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Magnetization Reversal Behavior in Cobalt Rare-Earth Thin Films

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Abstract - Cobalt Rare-Earth (CoR, R = Pr,Sm) thin films on a Cr underlayer have shown promise as future ultra high density magnetic recording media. The activation volume or the magnetic switching volume (V^*) is an important consideration for thermal stability and media noise in high density recording media and V^* can also provide information about the magnetization reversal behavior in these films. The magnetic switching volume was estimated for the CoPr films with thicknesses from 28 to 639 nm with a Cr underlayer of 80 nm annealed at 500 °C. The measured switching volume ranges from 1.3 to 1.7×10^{-18} cm³. We have also studied the Cr underlayer thickness and temperature effects on the switching volume for the CoSm films.

INTRODUCTION

CoSm films with a Cr underlayer prepared at room temperature with high magnetic coercivity (H_c) of about 3-4 kOe [1]-[3] and annealed CoPr films on Cr underlayer with H_c of up to 10 kOe [4] have shown promise as future high density recording media. It has been shown that the grain size in high density recording media significantly influences the media noise and thermal stability [5,6]. However, it should be emphasized that the magnetic grain rather than the structural grain is responsible for these characteristics. For example, the switching volume (V^*) may be much larger than the structural grain if the interactions between the structural grains are strong enough to make them undergo reversal together. Therefore V^* is an important consideration for understanding the magnetization reversal in high density recording media. The magnetic switching volume can be obtained by measuring the coercivity as a function of the sweep rate of the applied field and also through magnetic viscosity and remanence measurements. Singleton et al. [7] reported measurements of V^* on the order of 10^{-18} ~ 10^{-17} cm³ for CoSm films depending on the CoSm film thickness, Cr underlayer thickness and Ar sputtering pressure. The diameters of the magnetic grains calculated from the measured switching volume for the CoSm layer at room temperature were in the range of 14 to 26 nm which are roughly similar to the average size of the Cr underlayer grains as determined by transmission electron microscopy (TEM).

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In this work the magnetic switching volume was measured for a series of CoPr films with thicknesses from 28 to 639 nm with an underlayer of 80 nm annealed at 500 °C. Here we also report the results of the dependence of the switching volume for CoSm films with and without a Cr underlayer as a function of temperature from 50 to 300 K. The switching volume is correlated to the magnetic properties and microstructure of the films.

EXPERIMENT

Co₇₈R₂₂ films were prepared by dc magnetron sputtering from composite targets. The CoR targets were made of pressed and sintered powders and the Cr target was obtained commercially and had a purity of 99.9%. The Ar pressure during sputtering for CoSm//Cr films was 7 mTorr for the Cr underlayer and 25 mTorr for the CoSm layer. For the CoPr//Cr films the sputtering pressure was 20 mTorr of Ar gas. The sputtering rate for CoPr and CoSm was 0.1 nm/sec. and for Cr was 0.5 nm/sec. The magnetic properties of the films were measured using an Alternating Gradient Force Magnetometer. The sweep rate of the magnetic field was varied from 50 Oe/s to 10,000 Oe/s and coercivity changed as a function of the sweep rate. During viscosity measurements, a maximum field of 14 kOe was applied to saturate the films magnetization. A reverse field near the coercive field was then applied and the magnetization was measured as a function of time. The irreversible susceptibility χ_{irr} was derived from the dc demagnetization curves.

RESULTS AND DISCUSSIONS

We first discuss the measured switching volume for the CoPr//Cr films with a Cr underlayer of 80 nm annealed at 500 °C. The as-deposited CoPr//Cr films are mostly amorphous and then crystallized by annealing at 500 °C. The as-deposited films show a H_c of only about 100-300 Oe but after annealing at 500 °C the H_c of the films ranges from 10 kOe to 5.9 kOe as the film thickness increases from 28 nm to 639 nm. The 28 nm thick CoPr film annealed at 500 °C was nearly 100 % crystalline with a grain size of 10 nm resulting in the large increase in the coercivity [4]. The switching volume was measured by the dependence of apparent coercivity on the sweep rate of the magnetic field and also by magnetic viscosity and remanence measurements for some of the samples.

