$L1_0$ Fe-Pt on Nanocrystalline HITPERM Soft Magnetic Underlayer for Perpendicular Recording Media

S. Kumar, Anup G. Roy, and David E. Laughlin

***Abstract*—Fe-Pt films with (002) perpendicular orientation have been prepared on HITPERM soft magnetic underlayers. Subsequent to preparing the HITPERM underlayer film at room temperature, Cr seed layers (20–80 nm), Pt buffer layers (~ 3 nm), and Fe-Pt recording layers (8–30 nm) were sputter-deposited *in-situ* over a range of temperatures. The desired Cr (200) texture was obtained at $\sim 250-280^{\circ}$C. With the Cr seed layer (200) oriented, thick (80 nm) Cr films were seen to promote (002) orientation in thick (30 nm) Fe-Pt films, whereas thin (20 nm) Cr films promoted better (002) texture in thin (8 nm) Fe-Pt films. In the as-deposited state, the Fe-Pt films exhibited incomplete ordering to the $L1_0$ phase. Structural studies performed on these films, as well as domain images obtained from the HITPERM soft magnetic underlayer films, will be presented here.**

***Index Terms*—Fe-Pt, perpendicular recording, soft underlayers.**

I. Introduction

As THERMAL stability becomes an increasingly important limitation, it is expected that perpendicular recording, which offers better thermal stability at comparable recording densities, will replace longitudinal recording. It is generally believed that the addition of a magnetically soft underlayer generates the largest benefits for perpendicular recording [1]. The use of a soft magnetic underlayer (SUL) in the perpendicular mode effectively increases the writing head field and allows for the extension of the superparamagnetic limit to even higher recording densities due to the possibility of using media with higher anisotropies. Additional advantages are stronger playback signals and effectively lower demagnetization fields in the recording layer.

Owing to its high magnetic anisotropy, high coercivity, and good corrosion resistance properties, $L1_0$ phase Fe-Pt is a strong candidate for ultrahigh density perpendicular recording media [2], [3]. However, the Fe-Pt thin film deposited directly onto an amorphous substrate at room temperature (RT) tends to have the FCC structure and the (111) texture [4]. As a result, these films have to be deposited on a heated substrate or subsequently annealed at high temperatures in order to obtain the $L1_0$ ordered phase.

Manuscript received October 16, 2003. This work was supported by the Data Storage Systems Center (DSSC) at Carnegie Mellon University, Pittsburgh, PA.

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Digital Object Identifier 10.1109/TMAG.2004.832464

The task of obtaining $L1_0$ Fe-Pt film on a SUL with the c axis of Fe-Pt oriented perpendicular to the film plane is a significant challenge on film fabrication. An intermediate layer (seed layer) between the SUL and the recording layer becomes necessary to promote the crystallographic texture in the recording layer and also to magnetically de-couple these two layers. Cr seed layer films with the (200) texture have been found to promote the perpendicular growth of $L1_0$ Fe-Pt layers at lower temperatures [5]. Cr, when deposited directly onto amorphous substrates at RT, displays the (110) orientation, but when prepared at high temperatures (> 250 °C). it grows with (200) texture favored [6].

Previously, we reported on the excellent soft magnetic properties obtained when HITPERM alloy was prepared in the fine nanocrystalline phase. Low coercivity ($\sim 4-5$ Oe) and large saturation magnetization ($4\pi M_s \sim 19-20$ kG) was achieved [7], [8]. However, the presence of domains in the SUL can lead to playback noise. In this regard, domain image analysis performed on the HITPERM thin film is presented at the outset. Following this, we describe the preparation of (001) textured $L1_0$ phase Fe-Pt on nanocrystalline HITPERM soft magnetic underlayers.

