

Wall Motion by Reverse Néel Walls in Thin Films*

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Néel walls are presumed to exist as domain boundaries in thin films with thicknesses below 500 Å. Low-drive switching with a superimposed transverse field H_t may take place by reverse wall motion ($\mathbf{H}_t \cdot \mathbf{M}_{\text{wall}} < 0$) or normal wall motion ($\mathbf{H}_t \cdot \mathbf{M}_{\text{wall}} > 0$). Wall velocities are determined by intrinsic damping rather than eddy current losses, for films in this thickness region. Reverse wall mobilities have been measured by interrupted pulse flux reversal experiments, in agreement with calculations based on the Landau-Lifshitz equation and uniaxial anisotropy. With $h = H_t/H_K = 0.1$, normal wall mobility is about 20% greater than reverse wall mobility.

IN the low-drive region, $H < H_K$, domain wall motion is the dominant mechanism of flux reversal; H is the applied field, H_K the anisotropy field. For Permalloy films thinner than 500 Å, the domain wall is presumed to be of the Néel type.^{1,2} Domain wall velocities, for films in this thickness range, are limited by intrinsic damping of the Landau-Lifshitz type³ rather than eddy current losses.⁴

With a superimposed transverse field, a Néel wall may assume two distinct configurations as indicated in

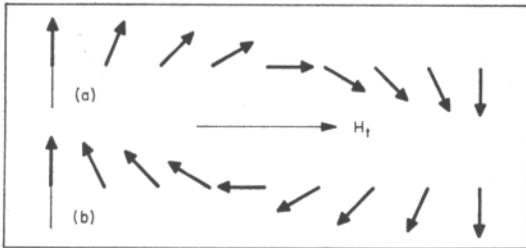


FIG. 1. Schematic of Néel wall, (a) normal wall, (b) reverse wall.

Fig. 1. The normal wall has $\mathbf{H}_t \cdot \mathbf{M} > 0$, and the reverse wall has $\mathbf{H}_t \cdot \mathbf{M} < 0$ for the magnetization in the wall; H_t is the transverse field, M the magnetization. When switching takes place with such a transverse field applied, wall nucleation is presumed to occur with the formation of normal walls, as prescribed by a minimal wall energy condition. For single wall motion, the direction of H_t may be reversed before the reversal has completed, thereby obtaining reverse wall motion.

The classic Stoner-Wohlfarth model⁵ is assumed to describe the anisotropy in thin films.⁶ Neglecting de-

magnetizing fields and considering only exchange and anisotropy contributions to the domain wall, minimal energy conditions prescribe a static Néel wall shape:

$$d\theta/dx = (K_a/K_x)^{1/2} \sin\theta. \quad (1)$$

Assuming a damping torque of the form $K(d\theta/dt)$ and a static wall shape for switching in a drive field only, integration of the torque equation for a single "spin" over the wall yields:

$$V = (2MH/K) \left[\int (\theta/dx) d\theta \right]^{-1}. \quad (2)$$

An equivalent derivation, based on power considerations, has been done by Galt.⁷

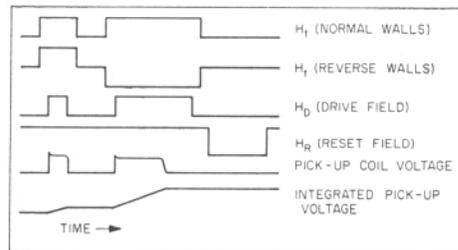


FIG. 2. Time sequence of the magnetic field configurations.

The torque expression for a static Néel wall in a transverse field is:

$$2K_x(d^2\theta/dx^2) - 2K_a \cos\theta \sin\theta \pm H_t M \cos\theta = 0 \quad (3)$$

with the \pm for normal or reverse Néel walls, respectively. Integration and evaluation of the constant as the energy at the wall edge, $\sin\theta = H_t/H_K$, yields a wall shape of the form:

$$(d\theta/dx)_{N,R} = (K_a/K_x)^{1/2} [\sin\theta \pm H_t/H_K], \quad (4)$$

where an approximation, requiring $h = H_t/H_K$ to be small, has been used in evaluating $(d\theta/dx)_R$. From (2) with $V = GH$, from $(d\theta/dx)_N$ and $\sim (d\theta/dx)_R$, the ratio

⁷ J. K. Galt, Phys. Rev. **85**, 664 (1952).

