JOURNAL OF APPLIED PHYSICS **104**, 023904 (2008)

# *$L1_0$* FePt-oxide columnar perpendicular media with high coercivity and small grain size

En Yang[a)] and David E. Laughlin
*Materials Science and Engineering Department and Data Storage Systems Center, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*

(Received 21 November 2007; accepted 11 May 2008; published online 21 July 2008)

Perpendicular $L1_0$ ordered FePt-oxide two-phase thin films with an average grain size of ~7 nm were prepared by alternate sputtering of FePt and oxide at 475 °C. Very uniform and well-isolated columnar grains were obtained with coercivity as high as 7 kOe. It is found that the texture of thin films depends greatly on the thickness of FePt; $SiO_2$ works better than MgO as the amorphous oxide, which provides for magnetic isolation of the FePt grains. The coercivity of the films rises with increasing grain size and thinner alternately sputtered single layers. Reducing the grain size to ~2.9 nm produces granular grains with a coercivity of 3.5 kOe. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2956691]

## INTRODUCTION

Because the size of magnetic grains approaches the superparamagnetic limit in current perpendicular media, it is necessary to produce thin film media made with magnetic alloys with larger magnetocrystalline anisotropy energies to achieve higher recording densities. Due to its high anisotropy field and good environmental stability, FePt ($L1_0$) is the most promising media for achieving such ultrahigh recording densities. However, there are several challenges associated with the development of FePt as a perpendicular media. In order to use it as a high density recording media, very small (less than 5 nm), uniform, and fully ordered isolated FePt ($L1_0$) columnar grains with excellent perpendicular texture and high coercivity are desired. This kind of media has not yet been reported in any work, although many efforts have been devoted to this area.[1,2] A MgO underlayer with (002) texture or a MgO(001) single crystal substrate has been widely used to promote the perpendicular orientation of FePt.[3–6] Various materials have been added to the FePt layer to magnetically decouple the FePt grains.[7,8] *In situ* heating,[9] postannealing,[10] and atomic sputtering of Fe/Pt multilayers[11] have been used to transform FePt from the fcc structure to the $L1_0$ ordered structure, since FePt alloy sputtered at room temperature has the fcc structure with (111) texture. In this paper, we report the results of our study on fabricating FePt recording media.

## EXPERIMENT

FePt/oxide multilayers and MgO/Ta underlayers were deposited on a Si substrate by rf sputtering. The base pressure was about $5\times10^{-7}$ Torr and the argon pressure varied between 10 and 45 mTorr. The FePt/oxide multilayers were fabricated by the alternate sputtering of $Fe_{55}Pt_{45}$ alloy and MgO or $SiO_2$ targets on a heated substrate. The substrate temperature was maintained at 475 °C during sputtering. X-ray diffraction (XRD) and transmission electron microscopy (TEM) were used to study the texture and microstructure of the films. The polar magneto-optical Kerr effect (MOKE) looper was used to investigate the magnetic properties.

## RESULTS AND DISCUSSION

It was found that Ta/MgO underlayers sputtered at room temperature and then heated to high temperature have better texture than underlayers sputtered at room temperature or underlayers sputtered on high temperature substrate. The full width at half maximum of MgO (002) decreased from 9° to 6° after postannealing, as shown in Fig. 1. The MgO underlayer often has (111) texture when deposited directly on a heated substrate. However, annealing changed the texture to a strong (002) texture. FePt alloy was subsequently sputtered on top of the heated underlayers. XRD scans of the Ta/MgO/FePt thin films deposited with different thicknesses of FePt are displayed in Fig. 2. It can be seen that a strong FePt(001) superlattice peak appeared as the result of *in situ* chemical ordering. The thickness of the FePt layer has a great influence on the perpendicular texture of the FePt

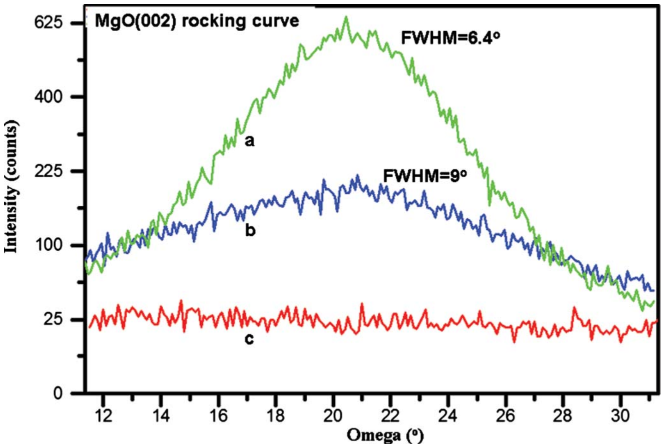

FIG. 1. (Color online) Rocking curve for MgO(002) underlayer. (a) Deposited at room temperature and postannealed at 475 °C. (b) As deposited at room temperature. (c) Deposited at 475 °C.

