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Thickness limit in perpendicular magnetic anisotropy $L1_0$ FePt(0 0 1) thin film

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Abstract

Perpendicular magnetic anisotropy $L1_0$ FePt (0 0 1) films with various thicknesses were prepared onto Pt(0 0 1)/Cr(0 0 2) bilayers. When the thickness of FePt layer was smaller than 30 nm, a single orientation of $L1_0$ FePt(0 0 1) texture was present, confirming that the easy axis was perpendicular to the film plane. But as the thickness increased over 30 nm along with the $L1_0$ FePt(0 0 1) orientation, the peak corresponding to $L1_0$ FePt (1 1 1) orientation was also observed, which indicated the quality degradation of perpendicular magnetic anisotropy. From our study, the critical thickness for growing perfect $L1_0$ FePt(0 0 1) single orientation is around 30 nm.

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Keywords: Magnetic anisotropy; $L1_0$ ordered structure; Magnetic recording; Thickness effect; Epitaxial growth

In order to increase the magnetic recording density to 1 Tb/in^2, perpendicular magnetic recording is believed to be one of the potential technologies to replace the current longitudinal magnetic recording in the near future. It is because, the volume of the recording bit in the perpendicular magnetic recording medium can be maintained well by increasing the medium thickness when the surface area of the recording bit is reduced [1]. However, it is still a question whether the film thickness of the perpendicular magnetic layer could be unlimitedly increased as the surface area of the recording bit is largely reduced. So far, most investigations focused on the processes to induce perpendicular magnetic anisotropy [2,3]. The thickness effects on perpendicular magnetic properties were seldom discussed in the past. Hence, it is important to understand how film thickness affects the magnetic properties and microstructures in perpendicular magnetic recording media. In this investigation, the $L1_0$ FePt (0 0 1)-thin films were employed to determine the thickness effects on the magnetic properties and microstructures. The mechanism of the thickness limitation on the recording layer was also examined.

$Fe_{48}Pt_{52}(t)$/Pt(3 nm)/Cr(70 nm) trilayer films ($t = 10$–50 nm) were prepared on preheated 7059 glass substrate by conventional DC magnetron sputtering in a ultra-high vacuum sputtering system. The substrate was heated to 350 and 420 °C for depositing the Pt/Cr bilayer and FePt magnetic layer, respectively. Magnetic properties were measured by a vibrating sample magnetometer (VSM) at room temperature with a maximum applied field of 1.2 T. The crystal structure and cross-sectional microstructures of the films were investigated by X-ray diffraction (XRD) using Cu-K_α radiation and high-resolution transmission electron microscopy (HRTEM).

Fig. 1 displayed the *M–H* loops of the FePt/Pt/Cr trilayer films with different thickness. The out-of-plane coercivity ($H_{c\perp}$) was increased from 2.5 to 5 kOe as t increases from 10 to 30 nm. Then it declined to 3.5 kOe as t was further increased to 50 nm. The out-of-plane squareness ($S_\perp$) ≈ 1 when $t \leqslant 30$ nm. $S_\perp$ was reduced as t was larger than 30 nm. However, the in-plane coercivity ($H_{c\parallel}$) and squareness ($S_\parallel$) were always increasing with the thickness of the FePt layer. The perpendicular magnetic

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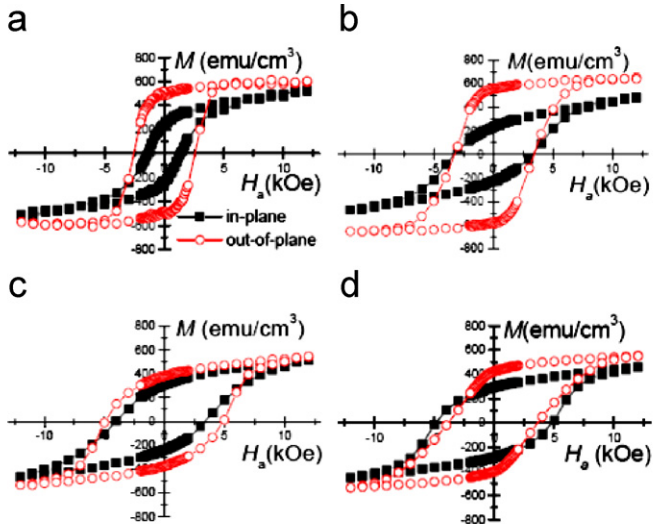

