Synthesis, Characterization, Electrical and Magnetic Properties of Ni Doped ZnO Based Diluted Magnetic Semiconductors

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INTRODUCTION

Diluted magnetic semiconductors (DMSs) have gained interest in the recent years because of their ability to exhibit room temperature ferromagnetism which is a necessary requirement in the fabrication of spintronic devices [1]. In this type of devices the spin of electrons instead of or in addition to their charge is used to transport information within the device and beyond. Presently lot of experimental and theoretical research is being done to understand and develop DMS materials. Largely the experimentation is based on the doping of ZnO with wurtzite structure as a semiconductor material with energy band gap of around 3.4 eV, with transition metals (TM) like Ni, Co, Mn etc [2]. However, the origin of ferromagnetism in these DMSs remains controversial even today. Several reports suggest that the room temperature ferromagnetism in TM-doped oxides originates from precipitation of magnetic cluster or secondary magnetic phases [3], while other reports say that ferromagnetic ordering may be intrinsic [4]. In the present investigation nanoparticles of Ni doped ZnO with the composition $Zn_{(1-x)}Ni_xO$ (x=0.05, 0.15, 0.2) were prepared by auto combustion technique. The nanoparticles so obtained were investigated for their physical, structural, electrical and magnetic properties. Interesting findings observed in the course of these investigations are reported in this article.

EXPERIMENTAL

Samples of Zinc oxide doped with Nickel with composition $Zn_{(1-x)}Ni_xO$ where x=0.05, 0.15, 0.2, were prepared using auto combustion method. Metal salts in the form of nitrates with Glycine [NH_2·CHOOH] as a fuel for combustion along with a suitable complexing agent to facilitate the chemical reaction dissolved in distilled water were used as raw materials to prepare the required nanoparticles of the material. The crystal structure and the particle size of the samples were determined from the X-ray diffraction data. FTIR was also obtained as a part of normal characterization of the samples prepared. The magnetic properties of the samples were obtained on Quantum Design Versa Lab 3T SQUIDVSM. Thermopower and resistivity profiles as functions of temperature were recorded on automated standard setups.

V. Rajendran, K. Thyagarajah and K.E. Geckeler (eds.)
Nanoelectronics and Sensors, pp. 85-88 (2015)

RESULTS AND DISCUSSION

XRD and FTIR Analysis

Figure 1 shows the XRD pattern of $Zn_{0.85}Ni_{0.15}O$. Similar patterns were also obtained for the other two samples. The diffraction peaks obtained agree well with the jcpds card number 36-1451 indicating formation of hexagonal wurtzite structure of ZnO. This confirms formation of monophasic samples. The lattice parameters for the sample as calculated are a = 3.227Å and c = 5.269Å. The crystallite sizes of the samples obtained in the powdered form were calculated using the Debye –Scherrer formula. The average crystallite sizes obtained for the three samples with 5%, 15% and 20% Ni concentration were 43.4 nm, 30.9nm and 30.3nm respectively.

