Co-Existence of Biquadratic and Unidirectional Anisotropy in IrMn/CoFe/FeO_x/CoFe Films

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During the past years, interlayer coupling between the ferromagnetic layers separated by a spacer attracted much attention. Most of the interlayer couplingwas bi-linear, resulting in either ferromagnetic (FM) or antiferromagnetic (AFM) coupling. To enhance magnetoresistance (MR) ratio in spin valves, nano-oxide layers (NOLs) were inserted in free or/and pinned layers [1], [2]. Various couplings were observed between adjacent FMs through NOLs. Ferromagnetic coupling occurred through most NOLs so the pinning AFM layer can also exert an exchange biasing on the FM layers on the NOL. In this work, we inserted the FeO_x layers in the pinned layer of CoFe. Not only the uniaxial biquadratic coupling but the uni-directional exchange coupling was observed between the pinned CoFe layers separated by the FeO_x layer. The mechanism of the interlayer coupling through FeO_x –NOL was discussed.

Spin valves with the structure of Ta 3 nm /Cu 1.2 nm / IrMn 8 nm /CoFe (FM1) 2 nm /FeO 2.2 nm /CoFe (FM2) 2 nm / Cu 2.3 nm /CoFe (F) 4 nm /Ta 3 nm were deposited on Si (100) wafers by using a sputtering system at a base pressure of 5 x 10^{-7} Torr. FeO_x layers were formed by exposing 1.5 nm Fe films to oxygen plasma for 10 s at an oxygen partial pressure of 3 mTorr. To set the exchange biasing direction (0^o), all films were postannealed in vacuum at 200 ^oC for 15 min at a presence of 1 kOe.

MR curves of a spin valve with a FeO_x layer exhibited an unusual behavior, shown in Fig. 1(a) and (b), measured parallel (0^o) and perpendicular (90^o) to the field-annealing axis. The 90^o curve showed a pseudo-spin-valve-like behavior [Fig. 1(b)], different from the typical spin valves.

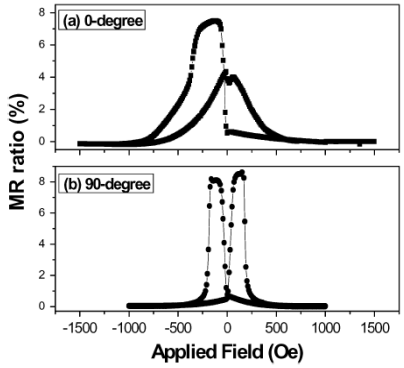

Figure 1. R-H loops of spin valves measured at (a) 0^o and (b) 90^o with respect to the annealing direction.

The unusual behavior occurred when the FeO_x layers inserted into the exchange biased films; therefore, the characteristics of the FeO_x layers played important roles. XMCD analyses were performed on the FeO_x layers by gathering the Fe signals to clarify their magnetic characteristics. A significant difference was observed by using right-hand and left-hand polarized light (Fig. 2), and a clear MCD signal was observed, which strongly suggested that the FeO_x possessed ferromagnetic (or ferrimagnetic) components.

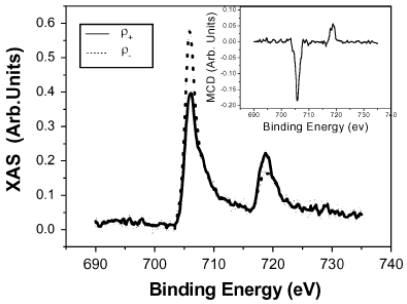

Figure 2. XMCD spectra at the Fe $L_{2,3}$ edges measured at RT. The XMCD spectra were taken with the projection of the spin of incident photons parallel (ρ^+, solid curve) and antiparallel (ρ^-, dashed curve) to the spin of the Fe 3d majority electrons.

Moreover, the XPS results revealed that mixed valance states of Fe, Fe^{2+} and Fe^{3+} co-existed in the FeO_x layer, as shown in Fig. 3. The un-oxidized Fe and/or the oxidized Fe-compounds (γ–Fe_2O_3, Fe_3O_4) in the FeO_x layers could form the magnetic channels so that the uni-directional anisotropy from IrMn can be exerted through the FeO_x layer on the FM2 layer. In addition, FeO_x, γ–Fe_2O_3, or Fe_3O_4 might exist in the FeO_x layer, which possessed antiferromagnetic or ferrimagnetic properties. The biquadratic coupling in CoFe (FM1)/FeO_x/CoFe (FM2) might be explained by the existence of the magnetic roughness at the FM2/FeO_x interface.

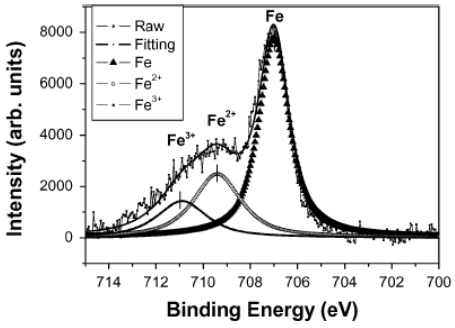

Figure 3. XPS results of the FeO_x layer.

Reference
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[2] C. H. Lai *et al.*, J. Appl. Phys. **89**, 6928 (2001).