Epitaxial Growth of $L1_0$–FePt Granular Thin Films on TiC/RuAl Underlayers

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Highly ordered $L1_0$ FePt-oxide thin films with perpendicular texture and small grains were fabricated on a TiC underlayer along with a RuAl small grain size layer and a MgO seedlayer. The epitaxial growth from the MgO seedlayer to the TiC\RuAl grain size defining underlayer to FePt magnetic layer was studied. Perpendicular texture can be further improved by adjusting the thickness of each layer to optimize the in-plane stain. From our microstructure study, TiC/RuAl grain size defining layer was found effective in reducing the volume fraction of oxide in the film and the center-to-center grain size of FePt grains. With a thin Ag sacrificial layer inserted between TiC and FePt magnetic layer, a smaller grain size can be achieved, the ordering temperature was lowered, and the (001) texture of FePt was enhanced.

***Index Terms*—FePt, magnetic recording, thin films.**

I. Introduction

DUE to its high uniaxial magnetocrystalline anisotropy, high coercivity, high saturation magnetization, good corrosive resistance, and large energy products [1], [2], FePt ($L1_0$) is a very promising media for achieving ultrahigh magnetic recording densities. However, obtaining smaller grain size while maintaining the order parameter has always been one of the major challenges. Furthermore, the as-deposited $L1_0$ FePt normally has a (111) texture. To enable FePt to be used as a perpendicular recording media, a (001) perpendicular texture is needed. In this work, highly ordered $L1_0$ FePt-oxide thin films with perpendicular texture and small grains were fabricated on a TiC underlayer along with a RuAl small grain size layer and a MgO seedlayer. The epitaxial growth was initiated from the MgO 002 layer, continued though the RuAl layer and extended into the TiC layer and finally into the $L1_0$ FePt magnetic layer. The small grain growth from the TiC/RuAl underlayer results in small and uniform grains in the FePt layer and possibly reduces the volume fraction of oxide in the film needed for small grains, which decreases the center-to-center grain size of FePt grains. Perpendicular texture was further improved by adjusting the thickness of each layer to optimize the in-plane strain. The epitaxial and strain relations were studied. With a thin Ag sacrificial layer inserted between TiC and FePt magnetic layer, a smaller grain size was achieved, the ordering temperature was lowered, and the (001) texture of FePt was enhanced.

II. Experimental Results and Discussion

FePt media with TiC/RuAl seed layers and MgO under layers were deposited on Si or glass substrates by RF sputtering. The base pressure was $5 * 10 - 7$ Torr and the argon pressure varied between 5 and 50 mTorr. The FePt/oxide layers were fabricated by sputtering from a $Fe_{55}Pt_{45}SiO_2$ composite target onto a heated substrate. The volume fraction of SiO_2 sputtered in the film was about 9%. All the MgO underlayers were deposited at room temperature, and the TiC and RuAl films were deposited at 300 °C. The FePt magnetic layers were deposited at 500 °C. X-ray diffraction and transmission electron microscopy were used to study the texture and microstructure of the films. A physical property measurement system (PPMS) was used to investigate the magnetic properties.

Titanium carbide (TiC) has a very high melting point (3433 K), which means it is less likely to sinter into larger grains at the FePt ordering temperature. Typical stoichiometric TiC has the NaCl crystal structure, with a lattice parameter around 0.433 nm, which is close to MgO. These properties make TiC a good candidate of underlayer for the FePt magnetic layer.

TiC with NaCl structure was obtained by sputtering a TiC target at elevated deposition temperature (from 300 °C to 500°C). It was found that TiC with the NaCl structure is stable over a wide range of deposition temperatures. TiC with perpendicular 002 texture was obtained by introducing an epitaxial MgO underlayer with (002) texture beneath the TiC. The in-plane XRD patterns show one overlapped peak of TiC(200) and MgO(200), indicating excellent coherent epitaxial growth between MgO and TiC. After obtaining NaCl structured TiC films with perpendicular (002) texture, FePt was deposited directly on the TiC under layer at elevated temperature. However, the perpendicular texture of FePt was not ideal; a small amount of FePt(200) in-plane variants was observed which needs to be eliminated. As shown in Fig. 1, the lined FePt(002) position is the calculated FePt(002) position from the position of peak FePt(001). The asymmetry of FePt(002) peak in Fig. 1(A) with a shoulder on the left-hand side indicates the existence of FePt(200) in-plane variants.