The coercivity as a function of the sweep rate of the magnetic field is given by [8],[9],

$$H_c = C + \left[\frac{k_B T}{V^* M_s} \right] \ln \left[\frac{dH}{dt} \right] \dots\dots(1)$$

where C is a constant independent of the field-sweep rate. The switching volume can be obtained from the slope of H_c vs. $\ln(dH/dt)$ plot. Figure 1 shows the dependence of H_c on $\ln(dH/dt)$ for different CoPr layer thicknesses. All the samples exhibit the approximate linear relation of H_c on $\ln(dH/dt)$. Measurements at higher sweep rates give a larger value of H_c than a lower sweep rate measurement. The measured switching volume values are given in Table 1 and V^* is on the order of 1.3 to $1.7 \times 10^{-18} \text{ cm}^3$. The switching volume was also determined for some samples by the time decay of magnetization and remanence curve measurements. In many materials it is found experimentally that the change in magnetization often follows the relation [10],

$$M(H,t) = M(H,t_0) + S(H)\ln(t) \dots\dots (2)$$

where M is the net magnetization, S the viscosity coefficient, and t the time elapsed since the last field change. The effective fluctuation field is given by [10],[11],

$$H_f = \frac{S}{\chi_{irr}} = \frac{k_B T}{V^* M_s} \dots\dots (3)$$

The maximum value of S and χ_{irr} reflect the behavior of the most numerous energy barriers and are generally found near the coercive field. In effect this means that the coercivity characterizes the switching of the most grains in the sample. The viscosity coefficient S is obtained from the plot of $M(H,t)$ vs. $\ln(t)$.

Figure 2 shows the dependence of S vs. applied field and the peak value of S is around 7500 Oe. The irreversible

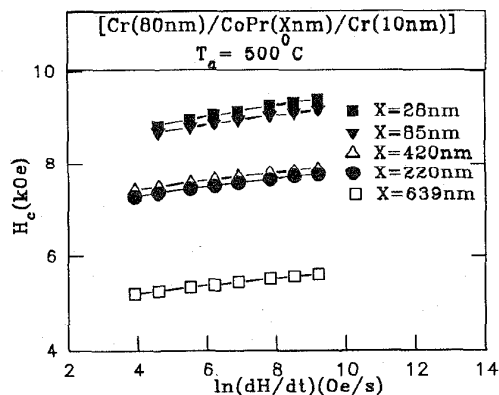


Fig. 1: H_c vs $\ln(dH/dt)$ for CoPr//Cr film.

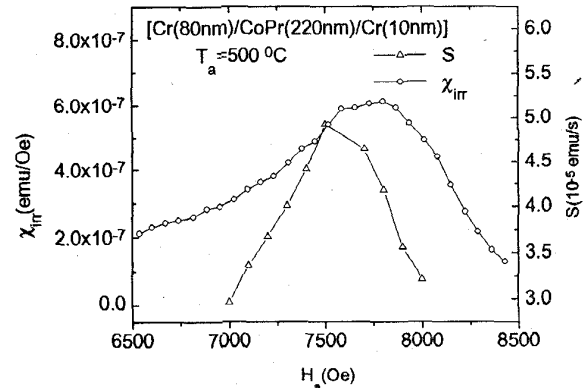


Fig. 2: Viscosity coefficient (S) & irreversible susceptibility χ_{irr} as a function of field for CoPr/Cr film.

susceptibility χ_{irr} is derived from the dc demagnetization remanence curve ($\chi_{irr} = dM_d/dH$). Figure 2 also shows the dependence of χ_{irr} vs. applied field for the sample. The switching volume estimated from the maximum value of χ_{irr} and S was found to be about $1.8 \times 10^{-18} \text{ cm}^3$. Table 1 gives the values of V^* for three different samples. The switching volume estimated by both of these methods have rather similar values which suggests that the V^* values in Table 1 are acceptable in analyzing the process of magnetization reversal.

