Activation Volumes in CoPtCr-SiO_2 Perpendicular Recording Media

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CoPtCr-SiO_2 perpendicular recording media with varying levels of SiO_2 were examined by two different methods to determine the activation volume. The first is based on the sweep-rate dependence of the remanence coercivity using Sharrock's equation. The second is based on the measurement of the fluctuation field from time-dependence data, determined using a magneto-optical Kerr effect (MOKE) magnetometer. The values of V_{act} measured at the coercivity for both methods are almost the same, with the fluctuation field and activation volumes increasing with the SiO_2 content. The difference between V_{act} and the grain volume measured directly from bright-field TEM images decreases as the SiO_2 content increases due to the reduction of intergranular exchange coupling. The experimental results indicate that values of V_{act} obtained from single- and double-layered media are consistent. It was also found that the coercivity and normalized hysteresis loop slope at coercivity varied with SiO_2 content, with the coercivity peaking at 8 at%SiO_2 (nearly 26 vol%SiO_2).

***Index Terms*—Activation volume, CoPtCr-SiO_2, fluctuation field, magneto-optic Kerr effect (MOKE), perpendicular recording media, thermal activation.**

I. Introduction

THE ACTIVATION volume V_{act} is the smallest unit of magnetization reversal, and the associated diameter D_{act} is of importance as it indicates the potential recording density of a medium. In this paper, V_{act} was measured by two methods for CoPtCr-SiO_2 media with varying levels of SiO_2. The first method is based on the sweep-rate dependence of the remanent coercivity using Sharrock's equation [1], [2], and the second is from the measurement of the fluctuation field [3] determined from time-dependence data measured using a highly stable magneto-optic Kerr effect (MOKE) magnetometer [4]. A comparison is made of the values of V_{act} obtained from the two techniques. The effect of soft magnetic under layers (SUL) on V_{act} was also studied.

II. Sample Preparation

CoPtCr-SiO_2 media were deposited on 2.5 inch glass disks by cosputtering with $Co_{90}Cr_{10}$, Pt, and SiO_2 targets using a UHV-magnetron sputtering system [5]. The composition of CoPtCr was fixed at $(Co_{90}Cr_{10})_{80}Pt_{20}$, and SiO_2 was added to this CoPtCr composition in varying amounts by controlling the deposition rate. The film thickness was fixed at 8 nm. Ru (20 nm) and Pt (10 nm) seed and preseed layers were used. No substrate heating was carried out during the deposition process. CoZrNb amorphous films (200 nm) were used for the soft underlayer.

III. Results and Discussion

A. Magnetic Properties

Hysteresis loops were measured for all samples using a MOKE magnetometer and loops for single-layered media containing 0, 5.5, 11.2, and 14.4 at.% SiO_2 are shown in Fig. 1. To enable a comparison of the films to be made, values of the coercivity H_c and the normalized slope of the magnetization curve $\alpha_{MOKE} = d(M/M_s)/dH$, as a function of the SiO_2 content for both single- and double-layered media, are shown in Figs. 2 and 3.

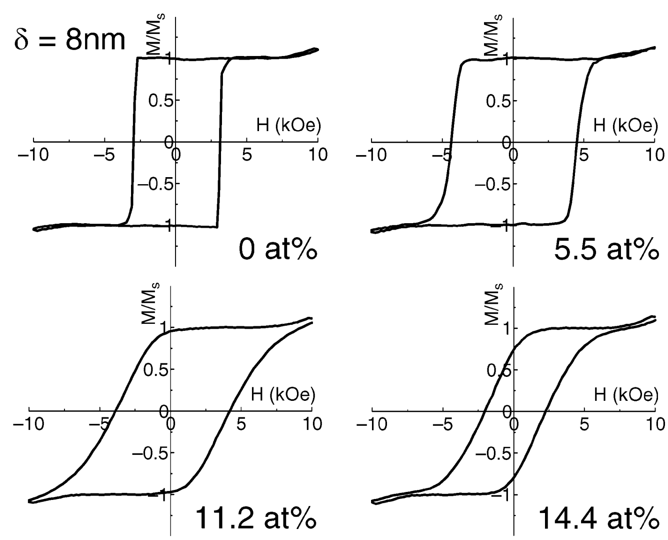

Fig. 1. Hysteresis loops of CoPtCr-SiO_2 single-layered media with various SiO_2 contents.

The coercivity H_c of the films increased significantly as the SiO_2 content increased and was coincident with the reduction of α_{MOKE}, reaching a maximum at around ~8 at%SiO_2 (=~26 vol%SiO_2). The initial increase in H_c is due to an enhancement of grain isolation on the addition of SiO_2 [5]. However, increasing the SiO_2 content above 8 at% reduced H_c significantly, although α_{MOKE} remained almost constant. There were no significant differences in the magnetic properties of single- and double-layered media.