In order to release the strain induced by the large lattice mismatch between FePt and TiC, create more thicker grain boundaries and obtain FePt small grains, SiO_2 was introduced in the FePt magnetic layer. As shown in Fig. 1(B), with the same

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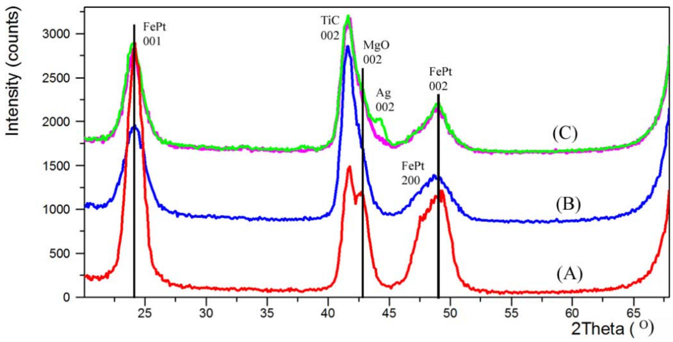

Fig. 1. Out-of-plane XRD patterns of (A) FePt(7 nm)/TiC(10 nm)/MgO(15 nm)/Si substrate; (B) FePt+9%SiO_2(7 nm)/TiC(10 nm)/MgO(15 nm)/Si substrate; (C) FePt+9%SiO_2(7 nm)/Ag(8 nm)/TiC(10 nm)/MgO(15 nm)/Si substrate before and after cleaning off the Ag sacrificial layer.

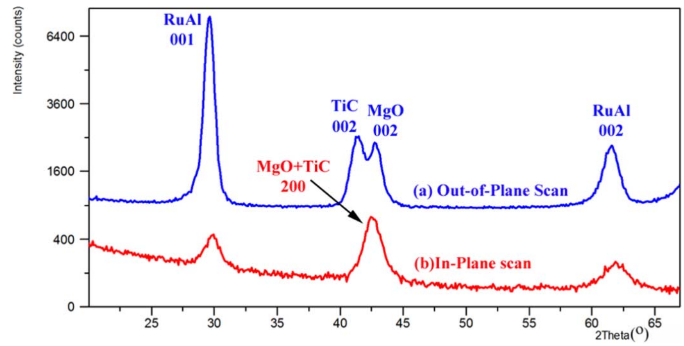

Fig. 2. (a) Out-of-plane and (b) in-plane XRD patterns of TiC films deposited at elevated temperature on RuAl/MgO film stack.

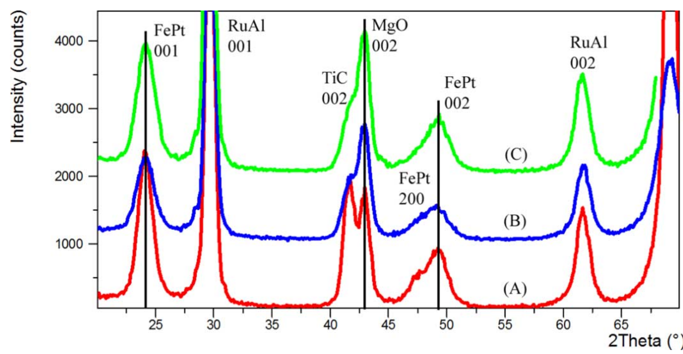

Fig. 3. Out-of-plane XRD patterns of (A) FePt+9%SiO_2(11 nm)/TiC(11 nm)/RuAl(12 nm)/MgO(15 nm)/Si substrate; (B) FePt+9%SiO_2(11 nm)/TiC(7 nm)/RuAl(12 nm)/MgO(15 nm)/Si substrate; (C) FePt+9%SiO_2(7 nm)/TiC(5 nm)/RuAl(12 nm)/MgO(15 nm)/Si substrate.

