Chapter 7

Conclusion

This dissertation has presented the studies of half-metal Fe_3O_4 and DMS (dilute magnetic semiconductor) ZnCoO material. In addition, we also investigate Fe_3O_4 and ZnCoO based magnetic tunnel junctions with a crystalline MgO layer. Several important results are summarized here.

Fe_3O_4 is predicted to possess ~100% spin polarization and has a high Curie temperature. In our studies, polycrystalline and epitaxial Fe_3O_4 films can be grown at room temperature by reactive ion beam deposition on Si (100) and MgO (100) substrates, respectively. EELS and XRD analyses suggested that the Fe_3O_4 phase can be obtained at room temperature. The T_V of 110K was observed on 195 nm epitaxial (100) Fe_3O_4 films, and significantly decreased with decreasing thickness. The reduction of T_V in thin films might be related to the effects of residual strain. To integrate epitaxial Fe_3O_4 films on Si substrates, the epitaxial Cu underlayer was deposited on Si substrates to obtain (111) Fe_3O_4 layers. The high-quality epitaxial (100) Cu/ (111) Fe_3O_4 films were achieved and were deposited at room-temperature. X-ray φ-scans revealed unusual 12-fold symmetry of (111) Fe_3O_4 films on Cu (001) underlayers. TEM diffractions verified that the two sets of the (111) epitaxial grains rotated by 90 degree with respect to each other along [111] direction were formed in the Fe_3O_4 layer. A clear Verwey transition observed at 116K indicates the formation of a stoichiometric Fe_3O_4 film.

A diluted magnetic semiconductor (DMS) is one of the promising candidates for spintronic devices due to its capability of manipulating both degrees of freedoms of electrons' spins and charges. Theoretical investigations predicted that Co-doped ZnO may possess room-temperature ferromagnetism. We used an IBD system to grow textured and epitaxial $ZnCo_{0.07}O$ films at room temperature on Si wafers. ZnCoO films were n-type semiconductors with high carrier concentrations (>$10^{19}/cm^3$). The epitaxial (0002) bi-crystalline ZnCoO films were obtained by using Cu underlayers on (001) Si wafers and showed room-temperature ferromagnetism. Room-temperature ferromagnetic behavior was observed with coercivity of 70 Oe. To integrate DMSs into devices, we studied exchange biasing scheme of ZnCoO/NiO. The quasi-epitaxial full-oxide exchange-bias system (ZnCoO/NiO) was prepared at room temperature. In this system, we simultaneously observed magnetization and field shifts in ZnCoO/NiO bilayers with a field-cooling (FC) process. The magnetization shift approached zero and temperature dependences of exchange fields showed a transition around 50 K, indicating that parts of ZnCoO magnetization were pinned through the FC process at temperatures below 50 K. In addition to the exchange coupling between NiO and ferromagnetic ZnCoO, the extra pinning mechanism arises at temperatures below 50 K, plausibly originating from the existence of "frozen" SGL phases, in which spins are strongly coupled to NiO. Those aligned "frozen" spins resulted in the observed magnetization shifts and enhanced exchange fields. Furthermore, the linear dependence of the exchange bias field on the vertical magnetization shift demonstrates that the exchange field is strongly related to the number of pinned uncompensated spins.

Finally, the Fe_3O_4 and ZnCoO layers were fabricated into the MTJ device with a crystalline MgO barrier. The main work of this topic focuses on the fabrication and spin-transport behavior of this fully oxides MTJs. The full stack MTJs of SiO_2// Ta 20nm/ ZnO 2.5nm/ MgO 1.2nm/ Fe_3O_4 50nm/ MgO 3nm/ ZnCoO 50nm/ Ta 10nm were obtained by using ion beam deposition system. This stack included a conducting electrode, Ta, suitable for a lift-off process, a textured MgO barrier with sharp interface and highly texture FM layers, Fe_3O_4 and ZnCoO thin films. The full stack MTJ was fabricated at room temperature. The non-linear I-V curves of the MTJs patterned by a lift-off process indicated that electron transport was dominated by tunneling. The MR of the full oxides stack MTJ was 2.68% at 150K. Furthermore, the clear plateau of the R-H curve was observed in the low field region, which represented the typical pseudo-spin valve switching behavior. It was a strong evidence to prove that DMS could provide the spin-polarized electrons.

This is the first report of the full oxide MTJs composed of Fe_3O_4 and ZnCoO FM layers. In addition, it also provides a strong evidence to prove that ZnCoO could provide the spin-polarized electrons. On the other hand, a highly textured (100) Fe_3O_4 thin films were directly grown on the amorphous bottom electrodes on Si substrate with room temperature process. The conventional deposition method, room-temperature process and simple requirement of the bottom electrode made Fe_3O_4 more capable in integrating into spintronic device.

Although the operation of MTJ device was demonstrated at 150K, the MR value of the stack is much lower than we expected. Several possibilities such as spin flip process due to the defective insulating barrier, formation of the magnetic dead layer at interface have been suggested. On the other hand, the lift-off process could be further improved to solve the pollution on the bottom electrodes and un-sharp side wall of the MTJ stacks. Finally, in the future plane, exchange-biased FM layer, ZnCoO, should be integrated into MTJ stacks. It enables us to well control the alignment of the Fe_3O_4 and ZnCoO FM layers, respectively, to obtain the complete anti-parallel state, and thus high MR value of the MTJ stacks.