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Effect of the underlayer (Ag, Ti or Bi) on the magnetic properties of Fe/Pt multilayer films

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Abstract

Fe/Pt multilayer films with an Ag, Ti or Bi underlayer were prepared by magnetron sputtering and effect of the underlayer on the magnetic properties of annealed Fe/Pt multilayer films was also investigated. Our results demonstrate that Ag underlayer has little effect on the in-plane coercivity H_c of the Fe/Pt multilayer film due to the formation of Ag and $L1_0$-FePt phases in the films. The H_c of Ti/$[Fe/Pt]_{13}$ film keeps on rising with the increasing annealing temperature T_a up to 500 °C and then decreases with the further increasing T_a. The reason should be attributed to the formation of some intermetallic compounds between Ti and Fe; Pt at a high T_a which is harmful to the structure of $L1_0$-FePt. The H_c of $[Fe/Pt]_{13}$ films is enhanced by the Bi underlayer, which can be understood by considering the promotion of the $L1_0$-FePt phase by Bi diffusion.

Keywords: $L1_0$-FePt thin films; Ordering temperature; Underlayer; Multilayer structure; Coercivity

1. Introduction

Recently, due to the large uniaxial magnetocrystalline anisotropy (7×10^6 J/m^3) [1,2] of the ordered $L1_0$-FePt alloy, FePt thin films have drawn considerable attention as a potential candidate for ultrahigh density recording media. The FePt thin film deposited at the room temperature has a disordered and face-centered cubic (fcc) structure which shows a soft magnetic behavior. Thus, it is necessary to deposit the film on a heated substrate or anneal it after deposition usually above 500 °C [3] to obtain an ordered and face-centered-tetragonal (fct) structure showing hard magnetic performance. But this high temperature process results in the undesirable large grain size and surface roughness which are drawbacks for improving the areal density. So how to reduce the ordering temperature of the FePt film and achieve a high coercivity are urgent problems [4].

Recently, several attempts have been made to lower the ordering temperature with the introduction of underlayers, such as Ag, Ti, Ta and AuCu [5–9]. Endo et al. [5] achieved the low-temperature ordering of FePt film at 300 °C with the introduction of Fe/Pt multilayer structure, but the coercivity of films was not high enough. Hsu et al. [6] found that an Ag underlayer was beneficial for reducing the ordering temperature of FePt films, and Chen et al. [7] reported that a Ti underlayer enhanced the coercivity of FePt films and obtained fine FePt grains. Our previous work [10] showed that Bi underlayer can accelerate ordering process of FePt films. But until now, the systematic research works on effect of Ag, Ti or Bi underlayer on Fe/Pt multilayer films are scarcely reported. In this paper, the $L1_0$-FePt films with Fe/Pt multilayer structure and an Ag, Ti or Bi underlayer simultaneously were prepared. Effect of the underlayer on the magnetic properties of annealed Fe/Pt multilayer films was investigated.

2. Experimental details

All films were prepared by a magnetron sputtering system with a base pressure of 5×10^{-5} Pa. Endo et al. [5] reported that the Fe/Pt multilayers films showed the highest coercivity when Fe and Pt layer have equal thickness. So, in this paper, the films with the structure of Ag, Ti or Bi (40 nm)/[Fe(1.5 nm)/Pt (1.5 nm)]$_{13}$ and [Fe(1.5 nm)/Pt(1.5 nm)]$_{13}$ were deposited on glass substrates by magnetron sputtering Ag, Ti, Bi, Fe and Pt

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targets with high purity (99.99%). The composition of FePt in all films was measured to be about $Fe_{48}Pt_{52}$ by inductively coupled plasma atomic emission spectrometer with the error less than 1%. To conveniently compare with above Fe/Pt multilayer films, FePt (40 nm) films with composition of $Fe_{48}Pt_{52}$ were deposited on glass at the same condition. All films were grown on 250 °C heated clean glass substrates. Ar pressure was kept at 0.45 Pa during sputtering. The as-deposited films were annealed at the temperature of 300–550 °C in a vacuum of 3×10^{-5} Pa for 20 min. Magnetic properties were measured using an alternating gradient field magnetometer (AGM Micromag2900) with an applied in-plane field up to 1432 kA/m. The crystal structures of all films were identified by a MXT21VAHF X-ray diffractometer (XRD) using Cu–Kα radiation (40 kV×200 mA) and a graphite monochromator using a continuous scanning mode with rate of 8° (2θ)/min. The chemical status of surface elements was studied using X-ray photoelectron spectroscopy (XPS). An Mg K_α radiation was used with the X-ray source running at 14.5 kV. The energy analyzer was operated at constant pass energy of 50 eV. The XPS detectable depth $d=3\lambda \sin \alpha$, where λ and α are respectively inelastic mean-free paths (IMFPs) for photoelectrons and a take off angle for photoelectrons with respect to the samples surface plane [11]. For an Mg K_α radiation source, the IMFPs for Bi 4f in Bi are about 2.15 nm. So the detectable depth d of Bi atoms is 6.45 nm when $\alpha=90°$.

