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Magnetic Properties and Nanostructures of Composite Co_xPt_{100-x}:C Thin Films

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***Abstract*—Nanocomposite Co_xPt_{100-x}:C thin films with $x = 57$ and $x = 50$ were prepared by magnetron sputtering. Structures and activation volumes were studied systematically in order to better understand the magnetic behavior. We found that activation volumes of these two samples were almost the same. However, physical grain sizes of these two samples were different. Magnetic grains in the sample with equiatomic Co and Pt composition were almost independently switched and magnetic grains in the sample with higher Co content were exchange coupled and switched together. The reduction of the physical grain size in the sample does not always cause the reduction of the exchange coupling in the sample. Our results indicate that the Co concentration is an additional factor to be used for controlling the properties of nanocomposite CoPt:C films.**

***Index Terms*—CoPtC, magnetic thin films, nanocomposite materials, recording media.**

I. Introduction

EXTREMELY high-density recording (EHDR), which is defined as an areal density of about 100 Gb/in^2, requires media to have a high coercivity and small grain size with weak intergrain interaction [1]. As potential media for EHDR, nanocomposite thin films, which consist of magnetic nanocrystallites in a nonmagnetic matrix, have been paid considerable attentions. For example, the studies of $FePt:SiO_2$ [2], $FePt:B_2O_3$ [3], Fe:C [4], CoPt:Ag [5] and $CoPt:SiO_2$ [6] films have been reported. Recently nanocomposite CoPt:C with equiatomic Co and Pt content have been reported [7]. The magnetic properties of CoPt:C films with C concentration and grain size with annealing process have been investigated systematically [7]. For extremely high-density recording media, besides the issues mentioned above, one of the key concerns is the thermal stability because it controls the life time of the stored data [8]. The thermal stability is closely related to the thermally activated magnetization processes via the ratio of the reversal barrier to the thermal energy. Usually for an isolated single-domain particle with a certain anisotropy and coherent rotation, its physical volume V determines thermal stability. For a real magnetic system, however, the size of the magnetic reversal unit can be different from that of a physical volume V because of the strong intergranular interactions. Activation volume V^*, which consists of many magnetic grains, determines the thermal stability instead of V. So a better understanding of activation volumes V^* is important to thermal stability of the thin film media. In this paper we report structures and activation volumes of nanocomposite CoPt:C thin films with different Co content.

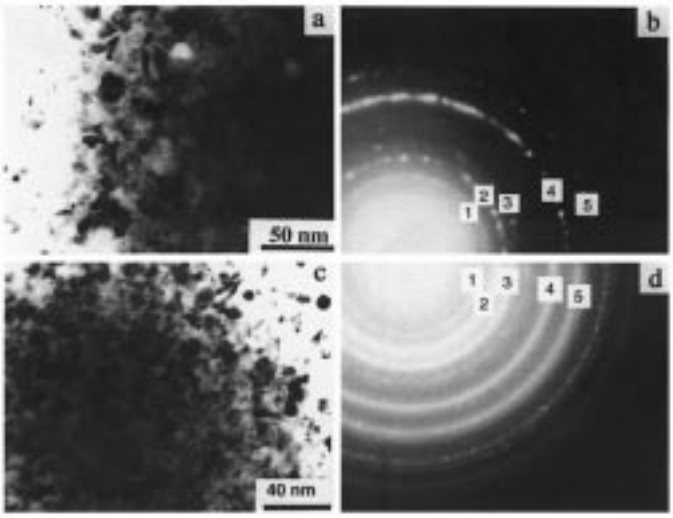

Fig. 1. (a) Bright field image and (b) electron diffraction pattern of sample $Co_{50}Pt_{50}$:C. (c) bright field image and (d) electron diffraction pattern of sample $Co_{57}Pt_{43}$:C. The indices for the rings are: 1 (001), 2 (110), 3 (111), 4 (202), 5 (311).

