Reprinted from JOURNAL OF APPLIED PHYSICS, Vol. 39, No. 2, (Part I) 857–858, 1 February 1968
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A Comparison of the Losses for Domain-Wall Motion and Ferromagnetic Resonance in Thin Ni–Fe Alloy Films

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The connection between the losses for domain-wall motion and ferromagnetic resonance in Ni–Fe thin films has been investigated by examining the thickness dependence and temperature dependence of the wall mobility and the linewidth for resonance with the static magnetic field in the plane of the film. The losses at room temperature were compared in terms of Landau–Lifshitz damping parameters for the two processes. The wall-motion damping is approximately equal to 0.014 independent of thickness while the resonance damping increases from 0.005 at 200 Å to 0.010 at 3000 Å. In view of the large differences in damping for wall motion and resonance at 300°K, the relaxation mechanism(s) which contribute to the losses at 300°K in each case must be quite different. The losses as a function of temperature have been compared on the basis of changes in linewidth and mobility between 300°K and 77°K. The linewidth for films is known to exhibit a peak at about 77°K. The wall mobility at 300°K and 77°K has been obtained from Kerr observations (300°K) and flux reversal measurements (300°K and 77°K) for films 150 to 1350 Å thick which exhibited, to varying degrees, the above linewidth peak. A strong correlation between linewidth increase and mobility decrease from 300°K to 77°K was observed. The largest mobility decrease observed was from 1.7×10^4 to 8×10^3 cm/sec·Oe for a particular 150-Å film which exhibited a linewidth increase of 15 Oe (from 10 to 25 Oe at 4 Gc/sec). The increase in the losses for wall motion was directly related to the increase in the losses for resonance from 300°K to 77°K. The relaxation processes which contribute to the temperature dependence of the resonance linewidth are important in limiting domain-wall motion in Ni–Fe alloy films.

Many investigators have been interested in either domain-wall motion or ferromagnetic resonance in thin films, but no systematic attempt to connect the losses for the two processes has been reported. A comparison of wall-motion and resonance losses has been made on the basis of room-temperature data, as was done for flux reversal and resonance in films by Conger and Essig[1] and on the basis of the wall mobility and resonance-linewidth temperature dependence as was done by Dillon and Earl[2] for Mn ferrite and Wanas[3] for Si-doped YIG. The extension of the approach based on the linewidth and mobility temperature dependence to thin films is particularly appropriate in light of recent developments in the understanding of the resonance-linewidth temperature dependence for Ni–Fe films by Patton and Wilts.[4]

The Ni–Fe alloy films were evaporated from a melt of 80% Ni and 20% Fe onto glass substrates at 300°C in a vacuum of 10^{-6} Torr. Linewidth measurements were made at 300°K and 77°K utilizing stripline excitation at frequencies from 1–9 Gc/sec, field modulation, and phase-sensitive detection, with the static magnetic field in the plane of the film.[4] Domain-wall mobility measurements at 300°K were made utilizing a quasi-static technique and the Kerr magneto-optic effect.[5] Such an optical technique is not easily adaptable to use at lower temperatures. However, switching data for flux reversal by wall motion can be related to the wall mobility. By comparing switching data at 300°K and 77°K for which the switching voltage waveforms are similar, the wall configurations during reversal can be assumed to be nearly the same at the two temperatures. With this assumption, the ratio of the wall mobilities at 77°K and 300°K can be obtained as the ratio of the slopes of the corresponding switching curves (inverse switching time vs easy axis field). From this ratio and the mobility at 300°K, the mobility at 77°K can be obtained. A modification of this technique was used by the authors with the hard-direction field instead of temperature as the variable.[6] It was also used to obtain the mobility for wall motion in laminated Ni–Fe films.[7]

A convenient basis of comparison for the resonance

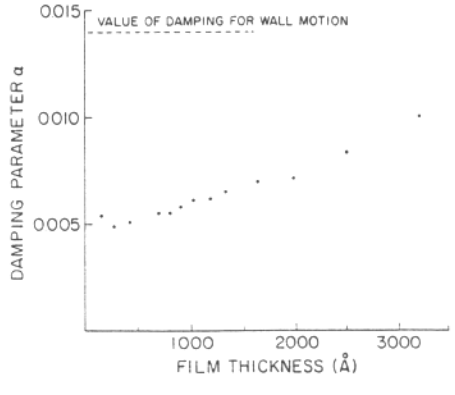

FIG. 1. Landau–Lifshitz damping α as a function of film thickness for domain-wall motion (dotted line) and ferromagnetic resonance with the static magnetic field in the film plane (data points) for 80–20 Ni–Fe alloy films.