Fig. 1. M–H loops of the FePt/Pt/Cr trilayer films, where the thickness of FePt films were (a) 10 nm, (b) 20 nm, (c) 30 nm and (d) 50 nm.

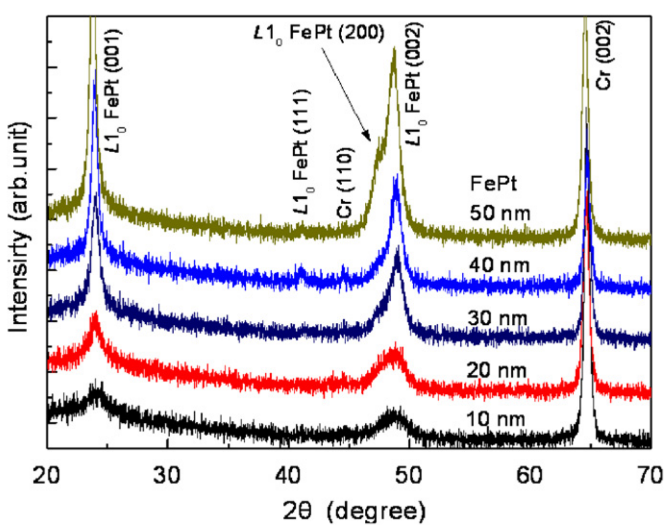

Fig. 2. X-ray diffraction patterns of FePt/Pt/Cr trilayer films with various thickness of the FePt magnetic layer.