---

[a)] Electronic mail: minienzy@gmail.com.

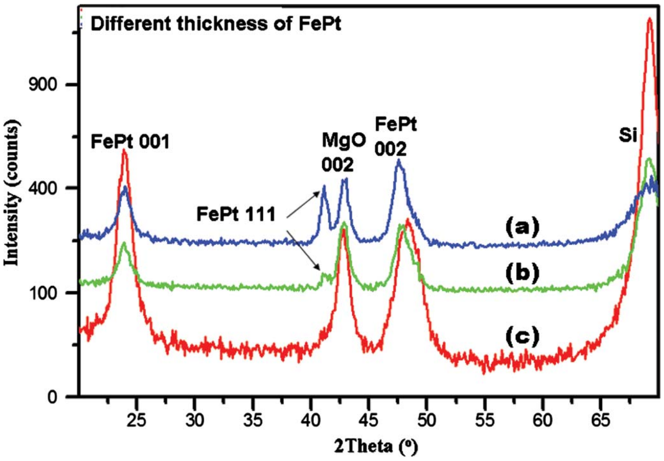

FIG. 2. (Color online) X-ray 2theta-omega scans of FePt thin films deposited on MgO underlayers at 475 °C, for different thicknesses of FePt: (a) 32, (b) 16, and (c) 9 nm.

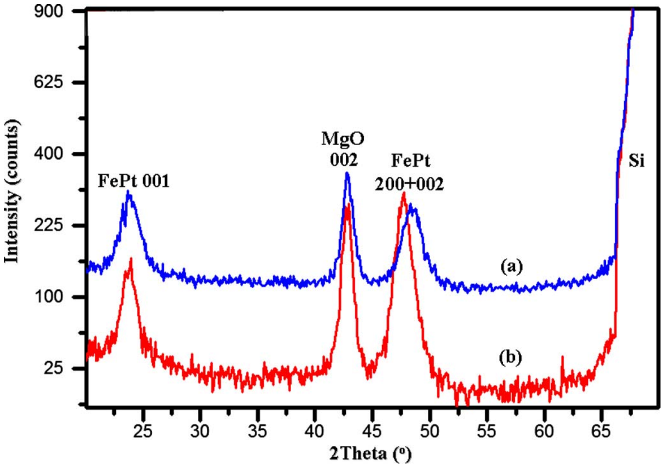

FIG. 4. (Color online) X-ray 2theta-omega scans of FePt-30% oxide thin films sputtered on MgO underlayers using $SiO_2$ (a) and MgO (b) as oxide.

magnetic layer. The intensity of the FePt(111) peak decreases with decreasing FePt thickness. The FePt(002) peak shifted to higher angles with decreasing FePt thickness, indicating that the media has less in-plane *c* axis variants.

In order to obtain columnar grains with uniform oxide isolation, ultrathin layers of oxide and FePt were alternately sputtered. MgO and $SiO_2$ were both used in this research. In Fig. 3, two cross-sectional images with equal oxide volume fraction are compared. Microstructures using MgO (a) and $SiO_2$ (b) both produce perpendicular media consisting of small FePt columnar grains surrounded by oxide. It is evident from these images, however, that $SiO_2$ produces smaller grain size and thinner oxide thickness. Moreover, even though the grain size of the $SiO_2$ sample is smaller, it still has much higher coercivity (*c*) than the MgO sample. Using $SiO_2$ as the isolation oxide resulted in a shift of the FePt(002) peak to higher angles compared to MgO, indicating that the FePt media has less of the FePt(200) in-plane variant. See the XRD pattern (Fig. 4). In addition, the media with $SiO_2$ is more fully ordered, as is evident from the relative intensities of the FePt(001) and (002) peaks. It was found that a columnar microstructure does not occur if the volume fraction of MgO is lower than 30%. For $SiO_2$, however, a columnar microstructure can be obtained for volume fractions as low as 15%.

