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Structure and magnetic properties of $L1_0$-FePt thin films on TiN/RuAl underlayers

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Highly ordered $L1_0$ FePt-oxide thin films with small grains were prepared by using a RuAl layer as a grain size defining seed layer along with a TiN barrier layer. Different HAMR (Heat Assisted Magnetic Recording) favorable underlayers were studied to encourage perpendicular texture and preferred microstructure. It was found that the epitaxial and small grain growth from the RuAl/TiN underlayer results in small and uniform grains in the FePt layer with perpendicular texture. By introducing the grain size defining underlayers, the FePt grain size can be reduced from 30 to 6 nm with the same volume fraction (9%) of SiO_2 in the film, excellent perpendicular texture, and very high order parameter at 520 °C. © *2011 American Institute of Physics*. [doi:10.1063/1.3565418]

I. INTRODUCTION

As the areal density in magnetic recording approaches 1 T bits per square inch, the required bit size is expected be smaller than 20×20 nm. Because the signal to noise ratio is proportional to the number of magnetically decoupled ferromagnetic grains within a recording bit,[1] the center to center magnetic grain size should accordingly be in the range of a few nanometers. Recently, much effort has been devoted to developing FePt ($L1_0$) as an ultrahigh density media due to its high anisotropy field and good environmental stability.[2,3] In order to achieve FePt grain isolation with small grain size, either O_2 reactive sputtering and/or oxide additions have been used in the previous studies.[4,5] However, a large volume fraction of oxide in the magnetic film leads to large distance between magnetic grains, which results in relatively large center to center grain size.[6] In this work, a RuAl seed layer with TiN barrier layer is introduced under the FePt magnetic layer as grain size defining underlayers. The epitaxial and small grain growth from the RuAl underlayer results in small and uniform grains in the FePt layer and possibly reduce the volume fraction of oxide in the film and the center to center grain size of FePt grains. In addition, different heat conducting metallic underlayers have been studied in order to replace the hydrophilic MgO underlayer.

II. EXPERIMENT

In this work, FePt media with RuAl grain size defining 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 Fe55Pt45SiO$_2$ composite target onto a heated substrate. The volume fraction of SiO_2 sputtered in the film was about 9%. The substrate temperature was varied from room temperature to 520 °C during sputtering. X-ray diffraction and transmission electron microscopes were used to study the texture and microstructure of the films. SEM was used to measure the composition of deposited films. A physical property measurement system (PPMS) was used to investigate the magnetic properties.

III. RESULTS AND DISCUSSION

In order to use RuAl seeds as a grain size defining layer for the top magnetic layer, RuAl with B2 structure, perpendicular texture, and small grain size is needed. B2 RuAl was obtained by sputtering $Ru_{50}Al_{50}$ at 300 °C. A repeatable RuAl (002) perpendicular texture was obtained by introducing an epitaxial MgO underlayer with (002) texture beneath RuAl. The rocking curve of RuAl (001) shows a FWHM of ~5.1°. The grain size of 20 nm thick RuAl deposited on MgO is ~4 nm. Details of obtaining RuAl seed layer with perpendicular texture and small grain size are described in the previous work.[7] After obtaining small B2 RuAl grains with perpendicular (001) texture, FePt was deposited directly on the RuAl seed layer at elevated temperature. However, it was found that a significant degradation of the FePt properties was induced due to interdiffusion of the FePt and RuAl layers. A thin barrier layer is needed in between FePt and RuAl layers to prevent the interdiffusion.