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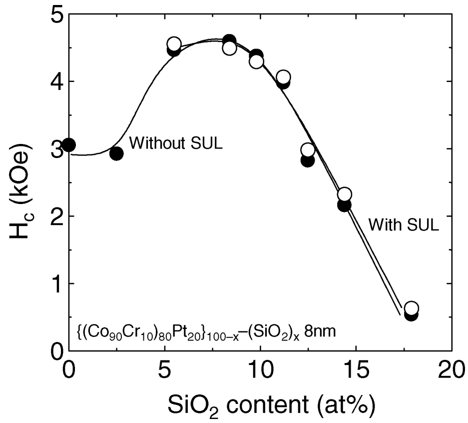

Fig. 2. Values of H_c as a function of SiO_2 content for CoPtCr-SiO_2 single- and double-layered media.

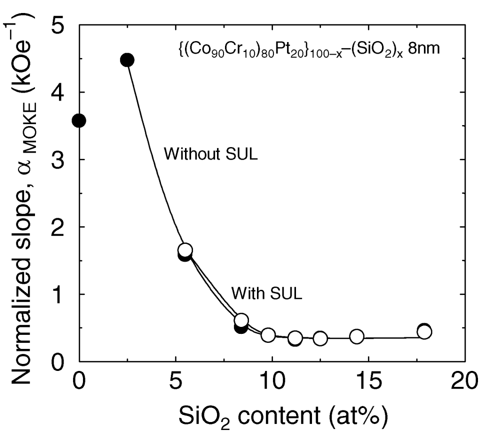

Fig. 3. Normalized slope of the hysteresis loop as a function of SiO_2 content for CoPtCr-SiO_2 single- and double-layered media.

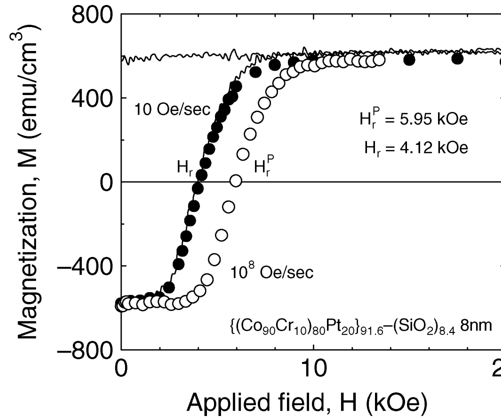

Fig. 4. Remanence curves at two different sweep rates for 8.4at% SiO_2 single-layered media.

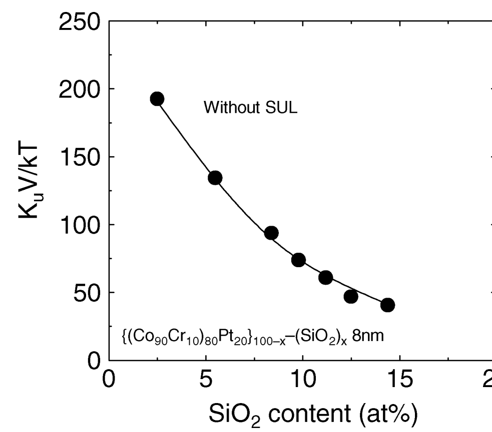

Fig. 5. Values of $K_u V_{\rm act}/kT$ as a function of SiO_2 content for single-layered media.

Fig. 4 shows remanence curves for a CoPtCr-SiO_2 medium with 8.4at% SiO_2 measured at sweep rates of 10 Oe/sec using a VSM, and 10^8 Oe/sec using a pulse field magnetometer. The magnetization curve measured at 10 Oe/sec is also shown in this figure. The remanent coercivity at $\sim 10^8$ Oe/s, H_r^P, is 5.95 kOe, which is larger than that at ~10 Oe/s, H_r by about 1.8 kOe.

The values of $K_u V_{\rm act}/kT$ were obtained by fitting the values of H_r^P and H_r to Sharrock's equation [1], [2] (K_u is the magnetic anisotropy, $V_{\rm act}$ the activation volume, k the Boltzmann constant and T the absolute temperature). Fig. 5 shows the values of $K_u V_{\rm act}/kT$ of single-layered media as a function of the SiO_2 content. $K_u V_{\rm act}/kT$ decreased monotonically as the SiO_2 content increased, mainly due to a reduction of the grain diameter $D_{\rm grain}$ [5]. This result indicates that the reduction in H_c on the addition of SiO_2 in excess of ~ 8 at% is mainly due to thermal agitation of magnetization.

B. Estimation of the Activation Volume

Fig. 6 shows the time dependence of magnetization in different applied fields for the 8.4 at% SiO_2 sample measured by the highly stable MOKE magnetometer [4]. The fluctuation field can be calculated from these results using the waiting time method [3] and (1)

$$H_f = \left. \frac{\Delta H}{\ln(t_1/t_2)} \right|_M \tag{1}$$

where ΔH is the difference in the applied field between two time-dependence measurements, and t_1 and t_2 are the times at which the data reaches a constant value of magnetization M. To reduce experimental error, a number of points are measured in preference to the two points described by (1). The fluctuation field is then determined from the gradient of the applied field versus the time to fall to the constant level of magnetization. The values of fluctuation field H_f, determined for each level of SiO_2 content for both double- and single-layered media, are shown in Fig. 7. H_f increased as the SiO_2 content increased, but there were no significant differences between single-layered media and media with an SUL.

