Time Dependence in Perpendicular Media With a Soft Underlayer

James D. Dutson, Jing Wu, Kevin O'Grady, Nigel C. Woolsey, Yukiko Kubota, and Chris L. Platt

***Abstract*—In this paper we describe measurements of magnetic viscosity or time dependence in magnetic thin films suitable for use as perpendicular recording media. Generally, such effects cannot be measured using conventional magnetometry techniques due to the presence of a thin (0.1 μm) soft underlayer (SUL) in the media necessary to focus the head field. To achieve our results we have developed an ultrastable MOKE magnetometer, the construction of which is described. This has enabled us to measure nominally identical films with and without the presence of the SUL. We find that the presence of the SUL narrows the energy barrier distribution in the perpendicular film increasing the nucleation field (H_n), reducing the coercivity (H_c) and results in an increase in the squareness of the loop. This in turn results in an increase in the magnitude of the viscosity in the region of the H_c but that the range of fields over which the viscosity occurs is reduced.**

***Index Terms*—Magnetic viscosity, MOKE magnetometer, perpendicular media.**

I. Introduction

DUE TO THERMAL loss of data, the current hard-disk technologies using longitudinal media are close to their theoretical limit of about 100 Gbit/in^2 and will be replaced by perpendicular recording [1]. Perpendicular media also exhibit thermal loss of data due to thermal activation of magnetization reversal. Consequently, it is important to characterize thermal activation in both types of materials for the purpose of predicting the probable lifetime of stored data.

Thermal activation is a phenomenon where the energy barrier of reversal ($\Delta E = KV(1-H/H_K)^2$) is too small to resist thermal energy (kT) and hence the magnetization can spontaneously reverse with a relaxation time τ:

$$\tau^{-1} = f_0 \exp\left(-\frac{\Delta E}{kT}\right) \tag{1}$$

where f_0 is the attempt frequency, ΔE is the energy barrier, and kT is the thermal energy. A number of factors affect the level of thermal loss such as the grain size, fluctuations in anisotropy, orientation, etc. Generally, these will be distributed, which leads to an energy barrier distribution ($f(\Delta E)$) [2]. The energy barrier distribution leads to a nonexponential variation of magnetization with time which is often observed to be logarithmic in time as first observed by Street and Woolley [3]. However, El-Hilo *et al.* have shown that the variation of M is not always linear with $\ln(t)$ and specifically will be nonlinear when there is a narrow energy barrier distribution [4]. They also show that a more accurate description of the variation of magnetization with $\ln(t)$ is

$$M(t) = M_0 \pm S_1 \ln(t) \pm (S_2 \ln(t))^2 \pm \cdots. \tag{2}$$

Equation (2) is capable of describing the variation of M with $\ln(t)$ when the data obtained is concave downwards and upwards, i.e., across the whole energy barrier distribution. For materials with perpendicular anisotropy, it is far harder to quantify time dependent effects due to the self-demagnetizing field ($H_D = -4\pi M$). As the magnetic moment decays over time, the demagnetizing field will change as M changes, and consequently the total field cannot be held constant.

A number of different techniques to investigate viscosity in films with perpendicular anisotropy have been developed. Le Phan *et al.* [5] calculated values of H_D to linearize M with $\ln(t)$, which is only valid for systems with a wide $f(\Delta E)$. In work from our own laboratory [6], an attempt was made to correct continuously for H_D during measurement. Unfortunately, the correction could not be made to high enough resolution. Recently, we have shown that measurements at constant M (i.e., H_D constant) allow for the determination of critical parameters such as the activation volume of reversal (V_{act}) obtained from the Nèel fluctuation field (H_f) [7]:

$$H_f = \left.\frac{\Delta H}{\ln\left(\frac{t_1}{t_2}\right)}\right|_M = \frac{KT}{V_{act}M_s}. \tag{3}$$

This expression relates to a measurement of magnetization with time where ΔH is the field step between successive measurements and t_1 and t_2 are the differences in time at which the value of M reaches a constant value. A full description of the measurement procedure has been provided in our previous work [7]. V_{act} is of considerable importance as it determines the smallest entity that can reverse and hence determines the intrinsic limit to recording density [2]. Hence, the ability to obtain accurate measurements of $M(t)$ is critical to the characterization of all types of media.