Figure 1 shows the x-ray diffraction pattern of FePt/barrier/RuAl/MgO film stacks with different barrier materials. FePt magnetic layers here were deposited at 520 °C. The MgO\RuAl seeds for all the five samples shown here are the same and have the same film structure, thickness, and texture. However, the RuAl shows different intensities with different barrier layer. Other than sample mounting differences, this is probably due to different degree of interdiffusion and

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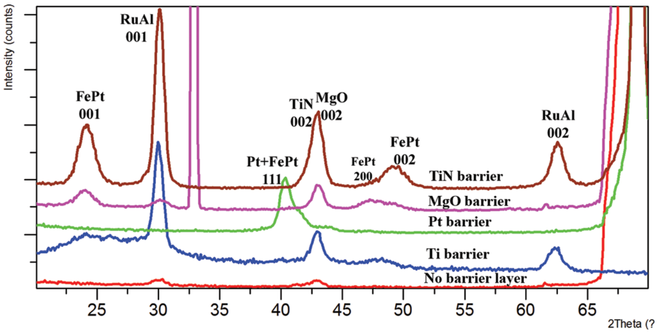

FIG. 1. (Color online) X-ray diffraction patterns of $FePtSiO_2$/barrier layer/RuAl/MgO film stacks with different barrier materials.

reaction between the RuAl and the barrier layers. It is also related to the absorption and reflection properties of barrier layer on top of MgO\RuAl seeds. For instance, Pt tends to block the x-ray peaks from materials underneath it. The important information from this figure is the FePt peaks and relative intensities. As shown in Fig. 1, without a barrier layer between FePt and RuAl, only RuAl and MgO peaks are observed, as the 8 nm of FePt deposited on RuAl layer is diffused into the RuAl layer and cannot be detected by x-ray diffraction analysis. With 5 nm of Ti deposited between RuAL and FePt as barrier layer, no improvement of the FePt properties is observed. Five nanometers of Pt barrier give FePt (111) texture. Later energy dispersive x-ray analysis (EDAX) composition analysis along the cross section interface of Pt barrier layer shows a small amount of interdiffusion between Pt and RuAl. With a 5 nm MgO barrier layer inserted between the FePt and RuAl layers, the FePt with $L1_0$ structure and perpendicular texture is obtained, showing that the interdiffusion between FePt and RuAl is effectively prevented. However, the FePt (200) peak and the relatively low intensity ration of FePt (001) to FePt (002) indicate in-plane variants and low ordering of the FePt film. Last, 5 nm of TiN with (002) texture was deposited as a barrier layer. It was found that TiN yields excellent perpendicular texture of FePt. Deposited at 520 °C, the FePt films have an integrated intensity ratio of (001) to (002) close to 3, indicating a very high order parameter. Both FePt and RuAl peaks have high intensities; the interdiffusion between FePt and RuAl is completely blocked.

Not only is TiN an effective barrier layer and an excellent perpendicular encourager, it is also an excellent grain size copier. The high resolution transmission electron microscopy (TEM) image shown in Fig. 2 reveals the lattice orientation of RuAl, TiN, and FePt layer and demonstrates the excellent epitaxial growth of RuAl (001)\\TiN(002)\\-FePt(001) layers. It can also be clearly seen that TiN has followed the grain growth and copied the grain size from RuAl grain size defining layer. However, the FePt magnetic layer did not pickup the grain size from the TiN barrier layer. The RuAl and TiN layers show an average grain size of ~3–4 nm, while FePt layer has an average grain size of ~6–7 nm. This might be attributed to the small volume fraction of SiO_2 (9%) in the magnetic film; there is not enough oxide in the film to isolate the FePt grains.

The main reason to introduce RuAl layer in this work is because RuAl layers form with small grain size. By depositing RuAl underneath FePt magnetic layer, the small grain growth from the RuAl underlayer may result in small and uniform grains in the FePt layer due to lower interfacial surface energy. This may reduce the volume fraction of oxide in the film and therefore the center to center grain size of FePt grains. So whether RuAl functions as a grain size defining layer or not is very important information. In Fig. 3(a), FePt films with 9% SiO_2 in the film without a RuAl grain size defining seed layer (FePt + 9%SiO_2/MgO/Si substrate) has a grain size of ~30 nm. With RuAl + barrier grain size defining underlayers (FePt + 9%SiO_2/TiN/RuAl/MgO/Si), as shown in Fig. 3(b), ~6 nm of FePt grains is obtained. It is clear that RuAl with small grain size is an effective grain size defining layer. With the same amount of Oxide in the film, much smaller FePt gains can be obtained by using RuAl seeds. With epitaxial MgO underlayer and TiN barrier layer, excellent perpendicular texture can be achieved without degrading magnetic properties of FePt recording layer.

