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Perpendicular magnetic anisotropy in $Ta/Pd/Co_2FeAl_{0.5}Si_{0.5}/MgO/Ta$ structured films

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ABSTRACT

In this work, the perpendicular magnetic anisotropy (PMA) was realized in $Ta/Pd/Co_2FeAl_{0.5}Si_{0.5}/MgO/Ta$ films, but not observed in $Ta/Pd/Co_2FeAl_{0.5}Si_{0.5}/Ta$ films without MgO cap layer. A strong PMA had been achieved for a thick $Co_2FeAl_{0.5}Si_{0.5}$ layer about 4.8 nm at the annealing temperature of 300 °C. Inserted Pd layer between Ta and $Co_2FeAl_{0.5}Si_{0.5}$ layers was crucial to obtain PMA in $Ta/Pd/Co_2FeAl_{0.5}Si_{0.5}/MgO/Ta$ structured films. However, the thickness of inserted Pd layer has no significant effect on the value (K_{eff}) of PMA. The films annealed at 300 °C remain a similar K_{eff} of around 1.23×10^6 erg/cm^3 while the inserted Pd layer is beyond a critical thickness.

1. Introduction

Nowadays, the current induced magnetization switching (CIMS) is a very promising technique which could be applied in the magnetic random access memory (MRAM). Reducing the critical current of magnetic reversal and enhancing the thermal stability are two of key issues for the MRAM applications. The perpendicular magnetic anisotropy (PMA) and high spin polarization of the ferromagnetic layer are theoretically predicted and experimentally verified to be useful for solving the issues [1–4]. Very high MR ratio has been reported in the systems with the Heusler alloy $Co_2FeAl_{0.5}Si_{0.5}$ (hereinafter referred to as CFAS) and a very high spin polarization has been demonstrated at room temperature too [5–7]. Therefore, the works on PMA of CFAS materials with the high spin polarizations are of significance for the scientific understanding and promising applications.

Moreover, many works on CoFeB alloys have indicated that the thickness of ferromagnetic layer and the heat treatment are two critical factors to influence PMA [8,9]. It was found that the underlayers of CoFeB layer's growth critically affect the interfacial PMA in CoFeB/MgO structures, which were explained with the decrease of the saturation magnetization of ferromagnetic layer, alloying with noble metals (Pt or Pd) or amorphous structure of the underlayer [10,11]. However, there are no many such works performed on CFAS alloy although CFAS possesses the different structural transformation and high spin polarization [12]. In this work, the effect of inserted Pd layer under CFAS layer on PMA was investigated. The dependence of PMA on annealing temperature and CFAS layer thickness was studied in detail.

2. Experimental

Three sets of samples were prepared as follows: Si/Ta (8 nm)/Pd (5 nm)/CFAS (t_{CFAS} nm)/MgO (2 nm)/Ta (5 nm) (t_{CFAS}=2.4–5.3) (hereinafter refer to Ta/Pd/CFAS (t_{CFAS})/MgO/Ta), Si/Ta (8 nm)/Pd (5 nm)/CFAS (50 nm)/Ta (5 nm) (hereinafter refer to Ta/Pd/CFAS (50 nm)/Ta), and Si/Ta (8 nm)/Pd (t_{Pd} nm)/CFAS (3.2 nm)/MgO (2 nm)/Ta (5 nm) (t_{Pd}=0–10) (hereinafter refer to Ta/Pd (t_{Pd})/CFAS/MgO/Ta). All films above were deposited on the Si substrates by magnetron sputtering system under a base pressure better than 3×10^{-5} Pa at room temperature. The metal layer Ta and inserted Pd layer were deposited under Ar pressure of 0.6 Pa with the DC power of 25 W and 50 W, respectively. The ferromagnetic CFAS layer was deposited with the DC power of 40 W and the Ar pressure of 0.3 Pa using the high purity $Co_2FeAl_{0.5}Si_{0.5}$ target. The MgO layer was grown with the RF power of 150 W and the pressure of 0.2 Pa using the MgO targets (99.9% purity).

