Exchange anisotropy depending on Interfacial Structure of the NiO/NiFe bilayers

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ABSTRACT- We have analyzed the effect of microstructure and interface conditions on the anisotropic exchange fields of NiO/NiFe bilayers. The NiO films were deposited by R.F. magnetron sputtering. By using different argon pressure NiO films, grain size and surface roughness of NiO can be manipulated. The exchange field is enhanced in the small grained NiO and this increment is based on the formation of small domains in NiO.

1. INTRODUCTION

A spin-valve multilayer structure is one of most promising candidates for use in high areal density giant magnetoresistive(GMR) heads and sensors because of its high sensitivity and output. Successful MR head designs require the suppression of noise associated with Barkhausen jumps, which result from domain-wall motion in magnetically soft NiFe sensor films. To achieve this, various antiferromagnetic materials, such as FeMn, NiO, NiMn, α-Fe_2O_3, were introduced as biasing layers which are exchange coupled with the sensing films.(1),(2) Among the above antiferromagnetic materials, NiO films are potential candidates for pinning layer because of their superior chemical stability, insulating properties, relatively high blocking temperature, large exchange coupling field, and simple fabricating process. However, large hysteresis has appeared in magnetoresistance curves for NiO/NiFe spin-valve multilayers because of large coercivity in the pinned layers, especially in those with smaller thickness. From this point of view, fabricating NiO/NiFe spin valves with both large exchange field Hex and small coercive field Hc is becoming increasingly important in order to fabricate high areal density GMR heads and sensors. It is necessary to determine, experimentally, how the microstrcture and interface conditions affect the exchange coupling and coercivity in NiO/NiFe bilayers in order to obtain superior NiO/NiFe spin valves with both large Hex and small Hc. In this article we report on the effects of the microstrcture and interface conditions on the exchange coupling and coercivity of NiO/NiFe bilayers. We also report on the successful fabrication of NiO/NiFe bilayer with both large Hex and very small Hc.

2. EXPERIMENTAL PROCEDURES

Ta/NiFe/NiO films were deposited onto a Si(100) substrate in a R.F. and D.C. magnetron sputtering system with a base pressure 8×10^{-7} Torr. High-purity 2-in. NiO and 3-in. NiFe(81 wt% Ni and 19 wt% Fe) targets were used. The NiO films with different microstructure and surface roughness is obtained by Ar pressure. The NiFe films were deposited on NiO layer in various pure argon gas pressure. A Ta capping layer was deposited immediately following the NiFe deposition to protect the environment. The film structure and crystalline texture studies were performed by using an x-ray diffractometer and high resolution cross-sectional TEM. The magnetic properties of the NiO/NiFe bilayers were measured using a vibrating-sample magnetometer(VSM). The surface, interface roughness and crystalline grain size were measured using atomic force microscope(AFM). The film thicknesses were ex-situ measured using a α-step surface profiler. The uniaxial in-plane anisotropic NiFe films were deposited on the NiO films in a 500Oe magnetic field. The exchange coupling field, Hex, was measured by the shift of the M-H hysteresis loop away from the zero-field axis. The coercive field, Hc, was measured by the half-width of the hysteresis loop at zero net magnetization. All the measurements were carried out at room temperature and the samples were in the as-deposited state.

3. RESULTS AND DISCUSSIONS

As shown in Fig. 1, the Hex gradually decreases with the increasing argon pressure and Hc increases dramatically from 2.5 to 3 in the range from 0.25 to 4mTorr.

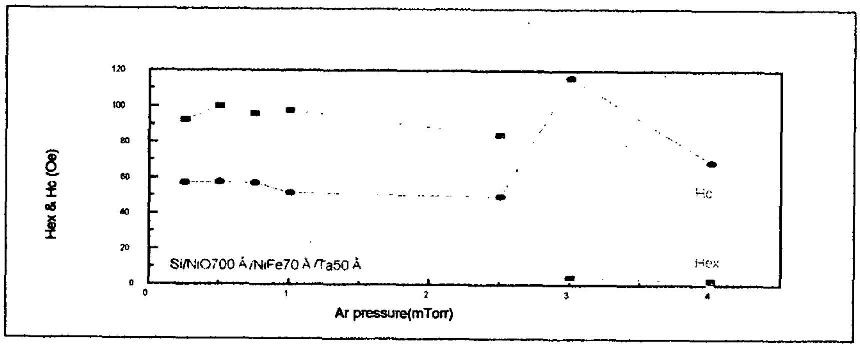


Fig. 1. Dependencies of exchange coupling field and coercive field on the Ar pressure of the NiO/NiFe bilayers.

So we are examined the argon pressure, 1, 2.5 and 4mTorr to be shown the dramatical behavior in above data by the XRD. The x-ray spectra of NiO/NiFe bilayers with argon pressure is shown in Fig. 2.

