

Effect of Composition and Thickness on Exchange-Biased NiCoO/Co and (Co,Mg)O/Co bilayers

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There is much ongoing activity directed towards developing a better understanding of "exchange bias" - which involves coupling of the magnetic field of a thin ferromagnetic (FM) layer (such as permalloy (NiFe) or Co) with an antiferromagnetic (AFM) layer (such as IrMn or NiO). The FM pinning and the sideways hysteresis shift caused by exchange biasing is highly beneficial in many types of magnetic logic and storage devices. We are currently collaborating in a systematic study aimed at establishing a quantitative and predictive model of exchange bias. Here we describe the effect of composition and thickness on the microstructure of exchange-coupled NiCoO/Co and (Co,Mg)O/Co AFM/FM bilayers. The films were grown by DC magnetron sputtering onto (001) Si wafers. Samples suitable for TEM examination were prepared by polishing, dimpling and ion-milling to perforation. Observations were made using a JEOL-4000EX high-resolution electron microscope operated at 400keV in standard diffraction contrast and high-resolution imaging modes.

The (Co,Mg)O samples were grown with compositions ranging from 0 to 100% Mg. Figure 1 compares the typical microstructure of two of these AFM oxides, as deposited directly onto the native oxide of the Si(001) substrate. Figure 1(a) is a low-resolution electron micrograph of the $\text{Co}_{0.8}\text{Mg}_{0.2}\text{O}$ layer showing the typical columnar growth mode, and Fig. 1(b) is a high resolution image of the $\text{Co}_{0.88}\text{Mg}_{0.12}\text{O}$ layer showing the crystallinity of individual grains. Further examination reveals that increased oxide layer thickness generally leads to lateral grain growth and it also appears, still to be verified, that increased Mg content leads to narrower grains. An important issue about the (Co,Mg)O material was whether or not the cations were randomly distributed or whether Mg cations were segregated to the grain boundaries. Figure 2(a) shows an annular-dark-field (ADF) image of a $\text{Co}_{0.8}\text{Mg}_{0.2}\text{O}$ layer and Fig.2(b) is the corresponding X-ray line profile taken from the region indicated in (a). There is no strong evidence for any Mg inhomogeneities across the grains.

For the exchange coupled bilayers, a major concern was the development of crystallinity in the FM material, and the dependence of the magnetic properties, especially coercivity and exchange field, on the total FM layer thickness. Figure 3 compares the microstructure of the Co layers with thicknesses of (a) 1nm and (b) 5nm grown on 500-Å-thick NiCoO AFM layer. Figure 3(a) clearly shows discontinuous film growth, whereas Fig.3(b) shows the development of a continuous film with good crystallinity. Our current efforts are directed towards correlating these microstructural and chemical characteristics of these FM/AFM bilayers with the marked changes observed in the magnetic response when the FM layer thicknesses are $\leq 5\text{nm}$.

References

- [1] A.E. Berkowitz and K. Takano, *J. Magn. Magn. Mater.* 200 (1999) 552

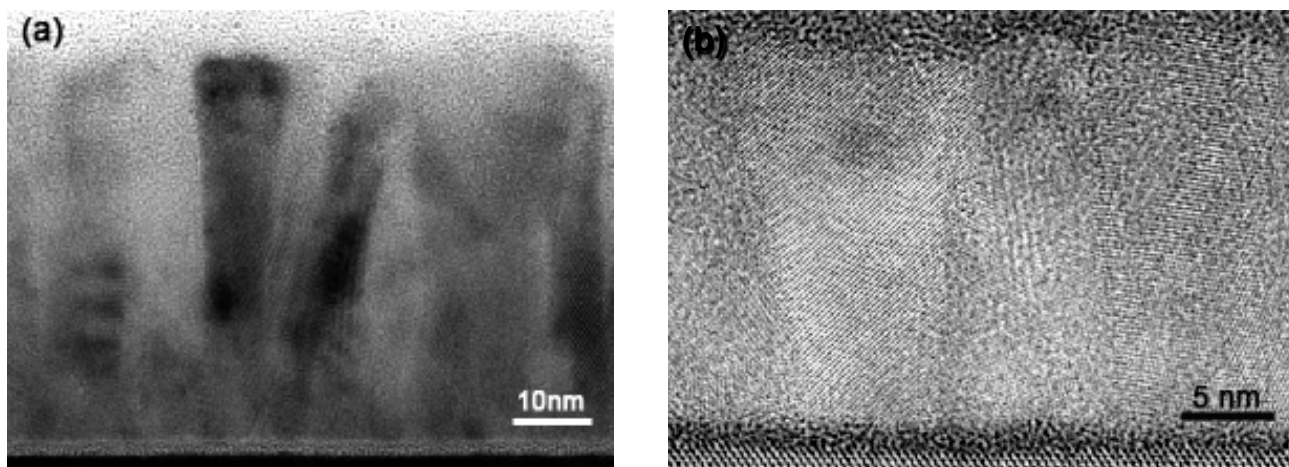


FIG. 1. (a) Low resolution image of $\text{Co}_{0.8}\text{Mg}_{0.2}\text{O}$ showing columnar growth mode.
 (b) High resolution image of $\text{Co}_{0.88}\text{Mg}_{0.12}\text{O}$ layer showing crystallinity of individual grains