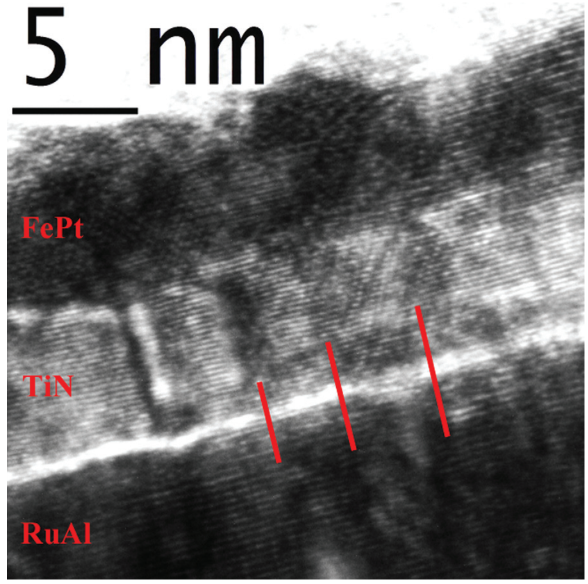

FIG. 2. (Color online) TEM cross section image of FePt + 9%SiO_2/TiN/RuAl/MgO film stack, the lattice orientation shows excellent epitaxial growth.

As a hydrophilic material and an insulator, MgO is not favorable for mass industrial production. A metallic underlayer is needed to replace the MgO underlayer underneath RuAl. As shown in Fig. 4, the TiN deposited on HF cleaned

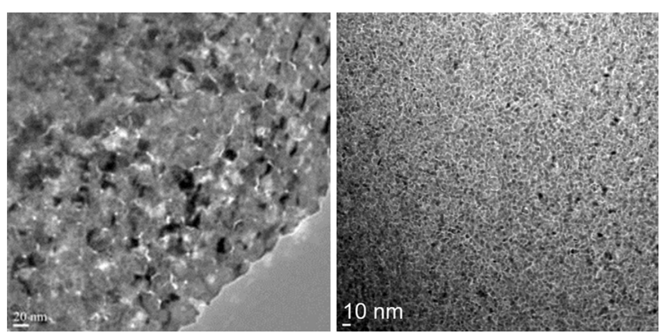

FIG. 3. TEM plan-view images of (a) FePt films with 9% SiO_2 deposited on MgO underlayer without RuAl seeds. The FePt grain size is ~30 nm. (b) FePt films with 9% SiO_2 in the film deposited on RuAl grain size defining seeds. The FePt grain size is ~6–7 nm.

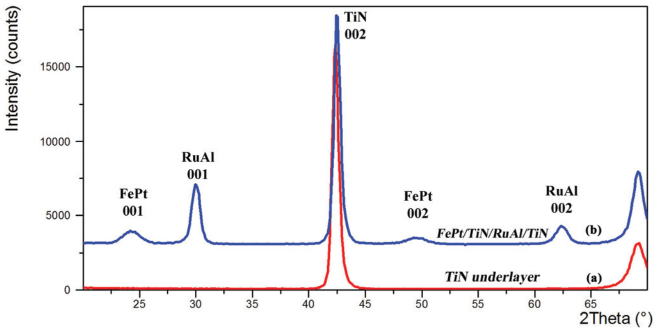

FIG. 4. (Color online) X-ray diffraction patterns of (a) TiN deposited on HF cleaned Si and (b) FePt/TiN/RuAl film stack deposited on TiN underlayer.

