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Effect of Hf underlayer on structure and magnetic properties of rapid thermal annealed FePt thin films

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ABSTRACT

FePt(20 nm) and FePt(20 nm)/Hf(10 nm) thin films prepared on the glass substrates by sputtering and post annealing are studied. For both samples, the as deposited films are disordered and $L1_0$-ordering is triggered by a 400 °C-annealing. At $T_a \geq 600$ °C, Hf–Pt intermetallic compound forms with increasing T_a, which consumes Pt in FePt layer and results in the formation of Fe_3Pt phase. The film becomes soft magnetic at $T_a = 800$ °C. The optimized condition of FePt/Hf film is in the T_a range of 500 to 600 °C where the interdiffusion between Hf and FePt layer is not extensive. The value of H_c is 8.9 kOe and M_r is 650–670 emu/cm^3. Unlike FePt films, the Hf-undelayered samples show significantly reduced out-of-plane remanent and coercivity. The values for both are around 50% smaller than that of the FePt films. Additionally, Hf underlayer markedly reduces the FePt grain size and narrows the distribution, which enhances magnetic intergrain coupling. Good in-plane magnetic properties are preferred for the uses like a hard biasing magnet in a spintronic device.

1. Introduction

$L1_0$ FePt thin films is commonly accepted as an highly potential material in a wide range of applications from self-assembled nanoparticles for bio-related labelling to solid-state devices like sensors or recording media because of both remarkable magnetic anisotropy (K_u) and chemical stability. $L1_0$ phase has an order structure of alternatively stacked Fe and Pt plans along the normal of (0 0 1) in fcc lattice and is thermodynamically stable at room temperature (RT). However, thin films or nanoparticles prepared by most of the approaches at RT have a metastable disorder structure, which is stable at temperatures higher than 1300 °C as shown by the phase diagram. To form the high-K_u $L1_0$ phase, a post thermal process is necessary.

Magnetic hardening of FePt thin films is sensitive to underlayers for altering the energy barrier of ordering [1–3] or even to top layers for microstructure modification through grain boundary diffusion [4–6]. Heavy metal underlayers or dopants such as Ta [7], Nb [8], W [9], Os [10], and Ir [11] also have significant effect on both structure and magnetic properties. The high melting point makes them have good diffusion barriers between FePt and substrates providing enhanced thermal stability [10] and strong grain refiner [8].

In this study, we report the effect of Hf underlayer on magnetic hardening of rapid thermal annealed (RTA) FePt thin films. Unlike isotropic magnetic hardening, that is, similar hysteresis behaviour in the directions in the film plane and out of plane that normally takes place in the FePt films, FePt/Hf films exhibit improved in-plane magnetic anisotropy. For specific applications like hard bias structures in a spin valve magnetic sensors or spintronic devices, proper hard magnetic properties of the hard bias structures that align the magnetization of free layer is essential.

2. Experiment

Thin films of FePt and FePt/Hf were deposited the Corning 1737 glass substrates at RT by RF sputtering. The base pressure is below 3×10^{-7} Torr and the working pressure is 10 mtorr. The thickness of the FePt layer was 20 nm; the Hf layer is 10 nm. After the deposition, the films were submitted to RTA under pressure of

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3×10^{-6} Torr at temperatures (T_a) ranging from 400 to 800 °C for 10 min at heating rate (R) of 5 and 40 °C/s. The crystal structure is characterized by both in-house X-ray diffractometer and 8-circle goniometer diffractometer with synchrotron radiation X-ray light source at beamline 17B in national synchrotron radiation research centre (NSRRC). Magnetic properties at RT were measured using a vibrating sample magnetometer (VSM). Samples before measuring in-plane hysteresis loops were pulsed magnetized at the external magnetic field of 5 T; while out-of-plane measurement are with as-prepared films. Surface morphology was observed with a scanning electron microscope (SEM). Magnetic domain structure was studied by magnetic force microscopy (MFM).

3. Results and discussion

X-ray diffraction profiles of the FePt and FePt/Hf thin films annealed at different T_a with R=5 °C/s are shown in Fig. 1(a) and (b), respectively. In the single layer films as shown in Fig. 1(a), the as-deposited sample is disordered. Ordering takes place at T_a=400 °C as indicated by the emergence of the superlattice peak (0 0 1) around 24°. With increasing T_a, the intensity of (0 0 1) peak largely increases and the (2 0 0) splits into (2 0 0) and (0 0 2) with growing area, which signal the development of grain growth.

In the FePt/Hf films as shown in Fig. 1(b), the XRD profile shows two peaks. The one near 35° represents Hf(1 1 0), the strongest peak of Hf of body-centered-cubic (bcc) lattice; the other is the fundamental peak of disorder (A1) FePt(1 1 1). The intensity of A1 (1 1 1) is greatly enhanced by Hf-underlayering as compared to the single layer film. With the increase of T_a to 600 °C, the Hf(1 1 0) peak is weakened and broadened while A1(1 1 1) peak becomes sharper and the 2θ angle increases by 0.3°, suggesting the ordering and interlayer diffusion. When T_a=700 °C, Hf(1 1 0) peak disappears and FePt(1 1 1) peak splits into FePt(1 1 1) and Fe_3Pt(1 1 1) as confirmed by their lattice spacings. Fe_3Pt becomes majority at T_a=800 °C; meanwhile, an intermetallic $Hf_{50}Pt_{50}$ phase with a structure of alternative atomic planes of Hf and Pt along (0 0 1) plane normal of a bcc lattice is formed as indicated by the HfPt (1 1 0) peak. The formation of $Hf_{50}Pt_{50}$ phase consumes the Pt in the FePt layer, leading to phase change from FePt to Fe_3Pt. Additionally, superlattice peaks of FePt are not observed in the FePt/Hf films in the whole range of T_a due to the strong (1 1 1) orientation, which might be induced by the Hf underlayer.