II. Experimental Procedure

HITPERM soft magnetic underlayer films of $\sim$ 100 nm thickness were prepared on 7059 Corning glass substrates by rf sputtering, using an alloy target of composition $(Fe_{0.7}Co_{0.3})_{88}Zr_7B_4Cu_1$. For this study, the HITPERM films were sputtered at a power density of 4.5 W/cm^2 at RT [8]. A wide-field Kerr microscope was used to obtain magnetic domain images from the HITPERM thin films. The specimen was cut into a 7-mm dimeter circular shape to minimize demagnetization effects. Subsequent to depositing the HITPERM soft underlayer at RT, Cr thin films of varying thicknesses (20–80 nm) were sputter deposited *in-situ* over a range of temperatures ($\sim 200-350$ °C). A thin Pt buffer layer $\sim$ 3 nm was then introduced, and Fe-Pt thin films of varying thicknesses (8–30 nm) were subsequently sputtered. The Fe-Pt thin films were sputtered from a composite target. The chemical composition of the Fe-Pt film was $\sim 52-54$ at % Fe (remainder Pt), determined by the X-ray fluorescence method. The Cr, Pt, and Fe-Pt layers were all prepared at the same temperature ($\sim 200-350$ °C). Structural analysis was performed using X-ray diffractometry (XRD) with Cu $K\alpha$ radiation. Transmission electron microscopy (TEM) was used to study the film's microstructure.

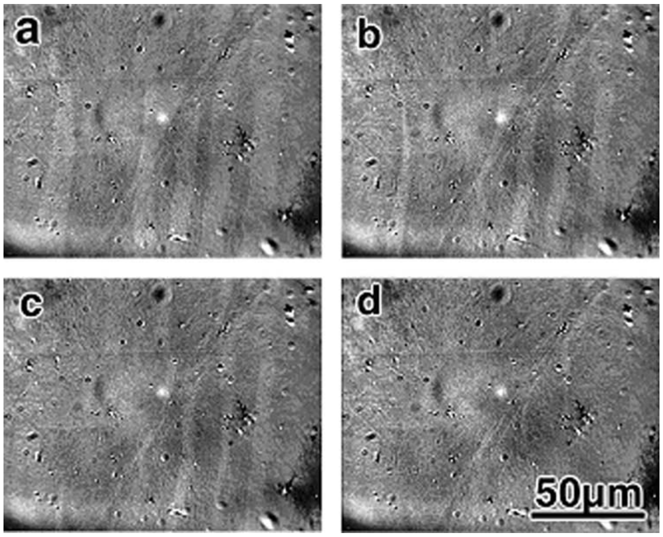

Fig. 1. Magnetic domain pattern in a HITPERM thin film (100 nm, prepared at RT and 4.5 $\mathrm{W/cm^2}$ sputter power density). The externally applied field H_{a} is from top to bottom. (a) AC demagnetized. (b) $H_{\mathrm{a}} = 10$ Oe. (c) $H_{\mathrm{a}} = 15$ Oe. (d) $H_{\mathrm{a}} = 40$ Oe.

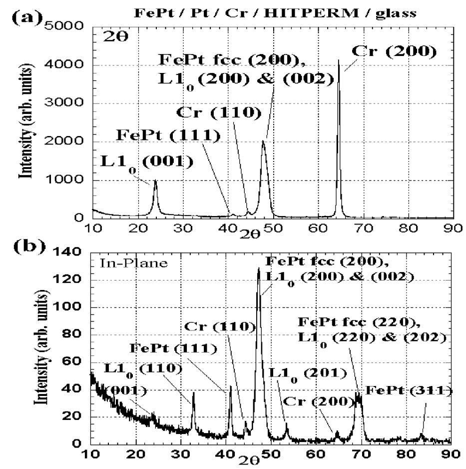

Fig. 2. (a) Conventional $\theta/2\theta$ and (b) in-plane $\theta/2\theta$ XRD spectra from Fe-Pt (30 nm)/Pt (3 nm)/Cr (80 nm)/HITPERM (100 nm)/glass thin film. The HITPERM was prepared at RT under 4.5 $\mathrm{W/cm^2}$ sputter power density, following which the substrate temperature was raised *in-situ* to $\sim 280\ ^\circ$C. The Cr, Pt, and Fe-Pt films were then sputtered at this temperature.