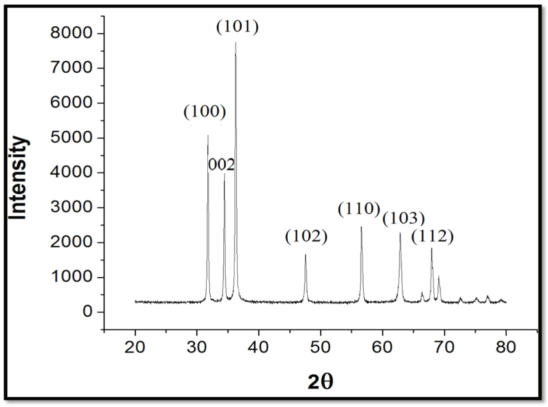

Fig. 1. XRD pattern of $Zn_{0.85}Ni_{0.15}O$

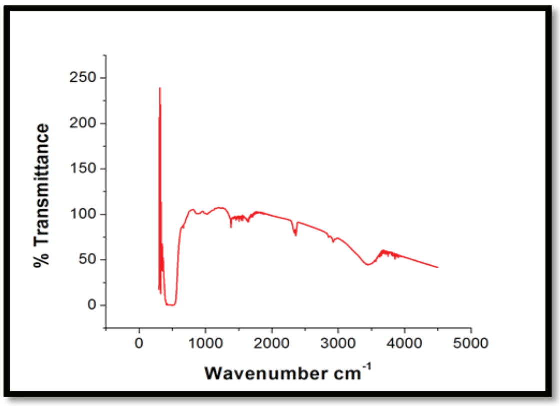

Fig. 2. FTIR spectrum of $Zn_{0.8}Ni_{0.2}O$

The FTIR spectrum as obtained for $Zn_{0.8}Ni_{0.2}O$ is shown in figure 2. Similar spectra were also obtained for the other two samples. The characteristic bands between 420 cm^{-1} and 640 cm^{-1} for all the samples are ascribed to the Zn—O stretching modes [5]. A broad band in the region 3000 - 3700 cm^{-1} can be attributed to O-H stretching modes [6]. Bands around 2200 cm^{-1} region are the overtone bands produced due to the adsorption of CO [5,7]. In addition to these bands, sharp absorptions bands at 2365 cm^{-1}, 2363 cm^{-1} and 2358 cm^{-1} observed in case of the three samples can be correlated to overtone bands from M-CO stretching (M- transition metal)[5].

VSM Analysis

M-H curve obtained for $Zn_{0.85}Ni_{0.15}O$ is shown in figure 3. It was found that $Zn_{0.95}Ni_{0.05}O$ showed a diamagnetic behaviour with a fine hysteresis which is a unique behaviour. Whereas the other two samples namely $Zn_{0.85}Ni_{0.15}O$ and $Zn_{0.8}Ni_{0.2}O$ exhibit ferromagnetic like behaviour with distinct hysteresis behaviours.

The mechanism responsible for the observed room temperature ferromagnetism, although not very clear as per the available reports, may be attributed to the dopant material Ni that is a ferromagnetic material.

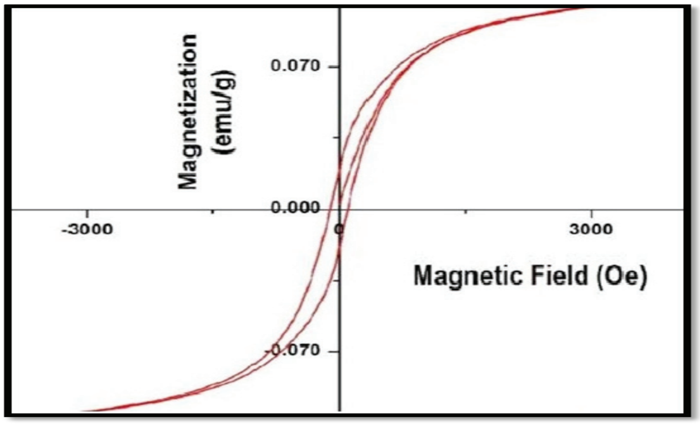

Fig. 3. Field dependence of Magnetisation (M vs H) curve for $Zn_{0.85}Ni_{0.15}O$

Electrical Measurements

The general trend of the resistivity is similar to the one that is observed in semiconductor. However, the same is found to vary with concentration of Ni in the sample which can be explained on the basis of band splitting model [8]. Partial overlap of anti-bonding *d* states with the conduction bands of host compounds can cause the itinerant electrons in the antibonding states to traverse to the conduction band leading to decrease in resistivity of TM ion doped ZnO systems [9]. The thermopower measurements give a negative seebeck coefficient for all the three samples indicating that the prepared samples are n type semiconductors. Sharp transitions observed in thermopower from high negative to low negative value at 65°C, 37°C and 61°C for $Zn_{0.95}Ni_{0.05}O$, $Zn_{0.85}Ni_{0.15}O$ and $Zn_{0.8}Ni_{0.2}O$ respectively may be due to a transition in magnetic phase of the samples. Nevertheless such behaviour is not observed in resistivity profile of the samples.

CONCLUSION

Nanocrystals of nickel doped zinc oxide with the composition $Zn_{(1-x)}Ni_xO$ (x=0.05,0.15,0.2) were successfully synthesized using auto combustion technique. X ray data revealed that the samples had crystallized in the hexagonal wurtzite phase. The average particle size was in the range of 30nm to 43 nm. Room temperature ferromagnetism is observed in samples with 15% and 20% nickel concentration making the samples good contenders for application in spintronics. The samples exhibited n type behaviour with probable ferromagnetic to paramagnetic transition at temperatures above room temperature. Hysteresis behaviour shown by the diamagnetic sample happens to be the unique behaviour seen in the first sample with x=0.05 that needs to be investigated further.

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