It was found experimentally that MgO sputtered at high temperature has the (111) texture. When MgO/FePt multilayers were sputtered at high temperature, MgO exhibits both (111) and (002) peaks, so it is possible that the MgO(111) texture sputtered at high temperature negatively influences

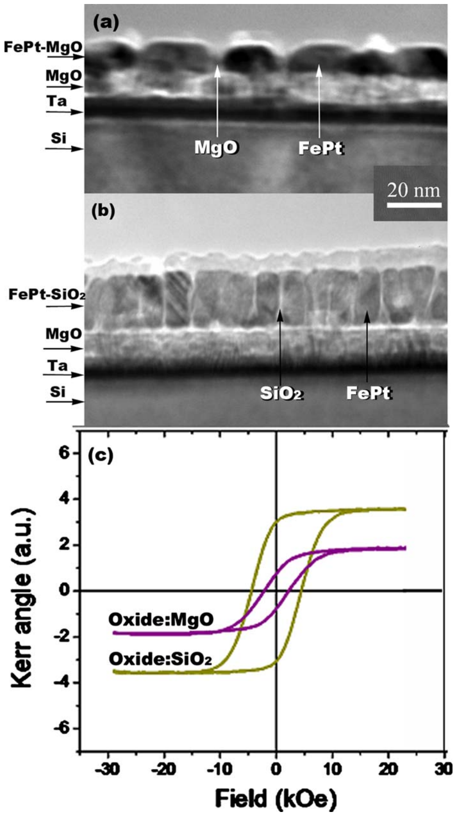

FIG. 3. (Color online) TEM cross-sectional images of FePt-30% oxide thin films using MgO (a) and $SiO_2$ (b) as oxide. The corresponding perpendicular hysteresis loops as measured by MOKE are plotted in (c).

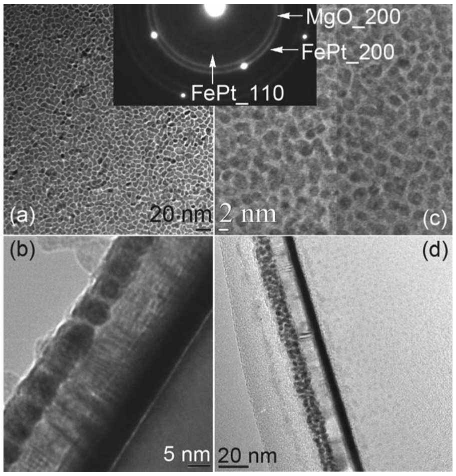

FIG. 5. TEM microstructure images of FePt-oxide thin films sputtered on MgO underlayers. Plan-view (a) and cross-sectional (b) images of FePt-38% $SiO_2$ thin films with 5 nm FePt grains. Plan-view (c) and cross-sectional (d) images of FePt-50% $SiO_2$ thin films with 2.9 nm FePt grains. TEM diffraction pattern inset in the upper center.

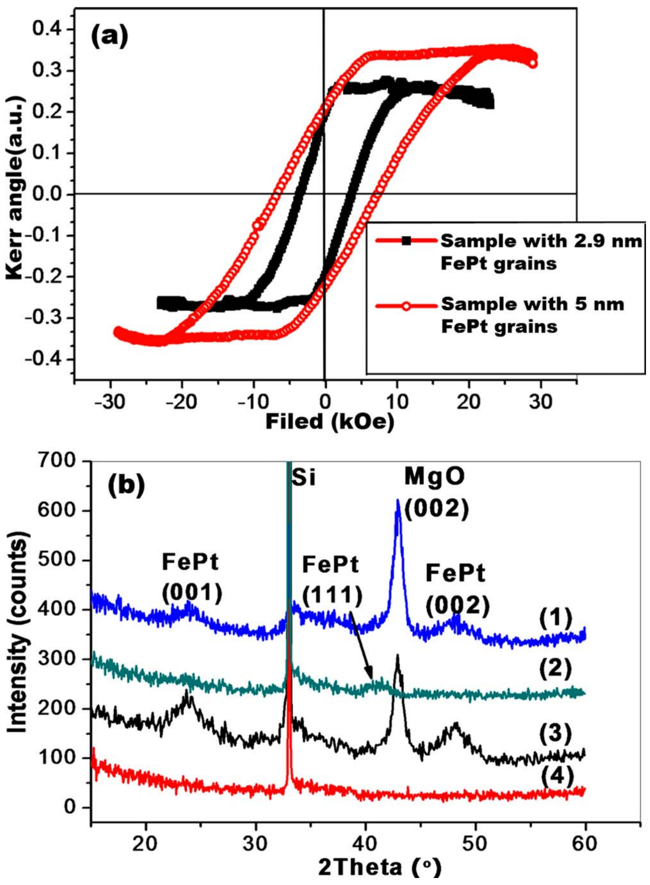

FIG. 6. (Color online) (a): Out-of-plane hysteresis loops of samples with 7 and 2.9 nm grains. (b) X-ray $2\theta$-$\omega$ scan for (1) sample with 2.9 nm FePt grains, (2) the same as (1) but without a MgO underlayer, (3) sample with 7 nm FePt grains, and (4) Si substrate.

