Control of growth and ordering process in FePt(001) film at 300 °C

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Abstract. FePt(20 nm)/Cr(200 nm) bilayer films were deposited on 300°C-heated glass substrate in order to study the sputtering rate effect on ordering process and growth mechanism of FePt films. The sputtering rate of FePt layer (R_m) was adjusted within the range from 0.1 to 2.0 nm/min. X-ray results show a high order parameter of ~0.8 in the sample with R_m = 0.1 nm/min and a disordered phase of FePt in the film with R_m = 2.0 nm/min. As R_m = 0.1 nm/min., the orientation of FePt lattice aligns along the Cr(002) to develop (001)-oriented FePt. However, an isotropic orientation is observed in FePt layer as R_m = 2.0 nm/min.. In the case of low deposition rate, the growth of the film is dominated by surface diffusion. In contrast, the process of bulk diffusion dominates in the rapidly-deposited film. The activating barrier of bulk diffusion is about an order of magnitude larger than that of surface diffusion leading to the appearance of disorder structure and isotropic orientations at high sputtering rate. In this study, FePt layers with well-developed (001) texture and high chemical ordering can be fabricated via surface diffusion mechanism at 300°C. Our result merits the use of FePt magnetic layer for magnetic recording media in the future.

1. Introduction
Magnetic FePt alloy thin film with ordered L1₀ structure is a promising material for perpendicular magnetic recording (PMR) application, due to its huge uniaxial magnetocrystalline anisotropy (K_u), high saturation magnetization (M_s), high coercivity (H_c) and outstanding corrosive resistance [1-3]. K_u value of L1₀ FePt is about 10⁸ erg/cm², which sets the superparamagnetic limit of L1₀ FePt as small as 2.8 nm [1]. Therefore, a possibility of over 10 Tb/in² density media with L1₀ FePt phase has been proposed [4]. However, some basic issues such as high order-disorder transformation temperature (T_t) [5-9] and tilting of magnetic easy axis ([001]-axis) [10-12] must be overcome before formally using FePt layer as recording media. With high T_t, coarsening of magnetic grains and interlayer diffusion will occur during high-temperature thermal treatment. In the issue of tilted magnetic easy axis, since the close-packing plane of L1₀ FePt structure is (111), the deposited L1₀ FePt in general has (111) plane, leading to tilting the [001]-axis 35° away from the plane normal direction. In PMR application the preferred orientation has to be transformed into (001) that makes the [001]-axis perpendicular to the film. Accordingly, developing an effective way to prepare L1₀ FePt(001) thin film with perpendicular magnetic anisotropy at low order-disorder transformation temperature is the concern of first priority.

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In the previous investigations it has been found that the sputtering rate shows a key effect on the formation of perpendicularly magnetic anisotropy CoCrPtTa thin film [13,14]. In their studies, the inter-granular exchange coupling of CoCrPtTa was reduced while the sputtering rate declined, because slower sputtering rate of CoCrPtTa not only gives Cr atoms sufficient time to diffuse to grain boundaries so that magnetic grains will separate with each other, but also reduces the possibility of atomic misplacement.

Despite efforts mentioned above, little work has been done on FePt to investigate the sputtering effect on the formation of \( L_10 \) FePt(001) at low temperature. Previously it has been found that FePt films with (001) texture can be obtained at the temperature as low as 300°C [15]. Herein, we propose a process to identify the dependence of deposition rate on the FePt(001) texture and growth mechanism of \( L_10 \) FePt(001) thin film at low deposition temperature. In this investigation, the (001) orientation and growth mechanism of the FePt layer can be well controlled with the adjustment of deposition rate. FePt layers with well-developed (001) texture and high chemical ordering can be fabricated via surface diffusion mechanism even at a temperature as low as 300°C.

2. Experiment

Bilayer films of FePt/Cr were deposited on 300°C-heated glass substrate by dc magnetron sputtering in an ultra-high vacuum sputtering chamber. Before sputtering, the base pressure reached \( 5\times10^{-9} \) Torr. The working pressure was set at 10 mTorr. The textured Cr(200) underlayer was prepared at 1.9 nm/min. with -200V-biased voltage. The sputtering rate of FePt layer (\( R_m \)) was adjusted within the range from 0.1 to 2.0 nm/min. In order to control the sputtering rate of FePt film, the sputtering powers of Fe and Pt targets were adjusted. The chemical composition of FePt film was controlled at around Fe\(_{50}\)Pt\(_{50}\), which was detected with the energy dispersive x-ray diffractometry (EDS). The thickness of Cr underlayer and FePt magnetic layer were 200 nm and 20 nm respectively determined by an atomic force microscope (AFM). The crystal structure and microstructure of the films were characterized by x-ray diffraction (XRD) with Cu-K\( \alpha \) radiation and transmission electron microscope (TEM). The magnetic properties were measured by a vibrating sample magnetometer (VSM) at room temperature with a maximum applied field of 2.0 T.

