Effect of Substrate Temperature on Properties of BaM/Pd-Pt Double Layered Thin Film

N. N. Shams, X. Liu, M. Matsumoto and A. Morisako
Department of Information Engineering, Faculty of Engineering, Shinshu University, 4-17-1 Wakasato Nagano 380-0928, Japan

Magnetic and crystallographic properties of barium ferrite (BaM) thin films, deposited onto Pt, Pd, and Pd-Pt underlayer at the different substrate temperature ($T_s$) of 400 to 600°C have been studied. The thickness of underlayer is about 20 nm and the thickness of barium ferrite film is 30 nm. From x-ray diffraction patterns, all of the BaM films grown on the three kinds of underlayer show its c-axis orientation perpendicular to the films plane. It is found that the coercivity values in perpendicular direction ($H_{c_{\text{perp}}}$) of the BaM/Pd-Pt films are higher than those of the BaM films deposited on Pd and Pt underlayer. Substrate temperature $T_s$ for crystallization of BaM was reduced from 600°C to 450°C. The $H_{c_{\text{perp}}}$ of 2.1 kOe for BaM (30nm)/Pd-Pt (20nm) film can be achieved with c-axis orientation. Pd-Pt underlayer not only improve the value of c-axis dispersion angle $\alpha_{0_{50}}$ and perpendicular coercivity $H_{c_{\text{perp}}}$ but also effective to reduce grain size of BaM thin film.

Key words: Ba-ferrite, magnetic recording, magnetic material, Pd-Pt underlayer, thin film

1. Introduction

For high density magnetic recording, one of the important requirements is to prepare magnetic media with small grains in the range of nanometer. Barium ferrite having the chemical formula of BaO-6Fe$_2$O$_3$ (BaM) can satisfy such goal. High anisotropy field, mechanical hardness, and good chemical stability make BaM as an excellent candidate for magnetic recording medium. Moreover the easy axis of the magnetization can be hold out of plane in the BaM thin film. Due to this characteristic, BaM is an attractive material for perpendicular recording application. But high processing temperature $T_p$, ranging from 550 to 600°C is necessary for complete oxidation and proper arrangement of the Fe and Ba atoms in BaM film which results subsequent formation of large grains. Further reduction of substrate temperature is necessary for the practical fabrication of BaM thin film. Moreover to fabricate thin films for perpendicular recording media, much effort has been concentrated on epitaxial growth of the films. It is clarified that Pt underlayer with (111) orientation is effective for promoting c-axis orientation of BaM. In this paper, the crystalline and magnetic properties of BaM thin film deposited on Pt (111), Pd (111) and an alloy of Pd-Pt (111) underlayers at different substrate temperature have been studied.

2. Experimental Procedure

A facing targets sputtering (FTS) system was used to deposit BaM thin films on SiO$_2$/Si substrates. After evacuating the chamber to a pressure below $5 \times 10^{-8}$ Torr, argon (Ar) and oxygen (O$_2$) gases were introduced. The total sputtering pressure was set at 2 mTorr with 10% of oxygen partial pressure. Sintered ferrite disks with the stoichiometric composition of BaFe$_{12}$O$_{19}$ were used to deposit the BaM layer. On the other hand, pure Pt and Pd metal disks were used to deposit the underlayer in presence of only Ar gas at a sputtering pressure of 1.8 mTorr. Thicknesses of the underlayers were kept to 20 nm. All the underlayers were deposited without substrate heating. Then BaM layer was deposited successively onto these underlayers at the substrate temperature in the range of 400-600°C. Thickness of the BaM was kept to 30 nm. The crystallographic properties of the films were characterized by an x-ray diffractometry (XRD). A vibrating sample magnetometer (VSM) was used to measure magnetic properties of the BaM films. The grain size was calculated by scanning probe microscope (SPM) respectively.

