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The technique of ''field sweep-rate dependence of coercivity'' together with the delta-M curves, transmission electron microscopy, and media noise measurement have been employed to reveal the correlation among the magnetic switching volume, physical grain size, intergrain interaction, and noise properties. The switching volume for both CoCrTa and CoCrPtTa films was found to be ~15 nm in diameter, and weakly dependent on grain size and coercivity for the systems studied. In films with physical grain size larger than the switching volume, strong intergrain interaction and high media noise is observed. In films with the physical grain size close to the switching volume, smaller interactions and lower media noise is found. It is argued that a change of the grain size results in a change in the nature of the magnetic interactions. [S0021-8979(97)20708-5]

I. INTRODUCTION

Previous studies have suggested that the magnetic film grain size and switching volume are important quantities for media performance and thermal stability in high density recording media.[1–3] For low noise performance a small grain size is preferred. For sufficient thermal stability of the written information, estimations of minimum ratios $K_u V/k_B T$ have been made,[4] where K_u, k_B, T, and V are the uniaxial anisotropy constant, the Boltzmann constant, the temperature, and the grain volume, respectively. For a better understanding of the magnetization reversal process and correlation between the reversal process and media noise, it is instructive to investigate the switching (activation) volumes and the physical grain sizes. It is known that these do not match for most materials, which is not fully understood at present. It is expected, however, that medium noise should be related to the volume of the grains and/or the switching volume, since both quantities contain information on the possible spatial resolution for recordings on these films.

II. EXPERIMENT

CoCr(Pt)Ta alloy thin films were dc magnetron sputtered on a 95 mm Al/NiP light textured substrate using a static production type sputtering machine with a base pressure of 5×10^{-7} Torr. The magnetic alloy, underlayer and sputtering process were varied to make films with similar magnetic properties but different grain sizes. The film coercivity H_c is in the range 1.8 to 2.4 kOe and the remanence-thickness product $M_r\delta$ is in the range 0.8–1.0 memu/cm^2. The physical grain size was examined by transmission electron microscope (TEM) and the switching volume was determined from the field sweep-rate dependence of H_c and time decay of the magnetization near H_c. The intergrain interactions were investigated with the δM technique using an alternating gradient force magnetometer (AGFM). The signal-to-media noise ratio (SNR) was measured at 130 kfci using a magneto resistance (MR) head over an integrated bandwidth of 5–155 kfci.

III. RESULTS AND DISCUSSION

It has earlier been shown[3,5] that the coercivity H_c as a function of field sweep-rate under thermal switching can be expressed as

$$H_c = C + (k_B T/M_s V^*)\ln(dH/dt), \tag{1}$$

where C is a constant independent of field sweep-rate (dH/dt) and dH/dt is measured in Oe/s. Therefore, the experimental curve of ''H_c vs $\ln(dH/dt)$'' should be a straight line with a slope,

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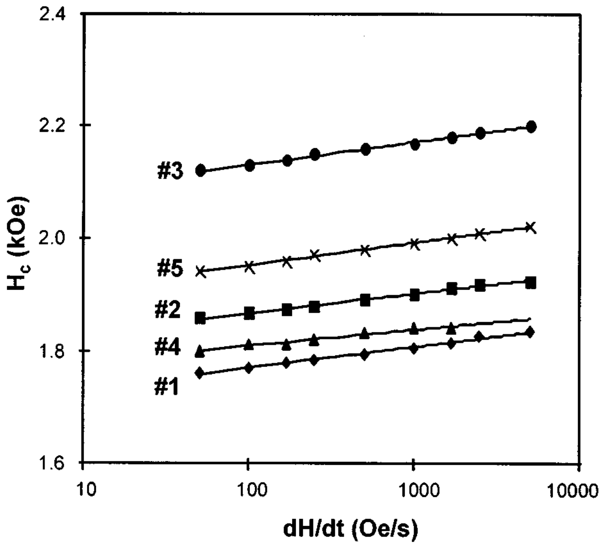

FIG. 1. Coercivity as a function of magnetic field sweep-rate for samples 1–5 listed in Table I.

$$S = k_B T / M_S V^*, \tag{2}$$

i.e., the switching volume is

$$V^* = k_B T / M_S S. \tag{3}$$

Equation (1) was derived assuming a single energy barrier and no interactions between grains. A recent study[6] has shown that, if $k_B T / M_S S$ is multiplied by a corrector factor m close to unity, Eq. (3) is also valid for the case involving intergrain interaction, uniformly distributed energy barriers when the applied field is not aligned with the easy axis of grains.