3. Results and discussion

Figures 1(a) and 1(b) plot the XRD patterns and ordering parameters (\( S_{\text{order}} \)) of FePt films with \( R_m \) of 0.1 nm/min. to 2.0 nm/min. All films were prepared at 300°C. In figure 1(a), except for the peaks of Cr(110) and Cr(002), all visible peaks are attributed to fcc or \( L_10 \) FePt phase, indicating that no new phase formed during the sputtering of FePt film onto Cr underlayer. Therefore, no significant interlayer diffusion between FePt magnetic layer and Cr underlayer occurs. The intensity of the (002) peak from Cr underlayer is almost identical and the intensity of FePt(111) peaks that are from fcc and \( L_10 \) phase is very weak for all samples so that any variation in the FePt(001) textures is directly caused by changing the sputtering rate of FePt. When \( R_m = 2.0 \) nm/min., no ordered FePt structure appears.

![Figure 1](image-url)
and the dominated phase is fcc FePt(200). The appearance of ordered $L_1_0$ FePt(001) peak with low intensity at $R_m = 0.66$ nm/min. suggests the onset of hard magnetic FePt phase with perpendicular anisotropy. Further reducing the sputtering rate of FePt will result in $L_1_0$ FePt(001) peak with higher intensity. The position of FePt(200) peak also shifts from $47.5^\circ$ to $49^\circ$ as $R_m$ is gradually decreased, indicating a progressive transformation from fcc FePt into $L_1_0$ FePt phase. An excellent ordered FePt(001) preferred orientation is achieved when the sputtering rate of FePt is reduced to $0.1$ nm/min.. Therefore, the order-disorder transformation from fcc FePt to $L_1_0$ FePt can occur at $300^\circ$C by varying the sputtering rate.

The ordering parameters are calculated from the following formula [16] and the results are plotted in figure 1(b).

$$ S_{\text{order}} = 0.85 \times \left( \frac{I_{001}}{I_{002}} \right)^{1/2} \quad (1) $$

where $I_{001}$ and $I_{002}$ represent the integrated intensities of the FePt(001) and (002) peaks, respectively. As shown in figure 1(b), $S_{\text{order}}$ decreases markedly with increasing sputtering rate, revealing that the amount of FePt of ordered phase is reduced. When $R_m$ is over $0.66$ nm/min., the FePt(001) peaks disappear causing difficulty in integrating $I_{001}$ peak. Therefore, $S_{\text{order}}$ is only present in figure 1(b) with $R_m$ up to $0.66$ nm/min.

Figure 2 shows the cross-sectional TEM bright field images of (a) $R_m = 2.0$ nm/min and (b) $R_m = 0.1$ nm/min. The Cr underlayers are determined to be identical as displayed in figures 2(a) and (b). The crystal structure is body-centered cubic with (200) single orientation, promoting the formation of FePt(001) texture by epitaxial growth at FePt/Cr interface. However, although the Cr(200) underlayer is well defined in figure 2(a) with $R_m = 2.0$ nm/min., the epitaxial growth of FePt(001) cannot extend into the whole FePt magnetic layer. In order to easily identify the grain boundaries, the dotted lines to mark the grain boundaries are used. Apparently, multi-oriented FePt grains are present in the FePt layer and are found to stack with each other in the FePt layer. After reducing the sputtering rate of FePt to $0.1$ nm/min., a complete FePt layer with (001) texture appears as shown in figure 2(b). This result is wholly different from that in figure 2(a). It is clearly seen that the easy axis, [001], of FePt is along the plane normal direction. The lattice constant along [001] is about $0.378$ nm, which is in agreement with our previous result [15]. Comparing figure 2(a) with 2(b), reducing the sputtering rate of FePt layer significantly exhibits an advantage to epitaxially growing ordered FePt(001) structure.

In the case of low deposition rate, the growth of the film is dominated by surface diffusion, a low activation energy path for thin film growth [17]. During the deposition process the adatoms deposit on the surface randomly and subsequently relax to nearby positions where the binding is strongest. Consequently, the lattice orientation of the FePt layer grown under this condition tends to align along the texture of the Cr(002) underlayer throughout the whole thickness. In contrast, the rapidly-

![Figure 2](image-url). Cross-sectional TEM bright field images of (a) $R_m = 2.0$ nm/min. and (b) $R_m = 0.1$ nm/min.
deposited film nucleates isotropically due to the rapid solidification from gas state. The ordering is caused by bulk diffusion and the activating barrier is about an order of magnitude larger than that of surface diffusion [18]. Therefore, disorder structure and isotropic orientations are expected in FePt film as \( R_m = 2.0 \) nm/min.

4. Conclusion
In this study, it has been found that growth and ordering mechanism of the FePt layer can be well controlled with the adjustment of deposition rate. Different deposition rate can produce significant differences in chemical ordering and the development of (001) texture. FePt layers with well-developed (001) texture and high chemical ordering can be fabricated via surface diffusion mechanism even at a temperature as low as 300°C. Our results may provide useful information for the development of magnetic recording media in the future.

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