The measurements described in [7] were performed on samples with a single recording layer. In disks, a soft magnetic underlayer (SUL) is required below the recording layer to enable writing of data on perpendicular materials. This affects the magnetic properties of the medium and makes the measurement of such materials by conventional magnetometry impossible as

Manuscript received October 20, 2003.

J. D. Dutson, J. Wu, K. O'Grady, and N. C. Woolsey are with the Physics Department, University of York, Heslington, York, Yorkshire YO10 5DD, U.K. (e-mail: jdd103@york.ac.uk; jw50@york.ac.uk; kog1@york.ac.uk; ncw2@york.ac.uk).

Y. Kubota and C. L. Platt are with Seagate Research, Pittsburgh, PA 15217 USA (e-mail: yukiko.a.kubota@seagate.com; christopher.l.platt@seagate.com).

Digital Object Identifier 10.1109/TMAG.2004.832259

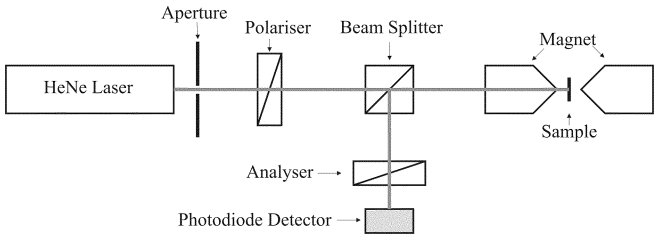

Fig. 1. Schematic of MOKE apparatus.

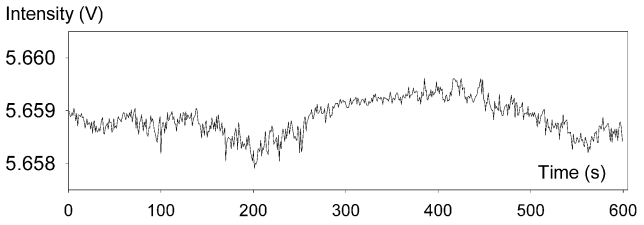

Fig. 2. Laser stability measurements.

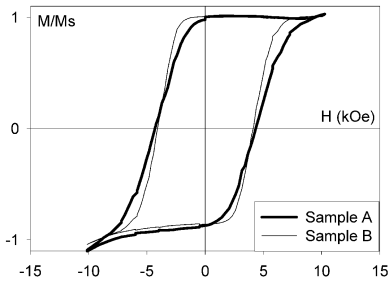

Fig. 3. MOKE hysteresis loops for samples A and B.

the signal from the SUL is significantly larger than that from the recording layer. The only method to measure samples with an SUL is to use the magneto-optical Kerr effect (MOKE) [6]. Using a high-stability MOKE system, it is possible to measure the time dependence in the recording layer alone.

II. Details and Results

A. Development of the MOKE

Most MOKE systems utilize lasers which at best have a stability of 0.2%/min [6]. This is not sufficient for the measurement of the time-dependent effects to an adequate resolution. We have rebuilt our system with a Melles Griot stabilized HeNe Laser (Model 05-STP-903) which has a stability of $<0.01\%$ over 1 min. The stability of the laser enabled us to reduce drift and noise in the laser such that small changes in polarization, and hence magnetization, are now detectable. A diagram of the revised MOKE set-up is shown in Fig. 1.