The coercivity H_c as a function of the field sweep-rate for samples 1–5 is shown in Fig. 1. All data points can be fitted to a series of straight lines. This implies that field sweep-rate dependence of H_c as given by Eq. (1), is valid for our CoCr(Pt)Ta film samples. The switching volumes V^* calculated by Eq. (3) are listed in Table I. Assuming a cylindrical shape of the magnetic grain with a height t, equal to the magnetic film thickness, the diameter d^* of the switching volume V^* is

$$d^* = (4V^*/\pi t)^{1/2}, \tag{4}$$

and the calculation of d^* for these five samples has been performed. All the samples have quite similar switching volume of ~15 nm in diameter as summarized in Table I. It was noticed that the switching volume is not dependent on film physical grain size, is weakly dependent on underlayer variation and film preparation process, but is dependent on the alloys and film thickness for the films we studied.

TABLE I. Grain and switching volume dimensions, δM curve max, and noise power for film systems studied.

No.	Sample	d (nm)	d^* (nm)	V^* (nm^2)	δM	Nm (a.u.)
1	Cr/CoCrPtTa	50	14	3.9	+0.29	249
2	Cr/Cr/CoCrPtTa	40	15	4.1	+0.24	149
3	Cr/CrV/CoCrPtTa	30	14	3.9	+0.21	122
4	Cr/CoCrTa(alloy 1)	20	13	3.3	±0.10	90
5	Cr/CoCrTa(alloy 2)	15	11	2.3	−0.16	75

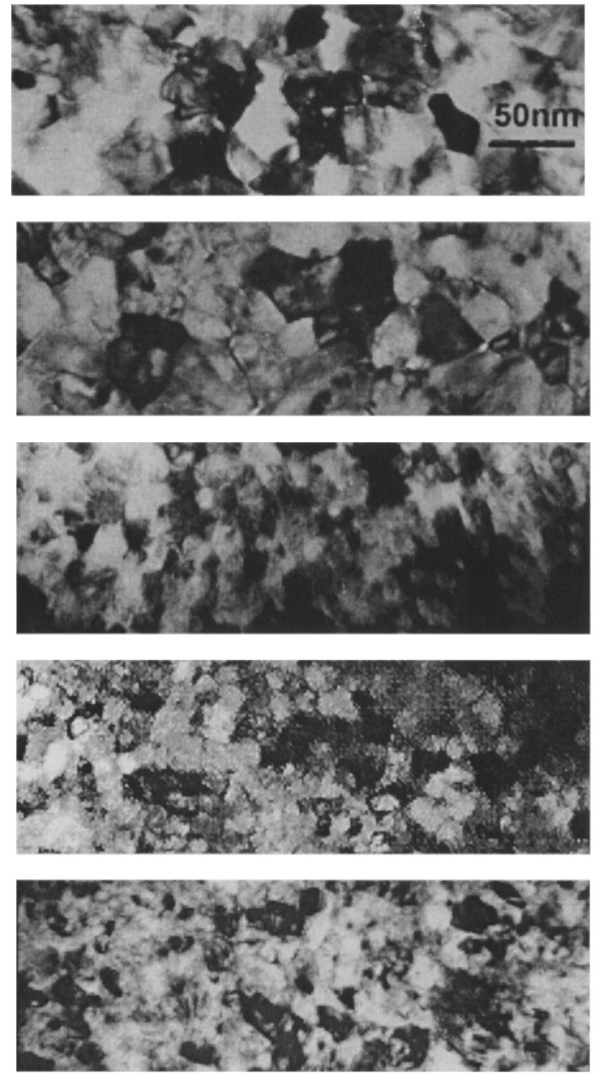

FIG. 2. TEM bright field images of the five samples studied. From top to bottom: samples 1, 2, 3, 4, and 5.

The TEM bright field images in Fig. 2 were used to estimate the physical grain size d; these data are also listed in Table I. Even though the switching volumes were found to be very similar, the physical volumes are quite different. Depending on alloys, underlayer, and film preparation process, the samples have grain diameters ranging from 15 to 50 nm. This indicates that the physical grain size has no apparent correlation with the switching volume. To investigate the intergrain interactions, δM curve measurements have been performed and the results for samples 1–5 are presented in Fig. 3. Samples 1, 2, and 3 exhibit larger positive δM values and steeper slopes at the intersection with the field axis compared with samples 4 and 5. The lowest δM values are found for the sample in which the grain volume is close to the switching volume. Here the positive sign implies that the exchange interaction is the dominant interaction between the magnetic grains, and the slope qualitatively estimates the degree of exchange interaction. When the δM curve values are

