A study on the magnetic properties of Mn-doped ZnO films with oxygen vacancy

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The ferromagnetic Mn-doped ZnO film, grown by an elaborate deposition technique, is needed because their ferromagnetic ordering is significantly sensitive to the charge carriers in a spin-split impurity band formed by the extended donor states, which is induced by native defects such as oxygen vacancy. All of Zn$_{0.95}$Mn$_{0.05}$O$_{1.5}$ films with a thickness of 100 nm were prepared by magnetron co-sputtering in reactive oxygen. High-purity oxygen gas (99.999%) was introduced into the vacuum chamber for a $P_{O_2}$ range of $1.2 \times 10^5$ to $2.2 \times 10^7$ Torr during growth, were monitored with a residual gas analyzer. The crystalline structures and the compositions were determined by XRD and Rutherford backscattering spectroscopy (RBS), respectively. The magnetic properties were measured with a superconducting quantum interference device magnetometer. All the films were found to be highly oriented along the $c$-axis of hexagonal structure, and no peak from other phases has been seen. The resistivity is decreased with increasing the oxygen vacancy which is determined by RBS in the oxygen-resonance mode. These results indicate that the increment of conductivity, which might be due to the formation of donor level, could be controlled by $P_{O_2}$. The $M$-$H$ curves show that the film, prepared at a $P_{O_2}$ of $2.2\times10^7$ Torr, exhibits a large magnetic moment of $3.27\mu_B$ at room temperature and a $T_C$ above 350 K, while the films at an partial pressure of higher than $1.2\times10^6$ Torr reveal the nonmagnetic behaviors. These magnetic results suggest that the important role of oxygen vacancy is confirmed evidently for the ferromagnetic ordering in Mn-doped ZnO film, and open up another possibility for the realization of spintronic devices.