Effect of Initial Stress/Strain State on Order-disorder Transformation of FePt Thin Films

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FePt $L1_0$ phase have received considerable attention in the recent years due to its remarkable properties including high magnetocrystalline anisotropy (K_u~7×10^7 erg/cm^3), [1] Curie temperature (~450˚C), and chemical stability, etc., which allows potential applications in various fields. The A1-L10 ordering transformation is sensitive to several intrinsic factors such as binary composition, film thickness, [2] and type of substrate. Thin film contains strong internal strain/stress due to high traction interface between film and substrate. This intrinsic strain/stress is equivalent to an external pressure, which could play an important role on phase transformation. However, this effect on $L1_0$ ordering has not been reported. In this letter, we control the initial stress (σ_i) of room-temperature (RT) deposited FePt single layer films to study the order-disorder transformation.

Single-layer FePt thin films with nominal thickness of 40 nm were deposited at RT on Corning 1737 glass substrates by rf magnetron sputtering. Background vacuum is better than 2×10^{-7} Torr and working power is 80 W. The composition of the studied FePt films was controlled to be $Fe_{52}Pt_{48}$ (±1 at %) as analyzed by inductivity coupled plasma spectrometry (ICP). The initial in-plane stress/strain state was manipulated by varying working pressure of argon from 5 to 25 mtorr. After deposition, the films were post-annealed immediately in the sputter chamber at temperature (T_a) ranging from 200 to 700˚C in argon atmosphere for 10 min. In-plane stress/strain was obtained by $\sin^2\psi$ method using synchrotron radiation with energy of 8 keV (λ = 1.55000 Å). Crystallographic structure was examined by conventional XRD with Cu K_α (λ = 1.541 Å). In-plane magnetic properties of the samples were measured by vibrating sample magnetometer (VSM) with maximum applied field of 1.2 tesla at RT. Microstructure and selected area electron diffraction (SAD) were investigated with a field-emitted transmission electron microscope (FETEM).

The relation between d_{111} and $\sin^2\psi$ for the RT-deposited thin films with different working pressures indicates that the σ_i increases drastically from –1.01 GPa (compressive) to 0.18 GPa (tensile) with the increasing of the working pressure from 5 to 25 mTorr. Dependences of order parameter, S, and H_c on σ_i for FePt thin films annealed at 275 to 400˚C for 10 minutes are shown in Figs. 1(a) and 1(b). As indicated by Fig. 1(a), σ_i shows no visible effect on ordering for the films with T_a = 275˚C. In the films with T_a = 300˚C, $L1_0$ ordering occurs in the samples whose σ_i are higher than –0.39 GPa. With the increasing of T_a to 350˚C, the onset point of ordering shifted to σ_i = –0.5 GPa. The film with the largest compressive σ_i of –1.01 GPa finally orders at T_a = 400˚C, the S of which is about 0.4, close to those of the films with σ_i = –0.18 and 0.18 GPa annealed at 300˚C. A difference of 100 ˚C in T_{ord} is clearly indicated. Dependence of H_c shows a perfect consistence to S as indicated in Fig. 1(b). With the rise of S, H_c is drastically enhanced from below 0.5 kOe to about 8 kOe. To further investigate the role that σ_i plays during ordering, we study the dependence of T_a on residual strain (ε_r). The corrected ε_r vs. T_a curves for the FePt films with various σ_i are shown in Fig. 2. A significant change in ε_r was observed before the rise of S. As T_a was raised, ε_r increased exponentially to a maximum (ε_{max}) toward the tensile direction then rapidly relaxes to a local minimum, after that ε_r slowly increased again with T_a to 700 ˚C. We found that densification induces a strong tensile strain of about 1 GPa before ordering. This strain provides extra driving force for the nucleation of order phase because the volume expansion caused by ordering, confirmed by SAD (inset of Fig. 2), and atomic rearrangement can effectively neutralize the tensile strain. Besides, the control of initial stress from -1.01 to 0.18 GPa results in a decrease in activation energy of phase transformation from 0.387 to 0.23 eV/atom, leading to reduction of about 100˚C in ordering temperature of FePt films.

References

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