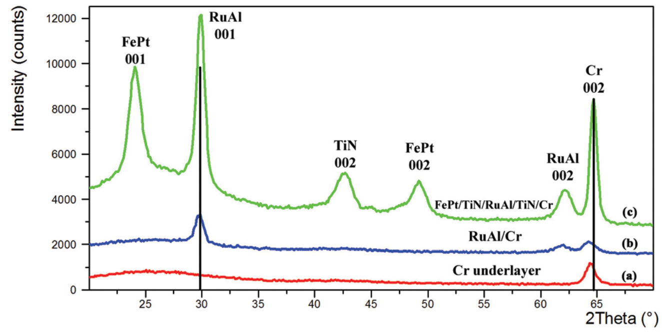

FIG. 6. (Color online) X-ray diffraction patterns of (a) Cr layer deposited on glass substrate, (b) RuAl on Cr underlayer, and (c) FePt + 9%SiO_2/TiN/RuAl/TiN/Cr film stack.

Si substrates at 300 °C shows excellent perpendicular texture; RuAl and FePt (001) texture is obtained with epitaxial TiN underlayer. However, as shown in Fig. 5, the epitaxial growth of TiN on the single crystal Si substrate yields large TiN grains in the underlayer, which influences the microstructure of the whole film structure negatively.

In Fig. 6(a), Cr with the (002) texture was deposited at 280°C on glass substrate as an underlayer. By epitaxial growth from Cr underlayer, a RuAl (002) texture is obtained in Fig. 6(b). This glass substrate\Cr\RuAl film structure with perpendicular texture is stable and repeatable. However, a small amount of interdiffusion was observed between RuAl and Cr. To further improve the texture of both Cr and RuAl, a thin layer of TiN was introduced between Cr and RuAl in Fig. 6(c). with the TiN layer on top of Cr, the Cr (002) peak shifts to a higher angle, indicating an in-plane tensile strain due to the lattice misfit from TiN layer. FePt film deposited on the TiN/RuAl grain size defining underlayers and Cr underlayer shows excellent perpendicular; the integrated intensity ratio of FePt (001) to (002) is ~3.4. Later TEM images showed us that the Cr underlayer did not negatively influence the FePt film microstructure. With 9% SiO_2 in the film, the FePt grain size is ~7 nm.

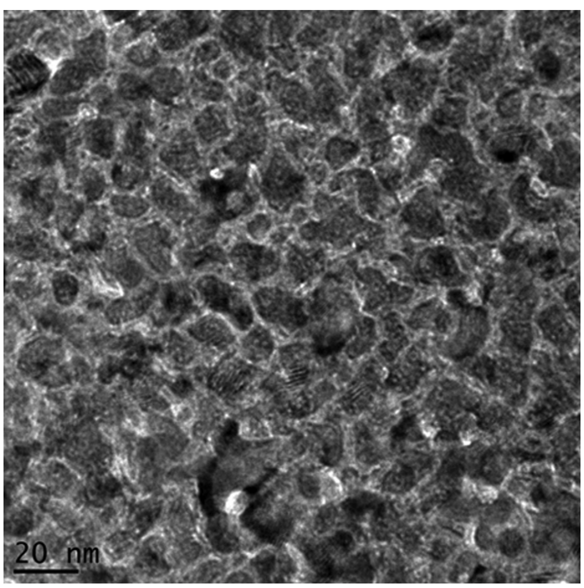

FIG. 5. TEM plan-view image of FePt + 9%SiO_2/TiN/RuAl/TiN film stack deposited on HF cleaned Si substrate.

IV. CONCLUSIONS

RuAl seed layer with TiN barrier layer are used as grain size defining underlayers to reduce the volume fraction of oxide in the film and the center to center grain size of FePt grains. By introducing the grain size defining underlayers, ~6–7 nm of FePt grains can be obtained at 520°C with 9% SiO_2 in the film. Since the FePt grains are slightly larger than RuAl and TiN grains, further effort is needed for the grain size defining layer to accurately "define" the grain size in the magnetic layer. Cr, acting as a metallic underlayer, seems promising to encourage the perpendicular texture and preferred microstructure of FePt films.

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