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Structural, Optical and Magnetic Properties of (In$_{0.90}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$ Nanoparticles

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Abstract. This study examined structural, optical and magnetic properties of ITO (In$_{0.95}$Sn$_{0.05}$)$_2$O$_3$ and Cu doped ITO (In$_{0.90}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$ nanoparticles synthesized by solid state reaction method. The synthesized nanoparticles were subjected to structural, optical and magnetic studies. The structural properties of the nanoparticles were carried out using XRD, Raman, FT-IR characterization techniques. Optical properties of the samples were studied using UV-Vis-NIR spectrophotometer. The magnetic measurements were carried out using vibrating sample magnetometer. The ITO (In$_{0.95}$Sn$_{0.05}$)$_2$O$_3$ nanoparticles exhibited room temperature ferromagnetism with clear hysteresis loop. The strength of magnetization decreased in Cu doped ITO (In$_{0.90}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$. The ITO nanoparticles were also exhibited ferromagnetism at 100 K with a magnetic moment of 0.02 emu/g.

Keywords: Nanoparticles, Cu doped ITO, solid state reaction, Ferromagnetism

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INTRODUCTION

Since the discovery of ferromagnetism in Mn doped ZnO [1] with Curie temperature above room temperature, much focus is being put on wide band gap oxide semiconductors. Intensive research work had been carried out on transitional metal doped oxide semiconductors such as ZnO, TiO$_2$ and SnO$_2$ [2]. But results were quite controversial. In few research articles it was reported that the observed ferromagnetism was due to metal clusters/secondary phases whereas in other research papers it was reported that the observed ferromagnetism was intrinsic in nature and explained by considering different model such carrier mediated interactions [3], double exchange interactions [4] bound polaron magnetic (BPM) model [5]. Reports on the Cu doped ITO nanoparticles are meagre. Hence an attempt is made here for the synthesis and characterization of ITO and Cu doped ITO nanoparticles.

EXPERIMENTAL

ITO (In$_{0.95}$Sn$_{0.05}$)$_2$O$_3$ and Cu doped ITO (In$_{0.90}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$ nanoparticles were prepared by simple standard solid state reaction method. In a typical synthesis, commercially available In$_2$O$_3$, SnO$_2$ and Cu$_2$O (Sigma–Aldrich, 99.999% pure) powders were taken in desired ratios and mixed in Agate mortar and ground thoroughly for 16 hours using pestle. The ground fine stoichiometric samples were loaded into a small one end closed quartz tube of diameter 10 mm and length 10 cm, which was then enclosed by a bigger quartz tube of diameter of 2.5 cm and length of 75 cm with a provision to allow unwanted vapours to escape from the reaction chamber and it was evacuated to a pressure of 2x10$^{-3}$ mbar using a rotary vane pump. The complete set up was placed in horizontal tubular microprocessor controlled furnace and heated for several hours at different temperatures. After that the samples were subjected to their structural and optical properties.

RESULTS AND DISCUSSION

Structural Properties

Fig.1 shows the X-ray diffraction patterns of the Cu$_2$O, In$_2$O$_3$, Sn doped In$_2$O$_3$ (ITO) and Cu doped In$_2$O$_3$ nanoparticles, respectively. The X-ray diffraction patterns of Cu$_2$O, SnO$_2$ are provided here.
to confirm that no secondary phases related to impurities in any form are present.

FIGURE 1. X-ray diffraction patterns of Cu$_2$O, In$_2$O$_3$, Cu doped ITO nanoparticles.

All the diffraction peaks were exactly coincided with cubic structure of In$_2$O$_3$. The XRD patterns conformed that the impurity phases were not observed in In$_2$O$_3$ nanoparticles. The diffraction peaks such as (2 1 1), (2 2 2), (4 0 0), (4 1 1), (3 3 2), (4 3 1), (5 2 1), (4 4 0), (4 3 3), (6 1 1), (5 4 1), (6 2 2), (6 3 1), (4 4 4), (5 4 3), (6 4 0), (7 2 1), and (6 4 2) were found in all the In$_2$O$_3$ nanoparticles among which (2 2 2) peak was predominant. All the indexed peaks exactly coincided with the cubic structure of In$_2$O$_3$ (JCPDS No. #06-0416). Similar diffraction peaks were also observed for ITO and Cu doped ITO nanoparticles. The crystallite size was calculated using Scherer’s relation and found that it was about 30 nm.