Annealing process was carried out at temperatures varying from 200 °C to 450 °C for 30 min under a vacuum chamber below 10^{-4} Pa. Vibrating sample magnetometer (VSM: Lakeshore 7404) was used to characterize the magnetic properties. The surface morphology of buffer layer was checked by atomic force microscopy (AFM: Dimension Icon). The multilayer crystalline structure was examined by X-ray diffractions (XRD-7000, Shimadzu Limit.) and transmission electron microscopy (TEM: JEM-3010).

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3. Results and discussion

Fig. 1 shows the magnetic hysteresis loops measured along the in-plane and out-of-plane directions as a function of annealing temperature for Ta /Pd/CFAS (3.2 nm)/MgO/Ta film. The as-deposited sample exhibits isotropic magnetic anisotropy. Magnetic anisotropy did not change after annealing at a low temperature of 200 °C. With further increasing the annealing temperature, a strong PMA appeared as shown in Fig. 1(c, d). The out-of-plane loop presents a good square shape for the sample annealed at 300 °C. After further increasing the annealing temperature, the magnetic anisotropy shifts away from PMA to isotropic magnetic anisotropy or weak in-plane magnetic anisotropy, as shown in Fig. 1(e, f) annealed at 400 °C and 450 °C. The saturation magnetization of films was first enhanced and then kept a relative stable value about 780 emu/cm^3 within the range of annealing temperatures.

As shown above, the good PMA was realized at the annealing temperature of 300 °C. A model stack of Ta/Pd/CFAS (50 nm)/Ta with a thick CFAS was fabricated and annealed at 300 °C for better characterizations of XRD and TEM. As shown in Fig. 2, XRD pattern of annealed Ta/Pd/CFAS (50 nm)/Ta film presents three typical diffraction peaks corresponding to CFAS (200), (220), (400), respectively. The diffraction peak of (200) indicates that CFAS grains are formed with *B2* structure. The crystalline of CFAS was further confirmed by the selected area electron diffraction (SAED) pattern (as shown in the inset of Fig. 2), in which the diffraction ring of CFAS (200) appears implying a *B2* structure in consistent with XRD results.

Regarding the effective anisotropy of films, the bulk and interface effects are all contributing to the magnetic anisotropy of films, which can be described by the phenomenological relation of $K_{eff} \times t_{CFAS} = (K_V - 2\pi M_S^2) \times t_{CFAS} + K_S$, where K_{eff} represents the effective magnetic anisotropy of the magnetic thin film, K_V is the bulk magnetic anisotropy, K_S describes the interface anisotropy and t_{CFAS} means the thickness of ferromagnetic CFAS layer [13]. The effective magnetic anisotropy energy (K_{eff}) is the signal of the PMA, which was determined based on the difference of magnetization energy from hard and easy magnetic orientation in the *M–H* loops.

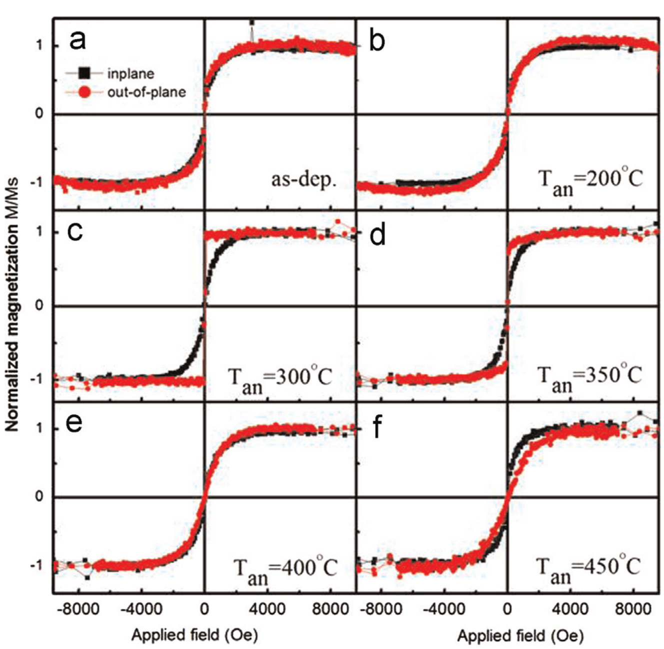

Fig. 1. In-plane and out-of-plane *M–H* loops for Ta/Pd/CFAS (3.2 nm)/MgO/Ta films annealed at temperatures ranging from 200 °C to 450 °C. For a better guide of eye, the magnetization was normalized by the saturation magnetization.

