NOTES

Effect of Cu surface segregation on the exchange coupling field of NiFe/FeMn bilayers

LI Minghua[1,2], YU Guanghua[1], ZHU Fengwu[1], JIANG Hongwei[2] & LAI Wuyan[2]

1. Department of Materials Physics, Beijing University of Science and Technology, Beijing 100083, China;
2. Institute of Physics, Chinese Academy of Sciences, Beijing 100080, China

Abstract **The NiFe/FeMn bilayers with different buffer layers (Ta or Ta/Cu) were prepared by magnetron sputtering. Results show that the exchange coupling field of NiFe/FeMn films with Ta buffer is higher than that of the films with Ta/Cu buffer. We analysed the reasons by investigating the crystallographic texture, surface roughness and surface segregation of both films, respectively. We found that the decrease of the exchange coupling fields of NiFe/FeMn films with Ta/ Cu buffer layers was mainly caused by the Cu surface segregation on NiFe surface.**

Keywords: NiFe/FeMn, exchange coupling field, texture, surface roughness, surface segregation.

The phenomenon of exchange anisotropy was discovered by Meiklejo et al. in 1956.[1] The exchange coupling between an antiferromagnet (AF) and a ferromagnet (FM) has attracted considerable interest in recent years. The studies are intensified because of the wide application of FM/AF systems in giant magnetoresistive (GMR) read heads and magnetoresistive sensors. The NiFe/FeMn FM/AF system is one of the most extensively studied model systems, and it was early used in giant magnetoresistive (GMR) spin valve.

The coupling between the ferromagnetic layer and the antiferromagnetic layer relates not only with the magnetism of the FM layer and the AF layer but also with the microstructures of the films such as grain size[2], texture, surface roughness and newly discovered interlayer diffusion[3] and interface reaction[4]. The processing of sample preparation [5] can affect the microstructure, and hence the exchange coupling. In some previous papers it was found that the exchange coupling field of films with proper buffer was much higher than that of the films without buffer[6].

In our experiment, the NiFe/FeMn bilayers with Ta buffer and Ta/Cu buffer were prepared by magnetron sputtering. The results show that the exchange coupling field (H_{ex}) of NiFe/FeMn films with the Ta buffer is higher than that of the films with the Ta/Cu buffer, which is accordant with Fujiwara's results[7]. They suggested that this phenomenon was caused by the texture difference, i.e. the film with Ta buffer has a higher oriented (111) texture of NiFe and FeMn. However, we found that there is no apparent difference in crystallographic texture and surface roughness for both films. That means that there must be other reasons for the H_{ex} decrease of the film with Ta/Cu buffer. In this note, the surface composition of Ta/Cu/NiFe film was studied using X-ray photoelectron spectroscopy (XPS). We found that Cu atoms can segregate to the NiFe surface. We believe that this is the main reason for the decrease of the exchange coupling fields of NiFe/FeMn films with Ta/ Cu buffer layers.

1 Experimental methods

The multilayers were prepared in a magnetron sputtering system. The Ta layers were deposited by rf magnetron sputtering while the other layers Cu, NiFe and FeMn were deposited by dc magnetron sputtering. Ta(8 nm)/ NiFe(13 nm)/FeMn(12 nm)/Ta(6 nm) and Ta(8 nm)/Cu 2.6 nm)/NiFe(13 nm)/FeMn(12 nm)/Ta(6 nm) because the spacer thickness is 2.6 nm in spin valve) were deposited on Si (100) substrates in a regular order. The base pressure was below 2×10^{-5} Pa. The deposition rate was 0.12 nm/s for Ta and Cu films, and 0.1 nm/s for NiFe and FeMn, respectively. The films were deposited in a uniform magnetic field of 20 kA/m (or 250 Oe), which produced an easy axis in the NiFe film and defined the exchange coupling axis. All layers were deposited at the same argon pressure of 0.6 Pa. The substrates were cooled by water.

The crystallography of the films was examined by using X-ray diffraction (XRD). The hysteresis loops were measured with the vibrating sample magnetometer (VSM). The surface roughness was characterized by atomic force microscope (AFM). The interface segregation was studied using the X-ray photoelectron spectroscopy (XPS).

