Defect induced ferromagnetic interaction in Co^{2+}-doped Y_2O_3 nanorods

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1. Introduction

In recent research, dilute magnetic oxide (DMO) systems are one of the promising candidates for potential spintronics application, because they display room-temperature ferromagnetism [1]. The recent literature on transition-metal-ion-doped room-temperature ferromagnetism in low-band-gap (~3.0 eV) ZnO, TiO_2, SnO_2 and In_2O_3 systems is vast [2-7]. Although the origin of such room-temperature ferromagnetism in these oxides is explained by the bound magnetic polaron (BMP) model [8], there remains controversy with respect to its scientific explanation. There have been few reports of the existence of ferromagnetism in Cr-doped In_2O_3 [7], whereas it has been established that Fe-doped TiO_2 exhibits paramagnetism [6]. Griffin [9] and Tian at al. [10] have reported non-intrinsic ferromagnetism due to the formation of ferromagnetic clusters or impurity. According to the BMP model, oxygen vacancies defects play an important role in determining the existence of ferromagnetism in such DMOs. Because the oxygen-vacancy concentration (V_o) can be controlled, the saturation magnetization can be modulated accordingly [8].

Meanwhile, for hybrid device application in the present research, high-κ dielectric systems such as Y_2O_3 are of great interest, though little attention has been paid to one-dimension (1D) nanostructures. In the present study, we synthesized $Y_{2-x}Co_xO_3$; (x = 0.00, 0.04, 0.08) nanorods by hydrothermal method and studied the room-temperature magnetic properties of pure and transition metal Co^{2+} ions doped Y_2O_3 nanorods.

2. Results

Co^{2+}-doped Y_2O_3 nanorods of 70-100 nm diameters and 0.3-2 μm lengths with different compositions (x = 0.00, 0.04, 0.08) in $Y_{2-x}Co_xO_3$ were synthesized by a hydrothermal method. The X-ray diffraction, Raman spectra, X-ray photoelectron spectroscopy and transmission electron microscopy (TEM) results indicated the formation of a pure cubic phase structure of Y_2O_3 doped with Co^{2+} ions without any secondary phase formation. The TEM analysis indicated that the nanorods were grown along the [100] axis. The pure Y_2O_3 nanorods showed diamagnetism whereas the Co^{2+}-doped ones exhibited room-temperature ferromagnetism. The existence of such room-temperature ferromagnetic behavior in Co^{2+}-doped Y_2O_3 nanorods is due mainly to the existence of oxygen vacancies defects originating after the doping of transition metal Co^{2+} ions in the Y_2O_3 host lattice. Oxygen vacancies act as defect centers in the bound magnetic polaron model to account for this dilute magnetic oxide of medium band gap with low transition metal Co^{2+} ions concentration. The presence of defect-related oxygen vacancies was further confirmed by the photoluminescence (PL) spectra analysis.

3. Discussion

The surface morphology was examined by SEM and TEM. The straight rod-shape morphology of the pure and Co-doped Y_2O_3 samples are of 70-100 nm in diameter and 0.3 μm-2 μm in length. The XRD patterns properly matched the pure-phase cubic crystal structure and Ia-3 space group. The analysis of the XPS spectra indicated the presence of three elements, Y, O and Co, in the $Y_{1.96}Co_{0.04}O_3$ composition, and the oxidation state of Y was Y^{3+}. As described in the bound magnetic polaron (BMP) model, ferromagnetism in such insulating DMOs occurs due to localized defects instead of the electron-mediated magnetism proposed for conducting diluted magnetic systems (DMSs). In our case, when the Co^{2+} ion is present, oxygen vacancies (V_o) surrounding it are created as Co^{2+}–V_o–Co^{2+}, and these act as defect centers that mediate the localized carriers and affect the ferromagnetic properties. Therefore, the magnitude of ferromagnetism is dominated by the incorporation of transition metal Co^{2+} ions, which creates defect centers associated with oxygen vacancies.

4. Conclusions

We synthesized pure and Co-doped Y_2O_3 nanorods of high aspect ratio of dimensions using a simple and inexpensive hydrothermal process and studied their formation mechanism as well as structural and magnetic properties. The pure Y_2O_3 nanorods exhibited linear diamagnetism, whereas the Co^{2+}-doped Y_2O_3 nanorods showed room-temperature ferromagnetism. The existence of ferromagnetism in doped samples is due to the creation of oxygen vacancies during defect formation in the host lattice. The ferromagnetic behavior is explained by the defect-mediated mechanism in the framework of the bound magnetic polarons. The present PL spectra confirmed the existence of additional oxygen vacancies in the doped Y_2O_3 nanorods. Such variation in the magnetic behavior of DMO through oxygen vacancy increase after doping with transition metal ion can be used for potential applications in spintronics.

5. References

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