An analysis of magnetic viscosity in MO films – I: experimental

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Abstract

Time dependence measurements have been made on two Tb/Fe multilayer films possessing square and rounded hysteresis loops. Both films exhibit a non-linear variation of $M$ with $\ln t$. Experimental curves of $dM/dt$ against reduced magnetisation have been compared with curves derived from a 2D theoretical model. These curves indicate that a two coercivity model may be applied to reversal in these films, and the nature of domain growth during reversal. MFM images of domains have been obtained and show that domain size correlates with the nature of reversal.

1. Introduction

In this work we compare reversal in magneto-optic (MO) multilayer thin films with the predictions of a simulation presented in an associated paper [1].

Tb/Fe and other multilayer systems are potential media for use in MO recording [2]. The reversal process in such films has been described using the two coercivity model originally devised by Mansuripur [3]. Two critical fields representing the nucleation field ($H_n$) and the domain wall field ($Hw$) are used. When $H_n > Hw$ then the hysteresis loop will be square because once nucleated, the reverse domains immediately overcome domain wall critical fields. If $H_n < Hw$ then the hysteresis loop will be rounded, due to the walls of reverse domains being pinned. This leads to the formation of smaller domains [4].

Most magnetic materials exhibit time dependent magnetisation arising from thermal activation over local energy barriers. This is observed as a logarithmic variation of magnetisation with time for materials with broad energy barrier distributions, such as particulate media. This is described by the (Street and Woolley) expression [5]:

$$M(t) = M(0) \pm S \ln t$$

where $M(0)$ is the initial magnetisation, and $S = dM/d\ln t$.

Materials with square hysteresis loops have a narrow energy barrier distribution and thus exhibit time dependent reversal which is non-linear with $\ln t$. A series expansion in $\ln t$ may be used to describe this behaviour [6]:

$$M(t) = M(0) - A[B_1(\ln(t/t_0)) + B_2(\ln(t/t_0))^2 + \cdots]$$

where $A$ is a constant and $B_1$ and $B_2$ are the first and second differentials of the energy barrier distribution function ($f(\Delta E)$) evaluated at the reduced critical energy barrier. El-Hilo et al. [7] have shown that when $f(\Delta E)$ increases with time $M(t)\ln t$ is concave downwards, whereas when $f(\Delta E)$ decreases with time, $M(t)\ln t$ is concave upwards. When $f(\Delta E)$ is constant around the peak in the distribution, $M(t)\ln t$ is approximately linear. This is consistent with data for permanent magnet systems published by Street et al. [8].

Time dependence curves are characteristic of the reversal mechanism dominant in a material. It is then logical to expect that $dM/dt\ln t$ curves will show behaviour which may be directly related to hysteresis and the reversal mechanisms applicable to the material. In the associated work [1] it is shown that $dM/dt\ln t$ generally takes the form of a non-symmetrical U shaped curve. Depending on the parameters used to derive the curve, the minima is skewed to one side. In this work we compare these predictions with data for Tb/Fe multilayer systems.

2. Experimental

Two sputtered Tb/Fe multilayer samples (19 Å Tb, 8 Å Fe), with an Al protection layer, were used, one of 6 and one of 18 bilayers.

Time dependence data was obtained using an AGFM by saturating the sample and then applying a reverse field and recording the reduced magnetisation ($M/M_s$) over a time period of up to 900 s. The reverse fields used varied over a range from $0.75H_c$ to $-3H_c$. This resulted in changes in $M/M_s$ from positive to negative saturation. Graphs of $dM/dt$ against $M/M_s$ were plotted for each reverse field.
Domain images of the samples in an ac demagnetised state were obtained using a Digital Instruments MFM.

3. Results and discussion

Fig. 1 shows hysteresis loops for the two samples used, the 6 bilayer sample exhibits a square loop, and the 18 bilayer sample a more rounded loop. Previous work has shown that for films possessing rounded loops reversal generally proceeds by more than one process [5].

Time dependence curves of $M/M_s$ vs. $\ln t$ are shown in Fig. 2. These clearly show that as expected both samples exhibit non-linear time dependence. Analysis of time dependence curves for each reverse field reveals that the 6 bilayer film exhibits an inverse S shape curve, and the 18 bilayer film exhibits slightly concave data.

The variation of $dM/dt$ with $M/M_s$ is shown in Figs. 3 and 4, which illustrate the two distinct forms of magnetisation reversal displayed by the two samples. The 6 bilayer film exhibits a minimum in $dM/dt$, for each reverse field at $M/M_s \sim 0.5$. $dM/dt$ decays continuously for the 18 bilayer film, no minimum is reached.

In the model used by Earl et al. [1] reversal is controlled mainly by local demagnetising fields rather than a pinning mechanism, and is dependent upon three dimensionless parameters, $k$ the ratio of the rates of domain wall propagation to domain nucleation, $W$ the wall energy, and $Z$ the demagnetising energy. Figs. 3 and 4 show behaviour very similar to the theoretical curves computed with the parameters shown in Table 1. This implies that the 6 bilayer sample has a lower rate of domain nucleation to domain wall propagation, higher wall energy, and less demagnetising energy, relative to the 18 bilayer sample. This implies that $H_n > H_w$ in the 6 bilayer sample and that $H_n < H_w$ in the 18 bilayer film, as observed experimentally.

MFM images are shown in Fig. 5 in which domains are clearly visible. The domains may be considered to be vestigial as the samples were in a demagnetised state when imaged. It is clear that the 18 bilayer film has smaller domains than the 6 bilayer film. This agrees with the findings of previous work [9]. The domains in the 18 bilayer film are approximately five times smaller than those in the 6 bilayer films.

4. Conclusions

From the parameters used in the model it is implied that the domain walls are extremely narrow consistent with the strong anisotropy, particularly for the 6 bilayer film. A
fuller discussion of the implications of the model is presented in the associated work [1].

Acknowledgements

We thank G. Bayreuther of Universität Regensburg for the original preparation of the samples. GNP acknowledges financial support from the UK EPSRC. This work was carried out within the CAMST programme of the CEC.

References