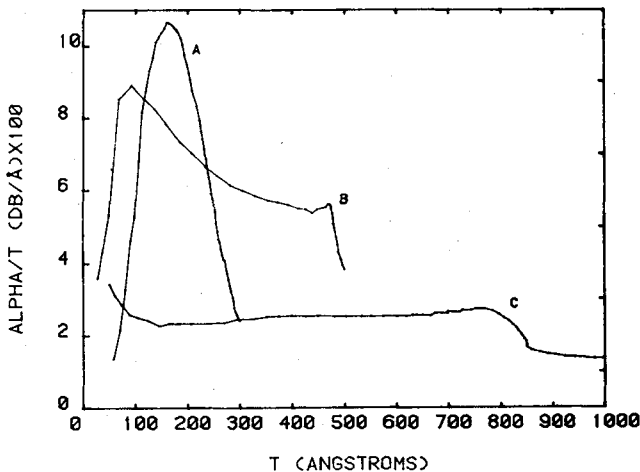


Fig. 3 α/T vs T for three film compositions at 700 MHz: Curve A, Ni 100%; Curve B, NiFe 95:05 weight %; curve C, NiFe 90:10 weight %.

at about 200Å corresponds to the film thickness for which maximum magnetic field response is observed. As film composition becomes more iron rich the positions of the broad peaks shift to greater thicknesses while for Ni-Fe 85:15 wt. % (not shown) α continually increases with thickness and no peak is observed /4/. If one may assume that the films have a single domain structure at least within some range of thicknesses then, in the context of our model, it is reasonable to assume that α should be proportional to the film thickness when the thickness is much smaller than the wavelength of the SAW /8/. Thus to see the intrinsic behavior of the film excluding this linear thickness dependence we have plotted α/T vs T in Figure 3. The resulting curve for 100% Ni may be fit by a Gaussian; the curve for Ni-Fe 90:10 appears to be a step function while that of Ni-Fe 95:05 appears to be some combination of the first two. It may be possible that magnetization ripple effects increasingly contribute to deviation from the ideal Stoner-Wohlfarth type film behavior as thickness is increased, however the magnetization ripple models of Hoffmann /9/, Harte /10/ and Feldtkeller /11/ do not provide features in their thickness dependences /12/ which correlate with the experimental curves of Figure 3. Another possibility could be that the film thickness corresponding to transitions between Neel walls, cross-tie walls and Bloch walls might correlate with the positions of the maxima in the insertion loss curves. Calculations by Middelhoek /13/ on permalloy (Ni-Fe 80:20) films indicate a cross-tie to Bloch wall transition at about 900Å. Further refinement of the domain wall model yields a Neel to cross-tie transition at 200Å. We have repeated the calculation for a film of 100% Ni and find a transition from cross-tie to Bloch wall at about 2100Å, while through extrapolation of Middelhoek's results for the energy of cross-tie walls at small thicknesses we find a transition from Neel to cross-tie walls at 210Å. Unfortunately these transitions appear to go in the opposite direction with alloying compared to the positions of the maxima in the insertion loss curves.

It is seen that at present, an adequate model for explaining the thickness dependence of SAW attenuation in magnetic thin films has yet to be developed; as this paper indicates it would seem that neither domain wall transitions nor magnetization ripple (as given by the standard theoretical treatments) play a direct role in the observed thickness dependence. Currently we are modifying our experimental setup in order to be able to check the hypothesis that film substrate stresses may provide the dominant mechanism for determining the effect.

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