AIP Journal of Applied Physics

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Citation: Journal of Applied Physics **99**, 08C907 (2006); doi: 10.1063/1.2170053
View online: http://dx.doi.org/10.1063/1.2170053
View Table of Contents: http://scitation.aip.org/content/aip/journal/jap/99/8?ver=pdfcov
Published by the AIP Publishing

JOURNAL OF APPLIED PHYSICS **99**, 08C907 (2006)

Effects of an Os layer on the magnetic properties of CoFe/IrMn

Tai-Yen Peng[a)]
Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan

C. K. Lo
Electronics and Optoelectronics Research Laboratories, Industrial Technology Research Institute, Hsin Chu 310, Taiwan, and Nanotechnology Research Center, Industrial Technology Research Institute, Hsin Chu 310, Taiwan

San-Yuan Chen
Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan

Y. D. Yao
Institute of Physics, Academia Sinica, Taipei 11529, Taiwan, and Department of Materials Science and Engineering, National Chiao Tung University, Hsinchu 30010, Taiwan

(Presented on 3 November 2005; published online 25 April 2006)

The uses of Os as an antidiffusion and buffer layer in IrMn exchange coupled CoFe film were investigated. For the purpose of antidiffusion, the inserted Os layer showed a distinct improvement of $S > 0.9$, with H_C slightly increasing by 1.6 times for the CoFe/Os/MnOs multilayer after 400 °C annealing, even though the Os thickness was as thin as 0.3 nm. Furthermore, with a 0.3 nm Os barrier, the 350 °C annealed CoFe/Os/IrMn/CoFe showed almost the same magnetic behavior as the as-deposited state, while the H_{ex} of the upper part of the CoFe/Os/IrMn changed from 100 to 190 Oe. In addition, as a buffer layer, the Os buffer layer could enhance the diffraction peak intensities of IrMn(111)/Os(002) and CoFe (111), and the H_{ex} of CoFe/IrMn was proportional to the Os thickness. A 120 Oe of H_{ex} was achieved by using an 11 nm Os buffer layer in a CoFe 10 nm/IrMn 15 nm bottom type film. These results show that Os has the potential to be an antidiffusion and buffer layer in a magnetic multilayer. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2170053]

I. INTRODUCTION

For high density data storage and nonvolatile memory applications, much work has been done on the basic unit in magnetic devices, such as spin valve (SV) and magnetic tunneling junction (MTJ) structure. Many kinds of compositions of Mn with other metals exhibiting antiferromagnetic behavior have been used to pin the ferromagnetic layer in these element structures mentioned. However, the diffusion of Mn atoms into another layer ruins the thermal stability.[1] Therefore, it is important to find a suitable element that can eliminate this problem. Many reports have demonstrated methods by which the thermal stability of the MTJ or SV system can be increased.[2–4] The noble metal osmium (Os) has also drawn attention due to the possibilities of its use in improving thermal properties in magnetic films.[5,6] In this article, the Os layer was investigated as a possible addition to CoFe/MnOs and CoFe/IrMn magnetic films for two uses: one as a diffusion barrier of Mn atoms, and the other as a buffer layer for IrMn (111) texture. The results of this study may suggest new ideas for designing the element film structure in magnetic devices.

II. EXPERIMENT

The magnetic multilayer samples were rf and dc magnetron sputtering deposited on 1 cm × 1 cm SiO_2/Si substrates as the following three series. The first series, with Ta/CoFe(10 nm)/Os(d)/MnOs(20 nm)/SiO_2 structure (T series), was used to characterize the thermal properties, where d stands for the thickness varying from 0 to 2 nm, and the Os in the MnOs layer was doped slightly to prevent the Mn atoms from diffusing. Another series (H_{ex}) was used to demonstrate that the Os layer enhanced the thermal stability of the exchange field of the Ta/CoFe(10 nm)/Os(t)/IrMn(30 nm)/CoFe(10 nm)/SiO_2 structure, where t was 0 and 0.3 nm, respectively. The third series was Ta/CoFe(10 nm)/IrMn(15 nm)/Os/Ta/SiO_2 (bottom series), in which the thickness of the Os buffer varied from 1 to 11 nm, and in which the Ta on the SiO_2 was to form the atomic surface to improve the Os deposition. The top Ta layer used in all samples was intended to protect the CoFe and IrMn layer from oxidation during annealing. All films were deposited under 200 Oe of external magnetic field at about a 4×10^{-3} Torr pressure of pure Ar gas. The T and H_{ex} series were annealed for 30 min at 400 and 350 °C, respectively, below 1×10^{-3} Torr pressure in a vacuum chamber under an applied filed of 1 kOe along the direction of the applied magnetic field during film deposition. The focus of the bottom series was to determine the proper conditions for CoFe to be exchange coupled by IrMn in the as-deposited state. The magnetization curves of all samples were measured by magnetic optical Kerr effect (MOKE) and vibrating sample magnetometer (VSM) at room temperature. Film structure was analyzed by an x-ray diffractometer (XRD) with a Cu k_α source.