The diagram shows the emission from the laser first passes through an aperture to remove stray light from the laser. The beam is then s-polarized and passed into a laser-line nonpolarizing dielectric cube beam splitter (part no. 03 BSL 042 from Melles Griot). This beam splitter is specifically chosen due to its ability to split the beam without affecting the polarization and this helps with both the overall stability and a more precise measurement of the change in polarization. From the beam splitter, half of the beam is passed through a crossed polarizer to reduce intensity and onto a detector to measure the initial laser intensity. This detector enables us to remove any small fluctuation in laser stability from the final signal. The second part of the beam from the beam splitter is shone through a pinhole in the magnet onto the sample. The reflected beam from the sample is reflected back through the beam splitter and on through the analyzer (a second polarizer) and finally onto the photodiode detector (PDB-716-100 Detector Amplifier Hybrid from Laser Components (UK) Ltd). The choice of photodiode is particularly important due to the very small signals obtained. The signal from the detector is fed to a Kiethley Data Acquisition Unit (Model 2700), which enables us to filter the noise from the signal, and from this to the computer for data logging.

Using this arrangement, we have performed time dependence measurements required for the determination of viscosity. The stability of the system over 10 min is shown in Fig. 2.

Samples were initially saturated and a reverse field applied and kept static. The decay of the magnetic moment was then measured over 5 min. The sample is resaturated and an increased reverse field is applied. The difference between fields chosen for successive measurements should be less than 5% of the width of the switching region. At the start of each time dependence measurement, a brief hysteresis loop was measured to obtain normalization values of M_s. The measurement of loops before each measurement enables us to correct for the long-term drift in laser stability that is inevitable over a sequence of time dependence measurements.

B. Samples Examined

In this work we have studied two $[\mathrm{Co}(2.5\ \text{Å})/\mathrm{Pd}(12\ \text{Å})]_{14}$ multilayer films, samples A and B. These samples had the same composition and structure except for the presence of a 240-nm-thick FeCoB SUL in sample B. A nonmagnetic exchange breaking layer (11 nm) was grown between the SUL and the multilayer. Sample A (without the SUL) was measured using an AGFM and time dependence data has already been published for this sample [7]. By comparing the AGFM and MOKE measurements we have found that both the hysteresis loops and time dependence measurements reproduce, validating our MOKE system.

C. Magnetic Measurements

It is clear from the hysteresis loops in Fig. 3 that the SUL has a significant effect on the magnetic properties of the film. Of specific note are the increase in nucleation field when the SUL is present, the decrease in coercivity, and the significantly steeper slope at coercivity. There is a slight background distortion on the loops at negative saturation due to a field distortion in the magnet used. However, we believe that as the loops close, all the irrersible components are saturated, allowing for time dependence measurements [7].

The time dependence measurements were made using the technique described in [7]. Measurements were grouped to obtain sufficient data to cover the entire switching region. Due to the different hysteretic properties, the field settings used were slightly different for each sample. To compare the measurements of both samples, the group of data that lies over the coercivity are shown in Fig. 4.

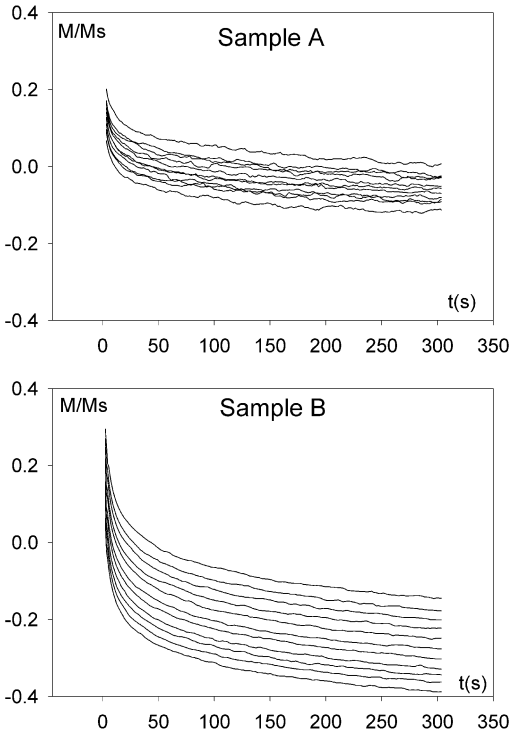

Fig. 4. Time dependence data from samples A and B at H_c.

