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Domain Wall Motion in Multilayered Magnetic Thin Films

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In order to determine whether increased domain wall mobility is a possible explanation for the anomalously fast flux reversal observed in laminated films, the details of wall motion have been investigated for multilayer samples with from one to five 350-Å Permalloy layers separated by 100-Å layers of SiO, as well as for thick 1500-Å films. Kerr effect quasistatic wall mobility measurements were made for the one- and two-layer 350-Å films and the 1500-Å films, yielding mobilities of 9.2×10^3, 6.0×10^3, and 8.6×10^3 cm/sec·Oe, respectively. Bitter patterns were used to confirm the existence of Néel walls in the single-layer 350-Å films. The pulse conditions for these measurements produced locked Néel walls in the double films, as confirmed by Kerr effect observations. Bloch walls occur in the 1500-Å films. Low-drive domain-wall-motion flux-reversal experiments were performed for all the laminated films, yielding S_w's of 1.9, 1.7, 1.9, 1.8, and 2.1 Oe·μsec, respectively. For linear switching curves the slopes $(1/S_w)$ are taken to be proportional to the domain-wall mobility. The measured mobilities for the single and double 350-Å films and the 1500-Å films do not differ significantly. The S_w values for all the laminated films are nearly equal. This mobility and switching data indicate that the anomalously fast flux reversal in laminated films can not be attributed to a mechanism involving domain wall motion.

ANOMALOUSLY fast flux reversal has been reported[1] in laminated Permalloy films for drive fields below the anisotropy field, where domain wall motion is usually the dominant reversal mechanism. In order to determine whether a higher wall mobility is a possible explanation for this effect, Néel wall mobilities were investigated for multilayer samples with from one to five 350-Å Permalloy layers separated by 100-Å layers of silicon monoxide. Comparison was made with Bloch wall mobilities in 1500-Å films. The measured mobilities are all nearly equal, but are not in agreement with mobilities calculated on the basis of intrinsic damping and a static wall shape, except for Néel walls in single layers. For Bloch walls, the calculated mobility is too low by a factor of ten and for locked walls it is too high by a factor of four. Nevertheless, the measured mobilities clearly indicate that the fast flux reversal in laminated films can not be due to a wall motion mechanism.

The Permalloy films used in this study were vacuum evaporated from a melt of 80% Ni and 20% Fe, onto a hot (300°C) glass substrate in a moderate (10^{-6} Torr) vacuum. For the 1500-Å films and the 350-Å single- and two-layer films, domain-wall-mobility measurements were carried out by pulsing the films with small ($H\approx H_c$) easy axis field pulses of long duration (10–50 μsec) and observing domain wall positions using the Kerr magneto-optic effect. As shown in Fig. 1, these pulse conditions produce simple wall configurations and systematic displacements of the walls after successive applications of the field pulse. Wall velocities, as determined from the wall displacements and the pulse lengths, were found to vary linearly with the easy axis field amplitude. A typical velocity versus field plot is shown in Fig. 2. The slope of this curve is the domain wall mobility. Through the use of the long pulses and extremely low-drive fields ($H\approx H_c$), the difficulties in this technique encountered by Copeland[2] and Ford[3] were avoided. Bitter patterns were used to confirm the existence of Néel walls, rather than crosstie walls, in the single layer 350-Å films. The existence of locked

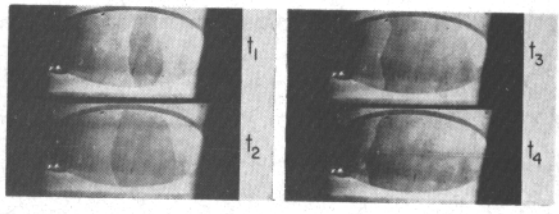

FIG. 1. Kerr effect observations of the simple wall configurations and the systematic wall displacements after successive application of four field pulses, t_1 through t_4.

Néel walls,[4–6] where the magnetization rotates in an opposite sense for two parallel 180° Néel walls juxtaposed in adjacent magnetic layers, was confirmed by Kerr effect observations on both sides of the double films. Direct mobility measurements were not made for films with more than two layers. However, low-drive domain-wall-motion flux-reversal experiments were performed for all the laminated films. The technique used was the same as reported previously,[7] in which the slopes of linear $1/\tau$ vs H curves (denoted by $1/S_w$) were taken to be proportional to wall mobilities.

