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**Article:**

Inaba, Y, Shimatsu, T, Muraoka, H et al. (2005) Activation volumes in CoPtCr-SiO<sub>2</sub> perpendicular recording media. IEEE Transactions on Magnetics. pp. 3130-3132. ISSN: 1941-0069

<https://doi.org/10.1109/TMAG.2005.854850>

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# Activation Volumes in CoPtCr-SiO<sub>2</sub> Perpendicular Recording Media

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CoPtCr-SiO<sub>2</sub> perpendicular recording media with varying levels of SiO<sub>2</sub> 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<sub>2</sub> content. The difference between  $V_{act}$  and the grain volume measured directly from bright-field TEM images decreases as the SiO<sub>2</sub> 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<sub>2</sub> content, with the coercivity peaking at 8 at% SiO<sub>2</sub> (nearly 26 vol% SiO<sub>2</sub>).

**Index Terms**—Activation volume, CoPtCr-SiO<sub>2</sub>, 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<sub>2</sub> media with varying levels of SiO<sub>2</sub>. 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<sub>2</sub> media were deposited on 2.5 inch glass disks by cosputtering with Co<sub>90</sub>Cr<sub>10</sub>, Pt, and SiO<sub>2</sub> targets using a UHV-magnetron sputtering system [5]. The composition of CoPtCr was fixed at (Co<sub>90</sub>Cr<sub>10</sub>)<sub>80</sub>Pt<sub>20</sub>, and SiO<sub>2</sub> 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

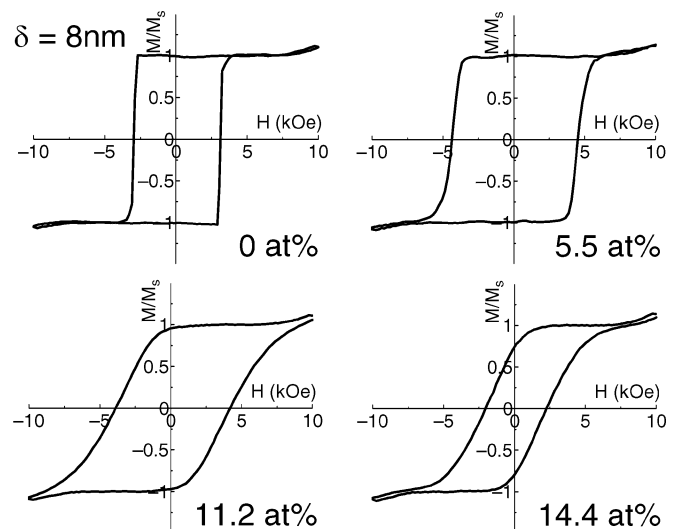


Fig. 1. Hysteresis loops of CoPtCr-SiO<sub>2</sub> single-layered media with various SiO<sub>2</sub> contents.

containing 0, 5.5, 11.2, and 14.4 at.% SiO<sub>2</sub> 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<sub>2</sub> content for both single- and double-layered media, are shown in Figs. 2 and 3.

The coercivity  $H_c$  of the films increased significantly as the SiO<sub>2</sub> content increased and was coincident with the reduction of  $\alpha_{MOKE}$ , reaching a maximum at around  $\sim 8$  at% SiO<sub>2</sub> ( $\sim 26$  vol% SiO<sub>2</sub>). The initial increase in  $H_c$  is due to an enhancement of grain isolation on the addition of SiO<sub>2</sub> [5]. However, increasing the SiO<sub>2</sub> content above 8 at% reduced  $H_c$  significantly, although  $\alpha_{MOKE}$  remained almost constant. There were no significant differences in the magnetic properties of single- and double-layered media.

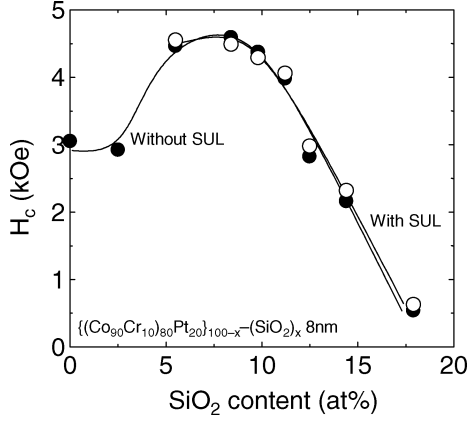


Fig. 2. Values of  $H_c$  as a function of SiO<sub>2</sub> content for CoPtCr-SiO<sub>2</sub> single- and double-layered media.