a)Author to whom correspondence should be addressed; electronic mail: terencepeng@itri.org.tw

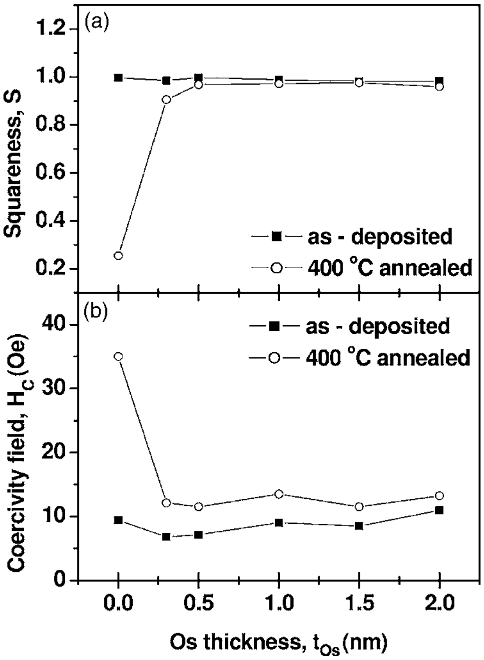

FIG. 1. The Os barrier thickness dependence of: (a) the magnetization curve squareness and (b) the coercivity field in the Ta/CoFe/Os (d nm)/MnOs/SiO_2 multilayer before and after annealing. The annealing conditions are 400 °C for 30 min at 1 kOe external field.

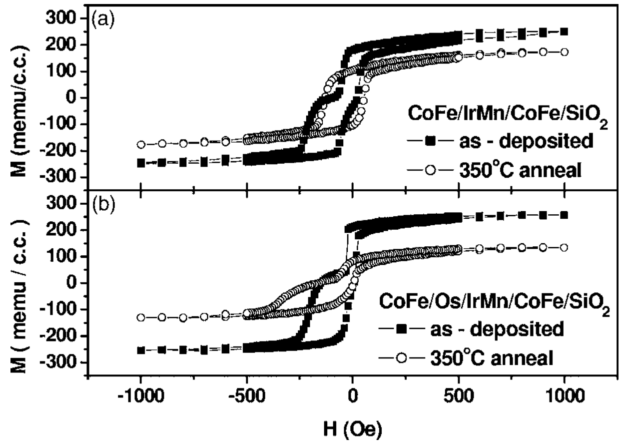

FIG. 2. The VSM measurement of the Ta/CoFe/IrMn/CoFe/SiO_2 multilayer: (a) without and (b) with a 0.3 nm Os barrier inserted in the upper part of the CoFe/IrMn interface. The H_{ex} of the annealed sample with the 0.3 nm Os barrier (○) was larger than that of the as-deposited state (■).