As has been previously established,[7] the equation:

$$V=(2MH/K)\left[\int_{\text{wall}}(d\theta/dx)d\theta\right]^{-1} \qquad (1)$$

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may be employed to relate the domain wall velocity to a particular wall shape. This expression assumes a steady state 180° wall shape, $\theta(x)$, and a damping torque of the form $Kd\theta/dt$. The damping K expressed in terms of the Landau–Lifshitz intrinsic damping parameter[8] α is equal to $M\alpha/\gamma$, where the magnetization M is 800 emu for Permalloy, α is approximately 0.014 for domain wall motion,[2] and γ, the gyromagnetic ratio, is 1.76×10^{7} $Oe^{-1}\cdot sec^{-1}$. For Bloch walls, the integral in Eq. (1) was approximated using a linear wall shape and a wall width as calculated by Brown and LaBonte.[9] For the Néel walls in single 350-Å layers, and for locked Néel walls in double films, this integral was evaluated on the basis of recent Lorentz microscopy static wall-shape measurements by Feldtkeller *et al.*[6] For single layers, the thickness dependence of Feldtkeller's calculated three-parameter wall shape[10] was used to scale down his experimental data for 700-Å films to correspond to 350-Å films.

The measured mobilities for Bloch walls, Néel walls, and locked Néel walls are given in Table I. These values are compared to mobilities calculated from Eq. (1), using the static wall shapes discussed above. The measured mobilities for these three types of walls are nearly the same. However, calculated mobilities

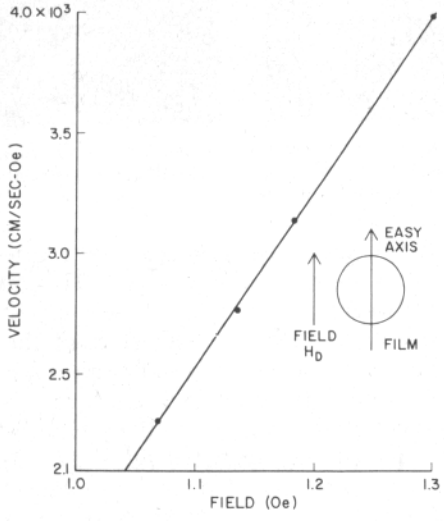

FIG. 2. Domain wall velocity as a function of field amplitude. The wall mobility is equal to the slope of the curve.

TABLE I. Measured (G_{exp}) and calculated (G_{calc}) mobilities for Bloch walls, Néel walls, and locked Néel walls.

	G_{exp}	G_{calc}
Bloch wall	8.6×10^{3} (cm/sec·Oe)	0.99×10^{3}
Néel wall	9.2×10^{3}	8.4×10^{3}
Locked walls	6.0×10^{3}	2.5×10^{4}

using the static wall-shape assumption are not in agreement with the measured values except for the Néel wall in single layers. This can not be explained on the basis of eddy current damping. It has been previously shown[2] that domain wall velocities, in film thinner than about 400 Å, are limited primarily by intrinsic damping rather than eddy current losses. Recent eddy current calculations[11] show that eddy current losses are not important for wall motion even in 1500-Å films. If intrinsic damping alone is the dominant loss mechanism, the different mobility values appear to suggest that either the shapes or widths for moving walls are different from those for static walls. Further analysis of the physical processes (micromagnetic or otherwise) involved in domain wall motion is required before a knowledgeable explanation will be possible. Even so, the experimental mobilities provide an adequate basis for interpreting flux reversal by domain wall motion.

The low-drive domain-wall flux-reversal experiments performed on the films with from one to five Permalloy layers yielded S_w values of 1.9, 1.7, 1.9, 1.8, and 2.1 $Oe\cdot\mu sec$, respectively. These values indicate that the wall mobility for domain walls in laminated films does not differ significantly with the number of layers. Néel or locked Néel walls in three-, four-, and five-layer films will therefore have mobilities similar to those for single and double films. On the basis of this mobility and switching data, which yield similar mobilities for domain walls in thick films, thin films, and thin laminated films, it is our contention that the anomalously fast flux reversal in laminated films can not be attributed to a mechanism involving domain wall motion.

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