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Preferentially Oriented Growth of $L1_0$ FePt on Si Substrate

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Tilting the magnetic easy axis of $L1_0$ FePt and/or introducing a magnetic buffer layer is most effective in realizing the $L1_0$ based magnetic recording media. Here we report on preferentially oriented growth of $L1_0$ FePt with tilted magnetic easy axis. FePt films of thickness up to 170 nm were deposited on Si substrate with a soft magnetic underlayer of glassy FeSiB, FeSiBP and CoFeTaB. Effects of processing conditions on the structural and magnetic properties were studied. A polycrystalline growth of FePt (i.e. mixed orientation) was observed with the underlayer of FeSiB and FeSiBP, but CoFeTaB promotes preferentially oriented growth along (111) crystallographic direction. Compared to FePt films grown on Si substrate, coercivity (H_c) reduces significantly with the introduction of soft magnetic underlayer. The magnetic easy axis of (111) $L1_0$ FePt is tilted 36 out of plane and it is very promising for tilted magnetic recording media.

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1. Introduction

$L1_0$ FePt is gaining a significant attention for the fabrication of magnetic recording media [1]. It needs to be grown along a preferential crystallographic orientation. Over the past decade, the focus was on the growth of (001) oriented $L1_0$ FePt for perpendicular magnetic recording media [1]. One of the major problems to use FePt in recording media is its extremely high coercivity (H_c) that results in a writability problem [1]. There are three approaches to solve the problem of writability [1–3] i.e. magnetic easy axis tilting, domain wall and heat assisted magnetic recording. Both domain wall and heat assisted magnetic recording techniques are actively pursued, but there is a little attention on the tilted magnetic recording. By tilting the magnetic easy axis to 45°, the switching magnetic field can be reduced to half. Feasibility of tilted magnetic recording media relies on the growth of $L1_0$ FePt with tilted magnetic easy axis. There are two approaches; one is the physical tilting by oblique angle deposition, and the second is crystallographic tilting. But it is difficult to achieve a large tilting of the magnetic easy axis by oblique angle deposition. The crystallographic or natural tilting of the magnetic easy axis is a better choice. The magnetic easy axis of $L1_0$ FePt is tilted to 36° out of plane for (111) and to 45° for (101) oriented grains.

There are very few reports on the growth of (111) and (101) oriented $L1_0$ FePt films [4, 5]. Almost in all the reports, growth is on a single crystal MgO substrate. For applications, a preferentially oriented growth on a glass or other substrate is required. To control the crystallographic orientation of FePt several aspects (like deposition conditions, substrate and underlayer) has to be taken into account. Therefore, here we report on the preferentially oriented growth of (111) $L1_0$ FePt on Si or SiO_2 substrate. We found that the glassy CoFeTaB underlayer promotes (111) orientation of $L1_0$ FePt on glass or Si substrates.

2. Experimental

Soft magnetic underlayers were deposited from alloyed sputtering targets, which were made by the arc-melting technique. High purity argon gas with a sputtering pressure of 0.2 Pa and dc power of 100 W were used. The sputtering chamber was evacuated to a base pressure of $\approx 10^{-5}$ Pa. Films were deposited on SiO_2/Si(100) substrate at room temperature (RT). FePt films were deposited *in situ* over RT deposited underlayer/SiO_2/Si(100) and SiO_2/Si(100) substrates by using a dc-magnetron co-sputtering technique. Substrate was rotated at a speed of 10 rpm during the deposition of FePt. The crystallographic information of the films was obtained by using an X-ray diffractometer (XRD). Electron probe micro-analysis (EPMA) was used for the compositional analysis. Vibrating sample magnetometer and quantum design SQUID magnetometers were used to study the magnetic properties. The surface morphology was imaged with an atomic force microscope (AFM).