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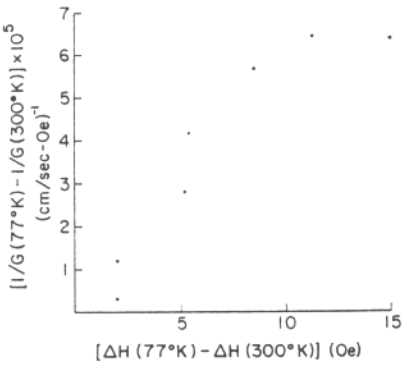

FIG. 2. Correlation of the change in losses from 300°K to 77°K for domain-wall motion ($1/G_{77°K}-1/G_{300°K}$) and resonance ($\Delta H_{77°K}-\Delta H_{300°K}$).

and wall-motion losses at room temperature is the Landau–Lifshitz damping parameter α. The thickness dependence of the damping for the two processes, obtained from wall-mobility and linewidth data at 300°K, is shown in Fig. 1. For wall motion, α is approximately equal to 0.014.[5] For resonance, α increases from 0.005 for $D\approx300$ Å to 0.010 for $D\approx3000$ Å. The large differences in the damping for resonance and wall motion at 300°K indicate that there are important differences in the relaxation mechanism(s) which contribute to the losses in each case. The thickness dependence of the linewidth (and the damping) has been explained in terms of magnon scattering.[8] From Ref. 8, for spin-wave frequencies in the Mc/sec range which are appropriate for wall motion,[3] such scattering should not be important for films in the thickness range considered here and should not contribute to the wall-motion losses. Most of the wall-motion damping (at least $\frac{2}{3}$ from Fig. 1) must come from relaxation processes which are not important for resonance.

While damping parameters for wall motion and parallel resonance in thin films are quite different at room temperature, a definite connection between the losses for the two processes can be obtained from the temperature dependence of the mobility and linewidth. Recently, Patton and Wilts[4] have reported a significant temperature dependence of the linewidth ΔH for thin films. The linewidth exhibits a maximum near 80°K and the effect is generally larger in thinner films. The amplitude of this temperature dependence can be reproducibly enhanced by heating the film at 150°C in air or eliminated by a similar treatment in hydrogen. The apparent importance of surface oxidation suggests two possible mechanisms, valence exchange[9] and exchange anisotropy,[10] which may contribute to the temperature dependence (as discussed in Ref. 4). If the same processes are of importance for wall motion, a decrease in the mobility between 300°K and 77°K should occur which is related to the linewidth increase between the two temperatures.

Wall mobilities at 77°K and 300°K have been obtained for a number of films between 150 and 1350 Å thick which exhibited linewidth increases at 77°K over $\Delta H_{300°K}$ by amounts ranging from 2 to 15 Oe, all of which had $\Delta H_{300°K}$ 10 Oe at 4 Gc/sec. The linewidth increase was independent of frequency.[4] Mobility decreases ranging from 8.9×10^3 cm/sec·Oe (corresponding to the 15-Oe linewidth increase) to 0.8×10^3 cm/sec·Oe (corresponding to the 2-Oe linewidth increase) were measured. Room-temperature mobilities ranged from 8×10^3 to 2×10^4 cm/sec·Oe, depending on thickness. The correlation between the increase in the losses from 300° to 77°K for wall motion and parallel resonance is shown in Fig. 2. The increase in reciprocal wall mobility from 300° to 77°K is plotted as a function of linewidth increase between the two temperatures. As can be seen by Fig. 2, the correlation between the loss increase for the two processes is quite good. Those films which exhibit an increase in the losses for resonance at 77°K also exhibit an increase in the wall-motion losses. It can be concluded, therefore, that there is a definite connection between the relaxation processes which contribute to the linewidth temperature dependence and the losses which limit wall motion.

In summary, wall mobilities for Ni–Fe films have been obtained at 300°K and 77°K from Kerr observations, and flux-reversal data and the losses for wall motion have been compared to the losses for parallel resonance. The data indicate that: (1) There are important differences in the relaxation mechanisms which contribute to the wall-motion and resonance losses at 300°K. (2) The relaxation processes which contribute to the temperature dependence of the resonance linewidth are important in limiting domain-wall motion.

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