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The effect of Os interlayers on the thermal stability of magnetic CoFe/OsMn films

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Abstract

The thermal stability of a multilayer structure of protection layer/$Co_{90}Fe_{10}$/Os (d nm)/$Os_{20}Mn_{80}$ has been studied as functions of annealing temperature (T_{an}) and thickness of Osmium (Os) layer. The insertion of a thin Os layer between the $Co_{90}Fe_{10}/Os_{20}Mn_{80}$ interface shows better thermal stability. No diffusion evidence was found for samples with $d \geqq 0.3$ nm as examined by Auger electron spectroscopy depth profile at different annealing temperatures up to 400 °C. These samples with Os layer showed the same magnetic behavior and the hysteresis loop with squareness (S) larger than 0.9 were observed before and after annealing.

Keywords: Thermal stability; Os interlayer; Mn diffusion; CoFe/Os/OsMn; CoFe/Os/IrMn

1. Introduction

The development of the high-performance magnetic devices has draw attention in recent years. One of the important factors for this is the increment of thermal stability, especially the magnetic element used in magnetic random access memory (MRAM), magnetic pickup head, sensor, etc. The magnetic behavior is very sensitive to chemical composition, interface and structure, and therefore, interdiffusion due to heat treatment may cause problems. Many Mn-metal alloys used as antiferromagnetic layer in magnetic device have been extensively studied [1–3]; however, the Mn atom causes interdiffusion problem to degrade the overall performance [4,5]. It was reported that the doping of Osmium (Os) may block the Mn diffusion channel up to 400 °C [6]. These motivated us to study the thermal stability of magnetic multilayer with insertion of Os layer and how does the Os layer play the role on preventing Mn atoms from diffusing. Results of the study may suggest a better way to enhance the thermal stability in magnetic devices.

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2. Experiment

The magnetic multilayer of protection layer/$Co_{90}Fe_{10}$/Os (d)/$Os_{20}Mn_{80}$ were RF-magnetron sputtered on SiO_2/Si (1 0 0) substrate with an in-plane magnetic field of 200 Oe during the growth. The thickness of the CoFe and OsMn were fixed at 10 and 20 nm, respectively. The thickness of the Os layer, d, was varied from 0 to 2 nm. It is also important to prevent the specimen from oxidation during annealing by protection layer. After the growth, these samples were ex-situ vacuum annealed for 30 min at different temperatures (T_{an}) with a stronger applied field of 1 kOe along the easy axis. The structure of the samples was examined by X-ray diffraction (XRD), while the magnetic hysteresis properties were measured by magnetic optical kerr effect (MOKE) and vibrating sample magnetometer (VSM). Auger electron spectroscopy (AES) depth profile was used to detect composition distribution along the surface normal.

3. Results and discussion

The AES depth profile results of $Co_{90}Fe_{10}$/Os(0, 1 nm)/$Os_{20}Mn_{80}$ of the as-grown and $T_{an} = 300$ °C are shown in

Fig. 1. Clearly all films were stable at room temperature (Fig. 1(a) and (c)). Without the Os interlayer, Mn migrates into the top layer at $T_{an} = 300\,^{\circ}C$, and also a small amount of Co moves downward as shown in Fig. 1 (b). Fortunately, 1 nm layer of Os is thick enough to stop the diffusion of Mn and Co up to 300 °C (as seen from Fig. 1(c) and (d)), and this is also confirmed by the MOKE and VSM measurements that no difference in the magnetic hysteresis loops before and after annealing. Once Mn is mixed up with $Co_{90}Fe_{10}$ layer (like Fig. 1(b)), the coercivity (H_C) and squareness (S) are found to be changed abruptly as shown in the insertion picture in Fig. 2. The insertion of 2 and 1 nm Os layer did not cause so much difference in the Auger depth profile signal; however, there are little increases in H_C and little decrease in S for the 2 nm Os inserted samples as shown in Fig. 2. The diffusion of Mn into the ferromagnetic layer also causes the reduction of S. All as-grown samples have rather square hysteresis loop. The S of the non-Os sample at $T_{an} = 400\,^{\circ}C$ is reduced to 0.25. Even no interdiffusion evidence were found for sample with either 1 nm or 2 nm Os layers; however, S is slightly reduced from 0.96 at $T_{an} = 400\,^{\circ}C$ to 0.75 at $T_{an} = 440\,^{\circ}C$. This could be due to our Auger system that the chemical information is too small to detect.