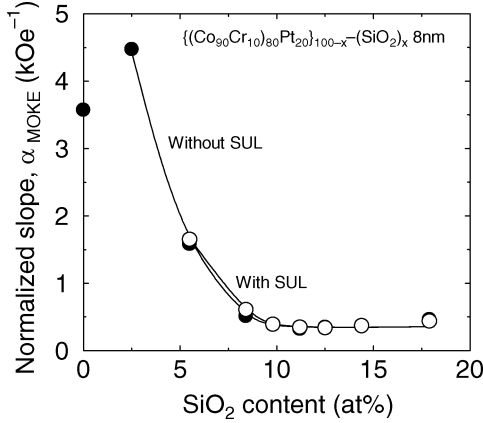


Fig. 3. Normalized slope of the hysteresis loop as a function of SiO<sub>2</sub> content for CoPtCr-SiO<sub>2</sub> single- and double-layered media.

Fig. 4 shows remanence curves for a CoPtCr-SiO<sub>2</sub> medium with 8.4at% SiO<sub>2</sub> measured at sweep rates of 10 Oe/sec using a VSM, and 10<sup>8</sup> 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  $\sim 10$  Oe/s,  $H_r$ , by about 1.8 kOe.

The values of  $K_u V_{act}/kT$  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,  $V_{act}$  the activation volume,  $k$  the Boltzmann constant and  $T$  the absolute temperature). Fig. 5 shows the values of  $K_u V_{act}/kT$  of single-layered media as a function of the SiO<sub>2</sub> content.  $K_u V_{act}/kT$  decreased monotonically as the SiO<sub>2</sub> content increased, mainly due to a reduction of the grain diameter  $D_{grain}$  [5]. This result indicates that the reduction in  $H_c$  on the addition of SiO<sub>2</sub> in excess of  $\sim 8$  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<sub>2</sub> sample measured by the highly stable MOKE magnetometer [4]. The fluctuation

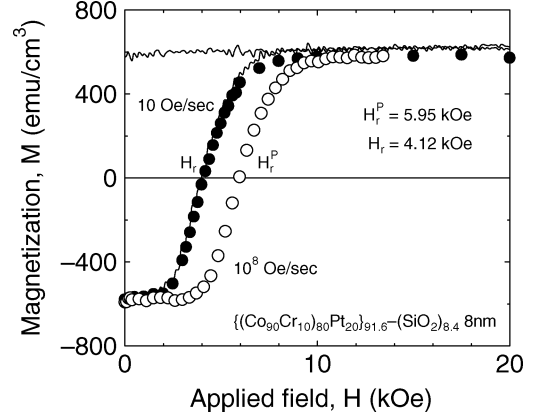


Fig. 4. Remanence curves at two different sweep rates for 8.4at% SiO<sub>2</sub> single-layered media.

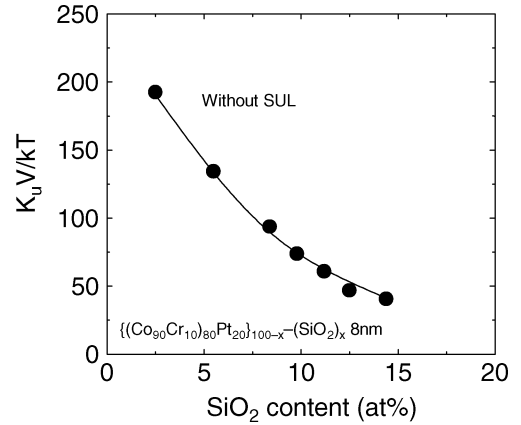


Fig. 5. Values of  $K_u V_{act}/kT$  as a function of SiO<sub>2</sub> content for single-layered media.

