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Orientation control in $L1_0$ FePt films by using magnetic field annealing around Curie temperature

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ABSTRACT

A new method to improve (0 0 1) texture of $L1_0$ FePt films was reported. In this work, in order to obtain the perpendicular orientation of $L1_0$ FePt films, the FePt films were annealed at 700 °C (T_{A1}) for 30 min and then annealed at T_{A2} (430–600 °C) for an hour either in a magnetic field of ∼3500 Oe along the normal direction of the films (Route A) or without magnetic field (Route B). Compared with the Route B, $I_{(001)}/I_{(111)}$ showed a peak value of 7 when T_{A2} was around 478 °C (around the Curie temperature of $L1_0$ FePt films) and the AFM image of FePt sample was annealed around 478 °C showed an obvious change of grains through Route A. It is related to the following reason: when the temperature is near Curie temperature of $L1_0$ FePt films, the thermal disturbing term is close to the exchange energy of the magnetization, therefore, the magnetic field of ∼3500 Oe is effective for promoting the preferential growth direction of $L1_0$ structure.

1. Introduction

$L1_0$ FePt films with perpendicular orientation have been studied extensively as one of promising candidates for future ultrahigh density magnetic recording media [1]. As well known, as perpendicular magnetic recording media, *c*-axis of FePt films should be normal to the films and a strong (0 0 1) texture is desired. However, the FePt films deposited directly on amorphous substrates tend to possess (1 1 1) texture because (1 1 1) plane is the close-packed plane [2,3]. Therefore, one of the key challenges is how to align the magnetic easy axis (*c*-axis) to normal direction of FePt films. Usually, several approaches are being used to obtain/enhance the (0 0 1) orientation in FePt films: expitaxial growth on single crystal substrates [4–8]; hetero-expitaxial growth on textured underlayers/seedlayers [9–20]; alternate deposition of Fe and Pt layers [21–26]; FePt–X (X = B_2O_3, SiO_2, MgO, C, Ag, etc.) nanocomposite deposition [27–34]; magnetic field annealing the antiferromagnetic/FePt structure by using antiferromagnetic exchange energy [35]; aligning the magnetic particles in a magnetic field by using magnetostatic energy [36–39]. Previous studies have demonstrated that magnetic field annealing is helpful to preferred orientation of alloy or nanowires [40,41]. In this work, in order to obtain the perpendicular orientation of $L1_0$ FePt films, we proposed a method to control the *c*-axis of $L1_0$ FePt by annealing the films in a magnetic field around the Curie temperature (T_c, the T_c of $L1_0$ FePt films is 477 °C). As for a ferromagnetic material, the magnetic moments spontaneously align to the same direction inside a single magnetic domain at a temperature below the T_c, while, their directions disperse randomly when the temperature is above the T_c. If $L1_0$ FePt alloys were annealed around its T_c in a magnetic field, the preferential direction of magnetic easy axis of $L1_0$ structure should be enhanced by the external magnetic field during the rearrangement process of Fe and Pt atoms.

2. Experiment

FePt films with structure of Si (substrate)/Fe (2 nm)/FePt (20 nm)/Pt (2 nm) were deposited by magnetron sputtering system. The base pressure in chamber is 2×10^{-6} Pa and the nominal composition of the FePt layer is $Fe_{50}Pt_{50}$. The substrate temperature was raised up to 550 °C for 30 min after the deposition. Then, the as-prepared FePt films were heated up to 700 °C (T_{A1}) for 30 min to enhance the formation of $L1_0$ FePt phase. Then these $L1_0$ FePt films were annealed at different temperature (T_{A2} = 400–600 °C) below 700 °C for 60 min either in a magnetic field of ∼3500 Oe along the normal direction of the films (Route A in Fig. 1) or without magnetic field (Route B in Fig. 1). The morphologies of the films were obtained via atomic force microscopy (AFM). The crystal structure of the films was characterized by X-ray diffraction (XRD) with Cu target. The magnetic properties were measured at room temperature by using a Quantum Design MPMS XL SQUID with applied field up to 7 T.

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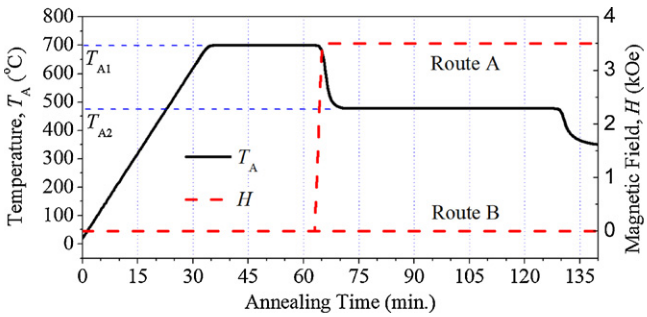

Fig. 1. Schematic diagram for two-step annealing process.