The magnetic switching volume for the 28 nm thick CoPr film is on the order of $1.3 \times 10^{-18} \text{ cm}^3$. The anisotropy K_u is $4 \sim 5 \times 10^6 \text{ erg/cm}^3$ for this film. Therefore the requirement for thermal stability in high density recording, i.e. $K_u V^* / k_B T > 100$, is satisfied. Using this value and the film thickness, the diameter of the magnetic grain can be estimated assuming that it is a cylindrical cell whose height is the thickness of the CoPr film. The magnetic grain diameter is about 8 nm and the magnetization reversal takes place roughly in the unit of the CoPr grains ($\sim 10 \text{ nm}$ in dimensions as determined by TEM [4]). The magnetic switching volume $V^* \approx (8 \text{ nm})^3$ for the 28 nm thick film is sufficient for both the thermal stability and noise

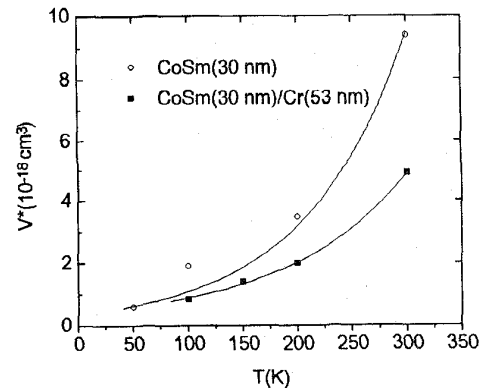


Fig. 3. Magnetic Switching volume as a function of T.

Table 1. Magnetic Switching Volume vs. PrCo Thickness

PrCo(Xnm)//Cr(80nm) $T_a = 500^\circ\text{C}$	H_c (Oe)	V^* (Determined by sweep rate dependence)	V^* (Determined by Time Decay and irreversible susceptibility)
X = 28 nm	9,150	$1.3 \times 10^{-18} \text{ cm}^3$	-----
X = 85 nm	8,950	$1.6 \times 10^{-18} \text{ cm}^3$	-----
X = 220 nm	7,570	$1.4 \times 10^{-18} \text{ cm}^3$	$1.8 \times 10^{-18} \text{ cm}^3$
X = 420 nm	7,710	$1.5 \times 10^{-18} \text{ cm}^3$	$1.4 \times 10^{-18} \text{ cm}^3$
X = 639 nm	5,450	$1.7 \times 10^{-18} \text{ cm}^3$	$2.8 \times 10^{-18} \text{ cm}^3$

considerations. The 28 nm thick PrCo film with a larger coercivity value compared to the 639 nm thick PrCo film has a smaller switching volume. Both H_c and V^* are related to the magnetization reversal mechanisms which depend on the microstructure.

It is of interest to consider the magnetic switching volume for CoSm films as a function of temperature. Figure 3 shows V^* measured by the sweep rate dependence of the applied field at temperatures from 50 to 300 K for CoSm films with and without the Cr underlayer. The H_c of the 30 nm thick CoSm film with a Cr underlayer of 53 nm is about 3.1 kOe and for the 30 nm CoSm film without the Cr underlayer the H_c is about 1.6 kOe. It is seen that at room temperature the V^* for the CoSm with the Cr underlayer is smaller than that of the film with no Cr underlayer. This is because the Cr underlayer develops the columnar morphology which is replicated by the CoSm layer and provides magnetically isolated grains in the CoSm layer. The absence of a Cr underlayer allows for larger magnetic interactions and an increased switching volume for the CoSm films. Liu et al.[12] have observed that for CoSm//Cr films the Cr underlayer has a grain size of about 24 nm and the CoSm layer consists of nanocrystallites of about 5 nm embedded in an amorphous matrix. At room temperature the magnetic grain diameter determined from the measured V^* for the CoSm//Cr films is on the order of the average grain size of the Cr underlayer. Thus the reversal of magnetization occurs in switching units of dimensions of the Cr grains.

It is also seen from Fig. 3 that the V^* decreases at lower temperatures for both of the samples. This temperature dependant behavior has been reported by Singleton et al.[7] and Givord et al.[13] and may be used to obtain information about the reversal mechanism. A temperature independent value of V^* would correspond to coherent rotation of single domain particles. The decrease of V^* with decreasing temperature suggests that the switching mechanism is more complicated and may involve incoherent rotation. Our further work on these samples shows a wall-pinning reversal mechanism which will be reported in detail in a paper to be published.

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