2 Experimental results and discussion

(i) Hysteresis loops of the NiFe/FeMn films with different buffer layers. Fig. 1(a) shows the hysteresis loops of the NiFe (13 nm) /FeMn (12 nm) film with Ta(8 nm) buffer. The coercivity H_c of the film with Ta buffer (0.98 kA/m or 12.3 Oe) is almost the same as that of the film with Ta /Cu buffer (0.93 kA/m or 11.7 Oe), but the exchange coupling field in the former (8.88 kA/m or 111.5 Oe) is much higher than that in the latter (7.99 kA/m or 100.5 Oe). Comparing Ta(12 nm)/ NiFe(75 nm)/FeMn(15 nm)/Ta(5 nm) with Ta(12 nm)/Cu(10 nm)/NiFe(7.5 nm)/ FeMn(15 nm)/Ta(5 nm), Fujiwara proposed that a higher pinning field may be obtained for the former than for the latter[7]. In other words, the decrease of the exchange coupling fields was caused by the Cu layer between the layers of Ta and NiFe. We first investigated the crystallographic texture and interface roughness in order to find the reason for the decrease of the exchange coupling.

(ii) X-ray diffraction of the NiFe/FeMn films with different buffer layers. Fig. 2 shows the X-ray diffraction patterns of the NiFe(13 nm)/FeMn (12 nm) films with different buffers Ta(8 nm)(see fig. 2(a)) and Ta (8 nm)/Cu

(2.6 nm) (fig. 2(b)), respectively. A good (111) texture of γ-FeMn is necessary to obtain a high exchange coupling[8]. The film with proper buffer has highly oriented (111) texture of NiFe. Thus, a stronger FeMn (111) diffraction peak is expected to form on a highly oriented NiFe (111) texture film. Comparing fig. 2(a) with fig. 2(b), we found that the perfect diffraction peaks of NiFe (111) and FeMn (111) were well grown when the films are deposited on either Ta or Ta/Cu buffer. The diffraction peaks of NiFe (111) and FeMn (111) were not apparently influenced by 2.6 nm Cu deposited on the Ta layer. It means that the texture is not the main factor for the decrease of the coupling field of NiFe/FeMn films with Ta/Cu buffer layer.

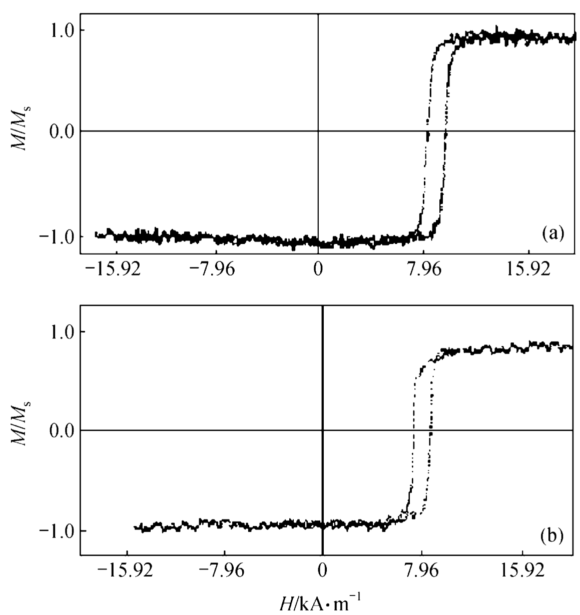

Fig. 1. Hysteresis loops of NiFe/FeMn bilayers with buffer Ta (a) and Ta/Cu (b).

(iii) AFM surface topography of the NiFe/FeMn films with different buffer layers. We measured the surface topography by using an atomic force microscope (AFM). Since Cu, NiFe and FeMn are all of an fcc structure and their lattice mismatch is smaller than 3%, the multilayers grow coherently when they are deposited sequentially in the same vacuum[4]. In this study we assumed that the surface morphology of the multilayer likely results from the interface morphology of the NiFe/FeMn layer. We measured the surface topography of Ta(8 nm)/NiFe(13 nm)/FeMn(12 nm)/Ta(6 nm) and Ta(8 nm)/Cu(2.6nm)/NiFe(13nm)/FeMn(12 nm)/Ta(6 nm) with root mean square roughness (R_{rms}) of 0.237 nm and 0.278 nm respectively by using an atomic force microscope. Generally, the "smooth" means the R_{rms} ranges from 0.2 to 0.4 nm, and the "roughness" R_{rms} ranges from 0.5 to 0.8 nm. We can see from the above that the surface was basically smooth although there was a little difference between Ta buffered R_{rms} and Ta/Cu buffered R_{rms}.