It was also told from the XRD analysis that our samples with $Os_{20}Mn_{80}$ layer does not show γ-phase which exhibited FM/AFM exchange coupling as reported by Ref. [6], however, our sample's properties do agree with Ref [7,8].

The Os interlayer thickness dependences of S and normalized H_C for 400 °C annealed samples are shown in Fig. 3. Samples with Os interlayer retained their $S > 0.9$ even though the Os thickness is as thin as 0.3 nm. The H_C increased after annealing until Os being added also indicated the improvement on thermal stability. The normalized H_C, which was defined as $H_C\ (T_{an})/H_C$ (as-grown), was used to ignore the area difference between samples. The normalized H_C of annealed sample without Os became near 4 times larger than that of as-deposited state, while the normalized H_C for the annealed sample

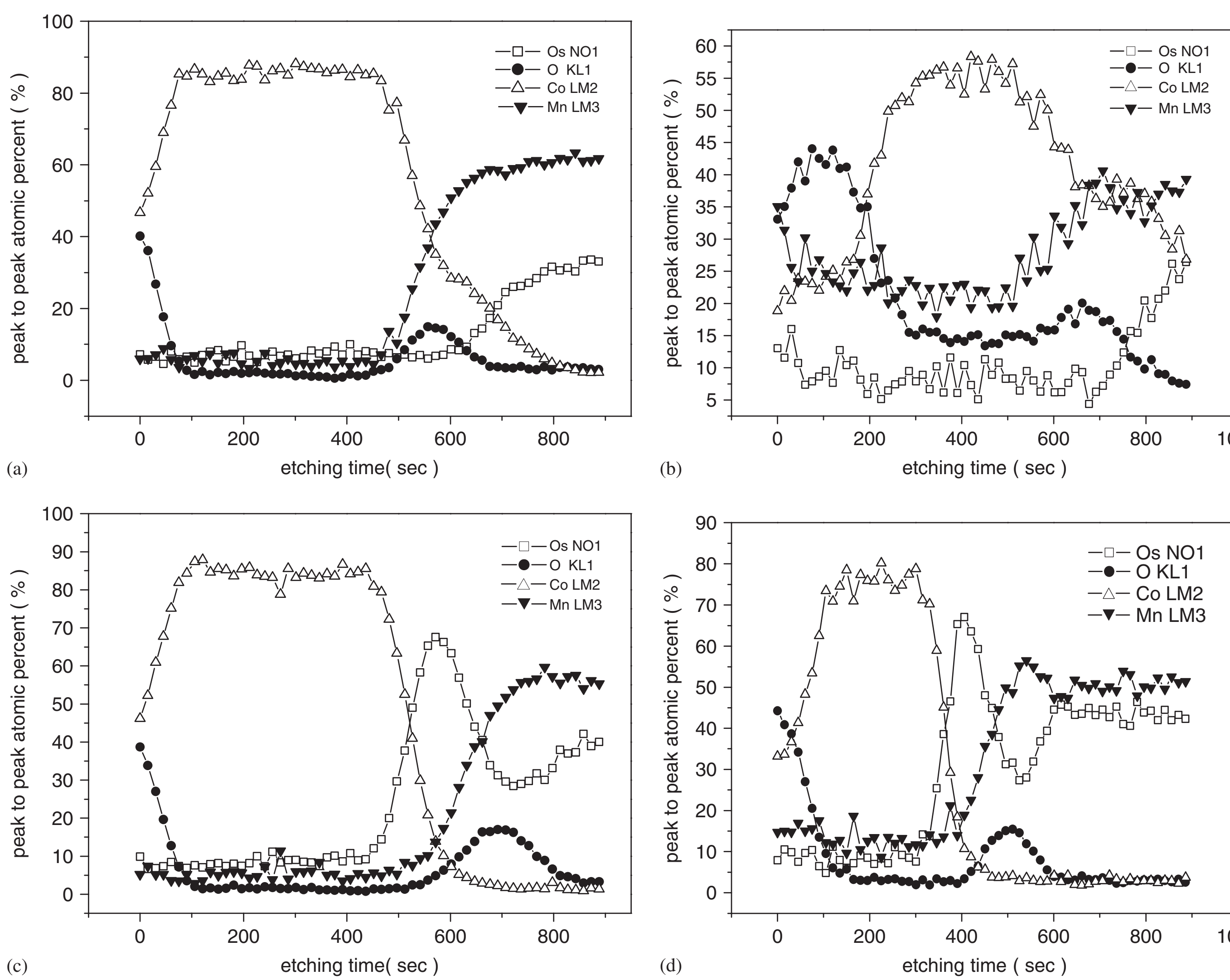

Fig. 1. AES-depth profile for the $Co_{90}Fe_{10}$/Os (d nm)/$Os_{20}Mn_{80}$ multilayer before (a), (c) and after (b), (d) annealing at 300 °C ((a), (b) $d = 0$; (c), (d) $d = 1$).

