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Magnetization Reversal in Permalloy Films

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Magnetization reversal in 80 Ni-20 Fe Permalloy films, which is completed in the course of monotonic variation of field, has been investigated with AC fields 60 to 700×10^3 cps. Measurements of the magnetoresistance effect are utilized to see whether the reversal is due to wall motion or rotation. All the reversals observed in this experiment are due to the wall motion. As dH/dt before the noticeable onset of the reversal increases, the effective field driving the reversal increases and eventually exceeds H_k. These results are interpreted in terms of the local deviation of the magnetization, and the threshold field for non-uniform rotation is estimated.

1. Introduction

In the experiments on the magnetization reversal in soft ferromagnetics with a pulse field, the reversal would for the most part be driven by the constant field of the pulse. However, aspects of the reversal might depend on the shape of the field versus time curve during the rise time, since the reversal would begin, in principle, at the threshold field smaller than the height of the pulse field. Fields during the rise time are given by $\int_0^t (dH/dt)dt$, so that the magnitude in dH/dt might be strongly dependent on the aspect of the reversal. Then, some aspects of the reversal would be revealed by applying the continuously increasing fields with various magnitudes in dH/dt.

In the present work, the magnetization reversal in Permalloy films, which is always completed in the course of a monotonic variation of field, has been investigated with not only slow-rise-time pulse fields having dH/dt 10^4 to 10^6 Oe/sec, but also AC field corresponding to dH/dt 3×10^3 to 7×10^7 Oe/sec. Then, the average field driving the reversal, the effective coercive force, as well as the notable threshold field are detectable.

2. Experimental

The films used were prepared by vacuum deposition of 80Ni-20Fe at normal incidence onto the glass substrate heated at 200°C in the presence of field 100 Oe. The thickness is about 1500 Å and the size is about 1 cm $\times$1 cm. The induced anisotropy field H_k is 3 to 4 Oe and the wall coercive force, H_w, is 1 to 1.5 Oe; H_k was determined by measurements of a linear hysteresis loop in a low AC field and also of the magnetoresistance effect[1,2] (ΔR), and H_w was determined by a quasi-static measurement of ΔR.

The reversal behavior is almost the same in all the films. The results which will be given hereafter concern R-492 film, $H_k=3$ Oe and $H_w=1.5$ Oe.

In the present experiment, measurements of ΔR are employed in addition to those of the flux $\phi_{\parallel}$ and the time derivative of $\phi_{\parallel}$, $\dot{\phi}_{\parallel}$. In Permalloy films, ΔR depends practically on the rotation alone; that is, it is represented by $\Delta R=(R_{\parallel}-R_{\perp})\cos^2\theta$, where θ is the angle between the directions of the magnetization and the measurement of the resistance, and $R_{\parallel}$ and $R_{\perp}$ are the resistances when $\theta=0$ and $\theta=\pi/2$, respectively. In the present films, $(R_{\parallel}-R_{\perp})/R_{\perp}\simeq2\times10^{-2}$.[1]

3. Results and Discussion

In Fig. 1 are shown $\phi_{\parallel}-H$, $\dot{\phi}_{\parallel}-H$ and $\Delta R-H$ curve observed in 10 kcps field with $dH/dt=6.3\times10^6$ Oe/sec which is applied along the easy direction. Here, the measurement of ΔR is made perpendicularly to the easy direction. The flux reversal in $\phi_{\parallel}-H$ curve or the switching signal in $\dot{\phi}_{\parallel}-H$ curve is essentially due to wall motion. This is definitely confirmed by a break in $\Delta R-H$ curve. The break roughly corresponds to the onset of the flux reversal in $\phi_{\parallel}-H$ curve and ΔR at the break is only about 10% as large as $(R_{\parallel}-R_{\perp})$ which stands for uniform rotational reversal. Such a small maximum in ΔR can hardly be expected even if the reversal results from nonuniform rotation.[3] Then the field at the break, H_b, may be taken as the noticeable threshold for wall motion reversal.

