

Improvement in Hard Magnetic Properties of FePt Films by Introduction of Ti Underlayer

S. C. Chen, P. C. Kuo, S. T. Kuo, A. C. Sun, C. Y. Chou, and Y. H. Fang

Abstract—The FePt/Ti double layer films were prepared by dc magnetron sputtering on corning glass substrates with FePt and Ti targets. The Ti underlayer with 100-nm thickness was deposited at substrate temperature 200 °C, and the FePt magnetic layer, 300 nm, was prepared at temperature from 200 °C to 600 °C for direct formation of ordered L₁₀ FePt phase on the Ti underlayer. X-ray diffraction analysis showed that the [002] axis of Ti grain was perpendicular to the film plane and the FePt grains had a preferred growth of (111) plane parallel to the film plane. The degree of ordering of the FePt films increased as Ti underlayer was introduced. Magnetic property measurements indicated that the in-plane coercivities ($H_{c\parallel}$) of the FePt/Ti films in which FePt films was deposited at different temperatures were all higher than that of FePt single layer film without Ti underlayer. When the deposition temperature of FePt film was fixed at 600 °C, the $H_{c\parallel}$ value of the FePt single layer film was 3.1 kOe, and it increased to 7.3 kOe as 100 nm Ti underlayer was introduced.

Index Terms—FePt/Ti double layers film, in-plane coercivity, magnetron sputtering, Ti underlayer.

I. INTRODUCTION

IT IS well known that the equiatomic FePt thin films with the L₁₀ ordered structure have extremely high magnetic anisotropy constant (K_u) and large coercivity (H_c), which make FePt thin films attractive as candidate for magnetic recording media [1], [2]. However, in order to obtain films with ordered L₁₀ FePt phase, a high-temperature treatment either by substrate heating during deposition or by post-deposition annealing at around 600 °C [3], [4] is necessary. Since high-temperature treatment results in larger grain size of the film, the ordering temperature of L₁₀ FePt phase must be reduced for application in magnetic recording media. Several works on the lowering of ordering temperature had been reported, such as doping Zr [5], Cu [6], Ag [7], and N [8] to FePt thin films.

It has been shown that the introduction of the Ti underlayer affects the grain size and out-of-plane coercivity of the CoCrPt recording films [9]. In this paper, we deposited the FePt film on heated substrate in order to form directly ordered L₁₀ FePt hard magnetic phase and investigated the effects of the Ti underlayer

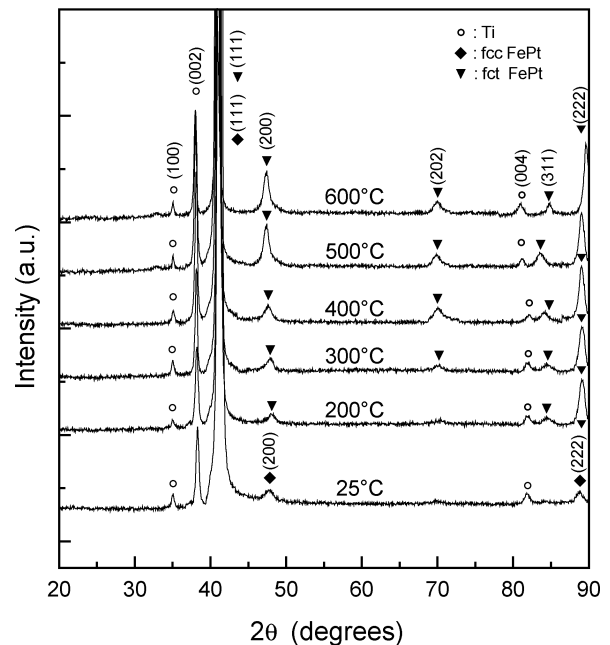


Fig. 1. XRD diffraction patterns of various FePt/Ti double layer films at different substrate temperatures.

and preparation temperature of the FePt film on the degree of ordering, microstructure, and magnetic properties of the film.

II. EXPERIMENT

The FePt/Ti double layer films were prepared by dc magnetron sputtering on corning 1737F glass substrates with high purity FePt (99.99%) and Ti (99.99%) targets. The base pressure of the sputtering chamber was around 3×10^{-7} torr. The FePt magnetic layer was sputtered at an Ar pressure of 10 mtorr and sputtering power of 40 W. The substrate was rotated at 38 r/min in order to enhance uniform composition of the film. A capped layer of SiNx, 30-nm thickness, was used to cover on the magnetic film to avoid oxidation.

Magnetic properties of the film were measured by using a vibrating sample magnetometer (VSM) with a maximum applied field of 12 kOe. The structure of the film was determined by an X-ray diffractometer (XRD). The composition and homogeneity of the film were analyzed by an energy-dispersive spectrum (EDS). The film thickness was measured by an atomic force microscope (AFM) and an α -step.