3. Results and Discussions

The misfit ratio of Pd-Pt (111) and BaM (00l) planes calculated from RHEED pattern is about 6.25%. However these values are 6.6% and 5.8% for Pd (111) and Pt (111) underlayer, respectively, calculated from standard XRD data. This means that c-axis orientation of BaM is possible with these three underlayers due to the epitaxial effect. Fig.1 shows the x-ray diffraction diagrams of the BaM thin films deposited on different underlayers at different substrate temperature $T_s$. The preferred [111] orientation of fcc lattice of Pt, Pd, and Pd-Pt underlayer has been detected in the XRD diagrams. The presence of diffraction lines from BaM (00l) planes reveals that c-axis orientation of BaM film can be prepared even at very low $T_s$ of 450°C. However BaM film is to be amorphous at the further decrease in $T_s$. It is hard to form the most closely packed oxygen plane of BaM crystal perfectly on fcc (111) underlayer and therefore BaM crystallites have been not able to grow along c-axis direction perfectly when $T_s$ is lower than 450°C. When $T_s$ is increased to 450°C, Ba, Fe and O atoms of BaM films seem to get sufficient energy to form BaM crystallites. This is due to the epitaxial effect between underlayer and BaM layer. Further
increase of $T_s$ makes the crystallinity more perfect. The c-axis dispersion angle, $\Delta \theta_{002}$, measured from the full width at half maximum of the rocking curve of BaM (008) plane as well as average grain diameter $<D>$ were plotted in the Fig.2. The value of c-axis dispersion angle, $\Delta \theta_{002}$, decreases when $T_s$ increases, which means better crystallization can be realized at higher $T_s$. But $<D>$ shows the opposite trends, increases with increasing $T_s$.

Magnetic hysteresis loops confirm the XRD results. All the films have a much higher coercivity in the perpendicular direction than those in the parallel direction as shown in Fig.3. It has been found that the $Hc_{\text{perp}}$ of the BaM/Pd-Pt films are higher than those of the BaM films deposited on Pd or Pt underlayer. This is because of the restricted grain growth for the underlayer in the alloy of Pd-Pt comparing with the pure metal of Pt or Pd.

Fig. 4 shows the surface morphologies of BaM thin film
Fig. 4 AFM images of BaM thin films deposited on different underlayers as a function of substrate temperature.

Fig. 5. SEM images of different underlayer.

Fig. 4: AFM images of BaM thin films deposited on different underlayers as a function of substrate temperature.

Fig. 5: SEM images of different underlayer.

BaM thin film deposited on different underlayers at different substrate temperature. The grains are larger when deposition temperature is higher. At 550°C average grain size of BaM film is about 300, 110 and 220 nm for Pd, Pd-Pt and Pt underlayer, respectively. Whereas at 450°C these values of grain size reduced to 130, 30 and 120 nm for BaM / Pd, BaM / Pd-Pt and BaM / Pt thin films respectively. It was found that high deposition temperature enhances the grain growth. However, among three underlayers BaM film deposited on Pd-Pt underlayer has shown the smaller grain size. Such a smaller grain size is might be the reason of higher $H_{c_{\text{perp}}}$ for BaM/Pd-Pt thin film even at a low $T_s$ of 450°C. This is because of Pd-Pt underlayer itself possesses finest grains among these three underlayers as shown in Fig. 5. Average grain sizes are 125, 16 and 25 nm for Pd Pd-Pt and Pt underlayer, respectively. It was found that the rate of grain growth is slower in BaM/Pd-Pt films than that of BaM/Pd or BaM/Pt films.

4. Conclusion

BaM thin film deposited on different underlayers has been studied. The magnetic properties and crystallographic characteristics of BaM thin film deposited on Pd-Pt underlayer at different $T_s$ shows better properties than those of BaM film deposited on Pd and Pt underlayer. BaM/Pd-Pt double-layered thin film shows perpendicular orientation with a perpendicular coercivity of 2.1 kOe even at a low $T_s$ of 450°C. $T_s$ can be reduced from 600°C to 450°C with proper c-axis orientation. Perpendicular coercivity value of BaM films deposited on Pd-Pt underlayer are almost similar at 475°C and 450°C. Moreover, Pd-Pt is an effective underlayer to prepare Ba-ferrite thin film with small grain.

Acknowledgements This work was supported in part by MEXT, Grants-in-Aid for Young Scientist and JSPS, Grants-in-Aid for Scientific Research (B).

References

Received October 6, 2004 ; Accepted January 14, 2005.