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(001)-Oriented Nonexpitaxial L1_0 FePt by rapid thermal annealing

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Abstract

Highly L1_0-ordered FePt thin films with a strong (001) texture were successfully fabricated on SiO_2//Si substrates by sputtering and rapid thermal annealing. Large biaxial tensile-stress was induced by controlling the heating rate, causing a transition of orientation from (111) to (001) texture of L1_0 FePt .We observed that not only heating rate, but FePt composition and the annealing time are strongly dependent on (001) texture. These factors also affect the magnetic properties of FePt.

Keywords: Rapid thermal annealing; Magnetic properties; Gas pressure; Magnet.

Introduction

In the past years, L1_0 FePt have been widely studied due to its promising applications such as high density recording media and permanent magnet [1]. L1_0-FePt has been proposed to be a promising candidate as ultrahigh-density perpendicular magnetic recording media due to its large magnetocrystalline anisotropy (Ku~7×10^7 erg/cc) [2] and excellent resistance to corrosion [3]. To efficiently promote the L1_0 ordering in the FePt thin film, deposition or post-annealing at high temperature is generally indispensable. This high temperature process is unfavorable in view of the compatibility for a practical device fabrication process. Many studies focusing on lowering the ordering temperature of L1_0 FePt were reported, for example, stress-induced phase transformation by depositing on a specific under layers (such as MgO [4], CrRu [5], Cr [6], TiN [7]) or by adding third elements (such as Cu [8], Ag [9], SiO_2 [10], B_2O_3 [11]). Then rapid thermal annealing (RTA) is also considered as a useful technique to enhance the nonexpitaxial FePt ordering. It was reported that different value of in plane tensile stress can be induced by controlling the heating rate of rapid thermal annealing (RTA) [12-14]. There are some important parameter would influence FePt ordering in the RTA process. In this letter, a multilayered structure was used to deposit FePt in order to well control of FePt composition and improve the film property. Dependence of preferred orientation on heating rate and annealing time of FePt film was also explored in details.

Experiment

Thin FePt films were prepared by alternating growth of Fe and Pt layers composed of $[Fe(x\ Å)/Pt(4\ Å)]_8$ on substrates of SiO_2(90nm)//Si through an ultra-high vacuum dual ion beam deposition system (DIBD) at an ambient temperature with a background pressure lower than 5×10^{-8} torr. A composition series of FePt were obtained by depositing different thickness of Fe layers. Ar gas pressure during sputtering was 4×10^{-4} torr. Samples were subsequently annealed in vaccum ($<1\times10^{-5}$ torr) at 550 °C with different heating rates (20, 40, 60, and 87 °C/s). Chemical compositions of all samples were determined by energy dispersive X-ray spectroscopy (EDS). A spherical aberration corrected (scanning) transmission electron microscopy of JEOL JEM-ARM 200F operating at 200 kV equipped with energy-dispersive X-ray spectroscopy (EDS) was used for elemental and microstructural analyses. Structures were identified also by using X-ray diffraction (XRD) with Cu Kα radiation. Magnetic hysteresis loops of FePt film were measured by a superconducting quantum interference device (SQUID, Quantum Design MPMS-XL) with a maximum field of 50 kOe at room temperature.

Result and Discussion

Figure 1A showed the θ-2θ scans of XRD for FePt films on SiO_2(90nm)//Si annealed at 550 °C with different heating rate and the related simulation of random directions by CaRIne Crystallography. FePt thin films deposited on amorphous substrates generally show the (111) preferred orientation since the (111) plane have lowest surface energy [15]. The (001) superlattice and (002) fundamental diffraction peaks of $L1_0$-FePt were observed for all samples, demonstrating good [001]-preferred orientation of $L1_0$-FePt [12]. Then we can find that all the peaks are shifted to higher angle compared with the XRD simulation, which means FePt films subjected to tensile stress. The full-width at half-maximum (FWHM) values determined from (001) reflection for all sample were lower than 1.8°, demonstrating that all samples with good crystal quality. Figure 1B showed the different compositions of FePt with heating rate of 40 °C/ s. The different composition of FePt was deposited by changing the Fe layer thicknesses, which was determined by EDS. Only around stoichiometric composition of FePt has good (001)-orientation. In the Fe-50 at % films, we successfully fabricated highly $L1_0$-ordered FePt samples with a strong (001) texture and the HRTEM image was showed in Figure 2. By comparing the local diffraction pattern obtained from FFT in FePt film with $L1_0$ ordered FePt simulated diffraction patterns, strong superlattice diffraction spots (001) with the magnetization easy axis [001] direction perpendicular to film plane were observed. This was consistent with perpendicular magnetic anisotropy property measured by XRD.