3. Results and discussion

Structural and magnetic properties of thin films deposited by sputtering technique depend on processing conditions such as sputtering pressure, T_s, film thickness (t) etc. To get best magnetic properties all the parameters need to be optimized. At first, $Fe_{51}Pt_{49}$ films were deposited ($t \approx 85$ nm) on SiO_2/Si (100) substrate at different T_s ($\approx$ 375 to 550 °C). Figure 1 shows the XRD patterns. Superlattice diffraction lines of (001) and (112) are clearly visible at $2\theta \approx 24$ °C and 60 °C, respectively, along with the fundamental peaks. The intensity of (001) peak increases with an increase of T_s. Relatively high intensity of (001) diffraction peak indicates that all the films have weak preferential orientation along (001). The long range chemical ordering parameter (S), which defines the transformation from disordered

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fcc phase to hard magnetic $L1_0$ FePt improved with increase of T_s. At low T_s ($< 400\,^{\circ}$C) the S is less than 0.90. The value of S approaches to 0.98 for the films deposited at 550 °C. In order to gain more information about the effect of T_s on surface morphology, films were observed with AFM. A mixed granular surface topography was observed (Fig. 1b and c). Such a topography may result from grains with different crystallographic orientations (Fig. 1a). The average surface roughness varies from ≈1 nm to 9 nm as the T_s varies from ≈350 to 550 °C.

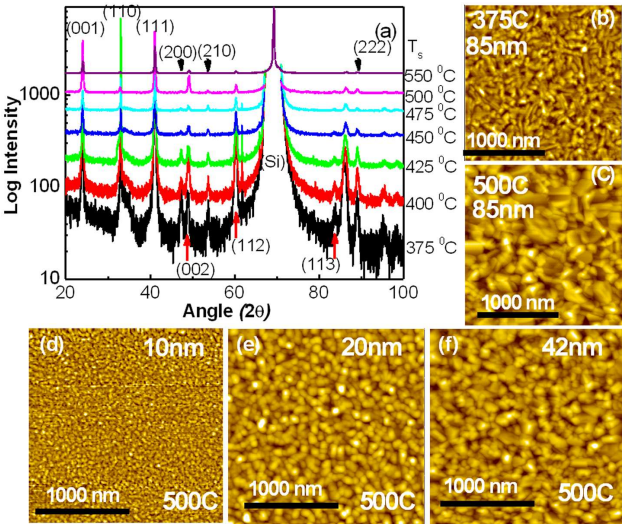

Fig. 1. (a) XRD curves of $Fe_{51}Pt_{49}$ films deposited on SiO_2/Si substrate at different T_s. AFM topographic image of ≈85 nm thick $Fe_{51}Pt_{49}$ films deposited at (b) 375 °C, (c) 500 °C, and films of thickness (d) 10 nm, (e) 20 nm and (f) 42 nm deposited at 500 °C.

The effect of film thickness (t) on structure and surface morphology was investigated. $Fe_{51}Pt_{49}$ films of $t \approx 10$ to 170 nm were deposited at $T_s = 500\,^{\circ}$C. XRD patterns were similar to Fig. 1a even for the thinnest film of ≈10 nm. The diffraction peaks were relatively broader at lower t, and tends to be sharper with increasing t. Results suggest that all the films have $L1_0$ ordering and grain size increases with an increase in t. The value of S was ≈0.85 for $t \approx 10$ nm. It increases rapidly and becomes almost constant ($S > 0.95$) at $t \approx 40$ nm. Very fine grains (≈circular in shape) with uniform size distribution was noticed at lower t (Fig. 1d). As t increases the grain size becomes larger (Fig. 1e and f). Grain growth seems to be larger for some grains and slower for others, which results in a sharp increase in surface roughness. For $t \approx 10$ nm, the surface roughness is less than 2 nm but it increased to ≈8 nm for 170 nm thick film. This may be due to grains of different crystallographic orientations (as observed in XRD, Fig. 1a).

Figure 2a shows the typical shapes of hysteresis curve in in-plane and out-of-plane directions for polycrystalline $Fe_{51}Pt_{49}$ thin films deposited at $T_s = 500\,^{\circ}$C. The magnetization is higher in out-of-plane direction as compared to in-plane direction, and it can be due to polycrystalline nature of the film. The volume fraction of grains with