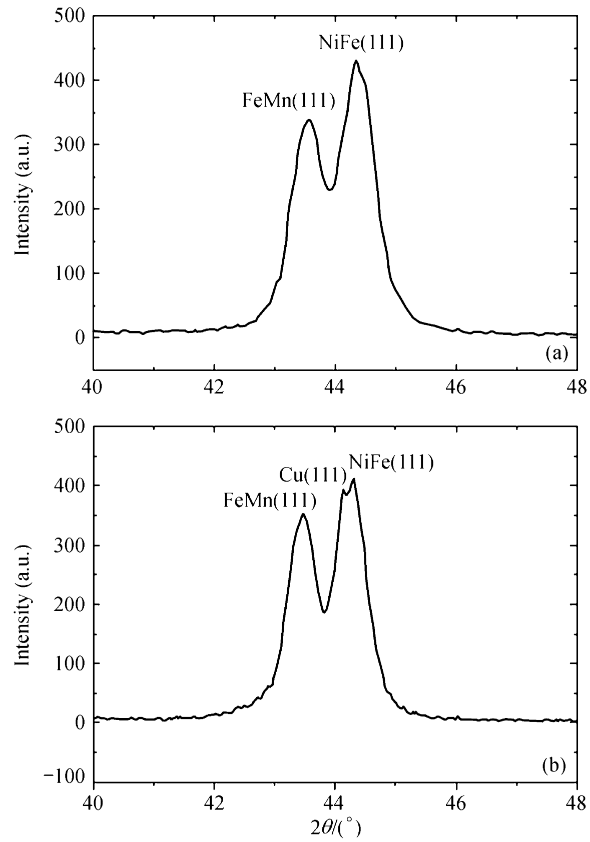

Fig. 2. X-ray diffraction of NiFe/FeMn bilayers with buffer Ta (a) and Ta/Cu (b).

(iv) XPS investigation of surface segregation of Ta/NiFe and Ta/Cu/NiFe. In order to obtain the reason for the decrease of the exchange coupling of NiFe/FeMn with Ta/Cu buffer, we measured element distribution in different depths by angle-resolved XPS. Ta(3 nm)/NiFe (5 nm) and Ta(3 nm)/Cu(2 nm)/NiFe(5 nm) were deposited on Si (10) substrates in the same way as the Ta/NiFe/FeMn/Ta and Ta/Cu/NiFe/FeMn/Ta layers by magnetron sputtering. The samples were introduced into a MICROLAB MK II X-ray photoelectron spectroscopy system instantly after being taken out of the deposition system. In order to detect the composition and chemical states on NiFe surface, the interfacial layer has to be within the XPS detectable sampling depth $d = 3\lambda\sin\alpha$[9], where λ and α are inelastic mean-free paths (IMFPs) for photoelectrons and a take-off angle for photoelectrons with respect to the samples surface plane, respectively. The IMFPs can be obtained by using the table compiled by Tanuma et al.[10]. The detectable depths changed from 0.6 to 2.3 nm when the take-off angle changed from 15° to 90°. The spectra of Cu and nickel acquired were fitted by the curve fitting software to determine the atomic fraction of Cu and Ni in all chemical states. Fig. 3(a) gives Cu 2p high resolution XPS spectrum for $\alpha = 15°$ and fig. 3(b) gives relationship between the Cu/Ni atomic number ratio and photoelectron emitting angle. In fig. 3(b) we can see that Cu decreased with the increase of the take-off angle. This means that Cu atoms segragate to NiFe surface in the Ta/Cu/NiFe films. However, there was no Ta segragation on NiFe surface for Ta/NiFe bilayer by the same analysis. As to NiFe/FeMn bilayer with Ta/Cu buffer layer, Cu segragation on NiFe surface decreased the effective contacting area between