III. RESULTS AND DISCUSSION

The Os interlayer thickness dependence of the magnetization curve squareness (S) and the coercivity field (H_C) for the annealed T series is shown in Fig. 1. All samples showed that the S of the as-deposited state was very close to 1, which indicated that the magnetization curve was very square. After 400 °C annealing, the samples with the Os diffusion barrier kept their $S>0.9$, even though the Os thickness was as thin as 0.3 nm, while the S for the non-Os sample was only 0.25. Furthermore, the same behavior could be found when focusing the H_C, which varied as the Os thickness increased. All samples showed roughly the same H_C of 10 Oe as the as-deposited. The H_C of the annealed sample without Os changed from 9.5 to 35 Oe (became nearly four times larger), while the H_C for the annealed samples with Os only slightly increased in the neighborhood of 12.5 Oe (became 1.2–1.6 times larger than as-deposited for each thickness of Os). According to our previous work, the depth profile results also indicated that a thin Os layer could prevent the diffusion of the Mn atoms into the ferromagnetic layer after annealing at temperatures greater than 300 °C.[6] The improvements of Os on the S and H_C of the annealed T series are distinct. Because the insertion of the metal layer in the ferromagnetic/antiferromagnetic (FM/AFM) interface decreased the FM/AFM exchange coupling,[7] the optimal Os barrier thickness that 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 in determining the barrier thickness. The inserted Os layer of 0.3 nm could not only maintain the S of the sample at larger than 0.9 but also increase the H_C to 1.6 times larger, and thus it seems to be a suitable interlayer for FM/AFM magnetic film.

Since the improvement of the Os layer on thermal properties was verified, a thin Os layer was added into the IrMn exchange coupled magnetic film to check the influence on the exchange field (H_{ex}). Figure 2 shows the VSM measurements for Ta/CoFe/IrMn/CoFe/SiO_2 (a) without and (b) with the 0.3 nm Os interlayer, respectively. The smaller H_{ex}($H_{ex,S}$) was contributed by the bottom CoFe seed layer, which was also exchange coupled by IrMn. In general, 350 °C was too high for the IrMn base magnetic multilayer due to the higher diffusion tendency of the Mn atoms. The $H_{ex,L}$ (which resulted from exchange coupling of the upper part of the CoFe/IrMn) of as-deposited and 350 °C annealed states were 100 and 190 Oe for the sample with Os, respectively. However, the sample without the Os barrier showed an $H_{ex,L}$ of 55 Oe after 350 °C annealing, while that of the as-deposited state was 105 Oe. These indicated that the Os stopped the Mn atoms from diffusing from IrMn into the upper CoFe and caused the $H_{ex,L}$ to increase at such a high temperature. Furthermore, the Os layer also seemed to decrease the tendency of Mn to diffuse to the bottom CoFe layer due to the retention of the $H_{ex,S}$ of the sample with Os, which was almost the same as that before annealing. The enthalpy of Mn in the Os and Co interfaces was −39 and −21 kJ/mole, respectively.[8] It indicated that the Mn had a higher tendency to remain in the Os/IrMn than in the CoFe/IrMn interface. From this, it could be found that the annealed sample with the inserted Os layer made the overall magnetic behavior almost the same as that of the as-deposited state. However, the sample without the Os layer not only lost the $H_{ex,S}$ but also showed a smaller $H_{ex,L}$. In addition, a diffusion model states that diffusion occurs when one small atom in a vacancy jumps to another vacancy across a neighboring large atom. Considering the sizes of the Mn and Os atoms, the smaller Mn atoms in the Os/IrMn interface could be seen as being positioned in the vacancy between the Os atoms. However, the Os atom was too large for the Mn atoms to jump from one side of the Os to the other. The lower enthalpy for Mn remaining in the Os interface also indicated that the Mn and Os formed a stable and cohesive layer, thus making it harder for other Mn atoms to move. This also proves that Os has strong possibilities as a diffusion barrier.

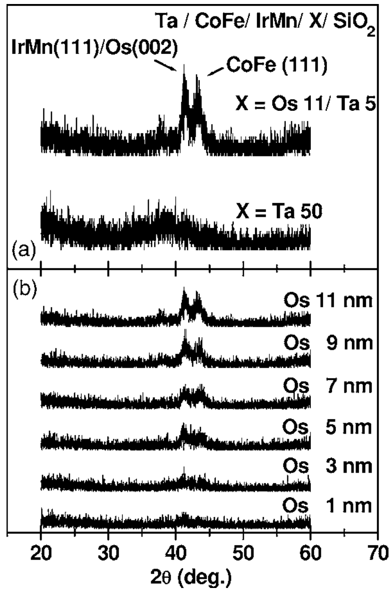

FIG. 3. The XRD measurements of the $Ta/CoFe/IrMn/Os/Ta/SiO_2$ multilayer: (a) the influence of the IrMn exchange coupled CoFe films with and without the Os buffer and (b) enhancement of the diffraction peaks varied as increasing of the Os thickness.