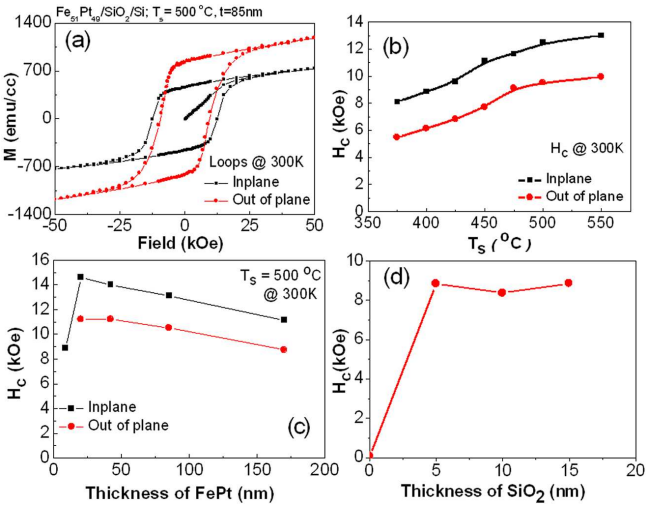

Fig. 2. (a) In-plane and out-of-plane hysteresis curves of ≈85 nm thick $Fe_{51}Pt_{49}$ film on SiO_2/Si deposited at $T_s \approx 500\,^{\circ}$C. (b) H_c dependence on T_s for ≈85 nm thick $Fe_{51}Pt_{49}$ film (c) H_c dependence on film thickness for $Fe_{51}Pt_{49}$ (t), and (d) effect of SiO_2 layer thickness on H_c.

magnetic easy axis in out-of-plane direction seems to be larger as compared to other directions. This is also evident from the XRD measurements (Fig. 1), which showed higher intensity of (001) diffraction peak. Similarly, hysteresis curves in out-of-plane and in-plane directions were measured for the films deposited at different T_s (Fig. 2b), and different t (Fig. 2c). Relatively low H_c at lower T_s is consistent with low value of S. As T_s increases further, the in-plane and out-of-plane H_c increases rapidly, and almost attains a saturation at $T_s = 550\,^{\circ}$C (the in-plane and out-of-plane H_c are 13 kOe and 10 kOe, respectively). The H_c decreases continuously with an increase in film thickness (Fig. 2c). This behavior of H_c is very different compared to epitaxially grown $L1_0$ FePt films on single crystal MgO (100) substrate. This is due to different mechanism of magnetization in epitaxial and polycrystalline films. The effects of SiO_2 underlayer thickness on structural and magnetic properties were also investigated. Reducing the SiO_2 layer thickness below 5 nm resulted in a large number of peaks in XRD. None of them matches with $L1_0$ FePt. The H_c decreases sharply as the SiO_2 underlayer thickness reduces to < 5 nm (Fig. 2d). Such a drastic change in H_c and a large number of peaks in XRD are due to diffusion of FePt with Si substrate.

The FePt films deposited on SiO_2/Si substrate have mixed orientation. We have also tried to deposit multilayered structures of [Fe(0.71 nm)/Pt(0.71 nm)/SiO_2/Si] and underlayers of Pt and Cr but in all the cases we do not succeed in obtaining the preferentially oriented growth of $L1_0$ FePt. Next, we tried with the soft magnetic metallic glass underlayers (FeSiB, FeSiBP, and CoFeTaB). Motivation for this was to get a smooth surface and effect of domain wall assisted magnetization switching in $L1_0$ FePt. Results inferred that the direct growth of $L1_0$ FePt on glassy FeSiB

or FeSiBP underlayer is difficult due to diffusion of Si in FePt. The glassy CoFeTaB underlayer showed some promising results. Figure 3a shows the XRD patterns of $Fe_{51}Pt_{49}$(42 nm)/CoFeTaB(≈30 nm)/SiO_2/Si multilayered structure deposited at different T_s (400, 500 and 550 °C). A preferentially oriented growth of $L1_0$ FePt along (111) crystallographic direction is clearly noticeable up to $T_s \approx 500$ °C. At $T_s = 550$ °C, in addition to (111) and (222) diffraction peaks, other peaks [(001), (002) etc.] of FePt were observed. Moreover, some extra peaks were observed, which may originate from the crystallization of CoFeTaB glassy layer. Preferentially oriented growth of $L1_0$ FePt was further confirmed by varying the thickness of CoFeTaB (up to ≈225 nm) and FePt (up to ≈85 nm). In all the cases, XRD patterns exhibit only (111) and (222) diffraction peaks of $L1_0$ FePt. The above results convincingly proved that the CoFeTaB glassy underlayer promotes the growth of FePt along (111) crystallographic orientation, and crystallization of it results in a mixed oriented growth.