It should be noted that small reversible rotation which increases with the field is observed until the field reaches H_b. Such a rotation might be attributed to the actual existence of local deviations of magnetization from point to point in the film. It was ascertained, from measurements of the transverse flux, that the reversible rotation occurs locally half and half in the left-handed and the right-handed direction, respectively. The average local deviation of magnetization at remanance is estimated as 6° to the easy direction from the static measurement of ΔR.

As will be mentioned later, H_b is increased with increase of dH/dt. The rotation till H_b, however, is always almost reversible; that is, every ΔR observed till H_b lies on almost the same curve, independently of the magnitude in dH/dt. Therefore, the average reversible rotation angles are computed from ΔR at different H_b with the relation $\Delta R/(R_{\parallel}-R_{\perp})=\sin^2\alpha$, where α is the angle beween the magnetization and the easy direction. In this computation, amounts of the reversed domains are neglected, since they are negligibly small compared with the whole volume of the film. The computed values are plotted as curve a in Fig. 2.

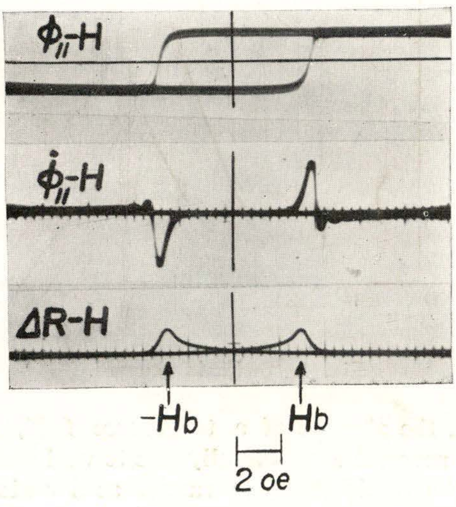

Fig. 1. $\varphi_{\parallel}$-H, $\dot{\varphi}_{\parallel}$-$H$ and ΔR-H curves in 10 kcps with dH/dt, 6.3x10^6 Oe/sec.

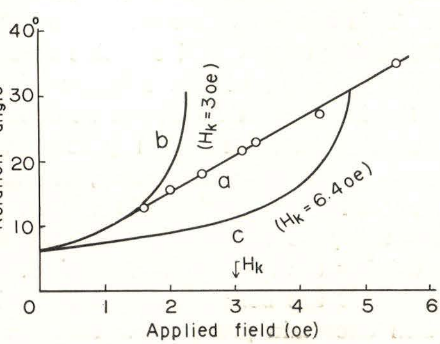

Fig. 2. Reversible rotation curves.

In Fig. 2 are also given curves b and c which are calculated in terms of the simple rotation model on the magnetization lying in the direction deviating 6° to the easy direction and when the uniaxial anisotropy fields in the direction are 3 Oe and 6.3 Oe, respectively. According to the calculation, the irreversible rotation takes place at the rotation angle 31°, independently of magnitudes of the anisotropy field.

In a real film, therefore, it might be presumed that irreversible rotation also occurs at the critical angle 31°. Thus, the threshold field for the rotation reversal is estimated as 4.8 Oe corresponding to the critical angle in curve a. This rotational reversal should, in principle, be nonuniform rotation, since the reversible rotation occurs locally and in both directions before the onset of the irreversible rotation, as mentioned previously.

From the comparison between the shapes of curve a and curves b and c, it is understood that the effective anisotropy field increases with increase of the applied field. Internal local fields and exchange fields which result from the local deviation of magnetization would be responsible for the increase of the effective anisotropy field, although "locking"[4] or "buckling"[5] mechanism may also possibly be responsible. The increase of the effective anisotropy field with increase of the applied field, therefore, would be attributable to the fact that the local deviation of magnetization increases gradually with increase of the applied field.

The observed reversal is essentially due to wall motion even for the fields above 4.8 Oe. The reason is evidently attributed to the fact that the switching time is much smaller for wall motion than for nonuniform rotation in the range observed.