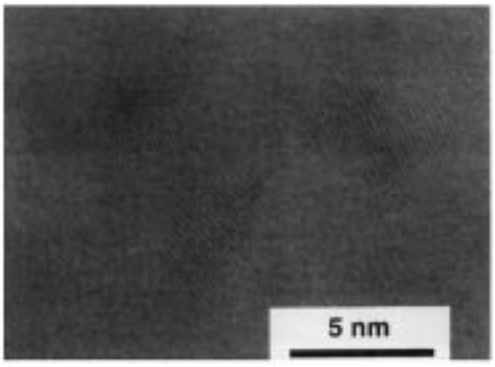

Fig. 2. High-resolution TEM image of $Co_{57}Pt_{43}$:C film.

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TABLE I
MICROSTRUCTURAL AND MAGNETIC PARAMETERS OF THE COMPOSITE CoPt:C FILMS

Sample	Thickness	Composition		H_c	H_{cr}	S	S*	M_s	M_rt	$V^*(H_{cr})$	d*	d
	(nm)	Co	C vol.%	(Oe)	(Oe)			(emu/cc)	(memu/cm^2)	(cm^3)	(nm)	(nm)
1	11	$Co_{57}Pt_{43}$	35	5280	5600	0.90	0.74	430	0.43	2.0×10^{-18}	15	5
2	11	$Co_{50}Pt_{50}$	35	5180	5900	0.81	0.51	280	0.26	2.0×10^{-18}	15	12

II. EXPERIMENTAL

The Co_xPt_{100-x}:C films were magnetron sputtered on water-cooled glass–ceramic substrates with multilayered structure of Co/Pt/Co/C. The composition of Co, Pt and C was well controlled by adjusting thickness ratio of Co, Pt and C layers. All as-deposited films were annealed at 600°C in vacuum for 30 minutes to obtain the fct phase. The details for sample fabrication have been reported previously [7]. In this study, the samples with two different Co concentrations ($x = 57$ and $x = 50$) and C concentration of 35 vol.% were prepared. The structural properties were analyzed by x-ray diffraction (XRD) and transmission electron microscopy (TEM). The magnetic measurements were made on an alternating gradient force magnetometer (AGFM) with the field applied in the plane of the film. Magnetic domain images were observed by a commercial magnetic force microscope (MFM) with a high coercivity tip. MFM images show that transition width of the higher Co-content film is larger than that of the film with lower Co content. This means that the coupling in the higher content film is stronger compared with the equiatomic Co and Pt composition films. Details of the intergranular interactions of $Co_{100-x}Pt_x$:C films were discussed elsewhere [9].

III. RESULTS

Fig. 1 shows the crystal structures and grain sizes of the films examined by TEM. Sample $Co_{50}Pt_{50}$:C has an average grain size of about 12 nm (Fig. 1(a)) and sample $Co_{57}Pt_{43}$:C about 5 nm (Fig. 1(c)). The more uniform diffraction pattern (Fig. 1(d)) of sample $Co_{50}Pt_{50}$:C in contrast to the spotty pattern (Fig. 1(b)) of sample $Co_{50}Pt_{50}$:C is consistent with the grain-size measurement. The diffraction pattern can be indexed by the $L1_0$ structure with the superlattice lines. It is known that Co atoms have smaller diameters than the Pt atoms and a lattice change is expected in the sample with different Co content. Fig. 2 is the HRTEM image for sample $Co_{57}Pt_{43}$:C. This image shows that CoPt grain is a single crystal and C matrix is amorphous. It is also clearly shown that CoPt grains are well separated from each other. The microstructural and magnetic properties for these two samples are listed in Table I. H_{cr} is the remanence coercivity obtained from remanance curve, S is the remanence ratio. S^* is the coercivity squareness, $V^*(H_{cr})$ is the activation volume when the applied field is equal to H_{cr}, $d^*[= (4V^*/\pi t)^{1/2}]$ is a lateral magnetic grain size obtained from the cylindrical magnetic grain model and d is the grain size obtained from TEM image. Measurement of hysteresis loops showed that coercivities are nearly the same for these two samples, but the slope of the loop around the coercivity is different. A rather square hysteresis loop was observed in the sample with a high Co content. The different form of the hysteresis loops indicates the difference of the magnetization reversal mechanism in these samples. $Co_{57}Pt_{43}$:C film is in accordance with the nucleation field being greater than the domain wall coercivity. A more square loop indicates that grains are exchange coupled and magnetization reversal is realized through the reversed domains. A more round loop, however, for the $Co_{50}Pt_{50}$:C film indicates that nucleation occurs but the propagation of the reversed domain is restricted. Intergranular exchange coupling is much smaller and reduced exchange coupling could be expected to result in the formation of smaller domains. In this case the magnetic grains may reverse individually. We have discussed magnetic interactions for composite Co_xPt_{100-x}:C film in an other paper [9].