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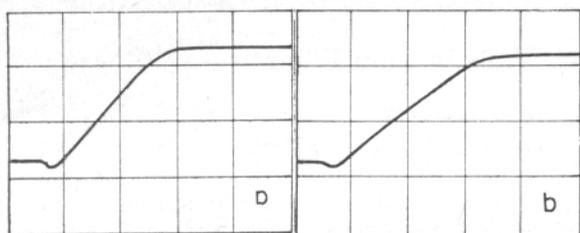


FIG. 3. Integrated switching signals, (a) normal wall, (b) reverse wall.

of wall velocities becomes:

$$\frac{V_R}{V_N} \approx \frac{\sim G_R}{G_N} = \frac{(1-h^2)^{1/2} - h \cos^{-1}h}{(1-h^2)^{1/2} + h \cos^{-1}h} \quad (5)$$

A correction term to compensate for the approximation in $(d\theta/dx)_R$ was obtained by graphical integration of the exact $(d\theta/dx)_R$ expression and added to $\sim G_R/G_N$. With $h=0.1$, $\sim G_R/G_N$ is 0.760, and the error term is +0.068.

Permalloy films 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. The films were 1-cm-diam disks with magnetic thicknesses from

100 to 300 Å. To obtain film uniformity, substrates were outgassed at 300°C for about 10 min prior to deposition and slow evaporation of the permalloy slug was commenced about 15 min prior to depositing the film to getter the vacuum system. The films had a nominal H_c of 3 Oe and H_K of 4 Oe as observed on a 17-cps hysteresis loop tracer.

Selected films exhibited rectangular switching signals over limited drive ranges in the low drive region, typical of single wall switching.⁴ These films were partially switched under a superimposed transverse field, H_t , with the nucleation of and partial switching with a normal wall. A second drive pulse completed the reversal. For normal wall motion during this second pulse, H_t was left at its initial value; or for reverse wall motion, H_t was reversed. The time sequence of the various fields

TABLE I. Experimental data.

$[G_R/G_N]_{\text{meas.}}$	$[G_R/G_N]_{\text{calc.}}$	H_t/H_K
0.802 ± 0.015	0.828 ^a	0.102
0.854 ± 0.00	0.868 ^a	0.074
0.846 ± 0.002	0.869 ^a	0.0735

^a The correction term was evaluated at $h=0.1$. G_R/G_N is the ratio of wall mobilities. H_t/H_K is the ratio of applied transverse field to anisotropy field.

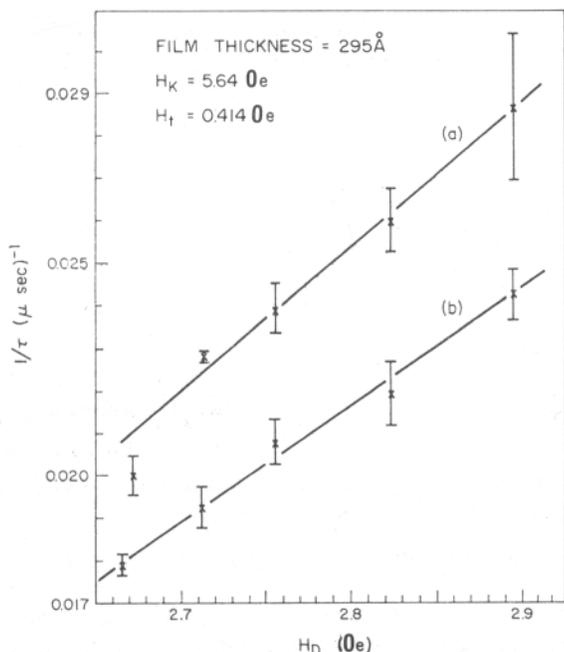


FIG. 4. Plot of $1/\tau$ vs H_D . (a) normal wall, (b) reverse wall. τ is the reversal time (10% to 90%) and H_D is the drive field.

is indicated in Fig. 2. Other fields were arranged to reset the film and cancel stray constant magnetic fields.

A 100-turn pickup coil, similar to the single turn loop described by Oguey⁸ was placed above the film. The induced switching voltage was amplified, integrated, and displayed on an oscilloscope. Switching times were taken to be the 10% to 90% rise time for the integrated pickup voltage for the second drive pulse. Since only very slow flux reversal was observed, the results were not affected by the long time constant of the 100-turn pickup loop. Typical signals are shown in Fig. 3 for the case of normal and reverse walls.

For single wall switching, plots of $1/\tau$ vs H_D can be seen in Fig. 4. The slope of each is proportional to the wall mobility. Ratios of slopes of such plots for reverse and normal wall switching during the second pulse correspond to mobility ratios for reverse and normal Néel walls. Results for three films are summarized in Table I. It can be seen that the experimental results are in good agreement with the model's predictions.

⁸ H. J. Oguey, Rev. Sci. Instr. **31**, 701 (1960).