In order to investigate the ordering process in FePt/Hf films, X-ray diffraction at χ=55°, at which the superlattice peaks of (0 0 1) and (0 0 2) of the (1 1 1)-textured films can be obtained. The results are shown in Fig. 2. $L1_0$(0 0 1) and $L1_0$(0 0 2) peaks clearly show in the sample with T_a=400 °C, confirming the onset of ordering. The order parameter (S_{ord}) represents the ordering of the $L1_0$ phase region obtained from the intensity of the (0 0 1) and (0 0 2) peak is 0.48. The intensity of the superlattice peaks as well as the value of S_{ord} increase with increasing T_a. At T_a=700 °C, the value of S_{ord} is about 0.81, which is slightly lower than that at T_a=600 °C (S_{ord}=0.85); a Fe_3Pt(2 0 0) peak appears embedded between the $L1_0$(0 0 1) and $L1_0$(0 0 2) peaks indicating the formation of a secondary phase. When T_a reaches 800 °C, $L1_0$ peaks are replaced by a weak $L1_2$(0 0 1) and Fe_3Pt(2 0 0), giving a small value of S_{ord} of less than 0.1.

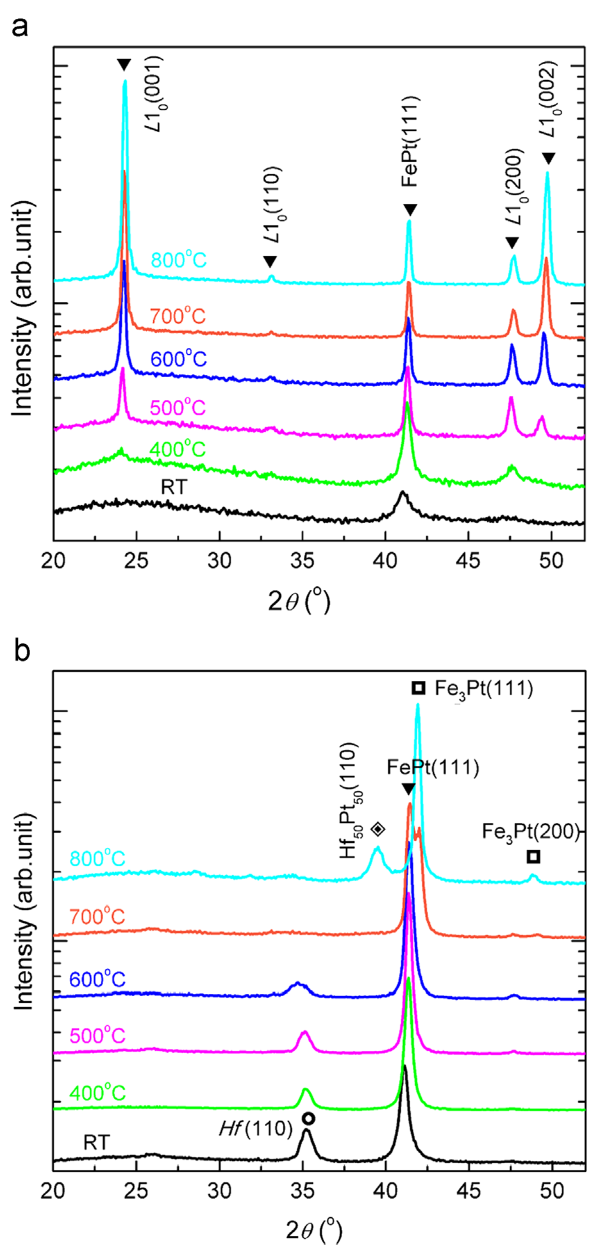

Fig. 1. XRD θ–2θ profiles of the (a) FePt and (b) FePt/Hf as-deposited and annealed films at T_a from 400 to 800 °C with heating rate of 5 °C/s.

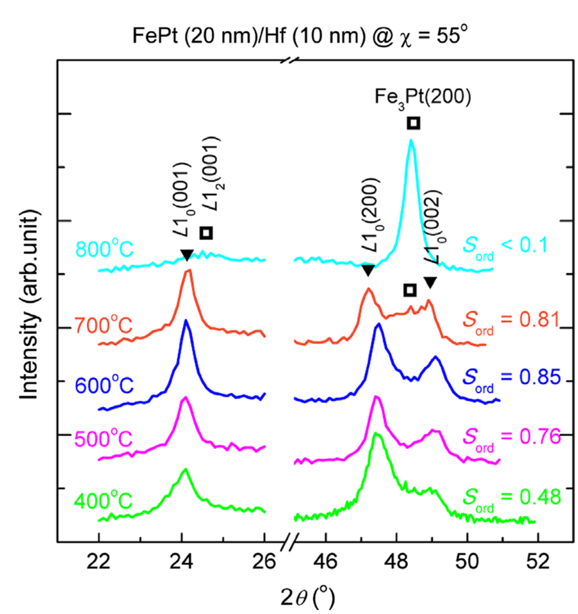

Fig. 2. XRD θ–2θ profiles of the FePt/Hf as-deposited and annealed films at T_a from 400 to 800 °C with heating rate of 5 °C/s obtained at χ=55°.