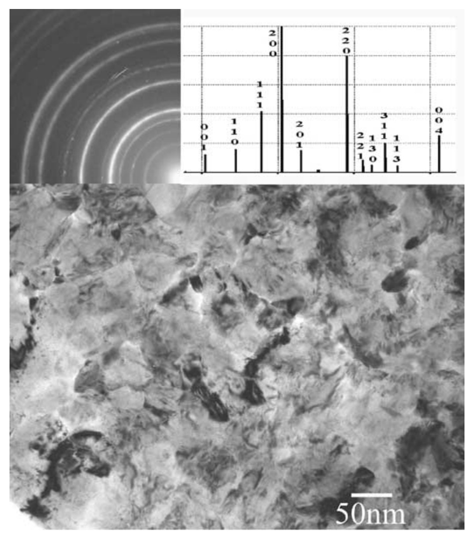

Fig. 3. Bright-field image and SAED pattern from Fe-Pt (30 nm)/Pt (3 nm)/Cr (80 nm)/HITPERM (100 nm)/glass. The HITPERM was prepared at RT under 4.5 $\mathrm{W/cm^2}$ sputter power density, following which the substrate temperature was raised *in-situ* to $\sim 280\ ^\circ$C. The Cr, Pt, and Fe-Pt films were then sputtered at this temperature. The integrated average radial intensity distribution obtained from the SAED is also plotted.

III. Results and Discussion

Fig. 1(a) presents the virgin ac-demagnetized state of the domains in the HITPERM thin film, which closely resembles a stripe domain pattern. There appears to be 180° vertical domains of size of several tens of micrometers, running from top to bottom. When a field was applied (directed from top to bottom in the images), those domains with moment favorably oriented (parallel) to the external field were seen to expand out [Fig. 1(b)–(c)] until saturation was reached at ~ 40 Oe [Fig. 1(d)]. Starting from the fully saturated state, the field was reduced to zero and reversed in the opposite direction. A nucleation event was observed which led to magnetization reversal, by growth of domains of reverse magnetization, by domain wall movement (not shown here). This is expected in soft magnetic materials, wherein the major part of the hysteresis occurs in that part of the magnetization curve where domain wall motion is taking place, and the irreversible component giving rise to hysteresis is generally attributed to some impedance to domain wall motion. Given that the domain wall motion can lead to soft underlayer playback noise, it is important to eliminate domains in the SUL to obtain low-noise perpendicular media. However, the size of the domains ($\sim 30\ \mu$m) seen in these HITPERM thin films is very large. This is directly related to the low anisotropy found in these FeCo-based nanocrystalline alloys ($K_{\mathrm{u}} \sim 8 \times 10^4$ $\mathrm{erg/cm^3}$). Nevertheless, internal stresses such as those due to partial crystallization or from the manufacturing process can produce induced anisotropies that lead to smaller domain sizes. Thermal annealing could help to eliminate the stripe domains through stress relief, but excessive annealing could lead to secondary crystallization.

Thick Cr seed layer films ($\sim$ 80 nm) developed strong (200) texture on nanocrystalline HITPERM underlayer films when deposited at elevated temperatures in the range of $\sim 250-280\ ^\circ$C. On these Cr films and with a thin Pt buffer layer, 30-nm thick Fe-Pt films displayed good (001) orientation. Fig. 2 shows the conventional and in plane (grazing incident angle 2°) $\theta/2\theta$ XRD scans obtained from one such Fe-Pt/Pt/Cr/HIPTERM film structure. The conventional $\theta/2\theta$ scan shows the presence of strong $L1_0$ (001) reflection, which indicates dominant perpendicular variant. However, we can also detect the (111) reflection. The Fe-Pt (200) reflection is broadened and asymmetric, which suggests that the peak combines FCC (200) with $L1_0$ (002) and possibly $L1_0$ (200) as well. The latter is not desired. However, the in plane $\theta/2\theta$ scan shows only a weak $L1_0$ (001) reflection along with strong superlattice reflections from (110) and (220)/(202). This indicates that the Fe-Pt is strongly c-axis oriented, but the presence of the (111) reflection suggests that a weak (111) fiber texture is also present. TEM corroborated these observations. Fig. 3 is the bright-field image along with the selected area diffraction pattern (SAED) from this film. The grain size is of the order of 10–50 nm. The integrated average ra-

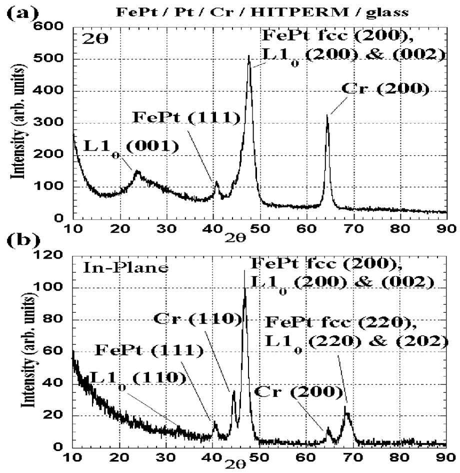

Fig. 4. (a) Conventional $\theta/2\theta$ and (b) in-plane $\theta/2\theta$ XRD spectra from Fe-Pt (8 nm)/Pt (3 nm)/Cr (20 nm)/HITPERM (100 nm)/glass thin film. The HITPERM was prepared at RT under 4.5 $\mathrm{W/cm^2}$ sputter power density, following which the substrate temperature was raised *in-situ* to $\sim 250\ ^\circ\mathrm{C}$. The Cr, Pt, and Fe-Pt films were then sputtered at this temperature.