It is clear from Fig. 4 that the sample with the SUL has significantly larger time dependence at H_c. To quantify this, we have determined the viscosity by measuring $d(M/M_s)/d\ln(t)$. Note that this is not the true magnetic viscosity, but just an indication of the change in magnetization over time. For sample A, we are able to use the approximation of Street and Woolley $M(t) = M(0) \pm S\ln(t)$, as the behavior of this sample is quasi-linear in log time. For sample B with significantly larger time dependence, this is no longer applicable and a second-order quadratic fit was applied to the data consistent with (2). The variation of S (or S_1) with H is shown in Fig. 5.

It is clear that the viscosity is larger in the vicinity of H_c for the sample with the SUL, however, the range of fields over which the viscosity occurs is less than is the case for the sample without the SUL.

The implications of this result are that the range of switching fields for perpendicular media with an SUL is reduced by its presence. Also, the increased nucleation field will improve the stability of written data as the energy barrier to reversal will be increased at fields around the demagnetizing field arising due to the bits. However, the narrowing of the switching region may be indicative of the SUL promoting cooperative reversal

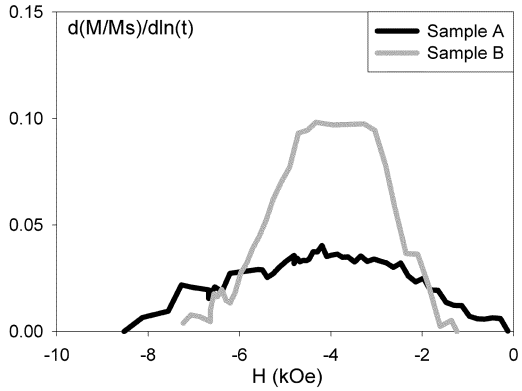

Fig. 5. S_1 coefficients for samples A and B.

between the grains, which will lead to an increase in noise from the medium. The origin of the narrowing of the switching region is not exchange coupling as an exchange breaking layer was included in the stack. Hence, we believe that dipolar effects are responsible. Of course, we can only speculate as to why the SUL changes the behavior. One mechanism may be a morphological change in the magnetic grains caused by them being grown on a different underlayer.

We have also attempted to determine the activation volume for the two materials using (3). Preliminary data indicates that the activation volume is not significantly affected by the SUL. However, the complexity of the multilayer and its interaction with the SUL means that the value of M_s is uncertain. Measurements of an alloy film are in progress and will be reported in the future.

REFERENCES

[1] R. Wood, J. Miles, and T. Olson, "Recording technologies for terabit per square inch systems," *IEEE Trans. Magn.*, vol. 38, pp. 1711–1718, July 2002.

[2] K. O'Grady, P. Dova, and H. Laidler, "Determination of critical volumes in recording media," in *Mater. Res. Soc. Proc.*, vol. 517, 1998, pp. 231–242.

[3] R. Street and J. C. Woolley, "A study of magnetic viscosity," in *Proc. Phys. Soc.*, vol. A62, 1949, pp. 562–572.

[4] M. El Hilo, K. O'Grady, R. W. Chantrell, and D. P. E. Dickson, "Time dependent magnetization in systems with distributed energy barriers," *J. Magn. Magn. Mater.*, vol. 123, pp. 30–34, 1993.

[5] K. Le Phan and C. Lodder, "Iterative method for intrinsic viscosity measurements on perpendicular recording media," *IEEE Trans Magn.*, vol. 38, pp. 2003–2005, Sept. 2002.

[6] J. Wu, L. Holloway, H. Laidler, K. O'Grady, S. Khizroev, J. K. Howard, R. W. Gustafson, and D. Litvinov, "Magnetic characterization of perpendicular recording media," *IEEE Trans. Magn.*, vol. 38, pp. 1682–1686, July 2002.

[7] J. D. Dutson, K. O'Grady, B. Lu, Y. Kubota, and C. L. Platt, "Determination of activation volumes of reversal in perpendicular media," *IEEE Trans Magn.*, vol. 39, pp. 2344–2346, Sept. 2003.