High-Coercivity CoCrPt–Ti Perpendicular Media by *In Situ* Interdiffusion of CrMn Ultrathin Overlayers

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***Abstract*—We have investigated the magnetic and structural properties of CoCrPt perpendicular films with respect to *in situ* interdiffusion of CrMn from top layers. We have observed a coercivity of 5700 Oe in the films with a thin CrMn overlayer, which is greater than two times larger than the similar type of films without a CrMn overlayer. This increment is attributed to the decoupling of grains by diffusion of CrMn from top layer through the grain boundaries.**

***Index Terms*—CoCrPt, CrMn, *in situ* interdiffusion, perpendicular media, sweep rate, switching volume.**

I. Introduction

To ACHIEVE high areal recording density (beyond 100 Gbit/in^2) by avoiding the superparamagnetic instability in the recording bits, a shift from longitudinal recording to a different form of technology will be necessary. Perpendicular recording technology seems to be the least difficult to make the transition and therefore, is a strong candidate for ultra high density recording. Several reports have been made on CoCrPt perpendicular media by using Ti buffer layers. The challenge to improve coercivity and squareness of this type of media is still extensive. It is generally agreed that segregation of nonmagnetic elements to the boundaries of the columnar grains can lead to higher coercivity and lower media noise. By such interdiffusion, CrMn underlayers have been shown to increase the coercivity of CoCrPt longitudinal media [1]–[3]. Increasing the coercivity of CoCrTaPt–Cr longitudinal media by interdiffusion of Mn and Cu overlayers by annealing has also been reported [4]. The effect of CrMn interdiffusion from overlayers on Co based perpendicular media has yet to be investigated.

In this paper, we discuss the effect of CrMn interdiffusion from an overlayer on improving the coercivity and decreasing the exchange coupling in CoCrPt perpendicular media.

II. Experiment

Two types of CoCrPt thin films were deposited at about 280 °C by RF diode sputtering onto naturally oxidized Si (111) wafers. The deposited films were heated during deposition. They were cooled in the chamber after completion. Type I films did not have a CrMn overlayer. Type II films did have a CrMn overlayer. The films (30 nm) were deposited on 50 nm of Ti which had been deposited on Si substrate.

By using a Tracor X-ray (Spectrace 5000), the CoCrPt film composition was determined to be as Co-13%Cr18%Pt and CrMn film as Cr-20%Mn. The Ar sputtering gas pressure was 5 mtorr and the base pressure was below 5×10^{-7} torr. The sputtering rate was about 0.1 nm/s. Magnetic properties were measured using alternating gradient force magnetometry (AGFM) and vibrating sample magnetometer (VSM). The structure of the films was studied by $\theta/2\theta$ scans and ω scans (rocking curve). The ω-scans were performed on a Philips X-pert Pro X-ray diffractometer. A JEOL JEM 2000-EXII and a PHILIPS TECNAI F20 were used to study the microstructure of the films.

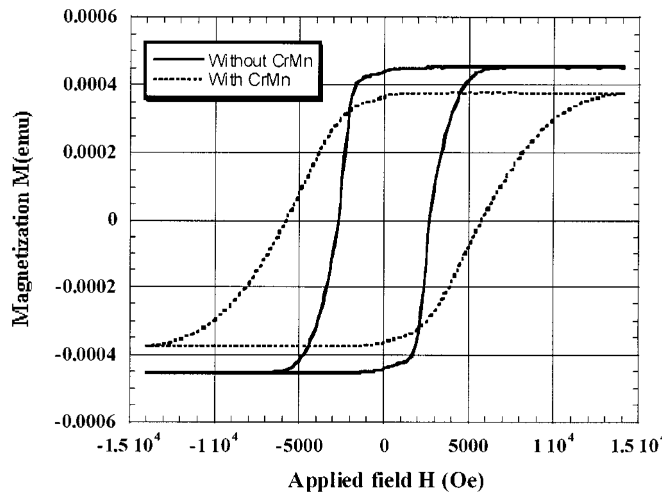

Fig. 1. Hysteresis loops for type I and type II films.