In Fig. 3 H_b is shown as a function of dH/dt. H_b increases with increasing dH/dt and eventually it exceeds H_k which corresponds to the threshold for uniform rotation; that is, the film appears to behave just like the so-called inverted film[4] for H_b in excess of H_k. The increase in H_b with dH/dt is, in principle, attributable to the fact that as dH/dt is increased the time to reach a certain field becomes smaller, so that the amounts of the reversed domains are smaller at that field. This is based on the assumption that the wall velocity is proportional to $(H-H_w)$ and also the number of walls available for growth is increased as a function of $(H-H_w)$. However, H_w must be increased with increase of the applied field, because it would depend on something like *transfixing* or *nailing* of wall motion. This would result from interactions between the walls and the locally deviated magnetization in the unreversed domains and would increase with the applied field. This increase in H_w must be more responsible for the increase in H_b with dH/dt.

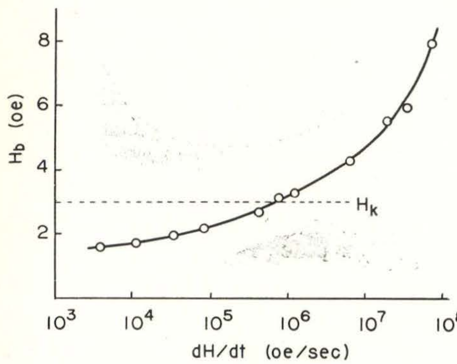

Fig. 3. Relation between H_b, the notable threshold field for the reversal, and dH/dt.

In the present films, it is presumed that many small reversed domains have already been created at both ends perpendicular to the easy direction before the field reaches H_w. This presumption is not incompatible with observations of powder patterns. The number of the reversed domains which are able to grow may be dependent on the magnitude of $(H-H_w)$, as mentioned previously.

In Fig. 4 are given switching curves, $1/\tau$ as a function of H_c, where τ is the switching time determined as usual from the switching signal of $\dot{\phi}_{\parallel}-H$ curve and H_c is the field corresponding to the peak in the same curve which roughly indicates the coercive force or the average field driving the reversal. As H_b is increased with increase of dH/dt, the average field driving the reversal is also increased, so that the switching curves are not significantly different from those obtained by the usual pulse field.

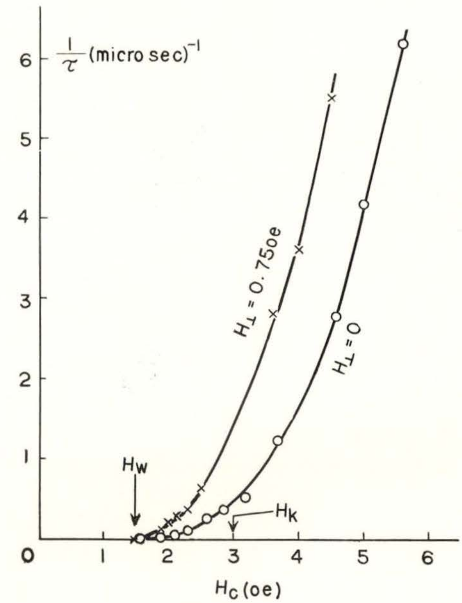

Fig. 4. Switching curves.

In the absence of a transverse field, $H_\perp$, the reversal is essentially due to wall motion in the whole observed range, as mentioned previously. In the presence of $H_\perp$, all the reversals observed are also likely due to wall motion, although the fact has not yet been the confirmed definitely. As $H_\perp$ becomes greater, the reversal time becomes shorter at the same field. This seems to be attributabe not only to decreasing of the wall coercive force, but also to increasing of the number of walls with the increase in $H_\perp$ at the same field.

In conclusion, the reversal process which is due to two mixed mechanisms, wall motion and nonuniform rotation, is suspected to follow the pure wall motion reversal as the field driving the reversal is increased. The experiments are being continued for solving the still uncertain problems which have been mentioned so far.

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