field can be calculated from these results using the waiting time method [3] and (1)

$$H_f = \frac{\Delta H}{\ln(t_1/t_2)} \Big|_M \quad (1)$$

where  $\Delta H$  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<sub>2</sub> content for both double- and single-layered media, are shown in Fig. 7.  $H_f$  increased as the SiO<sub>2</sub> 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  $V_{act}$ , if the bulk saturation magnetization is known from (2) [6]

$$V_{act} = \frac{kT}{M_s H_f}. \quad (2)$$

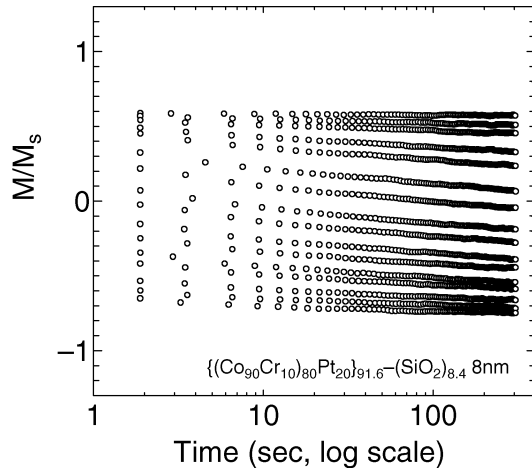


Fig. 6. Time-dependence data for single-layered media with 8.4 at% SiO<sub>2</sub> measured by MOKE.

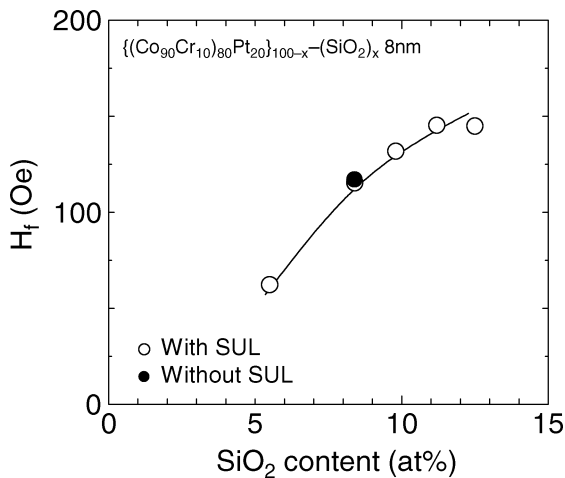


Fig. 7. Values of fluctuation field  $H_f$  as a function of SiO<sub>2</sub> content for CoPtCr-SiO<sub>2</sub> double- and single-layered media.

Values of  $V_{act}$  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  $K_u V/kT$  in Fig. 5 and  $K_u$ , measured by torque magnetometry. The values of grain volume  $V_{grain}$ , including the grain boundary thickness, have been obtained from TEM bright field images, and they are also plotted in the figure.

The values of  $V_{act}$  in both series of media decreased as the SiO<sub>2</sub> content increased. The reduction in  $V_{act}$  was in qualitative agreement with the reduction of  $V_{grain}$  on SiO<sub>2</sub> addition [5]. The values of  $V_{act}$  were larger than  $V_{grain}$  due to limited cooperative reversal. However, the difference between  $V_{act}$  and  $V_{grain}$  decreased as the SiO<sub>2</sub> content increased due to the reduction of intergranular exchange coupling [5].

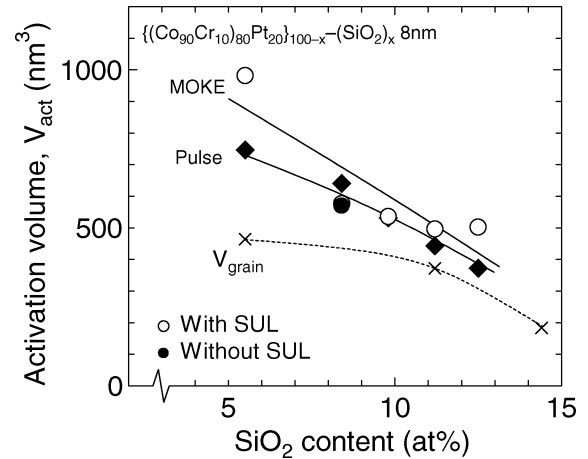


Fig. 8. Activation volume, for double- and single-layered media, as a function of SiO<sub>2</sub> content. The physical grain volume  $V_{grain}$  is also shown.

#### IV. CONCLUSION

There were no significant differences in the magnetic properties and  $V_{act}$  between single- and double-layered media. The value of  $V_{act}$  decreased as the SiO<sub>2</sub> content increased, which is consistent with a reduction in the average grain size. Furthermore, the difference between  $V_{act}$  and  $V_{grain}$  decreased as the SiO<sub>2</sub> 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  $V_{act}$  values obtained from single-layered media to predict the magnetic properties of double-layered media.

#### ACKNOWLEDGMENT

This work was supported in part by the IT program (RR2002) of MEXT and in part by SRC.

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Manuscript received February 7, 2005.