From the fluctuation field, it is possible to determine the activation volume $V_{\rm act}$, if the bulk saturation magnetization is known from (2) [6]

$$V_{\rm act} = \frac{kT}{M_s H_f}. \tag{2}$$

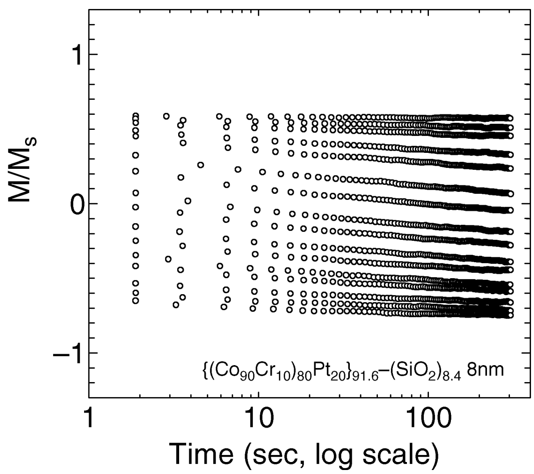

Fig. 6. Time-dependence data for single-layered media with 8.4 at% SiO_2 measured by MOKE.

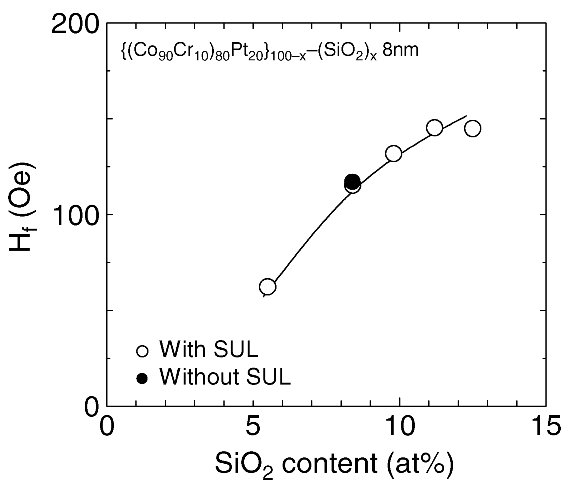

Fig. 7. Values of fluctuation field H_f as a function of SiO_2 content for CoPtCr-SiO_2 double- and single-layered media.

Values of $V_{\rm act}$ have been determined from both the fluctuation field and sweep-rate methods and are shown in Fig. 8. The values for single-layered media were calculated from the values of K_uV/kT in Fig. 5 and K_u, measured by torque magnetometry. The values of grain volume $V_{\rm grain}$, including the grain boundary thickness, have been obtained from TEM bright field images, and they are also plotted in the figure.

The values of $V_{\rm act}$ in both series of media decreased as the SiO_2 content increased. The reduction in $V_{\rm act}$ was in qualitative agreement with the reduction of $V_{\rm grain}$ on SiO_2 addition [5]. The values of $V_{\rm act}$ were larger than $V_{\rm grain}$ due to limited cooperative reversal. However, the difference between $V_{\rm act}$ and $V_{\rm grain}$ decreased as the SiO_2 content increased due to the reduction of intergranular exchange coupling [5].

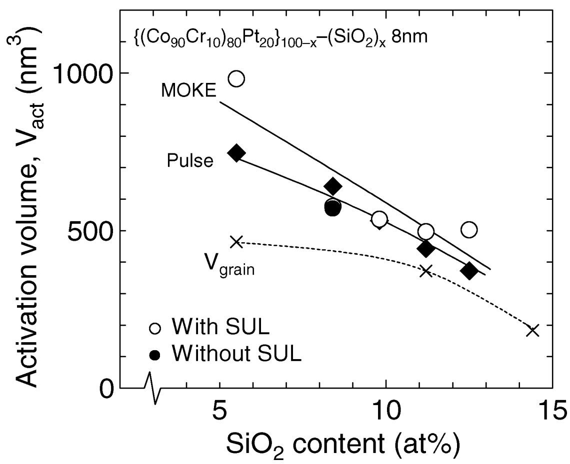

Fig. 8. Activation volume, for double- and single-layered media, as a function of SiO_2 content. The physical grain volume $V_{\rm grain}$ is also shown.

IV. Conclusion

There were no significant differences in the magnetic properties and $V_{\rm act}$ between single- and double-layered media. The value of $V_{\rm act}$ decreased as the SiO_2 content increased, which is consistent with a reduction in the average grain size. Furthermore, the difference between $V_{\rm act}$ and $V_{\rm grain}$ decreased as the SiO_2 content increased due to the reduction of intergranular coupling. The results for single- and double-layered media were almost the same, and we can use the $V_{\rm act}$ values obtained from single-layered media to predict the magnetic properties of double-layered media.

Acknowledgment

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