III. Results and Discussion

The $\theta/2\theta$ scans and ω scans were performed on the two types of deposited films to check their texture and c axis alignment. Both types of films have strong perpendicular texture. Rocking curve scans of the 00.2 CoCrPt peak give a full-width at half-maximum (FWHM) of $\sim 5^\circ$ for both types of films. In Fig. 1 the M–H loops for films deposited without (type I) and with (type II) CrMn overlayers are shown. The shapes of the loops are found to be quite different from each other. From the coercive squareness and the slope of the hysteresis loops, it can be concluded that the film with the CrMn overlayer is more exchanged decoupled than the film without the CrMn overlayer.

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TABLE I
MAGNETIC AND STRUCTURAL PROPERTIES FOR TYPE I AND TYPE II FILMS

Films	H_c (Oe)	M_s (emu/cm^3)	M_r/M_s	K_u (erg/cm^3)	V* (cm^3)	S*	FWHM (deg.)
Type I	2700	400	0.97	2.6×10^6	3.8×10^{-18}	0.64	~5
Type II	5700	350	0.97	2.3×10^6	2.6×10^{-18}	0.37	~5

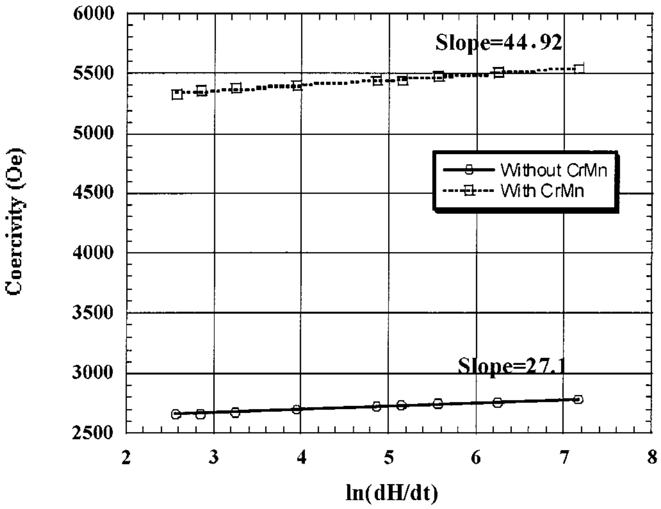

Fig. 2. Coercivity dependence on the field sweep rate for type I and type II films.

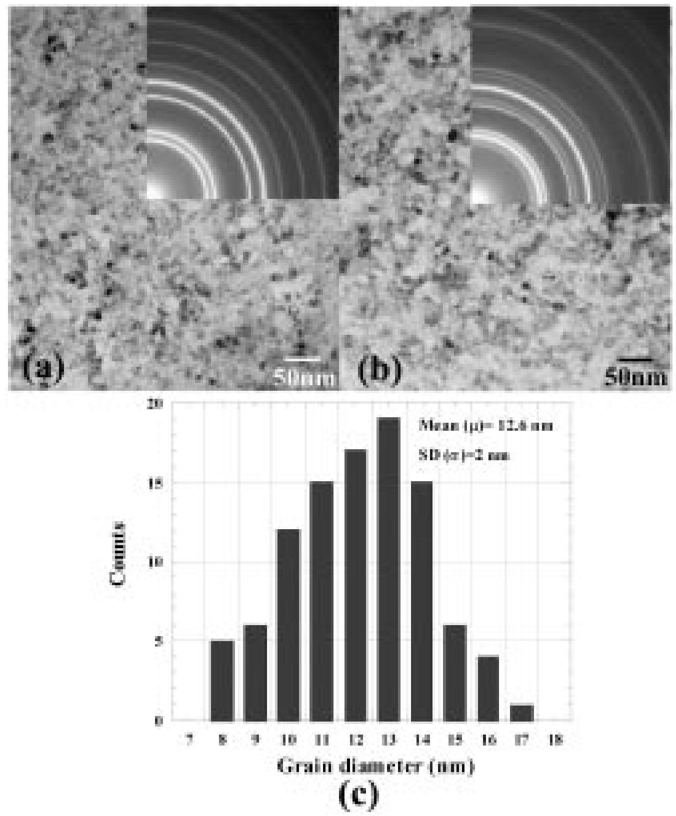

Fig. 3. TEM bright field images for (a) type I and (b) type II films. Insets are their corresponding electron diffraction patterns. (c) Grain size distribution of type II film.