the development of perpendicular texture in FePt. On the other hand, $SiO_2$ sputtered at high temperature is amorphous, allowing better texture development in FePt grains.

As shown in Figs. 5(a) and 5(b), the oxide thickness is still very thin for grains as small as 7 nm when the volume fraction of $SiO_2$ reaches 38%. The cross-sectional image 5(b) shows a very uniform columnar microstructure. Grains of size ~2.9 nm were obtained for a $SiO_2$ volume fraction of 50%. From the plan-view image, the grains appear to be uniformly isolated by a thin layer of oxide. However, from the cross-sectional image, the microstructure is no longer columnar. It is therefore important to view media microstructure in cross section to assure that the FePt grains are columnar and not equiaxed. Both TEM diffraction patterns show very clearly the FePt $L1_0$ (110), (200), and (220) rings, which indicate that the media has good perpendicular texture.

## CONCLUSIONS

Higher coercivity was achieved while maintaining the same small columnar grains by tuning the thickness of the $FePt/SiO_2$ single layers. A coercivity of 7 kOe was obtained when the thickness of each FePt single layer is decreased to approximately 0.5 nm for 7 nm grains. For the 2.9 nm grains, 3.5 kOe was obtained by sputtering 0.23 nm single FePt layers. Figure 6 shows the out-of-plane hysteresis loop (a) and XRD pattern (b) of the resulting small grain films. The coercivity increases with the Ar pressure as well, but the microstructure is negatively influenced by high Ar pressure. For larger 10 nm columnar grains, the same procedure (at the same heating temperature) can yield a coercivity of 15 kOe. Media with such high coercivities are possible in heat assisted magnetic recording.

## ACKNOWLEDGMENTS

We thank Seagate Research for providing financial support for this project and also Dr. Tim Klemmer of Seagate Research for helpful discussions. We also thank the Data Storage Systems Center of Carnegie Mellon University for use of their facilities.

[1] T. J. Klemmer, N. Shukla, C. Liu, X. W. Wu, E. B. Svedberg, O. Mryasov, R. W. Chantrell, D. Weller, M. Tanase, and D. E. Laughlin, Appl. Phys. Lett. **81**, 2220 (2002).

[2] Y. N. Hsu, S. Jeong, D. E. Laughlin, and D. N. Lambeth, J. Magn. Magn. Mater. **260**, 282 (2003).

[3] M. Weisheit, L. Schultz, and S. Fahler, Thin Solid Films **515**, 3952 (2007).

[4] T. Yokota, M. L. Yan, Y. F. Xu, L. Gao, R. Zhang, L. Nicholl, L. Yuan, R. Skomski, D. J. Sellmyer, and S. H. Liou, J. Appl. Phys. **97**, 10H306-1 (2005).

[5] C. L. Platt, K. W. Wierman, J. K. Howard, A. G. Roy, and D. E. Laughlin, J. Magn. Magn. Mater. **260**, 487 (2003).

[6] Y. G. Peng, J. G. Zhu, and D. E. Laughlin, J. Appl. Phys. **99**, 08F907-1 (2006).

[7] C. P. Luo and D. J. Sellmyer, Appl. Phys. Lett. **75**, 3162 (1999).

[8] J. S. Chen, B. C. Lim, J. F. Hu, B. Liu, and G. M. Chung, Appl. Phys. Lett. **91**, 132506 (2007).

[9] Y. N. Hsu, S. Jeong, D. N. Lambeth, and D. E. Laughlin, IEEE Trans. Magn. **36**, 2945 (2000).

[10] H. L. Wang, Y. Huang, Y. Zhang, G. C. Hadjipanayis, D. Weller, and A. Simopoulos, J. Magn. Magn. Mater. **310**, 22 (2007).

[11] Y. C. Wu, L. W. Wang, and C. H. Lai, Appl. Phys. Lett. **91**, 072502-1 (2007).