III. RESULTS AND DISCUSSION

Fig. 1 shows the XRD diffraction patterns of FePt (300 nm)/Ti (100 nm) films grown at various substrate temperatures

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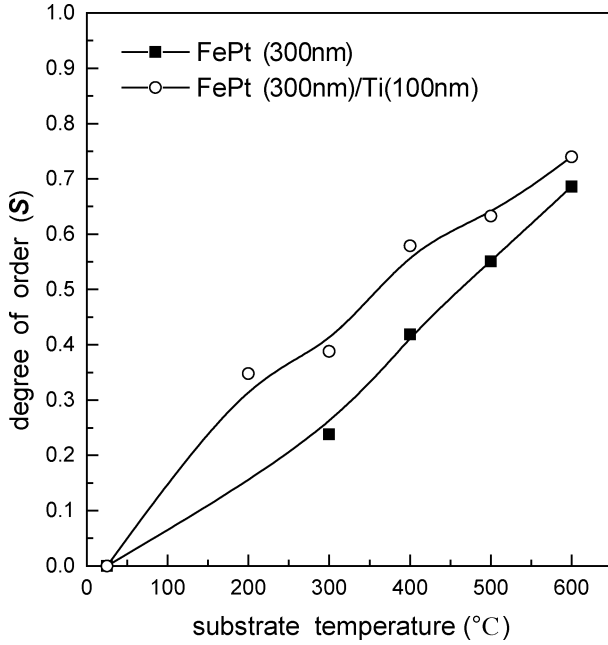


Fig. 2. Degree of ordering of FePt single layer and FePt/Ti double layer films as a function of substrate temperature.

during deposition of FePt film. The structure of FePt film exhibits chemically disordered face-centered-cubic (fcc) FePt phase as substrate temperature is 25 °C. By increasing the substrate temperature, the Fe and Pt atoms will be rearranged, transforming the film into ordered face-centered-tetragonal (fct) $L1_0$ FePt phase, as shown in Fig. 1. We can see that the [002] axis of Ti grain aligns perpendicular to the film plane direction. The preferred growth of the $L1_0$ FePt grains (111) is parallel to the film plane and the intensity of the (111) peak enhances with increasing substrate temperature. This indicates that the ordering of $L1_0$ FePt phase is further completed, i.e., the amount of the $L1_0$ FePt phase in the FePt layer increases as increasing substrate temperature.

The degree of ordering (S) affects the magnetic properties of FePt/Ti double layer films. The c/a ratio of lattice parameters of the partially ordered FePt films with different substrate temperature were determined by using X-ray diffraction peaks of (111) and (200) of $L1_0$ FePt phase. Hence, degree of ordering can be obtained and expressed as [10]

$$S^2 = \frac{1 - \left(\frac{c}{a}\right)_{S_f}}{1 - \left(\frac{c}{a}\right)} \quad (1)$$

where $(c/a)_{S_f}$ is 0.956 for the fully ordered FePt films [11]. Fig. 2 shows the degree of ordering of the FePt and FePt/Ti films as a function of substrate temperature. These results have shown that the degree of ordering of the FePt and FePt/Ti films both increase with increasing substrate temperature and the degree of ordering of the FePt/Ti film is higher than that of the single layer FePt film deposited at the same substrate temperature. The S value of FePt single layer film at substrate temperature of 400 °C is about 0.4. It increases to about 0.6 when a Ti underlayer is introduced. The $L1_0$ ordered FePt has the fct structure and its lattice parameters of the c and a axes are $a = 3.905 \text{ \AA}$ and

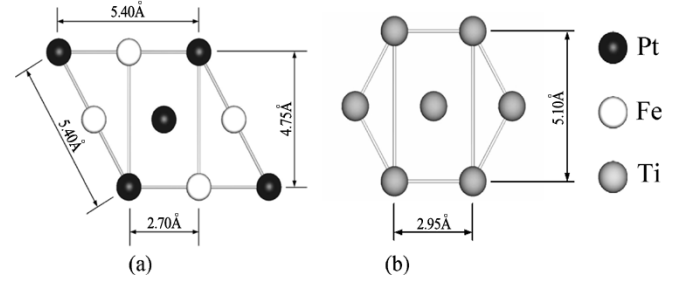


Fig. 3. Schematic of the lattice misfit between (a) $L1_0$ FePt (111) and (b) Ti (002) planes.