The film with CrMn overlayer has a lower saturation magnetization (M_s) (about 12%) than the film without the CrMn layer. The film with the CrMn overlayer registered a coercivity (H_c) of 5700 Oe, which is more than two times than that of type I films. Since the degree of texture is similar in both films, the increase is attributed to the decoupling of grains by the diffusion of CrMn from top layer. This decoupling is also apparent from the difference of the slope of hysteresis loops for the two films. A slight shoulder in the reversal of field is detectable in both hysteresis loops. This is due to the initial nontextured layer in the CoCrPt films as detected by high-resolution transmission electron microscopy (HRTEM) (see Fig. 5).

The anisotropy (K_u) of the two types of films was estimated from torque measurements. The results are summarized in Table I. The exchange coupling in the film can be qualitatively understood from the differences in the values of switching volumes (V^*). V^* can be evaluated by measuring the dependence of the H_c on the sweep rate of the applied field [5]. We cannot use the δM technique to determine if exchange coupling exists in the perpendicular films [6]. Here we have measured the coercivities with the various sweep rates (13–1300 Oe/s) to determine the V^* for the two different types of films. As seen in Fig. 2, the H_c displays a linear relationship with the logarithm of the sweep rate. The switching volumes were obtained from the slope of the curves. The estimated V^* and other properties are tabulated in Table I. The smaller V^* value for the films with the CrMn layer implies that a lower volume is coherently changing magnetization with field. This implies that the grains in type II films are less exchanged coupled than those in type I films.

To ascertain the microstructures that give rise to good properties, we have performed plan-view and cross-sectional transmission electron microscopy. Fig. 3(a) and (b) shows typical plan-view bright field images and the corresponding diffraction patterns of the two different types of films. The grain-contrast is clearer for type II film than type I. This supports the assertion that the CrMn diffuses down the grain boundaries from the overlayer and sharpens the grain contrast. The inset diffraction pattern for type I film shows two sets of hcp rings with hk.0 rings. The set with smaller diameter is for Ti and with larger diameter is for CoCrPt films. The diffraction pattern (inset) for type II films shows two sets of hcp rings with hk.0 indexing representing Ti and CoCrPt and a third set of bcc rings arising from the CrMn film. The presence of only the hk.0 rings in the both types of films shows that they are very strongly 00.1 textured perpendicular films. The grains of the films are small and equi-axed. The grain size of type II films shows a Gaussian distribution [Fig. 3(c)]. The mean grain size (μ) of this film is 12.6 nm and the standard deviation (σ) of the grain size distribution is 2 nm.

Cross-sectional TEM was used to examine if an epitaxial relationship exists between the Ti layer and CoCrPt layer. Fig. 4 shows bright and dark field images for the two types of films. It is clear that the diffraction contrast is not continuous from the Ti layer through the magnetic layer. It is also obvious that the two layers are separated by an amorphous layer having two slightly different contrasts [Fig. 4(a) and (c)]. This amorphous layer helps to provide good perpendicular texture in the films

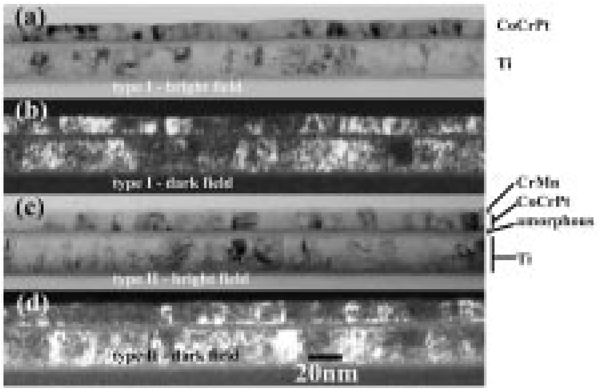

Fig. 4. TEM cross-sectional images: (a) bright field; (b) dark field image from type I films and (c) bright field; and (d) dark field image from type II films.