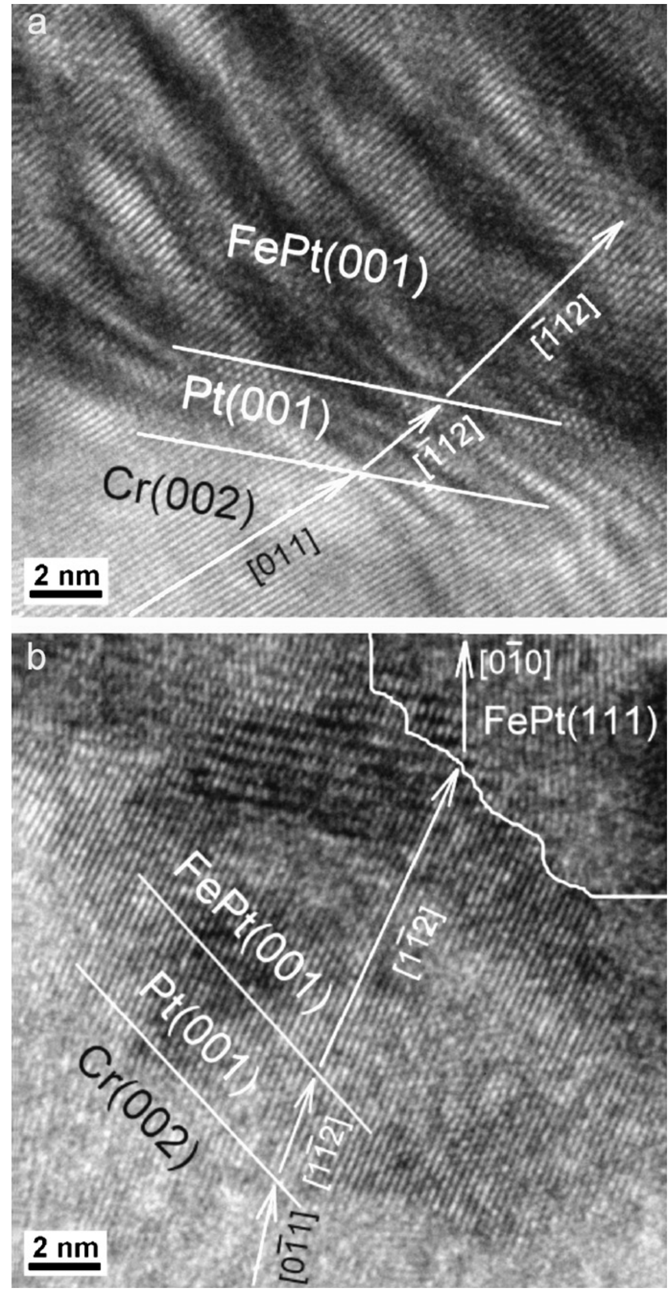

Fig. 3. Cross-sectional HRTEM images of FePt/Pt/Cr trilayer film. The thicknesses of the FePt layer were (a) 30 nm and (b) 50 nm.

anisotropy of the film deteriorated gradually as $t > 30$ nm, and eventually $H_{c\parallel}$ was found to be higher than $H_{c\perp}$ when $t = 50$ nm.

Fig. 2 shows the XRD patterns of FePt/Pt/Cr trilayer films. The $L1_0$ FePt(0 0 1) texture was found when $t \leqslant 30$ nm, indicating that the magnetic easy axis of the $L1_0$ FePt layer was perpendicular to the film plane. As t exceeded 30 nm, a small $L1_0$ FePt(1 1 1) peak appeared, revealing that the perpendicular magnetic anisotropy of FePt film began to be destroyed. It suggests that the critical thickness for growing perfect $L1_0$ FePt(0 0 1) orientation is around 30 nm.

The cross-sectional HRTEM images of FePt/Pt/Cr trilayer films are shown in Fig. 3, where the thicknesses of the FePt layer were (a) 30 nm and (b) 50 nm. As shown in Fig. 3(a), the epitaxial directions in the FePt/Pt/Cr trilayer films started with [0 1 1] in the Cr underlayer and ended with [$\bar{1}$ 1 2] in the FePt layer. There was only one [$\bar{1}$ 1 2] direction in the FePt layer, indicating that a well epitaxial FePt(0 0 1) growth established in the whole FePt layer. In contrast as in Fig. 3(b) with $t = 50$ nm, the [1 $\bar{1}$ 2] was not the only observed epitaxial direction in the FePt layer. The arrow apparently switched from [1 $\bar{1}$ 2] to [0 $\bar{1}$ 0], revealing that two orientations (0 0 1) and (1 1 1) were present in the FePt layer. Therefore, the epitaxial growth of FePt(0 0 1) cannot last over a long distance in thicker FePt films. When the FePt was epitaxially grown on the Pt lattice, both the in-plane a- and b-axis of FePt(0 0 1) was expanded by the Pt(0 0 1) plane. This is because the lattice constant of Pt(0 0 1) is 3.92 Å and is slightly larger than 3.86 Å of FePt(0 0 1). An increase in the elastic strain energy exists at the FePt(0 0 1)/Pt(0 0 1) interface and thus affects the formation of FePt(0 0 1). As the FePt layer was thinner than 30 nm, the $L1_0$ FePt(0 0 1) formed due to the effect of elastic strain energy in the FePt lattice. For the thicker FePt layer, the elastic strain energy effect from the Pt (0 0 1) lattice was substantially reduced and the FePt (1 1 1) plane formed [4].

In summary, the effects of FePt film thickness on the $L1_0$ FePt(0 0 1) orientation and the magnetic properties of the films were investigated. The $L1_0$ FePt(0 0 1) texture with perpendicular magnetic anisotropy was found as the thickness of the FePt layer was smaller than 30 nm. When the FePt film thickness was larger than 30 nm, the orientation switched from FePt (0 0 1) to FePt (1 1 1), leading to the degradation of the perpendicular magnetic anisotropy. The upper limit of the magnetic FePt layer thickness with good perpendicular anisotropic behavior was determined to be about 30 nm.

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