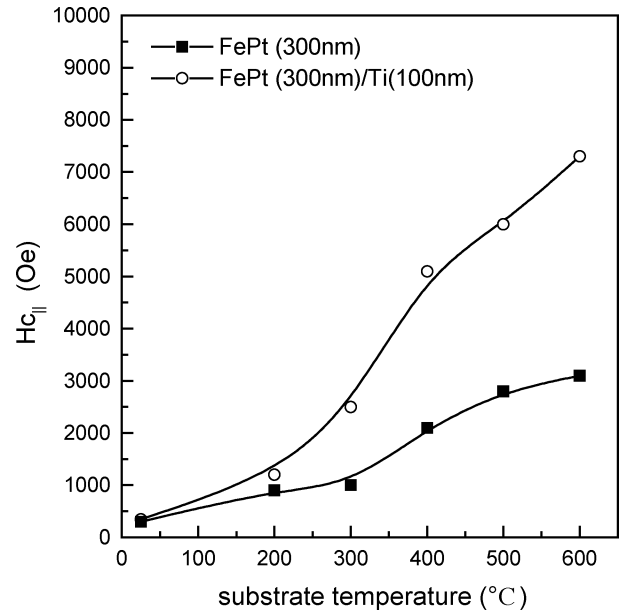


Fig. 4. In-plane coercivity of FePt single layer and FePt/Ti double layer films as a function of substrate temperature.

$c = 3.735 \text{ \AA}$ [11], respectively. In order to reduce the misfit strain energy resulting from the lattice misfit ($\sim 8\%$) between the FePt (111) and Ti (002) plane, as shown in Fig. 3(a) and (b), it is speculated that large amount of misfit dislocations and stacking faults need to be presented in the FePt layer. These defects promote the formation of hard magnetic fct $L1_0$ FePt phase, and therefore enhances the degree of ordering of the FePt layer.

Fig. 4 shows the correlations of the in-plane coercivity ($H_{c||}$) of the FePt and FePt/Ti films with substrate temperature. Since the FePt grain size increases rapidly as annealing temperature is above 500 °C [12], the maximum substrate temperature is chosen to be 600 °C in this study. The $H_{c||}$ values of the FePt single layer films deposited at different temperatures are also increased upon introducing a Ti underlayer of 100 nm thickness. When the FePt deposition temperature is 600 °C, the $H_{c||}$ value of the FePt single layer film is 3.1 kOe. It is observed to increase to about 7.3 kOe for the FePt/Ti double layers film. The Ti underlayer has been found to enhance the degree of ordering of the FePt layer and increase the amount of $L1_0$ FePt phase in the FePt layer, which in turn will increase the $H_{c||}$ value of the FePt film.

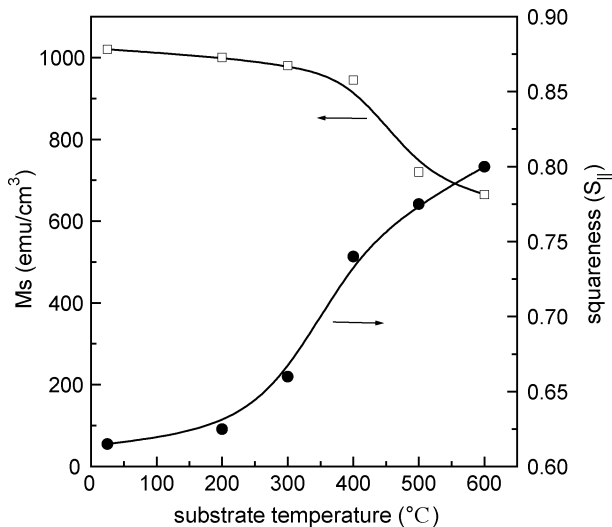


Fig. 5. Saturation magnetization (M_s) and in-plane squareness ($S_{||}$) of FePt/Ti double layers film as a function of the substrate temperature.

Fig. 5 shows the saturation magnetization (M_s) and in-plane squareness ($S_{||}$) of the FePt/Ti double layers film as a function of the substrate temperature. The result shows that the M_s value of the FePt/Ti film is reduced with increasing the substrate temperature. When the substrate temperature is 25 °C, the M_s value of the FePt/Ti film is measured about 1000 emu/cm³. It decreases to about 670 emu/cm³ as the substrate temperature is increased to 600 °C. The M_s value of the fct L1₀ FePt phase is lower than that of the fcc FePt phase [13]. The reduction of M_s mainly results from increasing L1₀ FePt phase content in the FePt film when the substrate temperature is increased. Besides, increasing the substrate temperature will also increase the inter-diffusion between FePt and Ti, which can also decrease the M_s value. On the other hand, the $S_{||}$ value increases with increasing the substrate temperature, where $S_{||}$ is defined as the ratio of in-plane remanent magnetization ($M_{r||}$) to M_s . The $S_{||}$ value increases from 0.62 to 0.8 as the substrate temperature increases from 25 °C to 600 °C. This has indicated that high substrate temperature favors in improving the in-plane squareness of FePt/Ti double layer films.

IV. CONCLUSION

Both the degree of ordering and $H_{c||}$ value of the FePt film are found to increase either by increasing the substrate temperature or/and by introducing a 100 nm Ti underlayer. Although increasing the substrate temperature enhances the $H_{c||}$ and $S_{||}$ values of the FePt/Ti film, the M_s value is observed to reduce as the substrate temperature increases.

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