Effect of Annealing Process on Internal Stain/Stress in FePt Thin Films

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$L1_0$ FePt phase have received considerable attention due to its remarkable properties including high magnetocrystalline energy ($K_u \sim 7 \times 10^7$ erg/cm^3) [1], Curie temperature (~450 °C), and chemical stability, etc., which allows potential applications in various fields. In FePt thin films, internal film stress, an unavoidable feature in thin-film preparation, might be relative to $L1_0$ ordering transformation, reported by Wierman *et al*. using curvature techniques. [2] In our previous works, we suggested that the stress transition (from compressive to tensile) be strongly associated with the early-stage ordering in *in-situ* annealed FePt thin films. Recently, we employed the initial stress/strain state of the FePt films to approach the problem, i.e., how significant the internal stress affect $L1_0$ ordering transformation in post-annealed FePt thin films. [3] In this paper, effect of annealing process on internal strain/stress are presented and discussed in detail.

Single-layer FePt films were prepared by rf magnetron sputtering with background vacuum better than 2×10^{-7} Torr. The films with nominal thickness of 40 nm were deposited on Corning 1737 glass substrates. Thin films were annealed at 200 – 700 °C by post-annealing or *in-situ* annealing for 10 minutes. The sputtering power and working pressure was 80 W and 10 mTorr, respectively. Crystallographic structure was identified by x-ray diffraction (XRD) using Cu K_α (λ = 1.541 Å) radiation. $\sin^2\psi$ method (ψ is the angle between diffraction vector and sample normal) was employed to measure residual strain (ε_r) using synchrotron radiation with beam energy of 8 keV (λ = 1.55000 Å). Chemical composition of the FePt films was confirmed to be 52:48 using inductively coupled plasma (ICP) technique.

The dependence of ε_r on annealing temperature is shown in Fig. 1. The thermal strain, induced by different coefficient of the thermal expansion (CTEs) between FePt film and glass substrate, was corrected using previous methods [4]. For post-annealed samples, the ε_r of the films transformed from –0.81% (compressive) to a maximum value of 1.02 % (tensile), while post- annealed temperature (T_a) was increased to 275 °C. With increasing T_a up to 300 °C, the ε_r dropped dramatically to 0.08 %. For samples annealed at T_a > 400 °C, the tensile strain increased again gradually to 0.75 % (T_s = 700 °C). For *in-situ* annealed films, the ε_r curve displays a different behavior, especially at low temperature region. It rapidly changes from –0.81 % to around –0.15 %, when samples were *in-situ* annealed at temperature (T_s) < 300 °C. With increasing of T_a up to 350 °C, ε_r almost vanished and, thereafter, the ε_r gradually increases in tensile direction. The XRD patterns of the post-annealed and in-situ annealed samples are shown in Figs. 2 and 3, respectively. The ordering temperatures for both series are 350 °C, confirmed by presence of superlattice peaks, e.g. (001), (110), (201), etc. Besides, the $L1_0$ ordering and crystalline domain size in post- and *in-situ* annealed samples exhibit similar features with increasing annealing temperature. According to the XRD results, we learned that the evolution of crystal structure and domain size couldn't explain the difference of ε_r that we mentioned above.

In our previous works, we demonstrated that the combined effect of tensile strain induced by densification and compressive strain resulting from phase transformation was mainly responsible for ε_r in post-annealed films [4]. We believe that the dynamic relaxation is the major factor in the discrepancy of ε_r, since the atomic mobility of adatom deposited onto substrates in *in-situ* annealed samples are much higher than that in post-annealed samples. In addition, we suggest that the discrepancy of ε_r in different annealing process lead to different ordering mechanism. This will be completely discussed in full paper.

References

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