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The physical properties of nickel doped indium oxide thin film prepared by the sol-gel method and its potential as a humidity sensor

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ABSTRACT

Ni doped In_2O_3 ($Ni_xIn_{2-x}O_3$: x=0.00, 0.02, 0.04, 0.06, 0.08 and 0.10) films have been successfully prepared by a sol-gel method. All films have nanograins, cubic structures and single phase. The Ni unsystematically affected the film thickness and surface roughness. All films showed high transmission percentage i.e. in the range of 92–99% at wavelength more than 380 nm. All films except film with x=0.02 and 0.06 have magnetic properties. It is also found that all of the films were sensitive towards the humidity changes and can be used as a humidity sensor.

1. Introduction

Diluted magnetic semiconductor (DMS) materials have attracted many researchers due to their high potential as room temperature spintronic devices [1,2]. Group II-VI semiconductor alloy such as $Zn_{1-x}Mn_xTe$ and $Cd_{1-x}Mn_xTe$ are the first so-called DMS materials studied in 1980s [3]. However, these materials have very low ferromagnetic critical temperatures and also small solubility of magnetic ions in the hosts, thus leading to the search of new candidates. DMS oxide (DMO) materials have been reported to have a Curie temperature (T_C) as high as ~700 K [4]. Ideally DMO materials should have the advantages of Curie temperature >500 K, a choice of p or n type doping, magneto-optic effects including magnetic circular dichroism and anomalous Hall effect. The DMO general formula is $A_{1-x}M_xO_{n-p}$, where A is a non-magnetic cation, M is a magnetic cation (dopant), p is the concentration of oxygen vacancies which depend on the growth conditions and n=1 or 2. In_2O_3 is a wide band gap n type semiconductor (e.g. ~3.7 eV) material. Its based compound has been widely used as a transparent conductor. Many researchers have reported on the effect of doping transition metal into semiconductor oxides [5–12]. Philips et al. have reported the possibility of Cr doped indium oxide as dilute magnetic semiconductors [5]. Hong et al. have reported on magnetic properties for $In_{1.99}Co_{0.01}O_3$ thin films prepared by pulsed laser deposition technique [6]. Ghazi et al. reported that Ni doped and undoped ZnO films show ferromagnetic properties at room temperature meanwhile paramagnetic behavior is dominant for Mn doped film. However, it was found that the dopant reduces the transmission of the films [7]. Lightly Cr doped ZnO was reported to show ferromagnetic behavior at room temperature [8]. Ma et al. prepared Ni doped In_2O_3 powders using solid state reaction and found that after annealed in vacuum the samples shows room temperature ferromagnetism. The ferromagnetic properties can be switched 'on' and

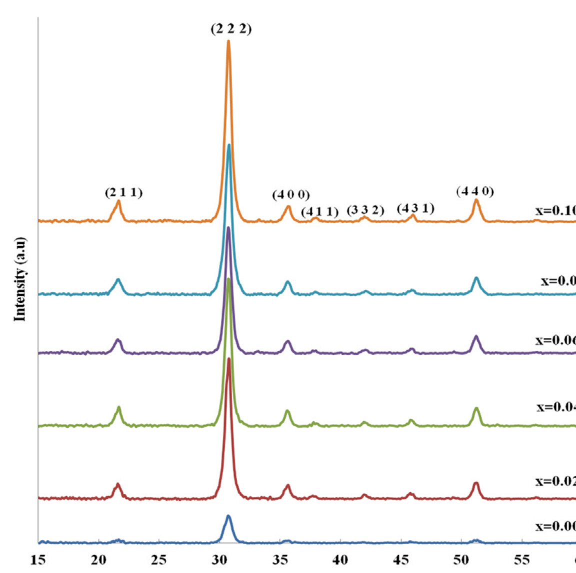

Fig. 1. X-ray diffraction patterns of $Ni_xIn_{2-x}O_3$ (x=0.00, 0.02, 0.04, 0.06, 0.08 and 0.10).

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'off' by alternate air and vacuum annealing [9]. Peleckis et al. reported on high temperature ferromagnetism and semiconducting behavior in Ni doped In_2O_3 powders prepared by conventional solid state synthesis technique [10]. Room temperature ferromagnetism of Ni doped In_2O_3 powders has also been reported by Prakash et al [11]. However, Ni dopant decreases the optical band gap of the samples. The room temperature ferromagnetism has also been reported in laser ablated Ni doped In_2O_3 thin films

Table 1
The lattice parameter, relative reliability of lattice parameter (R/R_0), grain size, thickness and surface roughness of films.

x contents	Lattice parameter (±0.001 Å)	R/R_o	Crystallite size (XRD) (±0.1 nm)	Average grain size (TEM) (±0.1 nm)	Thickness (±0.1 nm)	Surface roughness (±0.01 nm)
0.00	10.117	1.35	10.3	12.2	92.3	1.06
0.02	10.106	1.28	14.1	12.7	100.5	2.48
0.04	10.102	1.31	14.6	12.4	88.6	2.06
0.06	10.101	1.20	14.4	16.9	77.4	1.30
0.08	10.098	1.16	13.9	11.5	84.1	1.39
0.10	10.091	1.28	14.0	11.6	67.7	2.02

The relative reliability (R/R0) of lattice parameter is the simulation fitting of XRD pattern. The best fitting of R/R_o equals to 1.