film structure as Fig. 1(A) but 9% SiO_2 in the FePt layer, the FePt(200) in-plane variants were largely decreased. Further improvement of FePt perpendicular texture was achieved by introducing the Ag sacrificial layer scheme [3], which is a thin layer of Ag deposited in between the TiC and FePtSiO_2 magnetic layer. As shown in Fig. 1(C), in comparison to Fig. 1(B), with 8 nm of Ag inserted between FePt and TiC at 300 °C, the FePt(002) peak was shifted to a higher angle, where it is identical to the calculated FePt(002) peak position. The Ag(002) peak disappeared after cleaning off the sample surface, as described in our previous work [3]. By measuring the integrated FePt(001) to FePt(002) peak intensity ratio, taking into account the geometric features of the X-ray diffractometer, the crystallographic texture of FePt films, and the finite thickness of the films [4], the order parameter of FePt films can be calculated and was found to be improved from 0.87 to 0.96 by the 8-nm Ag sacrificial layer. Further TEM studies shows the improvement of film microstructure.

Another promising way to create more grain boundaries and obtain FePt small grains is to introduce an RuAl grain size defining layer with small RuAl grains between the MgO and TiC layer. It has been reported that RuAl with the B2 structure has a small crystallite size [5], [6], and the lattice distance between the two atoms along the face diagonal is 0.42 nm, which is nearly identical to lattice parameter of MgO. The epitaxial and small grain growth from the RuAl underlayer may result in perpendicular texture and small uniform grains in the TiC layer and then the FePt layer, and possibly reduce the volume fraction of oxide in the film and the center-to-center grain size of FePt grains.

RuAl with the B2 structure, perpendicular 002 texture, and small grain size was obtained by sputtering a RuAl target at 300°C on MgO(002) textured seedlayer. TiC was subsequently deposited on the (001) textured RuAl layer. The same strong perpendicular 002 texture of TiC was obtained. As shown in Fig. 2, with 9 nm of TiC deposited on top of RuAl(15 nm)\MgO(15 nm), the overlapped TiC\MgO(200) peak position is very close to out-of-plane MgO(002) peak, and the RuAl(001) peak position did not change much from out-of-plane scan to in-plane scan, indicating coherent epitaxial growth of FePt/RuAl/MgO film stack with the strain being mostly in the TiC layer. Further experiments found that the overlapped TiC\MgO(200) peak can be moved to a lower angle with a thicker TiC layer.

Since the strain condition can be largely changed by different thickness of TiC layer, optimizing the strain relationship between RuAl, TiC, and FePt by adjusting the thickness of each layer is crucial to achieving excellent perpendicular texture of FePt magnetic layer. As shown in Fig. 3, the lined FePt(002) peak position indicates where the (002) peak was supposed to be by calculating from the position of FePt(001) peak. In Fig. 3(A), 11 nm of TiC and 11 nm of FePt magnetic layer give obvious amount of FePt(200) in-plane variants. By reducing TiC layer to 7 nm, the in-plane variants were effectively decreased, as shown in Fig. 3(B). Further adjustment of the magnetic layer thickness to 7 nm and TiC layer to 5 nm completely eliminated the in-plane variants; no FePt(200) was observed in this film structure. The in-plane XRD patterns further confirmed this information.

Furthermore, the small grain growth from the TiC/RuAl underlayer results in small and uniform grains in the FePt. As shown in Fig. 4(A) and (B), with the same amount of SiO_2 (9%) in the film, the FePt grain size was reduced from ~30 to ~12 nm by using 10-nm TiC underlayer in comparison to FePt films deposited directly on MgO underlayer. However, the grain size is widely distributed, the uniformity of FePt grains needs to be improved, and the grain size needs to be further reduced. In Fig. 4(C), by using TiC/RuAl grain size defining underlayer,