The buffer layer with hcp structure was reported to enhance the IrMn (111) texture, resulting in exchange coupling.[9,10] Os, like Ru and Zr, is a hcp structure, and the IrMn (111) texture enhancement was found in the bottom series from the XRD analysis, as shown in Fig. 3(a). The 50 nm Ta layer did not result in IrMn (111) and CoFe (111) texture, and only the broadened and weak peak of Ta (110) could be found by XRD measurement. However, the buffer layer consisting of Os 11 nm/Ta 5 nm enhanced the IrMn (111) and the CoFe (111) texture can be found clearly. The IrMn (111) and Os (002) diffraction peaks were hard to distinguish because they had roughly the same spacing distance. Figure 3(b) shows that the IrMn(111)/Os(002) and CoFe (111) diffraction peaks could be clearly found when the thickness of the Os was greater than 5 nm. In addition, MOKE analysis showed that the exchange coupling was produced even when the Os buffer was as thin as 1 nm, as shown in Fig. 4. A 120 Oe of H_{ex} was achieved by using 11 nm of Os as a buffer layer. Although the IrMn(111)/Os(002) and CoFe (111) peak intensities were weak in the thinner Os inserted samples, the H_{ex} was still produced after deposition. With increases in the thickness of the Os buffer, these diffraction peak intensities became increasingly clear. The H_{ex} and diffraction peak intensities of IrMn(111)/Os(002) and CoFe (111) are proportional to the thickness of the Os. This means that the Os buffer not only enhances the IrMn (111) and CoFe (111) texture but also results in a clear H_{ex} in magnetic film.

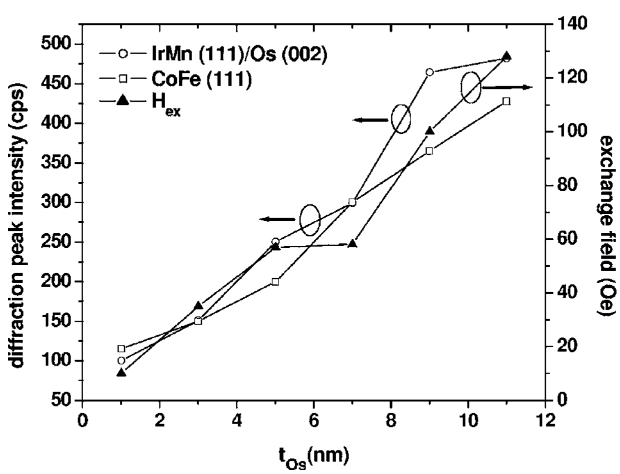

FIG. 4. The diffraction peak intensities of the IrMn(111)/Os(002) and CoFe (111), and H_{ex} varied as a function of the Os buffer thickness.

According to the above, Os has the potential to act as an antidiffusion and buffer layer in a magnetic film structure. The unit material for the antidiffusion and buffer layer would make the deposition system with a limited source more effective and efficient to use.

IV. CONCLUSION

Two applications of Os in magnetic film were investigated. As an antidiffusion layer, the 0.3 nm Os layer showed a distinct improvement of $S > 0.9$, with the H_C slightly increasing by 1.6 times after 400 °C annealing. With 0.3 nm Os barrier, the CoFe/Os/IrMn/CoFe showed almost the same magnetic behavior after 350 °C annealing, while the H_{ex} even increased. As a buffer layer, the Os layer could enhance the diffraction peak intensities of IrMn(111)/Os(002) and CoFe (111), and the H_{ex} of CoFe/IrMn was proportional to the thickness of the Os. A 120 Oe of H_{ex} was achieved by using an 11 nm Os buffer layer in CoFe 10 nm/IrMn 15 nm bottom type film. The results of this study indicate that Os may have great potential for application in magnetic films.

ACKNOWLEDGMENTS

The authors would like to express their gratitude for the technical support from the Nano Technology Research Center (NTRC), Industrial Technology Research Institute (ITRI), and are grateful for financial support from ROC MOEA under Grant No. A341XSFI10, Academia Sinica, and National Science Council of Taiwan (NSCT) under Grant No. NSC94-2120-M-001-004.

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