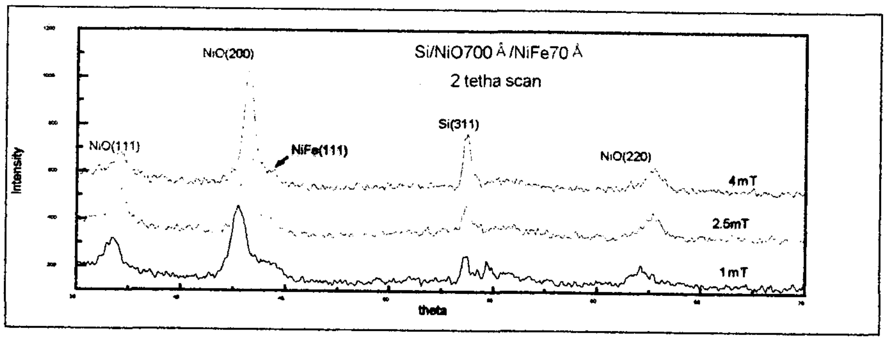
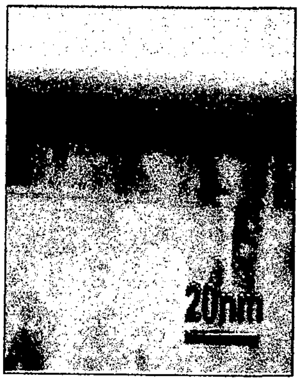


Fig. 2. XRD pattern with the change of Ar pressure in NiO deposition

The peak positions of the NiO diffraction peaks are shifted between the various films deposited under different argon pressure. This means that there are the changes of the



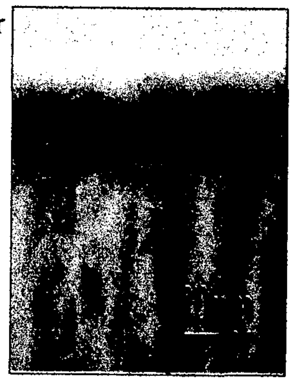
1mTorr

Ta

NiFe

NiO

(a)



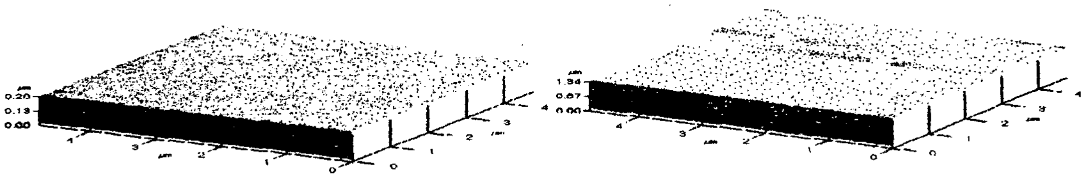
4mTorr

Fig. 3(a), (b). Cross-sectional TEM images of NiO/NiFe interface with Ar pressure change in NiO deposition. Bright field image.

(b)

microstructure and interface between NiO and NiFe. So we examine the microstructure and interface by TEM in order to check this phenomenon.The high resolution TEM images withargon pressure are shown in Fig. 3(a),(b) and (c). NiO films on the SiO_2 form more columnar grains with the increasing argon pressure. The microstructural changes affects the exchange anisotropy by the grain size and interface morphology. The interface between NiO and NiFe shows gradually roughened and disappeared with the increasing argon pressure. To study the effects of the roughness of the interface in real NiO/NiFe bilayers on the Hc of the pinned NiFe films, we measured the surface roughness using an AFM.

The AFM images show a large difference in the surface roughness in Figs. 4(a) and 4(b). Considering the face-centered-cubic(fcc) NaCl-type structure, the spin configurations in different planes are very different. For NiO, the spins align parallel



(a) (b)

Fig. 4. AFM images of NiO(70nm)/NiFe(7nm) bilayers surface/ interface roughness with Ar pressure (a) 1mTorr (b) 4mTorr

to each other and to the (111) planes; alternate (111) planes have opposite spins. In both the (200) and (220) planes, however, neighboring spins are separated by O^{2-} ions and aligned antiparallel by superexchange. If all the spins in NiO are aligned along one direction and in the same plane, it should result in a larger exchange-coupling field with NiFe spins than if the spins in NiO are aligned along two opposite directions, because all the spins in the NiFe film are aligned during the film deposition in a magnetic field in the same direction. According to the random-field model of exchange anisotropy proposed by Malozemoff, the presence of a random interfacial roughness gives rise to a random microscopic field acting on the interface spins. The random field at the interface causes the antiferromagnet to break up into the domains, whose size is inversely proportional to the exchange field offset. As for the fact that a rougher interface leads to a higher Hc of the pinned NiFe layer, we think that the interface roughness has a significant effect on the coercivity of the NiO/NiFe bilayers.

4. CONCLUSION

We have shown that the Hex and Hc of the NiO/NiFe bilayers with increasing argon pressure is changed. We know that the exchange anisotropy is based on the microstructural changes. The surface and interface roughness has a very significant effect on the coercivity of the NiO/NiFe bilayers. The key to obtaining a high exchange field and a low coercivity field is a reduction of the argon pressure.

5. REFERENCES

(1) C. Tsang, R. E. Fontana, T. Lin, D. E. Heim, V. S. Speriosu, B. A. Gurney, and M. L. Williams, IEEE Trans. Magn. 30, 3801 (1994).

(2) C. Tsang, R. E. Fontana, and J. K. Howard, IEEE Trans. Magn. 31, 2585 (1995).