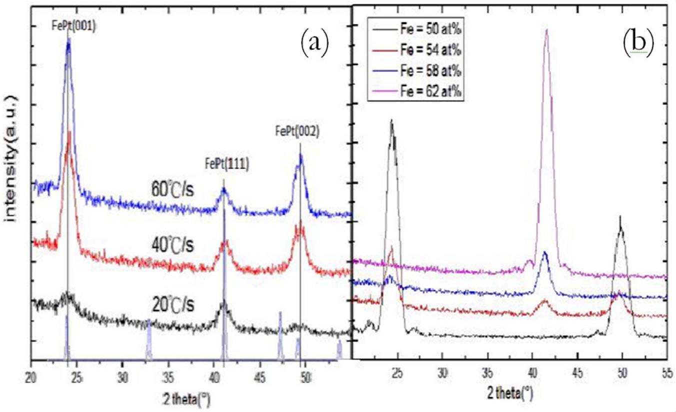

Figure 1: X-ray diffraction patterns of FePt (A) annealed with different heating rate and the XRD simulation. (B) of different chemical composition annealed at 550°C for 10s with heating rate of 40 °C/s.

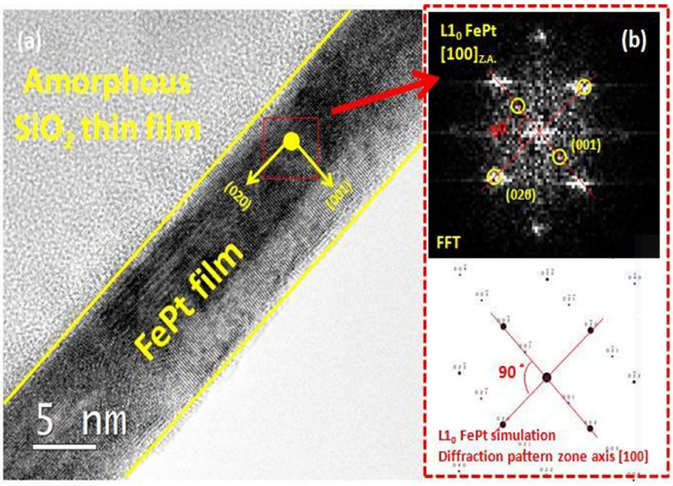

Figure 2: (a) Cross-sectional HRTEM of FePt thin film with the heating rate of 60 °C/s. (b)simulated diffraction pattern and FFT.

Figure 3 showed magnetization curves of the samples annealed with different RTA heating rates. With increasing heating rate, both the in plane and out of plane coercivities increased. This can be due to the reason that larger in-plane tensile-stress was induced by larger heating rate. Therefore, more defects were produced to be pinning sites, which can pin the domain walls and, therefore, the coecivity was increased [16].

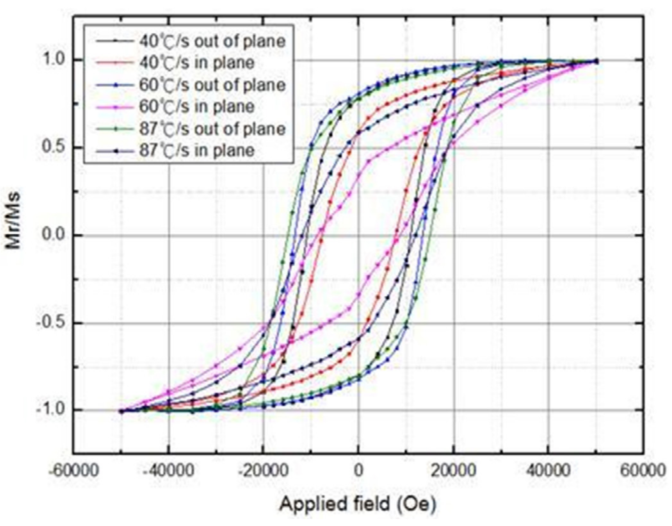

Figure 3: Hysteresis loops of FePt film annealed at 550 °C with different heating rate.

Conclusion

In summary, with different heating rate of RTA, different values of in-plane tensile-stress were induced to enhance FePt ordering, which result in pinning sites. More pinning sites will pin the domain walls and then increase the coecivities of FePt thin films. Ordering of FePt thin film is also strongly dependent on chemical composition. Only around stoichiometric composition of FePt has the good (001)-orientation. Finally, we produced nearly perfect (001) oriented FePt films by nonexpitaxial deposition.

Conflicts of Interest: The author(s) report(s) no conflicts of interest.

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