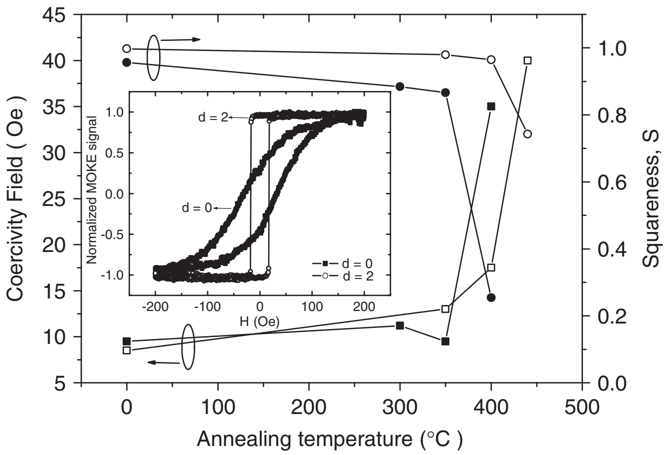

Fig. 2. The temperature dependence of H_C (■ and □) and S (● and ○) in the $Co_{90}Fe_{10}$/Os (d nm)/$Os_{20}Mn_{80}$ multilayer, which indicated by $d = 0$ (dark symbol) and $d = 2$ (open symbol). The annealing conditions are 30 min at 1 kOe external field. The inserted picture shows the hysteresis loop of samples with $d = 0$ and 2 nm after 400 °C annealing.

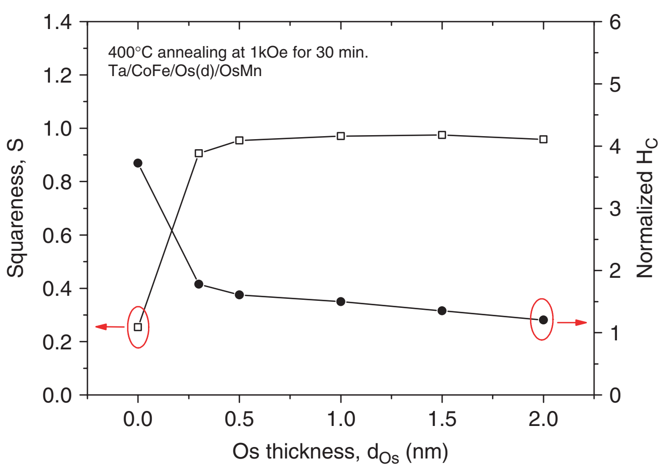

Fig. 3. The squareness and normalized H_C varies as a function of the thickness of Os interlayer.

with Os only slightly increased. Because the inserting metal layer in the FM/AFM interface decreased the FM/AFM exchange coupling [9], the optimal Os barrier thickness, which could not only retain the magnetic properties of the magnetic layer after annealing but also slightly decrease FM/AFM exchange coupling was an important factor to determine the barrier thickness.

According to our experimental data, the insertion of 1 nm Os layer can block the Mn diffusion channel and retain the magnetic behavior up to $T_{an} = 400\,°C$. The exchange field (H_{ex}) for $Co_{90}Fe_{10}/Ir_{20}Mn_{80}$ with 0.3 nm Os of as-deposited and 350 °C annealed state was 100 and 190 Oe, respectively. However, sample without Os barrier showed a H_{ex} of 55 Oe after 350 °C annealing while that of as-deposited state was 105 Oe. Detailed description of the Os layer on exchange bias effect can be found in Ref. [10]. It could be also found that the sample after annealing with inserted Os layer made the whole magnetic behavior almost the same with the as-deposited state.

The better thermal stability of $Co_{90}Fe_{10}/Os_{20}Mn_{80}$ structures could be achieved by inserting a thin Os layer. As the annealing temperature up to 400 °C, no diffusion evidence was found for samples with $d \geqq 0.3$ nm as examined by the AES depth profile, H_C and S measurement. After 400 °C annealing, the sample with Os layer with hysteresis loop showed little larger H_C and $S > 0.9$ could be obtained even though the thickness of Os was as thin as 0.3 nm.

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