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Preventing dewetting during rapid-thermal annealing of FePt films with enhanced $L1_0$ ordering by introducing Ag cap-layers

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ABSTRACT

High-order FePt continuous films with a strong (001) texture were fabricated on a glass substrate by introducing Ag layers and rapid thermal annealing (RTA). The dewetting of the (001)-textured FePt was suppressed during RTA with high heating rates (> 80 K/s). The Ag cap layers not only increased the in-plane tensile stress, but also improved the (001) anisotropy and $L1_0$ ordering of the FePt layers. All continuous Ag/FePt bilayer films possessed strong perpendicular anisotropies and high-ordered states irrespective of the Ag layer thickness.

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1. Introduction

Because of the continuous growth of the areal recording density of magnetic recording media, development of media with a small bit size, and constant thermal stability and writability is required. A promising technique to overcome the addressed concerns is bit-patterned media (BPM) in which each bit is patterned into a separated island through lithography [1]. A strong perpendicular magnetic anisotropy (PMA) of a magnetic material is vital for attaining the thermal stability of those separated bits. $L1_0$ FePt phase is the most promising material because of its high magnetization and magnetocrystalline anisotropy energy. Attributed to the high magnetocrystalline anisotropy energy (7×10^7 erg/cm^3) $L1_0$ FePt exhibits a considerably small critical size (< 5 nm) against superparamagnetism [2]. To obtain a PMA of FePt films, the alignment of [001] easy axis perpendicular to film plane is of particular importance, since the direct growth of FePt films on amorphous substrates will generally lead to a (111) preferred orientation.

Rapid thermal annealing (RTA) is a mature technique used for manufacturing materials. Recently, it has been also applied to various magnetic materials, such as soft magnetic materials, spintronic devices, recording media and high energy density permanent magnets [3]. RTA has also been considered as a potential technique for the fabrication of (001) textured FePt films on amorphous substrates [4–13]. In our previous study, we demonstrated that a high heating rate can induce a strong tensile stress, which energetically favoring the grain growth of (001) [8]. However, a strong tensile strain induced by a high ramping rate and high temperature annealing may also cause the dewetting process of the (001) textured FePt continuous films [7,8,11,13]. Dewetting during RTA is an undesirable phenomenon for the practical application of BPM because patterning an island-like film into a dot array with equal volume is impossible. Nevertheless, few groups have reported the prevention of dewetting process by introducing FeO_x or SiO_2 caplayers [14,15]. Moreover, the oxide-based cap layers may cause the degradation of the $L1_0$ ordering of the FePt phase or to suppress the interlayer exchange coupling for writability in media application [14,15].

In this study, highly (001)-textured continuous FePt thin films were successfully fabricated on amorphous substrates by introducing metallic Ag cap layer. The Ag cap layer suppressed the dewetting process of the (001) FePt thin films during high-temperature RTA at 800 °C at a heating rate of more than 80 K/s. In addition, the $L1_0$ ordering and (001)-preferred orientation increased in the FePt/Ag bilayer films. For comparison, another series of single-layered FePt films were prepared and are discussed. In

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addition, the dependence of the cap layer thickness on $L1_0$ ordering and the magnetic properties of the FePt films is explored.

2. Experimental

All samples were prepared on Corning 1737 glass substrates through rf-magnetron sputtering with a background pressure of lower than 2×10^{-7} Torr. 10 nm-thick FePt layers were sputtered at room temperature using an $Fe_{50}Pt_{50}$ alloy target. The thickness of the Ag cap layers varied from 1 to 7 nm. The chemical composition of the FePt layers was determined at $Fe_{53}Pt_{47}$ (± 1 at%) by using inductive-coupled plasma. After film deposition, the samples were annealed by using RTA at 800 °C for 0 s. The heating rate was 20–110 K/s. The in-plane residual stress/strain of the samples was measured using the asymmetric $\sin^2\psi$ method (so-called $\cos^2\alpha \sin^2\psi$ method), where ψ is the angle between normal direction of sample and scattering vector, and α is defined as the Bragg angle at ψ=0 minus the grazing incidence angle γ [16]. In this study, γ was fixed at 3°. The method can effectively increase the diffraction volume, thus facilitating the examination of residual stress in thin films with a strong texture. X-ray beam energy of 8.0 keV was used for analyzes of residual stress, supported by beamline 17B, Taiwan Light Source. Detailed experimental procedures of stress measurements can be found elsewhere [17]. The crystallographic structure of the samples was determined using X-ray diffractometry (XRD) with in-house Cu K_α source (18 kW) and Bragg–Brentano geometry. The thickness of the FePt films was confirmed to be 10 nm ± 1 nm using X-ray reflectivity. The surface morphology of the films was observed using field-emission scanning electron microscopy (FE-SEM). The surface element status of the films was studied using X-ray photoelectron spectroscopy (XPS) with a synchro tron radiation source at beamline 24A, Taiwan Light Source. The XPS binding energy was referenced to the bulk Au $4f_{7/2}$ line with binding energy of 84.00 eV. The magnetic properties of the films were measured at room temperature using a vibrating sample magnetometer (VSM). To approach the magnetically saturated state of the FePt phase, the samples were magnetized with a pulse field of ~70 kOe in prior to VSM measurements.