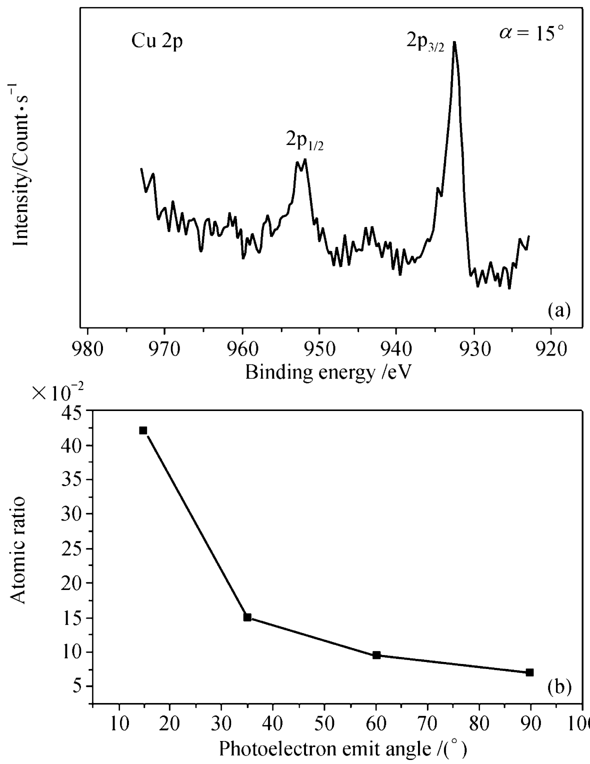

Fig. 3. (a) Cu2p high-resolution XPS spectra for α=15°, where α is a take-off angle for photoelectrons with respect to the samples surface plane. (b) Relationship between the Cu/Ni atomic number ratio and photoelectron take-off angle.

NiFe and FeMn layers, and this decreased exchange coupling field. It was reported by Chien[11] that when Cu, Au and Ag metals are insected at the NiFe/CoO interface as the spacer layer, the exchange coupling decreases with the spacer layer thickness increasing. It means that the impurity at the interface between ferromagnet and antiferromagnet can decrease the exchange coupling. For the Ta/NiFe/FeMn/Ta film there was no Ta at the NiFe/FeMn interface, i.e. the interface was relatively clean, it had a higher exchange coupling field. Therefore, the decrease of the exchange coupling fields of NiFe/ FeMn films with Ta/Cu buffer layers was mainly caused by the Cu segregation on NiFe surface.

3 Conclusion

The coupling between the ferromagnetic layer and the antiferromagnetic layer relates not only with crystal texture and surface roughness but also with the surface segregation caused by some buffer layers (such as Cu). The exchange coupling field of NiFe/FeMn films with the Ta buffer was higher than that of the films with the Ta/Cu buffer. The XPS analyses indicated that the decrease of the exchange coupling field of NiFe/FeMn films with Ta/Cu buffer layers was caused by the Cu surface segregation.

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References

1. Meiklejo, W. H., Bean, C. P., New magnetic anisotropy, Phys. Rev. B, 1956, 102: 1423.
2. Hou, C. H., Fujiwara, H., Metager, R. D., Grain size effect ferro-antiferromagnetic coupling of NiFe/FeMn systems, J. Appl. Phys., 1996, 80: 4528.
3. Qian, Z. H., Sicertsen, J. M., Judy, J. H., Magnetic behavior of NiFe/NiO Bilayers, J. Appl. Phys., 1996, 83: 6825.
4. Yu, G. H., Chai, C. L., Zhu, F. W. et al., Interface reaction of NiO/NiFe and its influence on magnetic properties, Appl. Phys. Lett., 2001, 78: 1706.
5. Mao, M., Cerjan, C., Law, B. et al., Influence of base pressure on FeMn exchange biased spin-valve films, J. Appl. Phys., 2000, 87: 4933.
6. Choe, G., Gupta, S., High exchange anisotropy and high blocking temperature in strongly textured NiFe(111)/FeMn(111) films, Appl. Phys. Lett., 1997, 70: 1766.
7. Fujiwara, H., Nishioka, K., Hou, C. et al, Temperature dependence of the pinning field and coercivity of NiFe layers coupled with an antiferromagnetic FeMn layer, J. Appl. Phys., 1996, 79: 6286.
8. Alexandre, M. C., Effect of interface on exchange coupling in NiFe/FeMn system, IEEE Trans. Magn., 1997, 33: 3676.
9. Atanassova, E., Dimitrova, T., Koprinarova, P., AES and XPS study of thin RF-Sputtered Ta_2O_5 layers, J. Appl. Surf. Sci., 1995, 84: 193.
10. Tanuma, S., Powell, C. J., Penn, D. R., Calulations of electron inelastic mean free paths for 31 materials, Surf. Anal., 1998, 11: 577.
11. Gokemejier, N. J., Ambrose, T., Chien, C. L. et al., Long-range exchange coupling between a ferromagnet and an antiferromagnet across a nonmagneticspacer layer, J. Appl. Phys., 1997, 81: 4999.

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