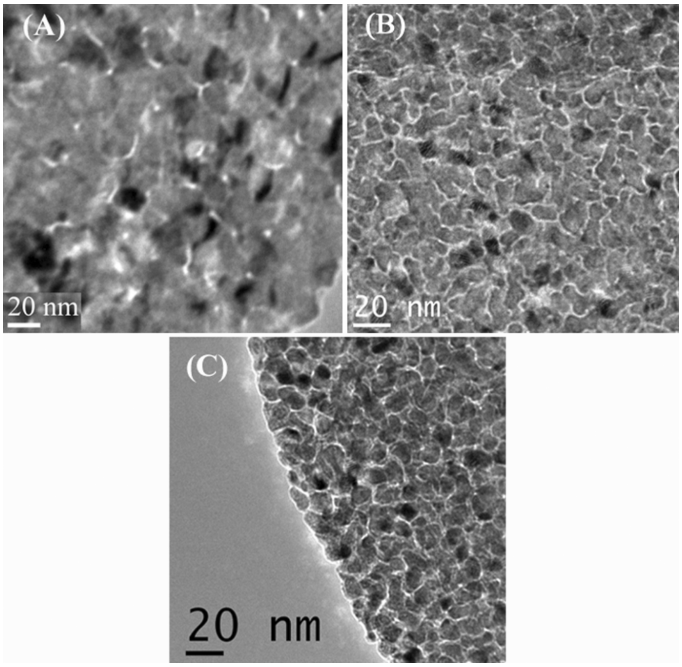

Fig. 4. TEM plan view images of (A) FePt films with 9% SiO_2 deposited on MgO underlayer without TiC/RuAl underlayer; (B) FePt films with 9% SiO_2 in the film deposited on TiC/MgO film stack; and (C) FePt films with 9% SiO_2 in the film deposited on TiC/RuAl/MgO film stack.

~9-nm FePt was obtained with narrower grain size distribution. Smaller FePt grain size can be achieved by introducing a greater volume fraction of SiO_2 or carbon in the film. It is worth mentioning that TiC layer in the FePt/TiC/RuAl/MgO film structure plays a very important role. Without the TiC layer, the FePt layer and the RuAl layer may interdiffuse, which degrades the magnetic properties and the epitaxial growth of FePt magnetic layer.

Fig. 5 shows the room temperature measured out-of-plane hysteresis loops for the film stacks with reasonable grain size shown in Fig. 4(B) and (C). By further introducing RuAl grain size defining underlayer between TiC and MgO layer, not only the grain size was reduced, but also the coercivity was improved from ~7 to ~10 kOe. The relatively low coercivity compared to high-order parameter might be contributed to the small volume fraction of SiO_2 in the magnetic film; the FePt grains are not fully magnetically decoupled. As for the in-plane loops, both film stacks cannot be saturated under 90-kOe magnetic field along the hard axis, indicating high magnetocrystalline anisotropy energy. However, they both show a ~2-kOe in-plane coercivity, indicating the existence of in-plane variants, which was not observed by XRD diffraction patterns.

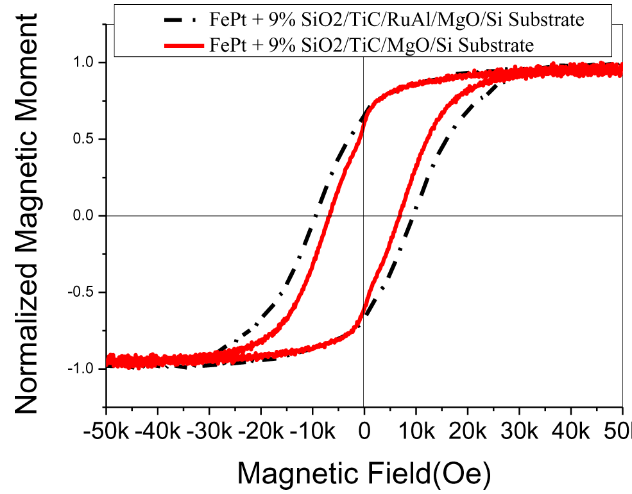

Fig. 5. Out-of-plane hysteresis loops for FePt films on TiC and MgO under layer with (dash line) and without (solid line) RuAl grain size defining layer.

III. Summary

TiC/RuAl grain size defining layer was used to reduce the volume fraction of oxide in the film and the center-to-center grain size of FePt grains. Excellent perpendicular texture was obtained by adjusting the thickness of FePt, TiC, and RuAl to optimize the in-plane strain. By introducing the TiC/RuAl grain size defining layer, ~9 nm of FePt grains can be obtained at 500 °C with 9% SiO_2 in the film. With a thin Ag sacrificial layer inserted between barrier layer and FePt magnetic layer, the ordering temperature can be lowered and the order parameter of FePt is improved.

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