dial intensity distribution [9] obtained from the SAED is also plotted. This gives an intensity profile similar to that obtained from the in-plane $\theta/2\theta$ scan, but can distinguish more quantitatively the perpendicular and in-plane structural variants. The SAED shows a strong (200) reflection, and only a weak (001) reflection. But there is no clear peak splitting of the (200). Since the $L1_0$ (200) overlaps with the FCC (200), it is difficult to do quantitative analysis of the ordering parameter. Nevertheless, we can conclude that these Fe-Pt films possess good perpendicular texture and exhibit a moderate degree of ordering. The tetragonality, or c/a, calculated from the superlattice reflections is ~ 0.98, which is somewhat larger than that found in bulk and thin films (~ 0.96) [10]. This is related to the imperfect texture and low degree of ordering seen in these films, since strain is believed to play an important role in promoting the formation of the $L1_0$ phase with the (001) texture at lower temperature [5], [10]. The strains are likely to be relaxed because of the thick nature of the Cr seed layers.

With thin Cr seed layers ($\sim$ 20 nm) and a Pt buffer layer ($\sim$ 3 nm), thick Fe-Pt films ($\sim$ 30 nm) displayed mixed texturing with both the Fe-Pt (111) and (200) textures present. However, when the Fe-Pt layer thickness was reduced (~ 8 nm), good perpendicular texture was obtained. Fig. 4 gives the set of conventional and in-plane $\theta/2\theta$ XRD spectra obtained from this film structure. Both the conventional and in-plane scans show weak Fe-Pt (111) reflection and, when taken together with the absence of peaks like $L1_0$ (201), suggest that the Fe-Pt texture is strongly (002) oriented. The broad nature of the (200) reflection and the absence of clear peak splitting indicates that these films are only partially ordered. The reason why thin Cr layers promote better (002) texture on thin Fe-Pt layers is related to the strain, since it is easier to sustain the strain misfit between Cr and Fe-Pt ($\sim 7\%$) across thin films compared to thick films.

In these films, changing the temperature range in which the Cr, Pt, and Fe-Pt films are *in-situ* sputtered was seen to worsen the perpendicular texture of the Fe-Pt. This was seen to be related to the simultaneous worsening of the Cr (200) texture when sputtered at temperatures below $\sim 250\ ^\circ\mathrm{C}$ or above $\sim 280\ ^\circ\mathrm{C}$.

Magnetic properties of the recording layer in such hard-layer, high-moment SUL perpendicular media are difficult to measure with conventional equipment like VSM. However, our preliminary investigations using a technique based on the anomalous Hall effect has indicated coercivities of ~ 5000 Oe for the Fe-Pt recording layer [11]. This will be the subject of future work.

IV. Conclusion

Fe-Pt thin films with good (002) texture have been prepared with Cr seed layers on HITPERM SUL. The desired (200) orientation for the Cr seed layers was obtained at $\sim 250-280\ ^\circ\mathrm{C}$. Both thin ($\sim$ 8 nm) and thick ($\sim$ 30 nm) Fe-Pt with (002) orientation have been obtained on thin ($\sim$ 20 nm) and thick ($\sim$ 80 nm) Cr seed layers, respectively. However, in the as-deposited state, these films exhibited only a moderate amount of ordering to the $L1_0$ phase. Further studies are required to optimize these films. Large domains ($\sim$ 30 $\mu\mathrm{m}$) were observed in the HITPERM SUL, which could possibly be eliminated by thermal annealing. If the problems encountered can be resolved, the Fe-Pt/HITPERM media could be a promising candidate for ultrahigh density perpendicular recording media.

Acknowledgment

The authors would like to thank C.-M. Park for assistance with the Kerr Microscope and Y. Peng for the Kerr image processing.

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