Metallic glasses do not have a crystal structure, therefore there is no concept of lattice parameters [6]. But if we notice the XRD curve of glassy CoFeTaB layer (Fig. 3b), there is a broad peak, which represents the average interatomic spacing. The average inter-atomic spacing of CoFeTaB glassy layer (Fig. 3b) is close to the interatomic spacing of (111) $L1_0$ FePt. For glassy SiO_2 the broad diffraction peak is around $2\theta \approx 20°$ which is much further than for CoFeTaB. Additionally, the growth of a crystal along a particular direction is dependent on the surface energy of a particular facet. Dannenberg et al. [7] calculated the surface energies of various $L1_0$ FePt facets from density functional theory (DFT). The growth of FePt along preferential (111) crystallographic orientation on CoFeTaB glassy layer may be due to the lowest surface energy of (111) facet and similar average interatomic spacing of glassy layer with (111) plane of FePt.

Figure 3c and d shows the in-plane and out-of-plane hysteresis curves (at 300 K) for $Fe_{51}Pt_{49}$/CoFeTaB/SiO_2/Si multilayered structure deposited at $T_s = 400$ °C. These curves were corrected for the substrate contribution. Thickness of FePt was fixed to ≈42 nm and thickness of soft magnetic CoFeTaB glassy layer was varied from 15 to 225 nm. Two phase like hysteresis curves were obtained in in-plane direction. The dip in magnetization near origin (zero magnetic fields) is most visible for the underlayer thickness of ≈225 nm. It reduces with a decrease in CoFeTaB glassy layer thickness. This dip in magnetization is basically originating from the switching of magnetization at lower fields in soft magnetic CoFeTaB glassy under layer. The high H_c of multilayered structure proved formation of chemically ordered $L1_0$ FePt phase, and presence of (111) and (222) diffraction peaks in XRD patterns confirmed the preferentially oriented growth of $L1_0$ FePt. The hysteresis curves in out-of-plane direction do not exhibit a sudden dip in magnetization near the origin (Fig. 3d). The shape of the curves is similar to that of a single phase like magnet. Moreover the H_c of this layered structure decreases with an increase in thickness of the soft magnetic under layer (Fig. 3d). This is very much desirable from the viewpoint of writability of $L1_0$ FePt based magnetic recording media.

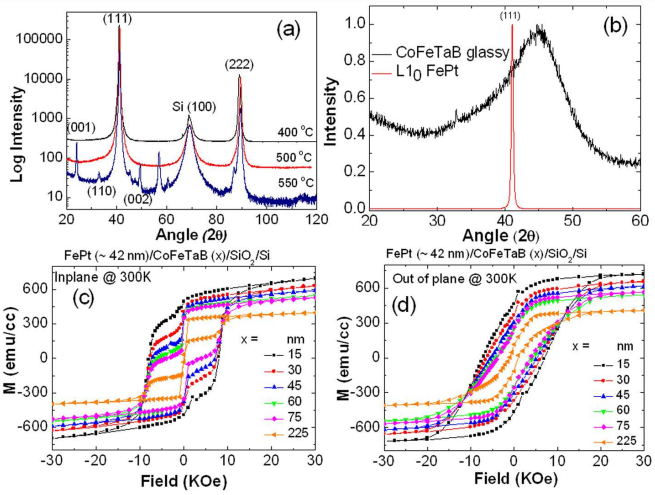

Fig. 3. XRD patterns of (a) multilayered structure $Fe_{51}Pt_{49}$/CoFeTaB/SiO_2/Si deposited at different T_s, and (b) glassy CoFeTaB along with $L1_0$ (111) FePt. (c) inplane, and (d) out-of-plane hysteresis curves of ≈42 nm thick $Fe_{51}Pt_{49}$ films deposited with different thickness of CoFeTaB underlayer on SiO_2/Si.

4. Conclusions

A maximum $H_c \approx 15$ kOe was obtained at $T_s = 500$ °C for a 20 nm thick mixed oriented $L1_0$ FePt films deposited on SiO_2/Si substrate. In the absence of SiO_2 buffer layer diffusion of FePt thin film with the Si substrate was observed. $L1_0$ FePt grows preferentially along (111) crystallographic direction on a glassy CoFeTaB soft magnetic underlayer at lower T_s (≈400 °C). The switching field of $L1_0$ FePt can be tailored to desirable value below 8 kOe, just by changing the thickness of soft magnetic metallic glass underlayer. The present results are promising for the fabrication of tilted magnetic recording media with $L1_0$ FePt.

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