Coexistence of Exchange-Bias Fields and Vertical Magnetization Shifts in ZnCoO/NiO System

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According to theoretical calculations, doped ZnO can be a dilute magnetic semiconductor (DMS) with a high Curie temperature.[1] To integrate DMSs into spintronic devices, an exchange-biasing scheme is quite important. Exchange coupling between a DMS ($Ga_{1-x}Mn_xAs$) and an antiferromagnetic (AFM) layer (MnO) has been reported;[2] however, very limited work has been reported on the exchange bias of oxide-DMS systems. In this work, we report the exchange bias between epitaxially grown $ZnCo_{0.07}O$ and NiO.

The Cu 40/ $ZnCo_{0.07}O$ 40/NiO 50 (nm) structure was grown on Si (001) substrates at room temperature by using an ion beam deposition (IBD) system. A composite target composed of a Zn target and Co chips was used for ZnCoO deposition. During the ZnCoO deposition, Ar and O_2 were simultaneously introduced. The XRD patterns indicated a good out-of-plane (0002) texture of ZnCoO and (111) NiO on (200) Cu underlayers. Epitaxial relationships were confirmed by performing the phi-scan measurements (Fig. 1). The high incident ion energy provided by IBD effectively promoted the epitaxial growth of ZnCoO at room temperature.

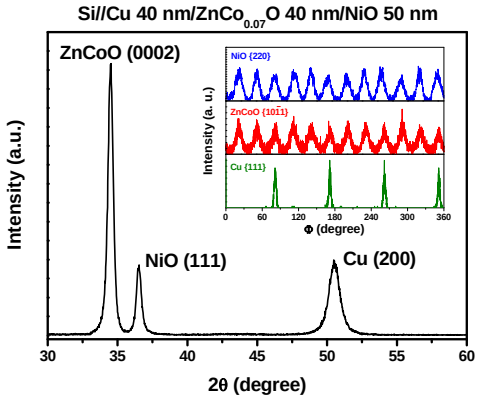

Figure 1. XRD pattern of the Si/Cu/ZnCoO 40 nm/NiO 50 nm film. The inset shows the phi-scans.

To rule out the existence of Co clusters, the valence state of Co in $ZnCo_{0.07}O$ was identified by using XPS with a synchrotron radiation beam. Only $2p^{3/2}$ peak of the Co^{2+} state locating at 781 eV can be observed and no metallic Co peak at 778 eV appears (Fig. 2). In addition, TEM observations and temperature dependence of resistance were also performed to exclude the existence of Co clusters in $ZnCo_{0.07}O$ films. Room-temperature ferromagnetic behavior was observed for $ZnCo_{0.07}O$ films.

The hysteresis loops of ZnCoO/NiO samples, measured at 5 K through a ZFC process, showed no field or magnetization shifts. The coercivity was 173 Oe, larger than that of ZnCoO films without the NiO layers (115 Oe),

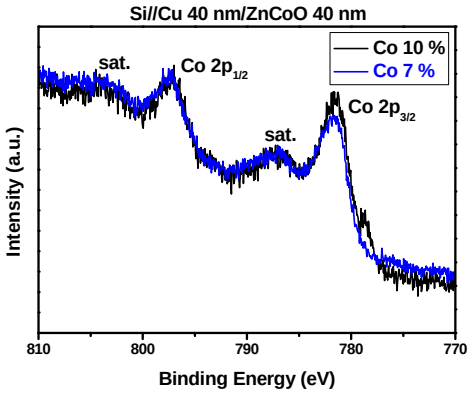

Figure 2. Co $2p^{3/2}$ peak of the $ZnCo_{0.07}O$ and $ZnCo_{0.1}O$

measured at 5 K. The enhanced coercivity of ZnCoO/NiO samples indicated the existence of exchange coupling between NiO and ZnCoO. Samples cooled down to 5 K in a field of 2 T (FC) showed an exchange field H_{ex} of 120 Oe and a clear vertical magnetization shift (Fig. 3) also shows that the direction of the horizontal loop shift is opposite to the cooling-field direction. Furthermore, the hysteresis loops revealed a higher saturation magne-tization in the positive-field side when the sample was cooled in a positive field and vice versa for the samples cooled in a negative field. These results implied that both directions of the field shift and magnetization shift were determined by the cooling-field direction.

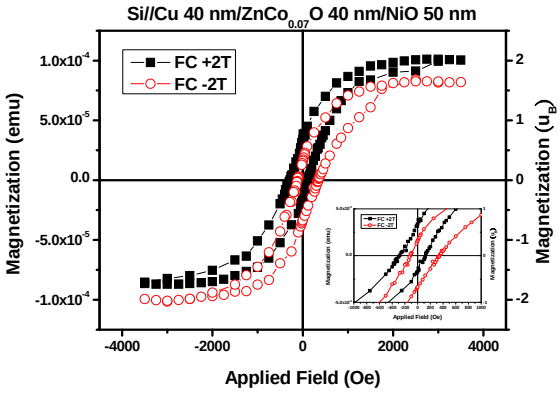

Figure 3. Hysteresis loops measured at 5 K of FC samples of Si/Cu/ZnCoO/NiO with cooling fields of +2 T and −2 T. Inset shows the magnified loops to demonstrate the direction of loop shifts.

Reference

[1] T. Dietl *et al.*, Science **287**, 1019(2000).

[2] K. F. Eid *et al.*, Appl.Phys.Lett. **85**, 1556 (2004).