PD10

Enhanced Ferromagnetic Properties of Diluted Fe Doped ZnO with Al Co-doping

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The transition-metal doped ZnO has drawn much attention for the suggested possibility of room temperature ferromagnetism in ZnO-based diluted magnetic semiconductor (DMS) [1]. The presence of magnetic ions such as 3*d* transition metal ions in these materials leads to an exchange interaction between itinerant *sp* band electrons or holes and the *d* electron spins localized at the magnetic ions, resulting in versatile magnetic field induced functionalities. We studied with an Al added and Fe doping novel II-VI oxide semiconductor, $Zn_{0.99-x}Al_{0.01}Fe_xO$ (x = 0, 0.02, 0.05) by solid reaction method, which has excellent magnetic properties and similar lattice constants to those of ZnO.

Al-added $Zn_{0.99-x}Fe_xAl_{0.01}O$ (x = 0, 0.02, 0.05) powders were prepared with annealing in Ar atmosphere at 1200℃. The crystalline structure for $Zn_{0.99-x}Fe_xAl_{0.01}O$ was determined with x-ray diffraction at room temperature. The magnetic property was studied of an applied field at various temperatures and temperature dependence of the moment curves by the vibrating sample magnetometer(VSM). The electric properties were characterized by a temperature dependence of resistance and Hall measurement.

The x-ray diffraction patterns of the Al-added ZnO based Fe doped samples showed a wurtzite single phase, without any segregation of Fe or Al. The lattice parameters for the $Zn_{0.94}Fe_{0.05}Al_{0.01}O$ were a_0 = 3.254 and c_0 = 5.209 Å at room temperature. The hysteresis curve for the $Zn_{0.94}Fe_{0.05}Al_{0.01}O$ at room temperature was indicated to the ferromagnetic phase as shown in Fig. 1. As the $Zn_{0.94}Fe_{0.05}Al_{0.01}O$, the ferromagnetic effect was explained to increasing exchange interaction between the neighboring magnetic polaron due to the carrier concentration increasing. The temperature dependence of magnetization curve is measured from 60 to 350 K and indicated that the Curie temperature has above the room temperature. The temperature dependence of resistance curve of all samples was shown magnetic semiconductor behavior.

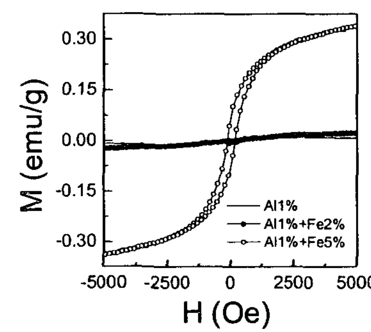

Fig. 1: The Hysteresis Loops for Diluted Fe-Ion Doped ZnO Powder at Room Temperature.

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PD11

Ferromagnetism of Ni Cluster in Ni Doped ZnO by Solid State Reaction

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Diluted magnetic semiconductor (DMS) has been intensively studied in recent years for its potential applications in spintronics material and basic research significance in magnetism[1-3]. K. Sato et. al. indicated that the ferromagnetic state could be stabilized by electron doping in the case of Fe-, Co- or Ni-doped ZnO.[4] Electron doped ZnO is easily achievable because the intrinsic defects such as O vacancies or Zn interstitials in ZnO may make it *n*-typed.[5] And also H.T. Lin et. al. found the ferromagnetism of $Zn_{1-x}Co_xO$ made by solid state reaction, could be enhanced by additional Cu doping.[6]

We present here our studies on the Ni-doped ZnO made by solid state reaction and make a discussion on the origination of its room temperature ferromagnetism.

The polycrystalline samples of $Ni_xZn_{1-x}O$ (x = 0.02, 0.03, 0.04, 0.05) were prepared by the standard solid state reaction. The raw materials are pure ZnO and NiO powders which are confirmed non-ferromagnetic. The raw materials of the two oxides are mixed and milled in agate vials with agate balls. The grounded mixture are sealed in quartz tube and calcined at 1273K for 24 hours. The ZnO as a raw material, is chosen for its easy obtainability, wide gap energy, high excitation binding energy and extensive applications. The solid state reaction is chosen for its reproducibility and easy control. Although the raw materials are non-ferromagnetic, the prepared $Ni_xZn_{1-x}O$ after the reaction are observed ferromagnetic at room temperature. Through X-ray diffractometry, VSM measurement, Hall effect and thermal gravimetric analysis under a magnetic field of 150Oe, all the experiments show that, the room temperature ferromagnetism originates from the nano-sized Ni clusters which are formed from the decomposition of NiO during calcinations. The magnetic properties can be explained by the microstructure of sparsely distributed, randomly oriented and magnetically saturated Ni clusters. Another group of NiZnCuO samples are also made with the same method, but no ferromagnetism is observed. The addition of Cu ions will block the decomposition of NiO because the Cu^{2+} is more likely reduced to Cu^{+}. Hall Effect confirms no exchange coupling between local spins and charge carriers.

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