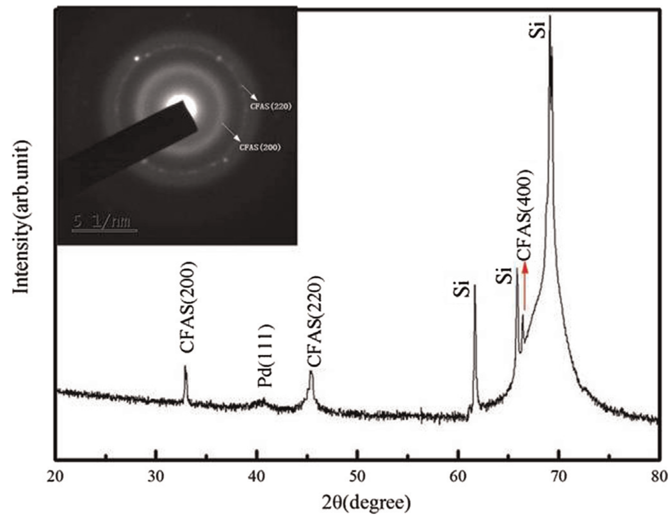

Fig. 2. XRD pattern of Ta/Pd/CFAS (50 nm)/Ta film annealed at 300 °C; the inset is SAED pattern.

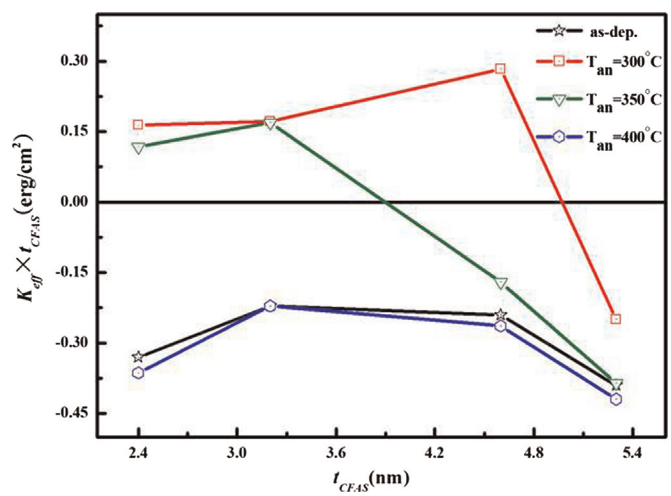

Fig. 3. CFAS layer thickness dependence of the product of $K_{eff} \times t_{CFAS}$ for Ta/Pd/CFAS (t_{CFAS})/MgO/Ta films annealed at the different temperatures.

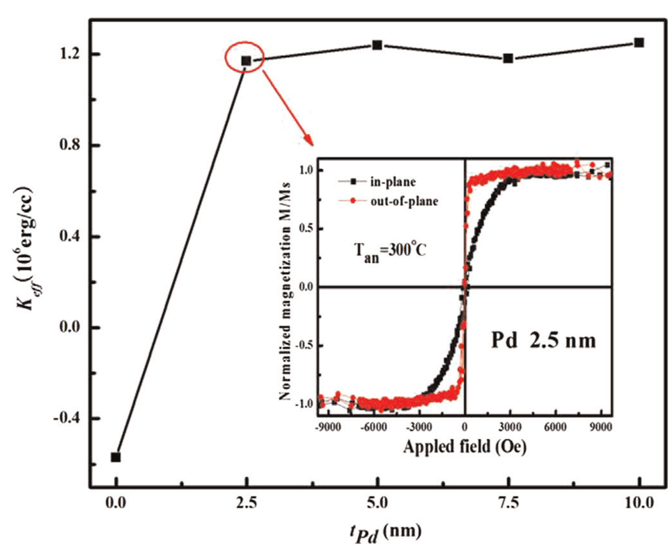

Fig. 4. The effective anisotropy constant (K_{eff}) dependence of the inserted Pd layer thickness (t_{Pd}) for Ta/Pd (t_{Pd})/CFAS/MgO/Ta films annealed at 300 °C; the inset is in-plane and out-of-plane *M–H* loops with t_{Pd}=2.5 nm. For a better guide of eye, the magnetization was normalized by the saturation magnetization.