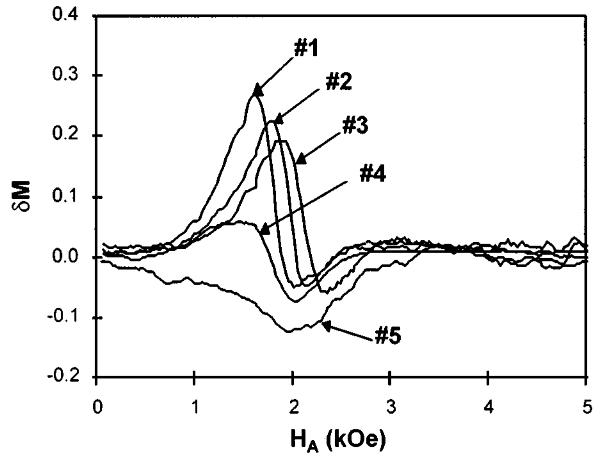

FIG. 3. Delta *M* curves for samples 1–5 listed in Table I.

negative, the contribution of exchange coupling to the overall magnetic interactions is less pronounced and magnetostatic interactions dominate.

Media noise characteristics of these samples were measured at 130 kfci with a MR head; the data are summarized in Table I. The samples which have large grain size compared with the switching volume, e.g., samples 1, 2, and 3, show a larger δM maximum value, as well as larger slopes of the δM curve near the remanent coercivity, as shown in Fig. 3, and larger noise. If the grain volume and switching volumes are similar, (samples 4 and 5) smaller δM maximum values and lower noise are observed.

In the simplest case, one would expect the physical grain and the switching volumes to coincide. This implies switching by homogeneous rotation. The observed mismatch between physical grain and switching volumes has been known[7] and attributed to inhomogeneous magnetization reversals. Typically, for rather large single domain particles, as they occur in magnetic tape media, switching volumes smaller than the particle volume are reported. Physically, this may be interpreted by assuming that the thermal energy $k_B T$ has to overcome only a certain fraction of the particle volume (i.e., the switching volume) in order to reverse the magnetization. An example for such an inhomogeneous, thermally assisted magnetization reversal process was theoretically analyzed in Ref. 8.

Referring to our measurement results, the magnetization reversal process in the ''large'' single domain grains will be inhomogeneous, most likely initiated at defect locations. The volume which is associated with the initial magnetization reversal is smaller than the grain size. On the other hand, the grains are too small to support a domain structure and they will switch entirely. Since the grain size determines the noise, these films are expected to be noisy.

In addition to that, the interpretation is affected by the magnetic interaction. Since the magnetic interactions have an influence on the magnetization reversal process, they will affect the switching volume as well. Experimentally, it is found, however, that decreasing the grain size did not change the switching volume significantly. On the other hand, the δM curves *do* change, meaning that the change of grain size controls the nature of the interactions in our films. One may speculate that making grain volume and switching volume the same is a good medium design.

IV. SUMMARY

In a series of CoCr(Pt)Ta thin films for high density magnetic recording, a variation of grain size has been shown to yield various degrees of magnetic interaction, while the switching volumes remain reasonably constant. Generally, the switching volume has been found to be smaller or equal to the grain size and films with physical grain size closer to the switching volume exhibit lower medium noise. It is concluded that changing the grain size essentially changed the nature of the magnetic interactions and therefore media noise characteristics.

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[1] M. P. Sharrock, IEEE Trans. Magn. **26**, 193 (1990); J. Appl. Phys. **76**, 6413 (1993).
[2] P. I. Mayo, K. O'Grady, P. E. Kelly, J. Cambridge, I. L. Sanders, T. Yogi, and R. W. Chantrell, J. Appl. Phys. **69**, 4733 (1991).
[3] S. S. Mathotra, Z. S. Shan, D. C. Stafford, S. H. Liou, and D. J. Sellmyer, IEEE Trans. Magn. **32**, 4019 (1996).
[4] P. L. Lu and S. H. Charap, IEEE Trans. Magn. **30**, 4230 (1994).
[5] P. Bruno, G. Bayeuther, P. Beauvillian, C. Chappert, G. Lugert, D. Renard, J. P. Renard, and J. Seiden, J. Appl. Phys. **68**, 5759 (1990).
[6] Z. S. Shan, S. S. Mathotra, J. X. Shen, Y. Liu, S. H. Liou, and D. J. Sellmyer (to be published).
[7] R. W. Chantrell, J. Magn. Magn. Mater. **95**, 365 (1991).
[8] H. B. Braun and H. N. Bertram, J. Appl. Phys. **75**, 4609 (1994).