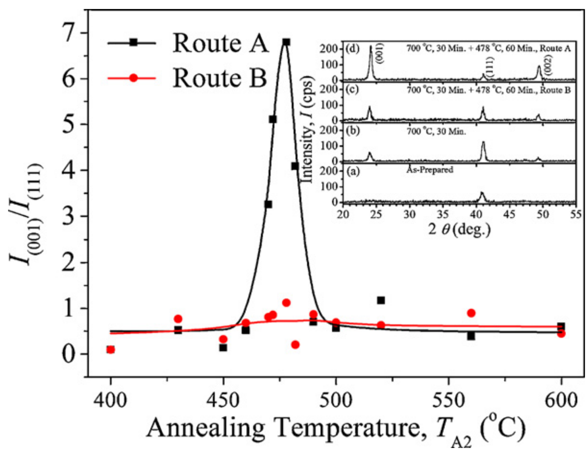

Fig. 2. Dependence of intensity ratio $I_{(001)}/I_{(111)}$ on T_{A2} for FePt (20 nm) films annealed through Route A and Route B; and insets: XRD patterns of FePt (20 nm) films: (a) as prepared, (b) post-annealed at 700 °C for 30 min, (c) annealed through Route B, and (d) annealed through Route A.

3. Results

Fig. 2(insets) shows the XRD patterns of the FePt films. As for the as-prepared FePt films, only (1 1 1) peak was detected. After annealed at 700 °C (T_{A1}) for 30 min, (0 0 1) and (002) peaks of $L1_0$ phase were observed. When the films were further annealed at 478 °C (T_{A2}) for 60 min, big difference can be seen in between those $L1_0$ FePt films annealed by Route A and Route B. Comparing with Route B (the integrated intensity of peak (0 0 1), I_{001} is comparable with that of peak (1 1 1), I_{111}), FePt films annealed by Route A showed much higher value of intensity ratio I_{001}/I_{111}. This indicated that the magnetic field at 478 °C did induce the preferential growth direction of $L1_0$ structure. In order to investigate the influence of the magnetic field on the orientation degree of the $L1_0$ structures during the annealing process, the $L1_0$ FePt films were annealed through either Route A or Route B. Fig. 2 shows the dependence of the intensity ratio of $I_{(001)}/I_{(111)}$ from XRD patterns on the different annealing temperature of T_{A2} for both of Route A and Route B. As for the Route B, there is no visible influence of T_{A2} can be seen, while $I_{(001)}/I_{(111)}$ showed a peak value of 7 when T_{A2} was around 478 °C (around the T_c of $L1_0$ FePt films [1]) through Route A. In order to demonstrate the role of the magnetic field when annealing around Curie temperature, the XRD pattern of FePt film annealed at 700 °C for 30 min and then annealed at 478 °C for 60 min in a magnetic field of 3500 Oe along the plane of the film was also obtained. The results shows that the (2 0 0) peak is observed and (1 1 1) peak intensity increases greatly when the magnetic field parallel to the film plane of $L1_0$ FePt films and these results indicate that annealing around Curie temperature in magnetic field can induce orientation of the c-axis of FePt toward particular crystal orientation.

Fig. 3 shows the typical hysteresis loops of FePt (20 nm) films. Comparing with the as prepared state, the in-plane and out-of-plane coercivities of FePt films were remarkably enhanced after heat treatment, which can be attributed to the formation of perfect $L1_0$ phase. It should be noted that the in-plane remanence and the squareness ratio of as prepared FePt films were both larger than the out-of-plane ones, while the situation reversed for FePt films annealed through either Route A or Route B. Moreover, as shown in Fig. 3(d), the out-of-plane squareness ratio increases drastically when the FePt films were annealed at 478 °C (T_{A2}) in a magnetic field applied along the normal direction of FePt films. This indicates that the (0 0 1) orientation of FePt films were much improved and perpendicular anisotropy were obtained, which is consistent with the XRD patterns shown in Fig. 2(insets).

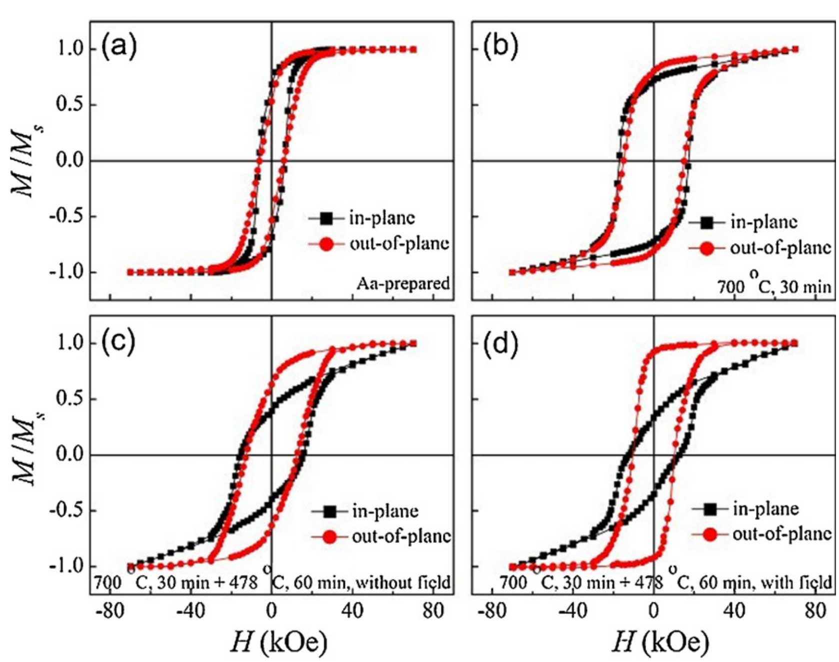

Fig. 3. Typical hysteresis loops of FePt (20 nm) films: (a) as prepared, (b) post-annealed at 700 °C for 30 min, (c) annealed through Route B, and (d) annealed through Route A.