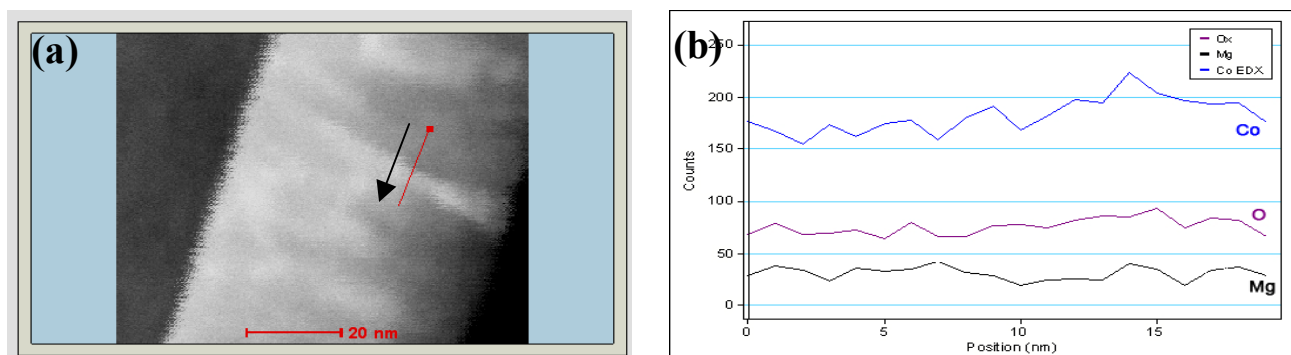


FIG. 2. (a) ADF image and (b) EDX spectrum of 490Å thick $\text{Co}_{0.8}\text{Mg}_{0.2}\text{O}$ (20% Mg) sample showing a uniformly distributed Co and Mg content across the width of the sample.

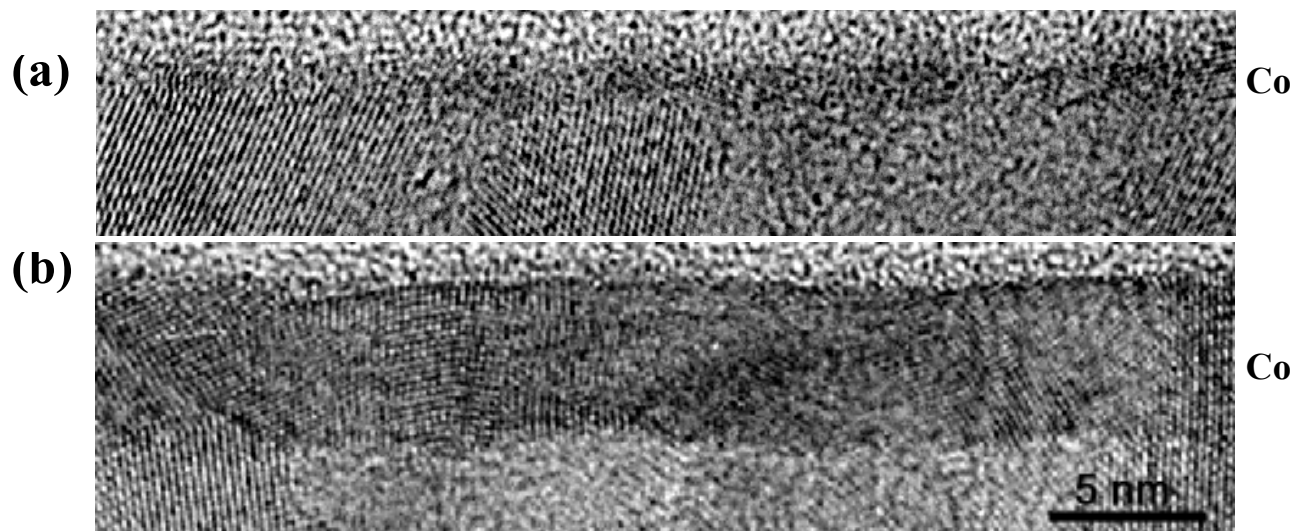


FIG. 3 High resolution electron micrographs of - (a) NiCoO/Co(1nm) and (b) NiCoO/Co(5nm) exchanged-coupled bilayers. Note the discontinuous Co grain growth in (a) becoming continuous for the thicker Co film in (b).