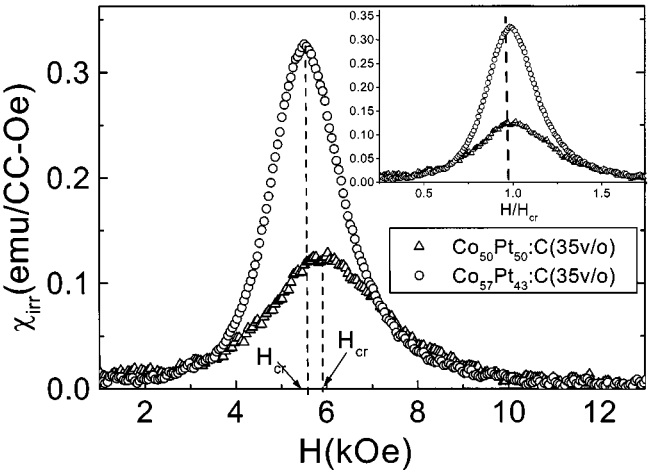

Fig. 3. The differential of DCD curves ($\chi_{\rm irr}$) for $Co_{50}Pt_{50}$:C and $Co_{57}Pt_{43}$:C films. The inset is normalized by remanence coercivity $H_{\rm cr}$.

Fig. 3 shows the differential of the dc demagnetization (DCD) curves ($\chi_{\rm irr}$) for these two samples. The inset is the plot that was normalized by remenence coercivity $H_{\rm cr}$. As shown in Fig. 3, the peak values of $\chi_{\rm irr}$ curves for these two samples appear near to the $H_{\rm cr}$ which values are different. According to O'Grady [10] and Donnet *et al.* [11], the differential of isothermal remanence measured from the demagnetized state determines the distribution of energy barriers to wall motion. The existing domains are increased in size by the usual domain wall movement process. The differential of dc demagnetization curves, where the process starts with the material already saturated, measures the energy barrier to domain nucleation and then determines the mechanism by which reversal proceeds. Usually, the switching field distribution (SFD) was obtained by normalizing the area under the $\chi_{\rm irr}$ curve and its shape is governed by intergranular coupling. Our data show that the energy barrier distribution

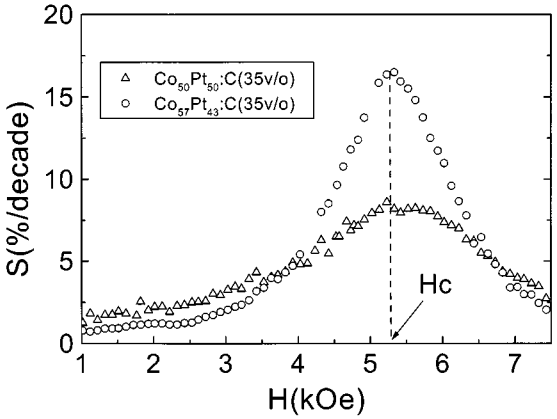

Fig. 4. Viscosity coefficients S as a function of the applied magnetic field for $Co_{50}Pt_{50}$:C and $Co_{57}Pt_{43}$:C films.