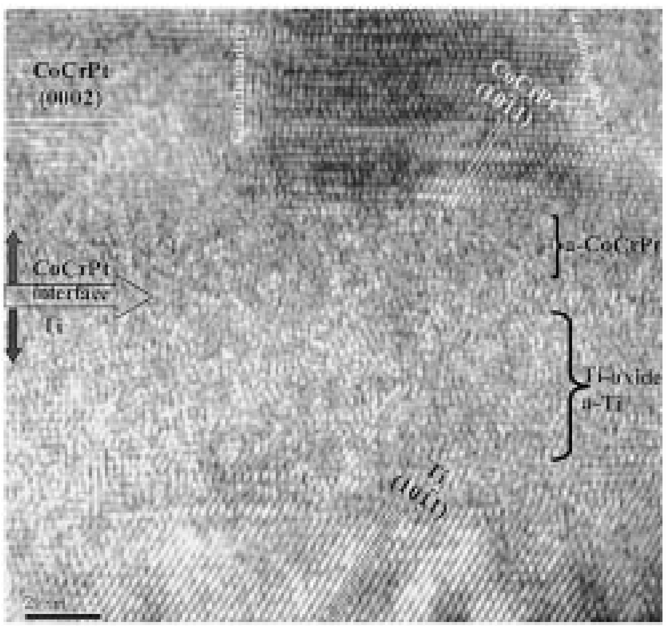

Fig. 5. HRTEM image of Ti–CoCrPt interface of type II film.

[7]. From HRTEM, as shown in Fig. 5, it is thought that the first amorphous region (the one with slightly brighter contrast) is from Ti-oxide and the one above it (with slightly darker contrast) is from an initial amorphous layer of CoCrPt film. This initial layer of the CoCrPt gives rise to the slight shoulder in the hysteresis loops because of its lower anisotropy.

To determine the interdiffusion of CrMn from the overlayer into the magnetic layer we performed elemental mapping by electron-energy-loss spectroscopy (EELS) and scanning transmission electron microscopy (STEM) on the type II films. From Cr and Mn mapping [Fig. 6(a)], it seems that both elements diffuse into the CoCrPt layer. The STEM line profiles [Fig. 6(b)] also show that the Mn diffusion is all through the CoCrPt layer and Cr diffusion is higher only at the top of the CoCrPt layer.

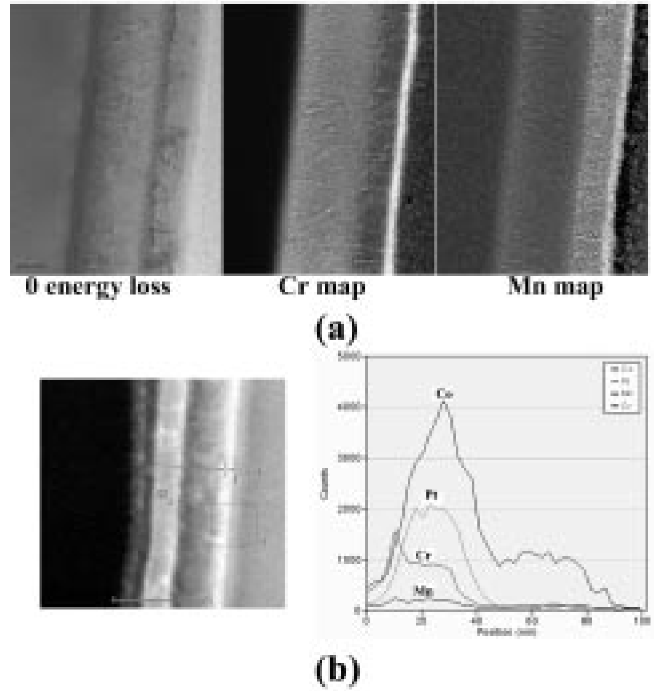

Fig. 6. Typical (a) EELS and (b) STEM line profiles of type II films.

IV. Conclusion

The effect of CrMn interdiffusion from the overlayer to the CoCrPt perpendicular media has been investigated. The interdiffusion from the top layer does not disturb the c axis texture of the CoCrPt layer. The CrMn interdiffusion effectively decouples the grains in the CoCrPt layer. The CrMn diffusion decreases the M_s of the films by only 12%, but gives rise to an increase of more than two times the coercivity. Since there is no orientation relationship between the amorphous Ti and CoCrPt layers, it is possible to have similar very good perpendicular properties with very thin Ti seed layers.

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