3. Results and discussion

Fig. 1 shows the dependence of the in-plane coercivity H_c for FePt (40 nm) and [Fe (1.5 nm)/Pt (1.5 nm)]$_{13}$ films on annealing temperature T_a. T_a ranges from 300 to 550 °C, and the annealing time is 20 min. It has been reported that the H_c of a FePt film is mainly affected with its ordering degree [12]. From Fig. 1, a T_a around 500 °C is required for realizing a high H_c=437.8 kA/m for the FePt film. On the other hand, T_a=350 °C is high enough for the [Fe/Pt]$_{13}$ film to remarkably increase H_c to 421.9 kA/m. Moreover, the H_c of [Fe/Pt]$_{13}$ films

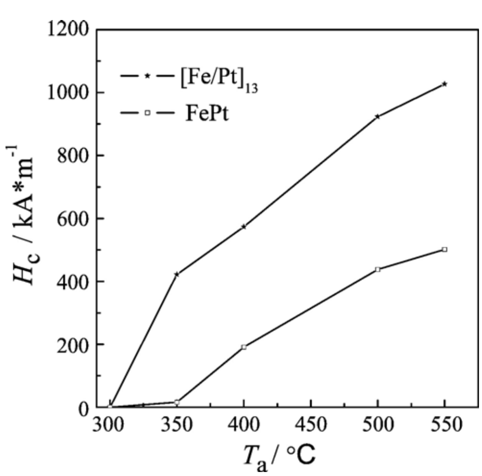

Fig. 1. The dependence of the in-plane coercivity H_c for FePt (40 nm) and [Fe (1.5 nm)/Pt (1.5 nm)]$_{13}$ films on annealing temperature T_a for 20 min. T_a ranges from 300 to 550 °C.

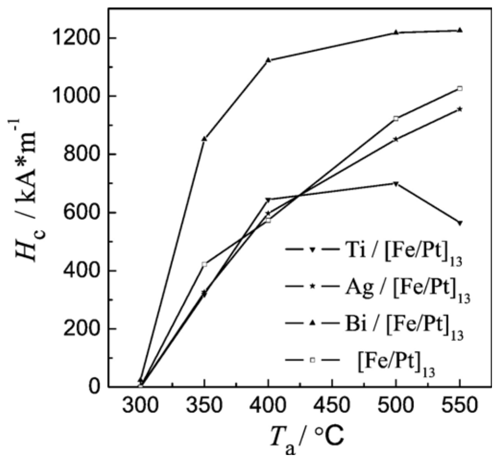

Fig. 2. The variation of H_c for Ag, Ti or Bi (40 nm)/[Fe (1.5 nm)/Pt (1.5 nm)]$_{13}$ and [Fe (1.5 nm)/Pt (1.5 nm)]$_{13}$ films with T_a for 20 min. T_a ranges from 300 to 550 °C.

is far larger than that of the FePt film at the same T_a. In other words, the low-temperature ordering $L1_0$-FePt films with enhanced coercivity have been achieved by introduction of Fe/Pt multilayer structure. As reported by Endo et al. [5], the structure of Fe/Pt multilayer structure offers an extra driven force—interfacial energy. So the appreciable reduction of ordering temperature is correlated with rapid diffusion at the interface of Fe/Pt, and subsequently the faster corruption of the multilayer structure which leads to form the better ordered $L1_0$-FePt phase and the enhanced H_c of films. So it was based on [Fe/Pt]$_{13}$ film that effect of underlayer on magnetic performance was studied below.

Fig. 2 shows the variation of H_c for Ag, Ti or Bi (40 nm)/[Fe (1.5 nm)/Pt (1.5 nm)]$_{13}$ and [Fe (1.5 nm)/Pt (1.5 nm)]$_{13}$ films with T_a. T_a ranges from 300 to 550 °C, and the annealing time is 20 min. As shown in the figure, the H_c of Ag, Ti or Bi/[Fe/Pt]$_{13}$ greatly increases beyond 319.4 kA/m at T_a=350 °C, implying Ag, Ti or Bi underlayer cannot further decrease the ordering temperature of [Fe/Pt]$_{13}$ film (350 °C). Compared with [Fe/Pt]$_{13}$ films without any underlayer, Ag underlayer scarcely affects H_c of films. The H_c of Ti/[Fe/Pt]$_{13}$ film keeps on rising with raising annealing temperature T_a up to 500 °C and declines by further increasing T_a. But the H_c of films is enhanced by Bi underlayer.

In order to study the reason for the influences of those underlayers on magnetic performance, we carefully explored the structural change for the Fe/Pt multilayer films with Ag, Ti and Bi underlayers depending on T_a. The XRD patterns are demonstrated in Fig. 3 (a)–(c). The ordering parameter S [5] can be cited to quantitatively describe the ordering process. Fig. 3 (d) shows the variation of c/a ratio of FePt lattice with T_a. The c/a ratio of all the films is round 1 at T_a=300 °C, indicating that the FePt lattice is still remaining unity. It is clearly see that the $L1_0$-FePt superlattice diffraction (001) and (110) peaks appear in the XRD patterns for all films and the c/a ratio decreases below 0.99, suggesting the formation of the FePt lattice with tetragonality and the ordering temperature of Ag, Ti or Bi/[Fe/Pt]$_{13}$ films are 350 °C. As to Ag/[Fe/Pt]$_{13}$ film, all $L1_0$-FePt superlattice peaks become stronger and the c/a ratio declines