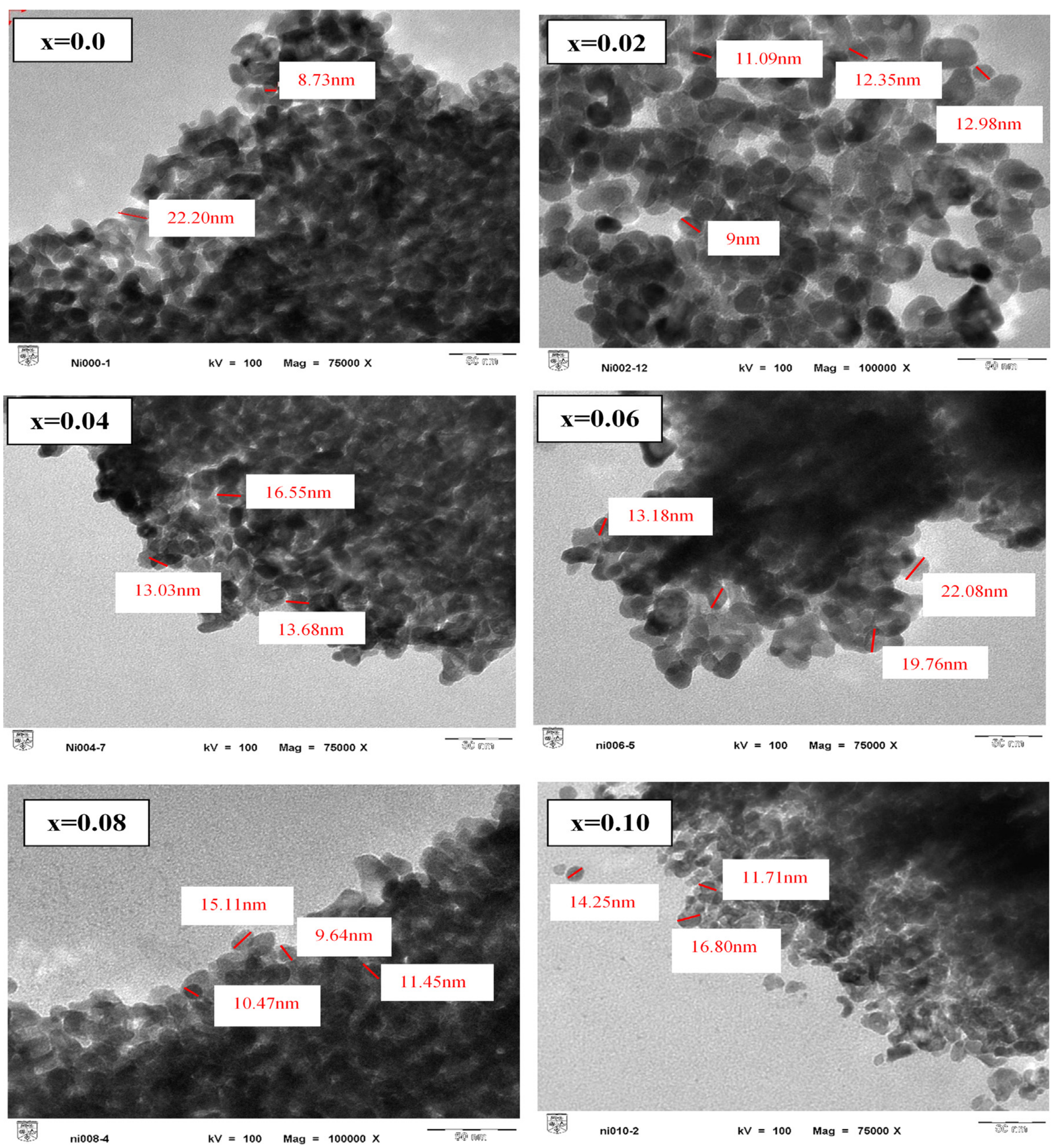

Fig. 2. TEM images of $Ni_xIn_{2-x}O_3$ (x=0.00, 0.02, 0.04, 0.06, 0.08 and 0.10).