Optical Properties

FIGURE 2. Diffuse reflectance spectra of In$_2$O$_3$, SnO$_2$, ITO and Cu doped ITO nanoparticles.

The absorption coefficient was calculated using Kubelka-munk function relation [6]. Fig. 3 shows the optical band gap of the (In$_{0.95}$Sn$_{0.05}$Ni$_{0.05}$)$_2$O$_3$ nanoparticles. The optical band gap (E$_g$) was obtained by plotting ($\alpha h\nu$)$^2$ versus the photon energy (h\nu) and by extrapolating the linear region ($\alpha = 0$). The optical band gap was estimated using the Tauc relation [7]. The band gap of 3.12 eV was found for the (In$_{0.90}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$ nanoparticles.

FIGURE 3. Plots of ($\alpha h\nu$)$^2$ versus h\nu of the In$_2$O$_3$ and Cu doped ITO nanoparticles.

Magnetic properties

FIGURE 4. Magnetic hysteresis loops (M–H) of ITO and Cu doped ITO nanoparticles at room temperature.

Fig. 4 shows the magnetic hysteresis curves of undoped and Cu doped ITO nanoparticles at room temperature. The In$_2$O$_3$ and SnO$_2$ exhibited diamagnetic nature at room temperature. But ITO (In$_{0.90}$Sn$_{0.05}$)$_2$O$_3$ nanoparticle exhibited ferromagnetism at room temperature and at 100 K. The clear hysteresis loop of the (In$_{0.95}$Sn$_{0.05}$)$_2$O$_3$ nanoparticle indicates that the Curie temperature for these nanoparticles is higher than room temperature. The hysteresis loop shows a high coercive field (Hc) of 683 G. The observed magnetic moment is almost equal to that of magnetic moment observed by Peleckis et al [8] in Ni doped In$_2$O$_3$ nanoparticles prepared by solid state synthesis route method.
Transition metal doped SnO$_2$ and In$_2$O$_3$ exhibited room temperature ferromagnetism in our earlier studies. In the present study, tin doped In$_2$O$_3$ (ITO) nanoparticles also exhibited room temperature ferromagnetism. The (In$_{0.95}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$ nanoparticles also exhibited room temperature ferromagnetism but the strength of magnetization decreased in (In$_{0.95}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$ nanoparticles.

![Magnetic hysteresis loops (M–H) of ITO nanoparticles at 100 K.](image)

**FIGURE 5.** Magnetic hysteresis loops (M–H) of ITO nanoparticles at 100 K.

The samples exhibited the saturation magnetic moment ($M_s$) of 0.05 emu/g, coeversity ($H_c$) of 683 G and retentivity ($M_r$) of 0.02 emu/g, respectively. Whereas the strength of magnetization decreased in Cu doped ITO nanoparticles. The observed saturation magnetic moments are better than that of saturation magnetic moment of Co doped SnO$_2$ nanoparticles prepared by co-precipitation method [9]. Fig 5 shows the M-H curve of ITO nanoparticles at 100 K. From the figure it is clear that the saturation magnetic moment decreased at lower temperature. It may due to antiferromagnetic or ferrimagnetism developed at low temperature. Room temperature ferromagnetism was also observed in Fe doped ITO nanoparticles also exhibited room temperature ferromagnetism at room temperature and the strength of the magnetic moment decreased after doping Cu into ITO lattice.

**CONCLUSION**

ITO (In$_{0.95}$Sn$_{0.05}$)$_2$O$_3$ and Cu doped ITO (In$_{0.95}$Sn$_{0.05}$Cu$_{0.05}$)$_2$O$_3$ nanoparticles were prepared using standard solid state reaction method and studied the structural, optical and magnetic properties systematically. The ITO and Cu doped ITO nanoparticles exhibited ferromagnetism at room temperature and the strength of the magnetic moment decreased after doping Cu into ITO lattice.

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**REFERENCES**