3. Results and discussion

To demonstrate that the effect of the Ag cap layer can influence the surface morphology and crystallographic re-orientation of the FePt layers, the following samples were annealed at high temperature 800 °C. Fig. 1(a) shows the plot of residual stresses (σ) of the annealed FePt and Ag (1 nm)/FePt films versus the heating rate. For the single-layered FePt films annealed at a heating rate of 0.5–40 K/s, σ dramatically increases from 0.98 to 2.37 GPa, and then decreases to 1.43 GPa at a heating rate of 110 K/s. A similar tendency was observed for Ag/FePt bilayer films. A maximum σ value of 2.58 GPa was obtained for the Ag/FePt films annealed at 40 K/s. As the heating rate was further increased to 110 K/s, σ value gradually decreased to 2.25 GPa. Fig. 1(b) displays the XRD patterns of the FePt and Ag/FePt films annealed at 800 °C at different heating rates. The intensity axis for each scan is plotted on a logarithmic scale and shifted for clarity. The $L1_0$ ordered phase was formed in the annealed samples because of the appearance of the (001) superlattice peak. The intensities of the superlattice (001) of the bilayer films were higher than those of the FePt samples, except for the samples annealed at a heating rate of 40 K/s. This implies that the (001) texture of the FePt grains was promoted with the deposition of the Ag cap layer. Moreover, ordering parameter S was estimated using the integrated intensities of (001) and (002) reflections and further corrected using several factors, as proposed by Warren [18]. The dependence of S values for the FePt and Ag/FePt films on heating rate is shown in Fig. 1(c). The S value for the FePt films annealed at 20 K/s was approximately 0.75. When the heating rate was increased from 20 to 110 K/s, completely ordered $L1_0$ FePt phase was formed. When Ag cap layer was deposited, an increase in ordering was observed for the bilayer films annealed at 20 K/s. To further examine the extent

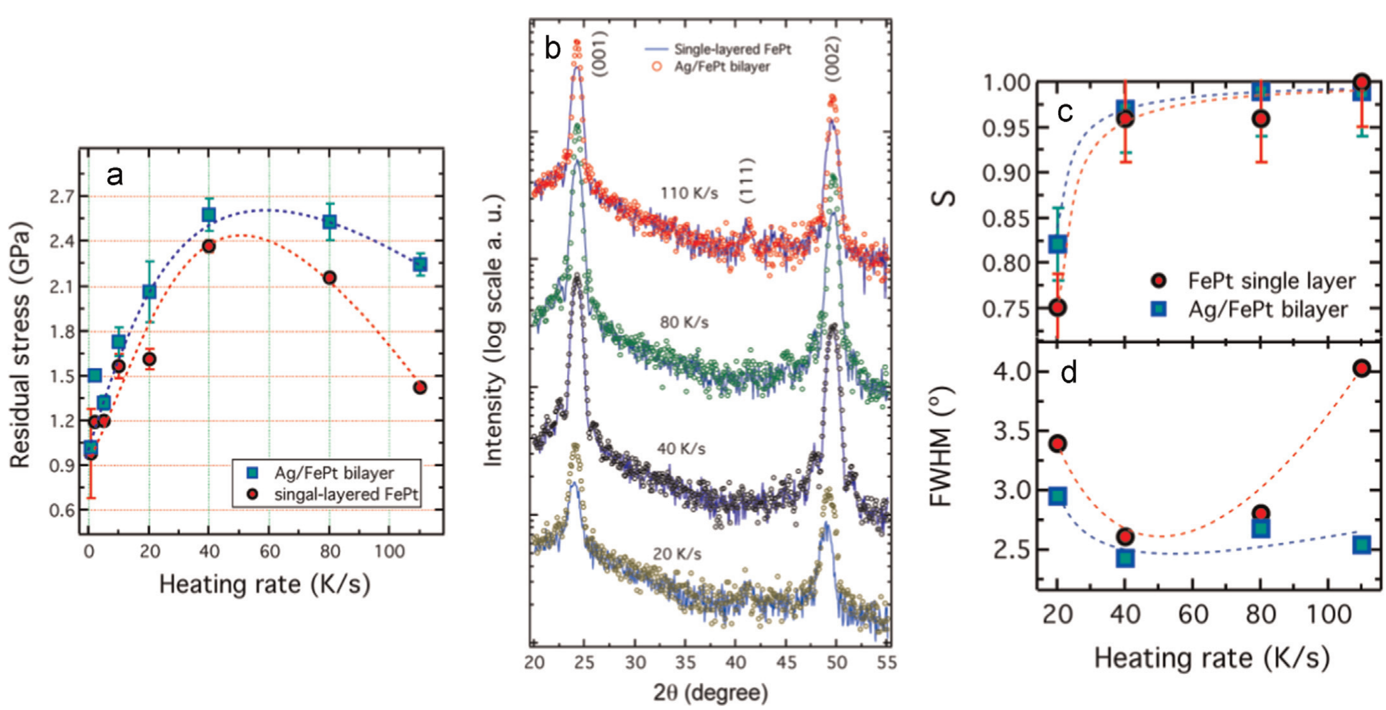

Fig. 1. (a) Residual stress as a function of the heating rate for the single-layered FePt films (circle) and Ag/FePt bilayer films (square). (b) X-ray diffraction patterns for the annealed FePt films (line) and Ag/FePt films (open symbol) with different heating rates. Dependence of (c) ordering parameter and (d) FWHM of the (001) reflection of the single-layered FePt films (circle) and Ag/FePt bilayer films (square) on the heating rate.

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