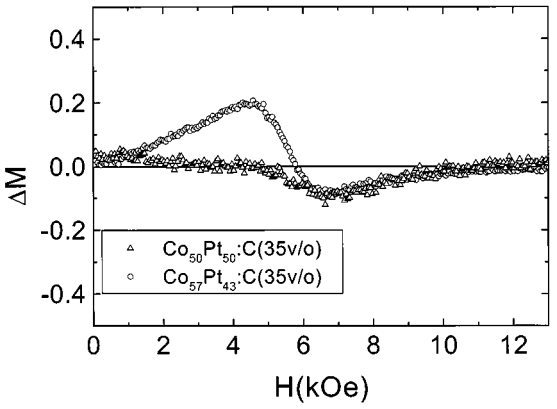

Fig. 5. ΔM curves for $Co_{50}Pt_{50}$:C and $Co_{57}Pt_{43}$:C films.

(SFD) broadens and is shifted to higher field for the $Co_{50}Pt_{50}$:C film.

Fig. 4 shows the variation of viscosity coefficient (S) versus applied magnetic field H. The S curves of two samples have peaks at the respective values of coercivity (H_c). For the sample with high Co content, the peak value of S is higher. For the sample with equiatomic Co and Pt composition, the width of the curve is broad and the peak value of S is lower. The difference in the value of S indicates that the energy barrier is different for these two samples.

ΔM curve measurement, which is obtained from the isothermal remanence (IRM) and the dc demagnetization (DCD) curves, is a common method to directly obtain the information about magnetic intergranular interactions.

Large-scale numerical micromagnetic models [12] have conformed the interpretation of the ΔM curve, where a positive value of the curve indicates intergranular exchange coupling and a negative ΔM profile indicates dipolar interaction. Fig. 5 shows ΔM curves for these two samples. It is seen that ΔM plot shows both positive and negative peaks for $Co_{57}Pt_{43}$:C film. This suggests that interactions are complex due to the presence of intergranular exchange coupling. However, the higher positive peak implies that itergranular exchange coupling is predominant for this sample. This result suggests that the magnetic particles are coupled. For $Co_{50}Pt_{50}$:C film, the negative peak indicates that only a small amount of dipolar interactions is present, which is a characteristic of isolated single domain particles.

Activation volume V^* is the unit volume of magnetic moments that switch together in magnetization reversal, which gives an estimate size of the smallest unit reversing in the media. In principle, it is the activation volume rather than the physical grain size that determines the smallest bit of information that can be stored. Activation volumes V^* can be obtained from $S(H)$ and $\chi_{\rm irr}(H)$ as shown by Street and Woolley [13]: $V^* = k_{\rm B}T\chi_{\rm irr}/M_{\rm s}S$. If we compare physical volume with the activation volume at near the remanence coercivity $H_{\rm cr}$ (See Table I), we can see that many grains form a magnetic cluster and magnetically act like one grain with volume V^* for the sample with high Co content. For the sample with equiatomic Co and Pt composition, physical grain volume V nearly equals the activation volume V^*, which suggests that magnetic grains switch almost independently. This result is consistent with the ΔM measurement: the intergranular exchange coupling of $Co_{57}Pt_{43}$:C film is stronger than that in $Co_{50}Pt_{50}$:C film.

IV. Conclusion

Through studies on microstructure properties and time dependence of nanocomposite Co_xPt_{100-x}:C thin films, the physical grain size and activation volumes were obtained. The results showed that average grain size was determined by the Co concentration and a small average grain size was obtained in the off-stoichiometry sample $Co_{57}Pt_{43}$:C. Our results also revealed that the magnetic grains switched almost independently in the film with equiatomic Co and Pt composition, and were exchanged coupled and switched together in the film with higher Co content. We have shown that Co content is an additional factor to control the magnetic properties of Co_xPt_{100-x}:C nanocomposite films. It is a useful parameter for optimizing media properties for extremely high-density recording.

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