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Structural, Magnetization and UV-Visible Study of Mn-Co-Ni Ferrite System

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Polycrystalline Mn-Co-Ni ferrite was synthesized by solid state reaction method at 950 ºC. X-ray diffraction pattern indicates that specimen has a cubic spinel type structure with lattice constant varies from 8.321 Å to 8.329 Å, X-ray density was calculated 5.39 g/cm^3 to 5.36 g/cm^3 and approximate particle size was found 36 nm. Magnetic measurements was carried out using VSM at room temperature (RT) where saturation magnetization (M_s) was found 55 emu/g to 42.19 emu/g, coercive field (H_c) was found 165 Oe to 88 Oe and magnetic moment (μ_B) was found from 2.30 μ_B to 1.75 μ_B. UV-visible measurement was recorded the maximum absorption was found at wavelength 213 nm to 222 nm and direct optical band gap found 3.32 eV to 3.96 eV.

Keywords: Ferrites; Magnetic; XRD; UV-Vis

1 Introduction

Spinel ferrite are soft magnetic materials with structural formula of MFe_2O_4 (M = divalent metal ion, *e.g.* Mn, Ni, Co, Cu, etc.). Ferrites are one of the well known attracting materials due to their interesting and important properties such as high specific heating, low melting point, large expansion coefficient, small saturation magnetic moment and lower magnetic transition temperature, *etc.*[1,2]. The spinel ferrites have many technical applications, such as in catalysis[3], photoelectric devices[4], nano devices[5] sensors[6], microwave devices[7,8] and magnetic pigments[9]. Magnetic properties of ferrites depend upon the nature of the ions, electronic configuration and their distribution among octahedral and tetrahedral sites[10]. Cobalt and Nickel ferrite are one of the most important soft ferrite materials because of its typical ferromagnetic properties, low conductivity and lower eddy current losses, catalytic behavior, high electrochemical stability, abundance in nature, etc. This ferrite is an inverse spinel in which eight units of $NiFe_2O_4$ go into a unit cell of the spinel structure. The ferric ions preferentially fill the tetrahedral sites and the others occupy the octahedral sites[11]. The synthesis of spinel ferrite materials have been widely reported in the recent years and the important role of the preparation methods on the structural features of the ferrites are discussed[12-15]. Wide - scale applications of ferrites have promoted the development of widely used chemical methods, including sonochemical reactions[16], hydrothermal[10], sol-gel methods[17], co-precipitation[18], microwave plasma[19], citrate precursor techniques[20], micro-emulsion methods[21], and mechanical alloying[22] for the fabrication of stoichiometric and chemically pure spinel ferrites. In this work, poly crystalline $Mn_xCo_xNi_{1-2x}Fe_2O_4$ (x = 0.20, 0.25 and 0.40) specimens were prepared via solid state reaction method and evaluating their particle size, structure, X-ray density, magnetic and optical properties.

2 Experimental Procedures

The poly crystalline specimens of $Mn_xCo_xNi_{1-2x}Fe_2O_4$ (x = 0.20, 0.25 and 0.40) ferrites were synthesized by solid state reaction method. A stoichiometric ratio of NiO (74.69), Cobalt Oxide (240.80), Manganese oxide and iron oxide (159.69) are taken provided by BDH with purity above 99% mixed in agate mortal with pestle manually grinded for two hours. This mixture was heated upto 950 ºC for 24 hours using a muffle furnace. Samples were grinded in a mortar again for two hours to get homogeneous powder. All compositions were sintered at 850 ºC for 24 hours. Finally get sample of desired compositions.

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3 Results and Discussions

3.1 Structural Analysis

Structural properties of prepared samples was investigated by x-ray diffraction using Phillips PW 1050 X-ray Diffractometer of wavelength (λ) 1.5406 Å from Cu-K_α radiation. Fig. 1 revealed X-ray diffraction (XRD) pattern of the prepared samples. The crystallite size D calculated by using the Debye-Scherrer equation[23].

$$D = \frac{0.9\lambda}{\beta\, cos\theta} \quad \ldots (1)$$

the lattice constant (a) was calculated using Bragg's equation[24] for a prominent peak (311).

$$a = \frac{d_{hkl}}{\sqrt{h^2+k^2+l^2}} \quad \ldots (2)$$

the actual x-ray density (ρ_x) was calculated using the following equation[25].

$$\rho_x = \frac{8M}{Na^3} \quad \ldots (3)$$

where M is molecular weight, N is Avagardo's number and a is lattice parameter.

The specific surface area defines as the area per unit mass. It is calculated using the following equation[26].

$$S = \frac{6000}{D\,\rho_x} \quad \ldots (4)$$

Figure 1 shows the XRD pattern of all three specimens. Pattern revels nine peaks (111), (220), (311), (222), (400), (422), (333), (440) and (533) located at 2θº = 18.54º, 30.41º, 35.77º, 37.41º, 43.43º, 53.94º, 57.39º, 62.89º and 74.48º. The most prominent peak (311) is confirmed the formation of cubic spinel structure belonging the Fd3m space group. In Table 1 the lattice constant was calculated 8.321 Å to 8.329 Å, X-ray density was found 5.39 g/cm^3 to 5.36 g/cm^3, average particle size calculated 36 nm and specific surface area was found 30.56 cm^2/g to 31.48 cm^2/g.

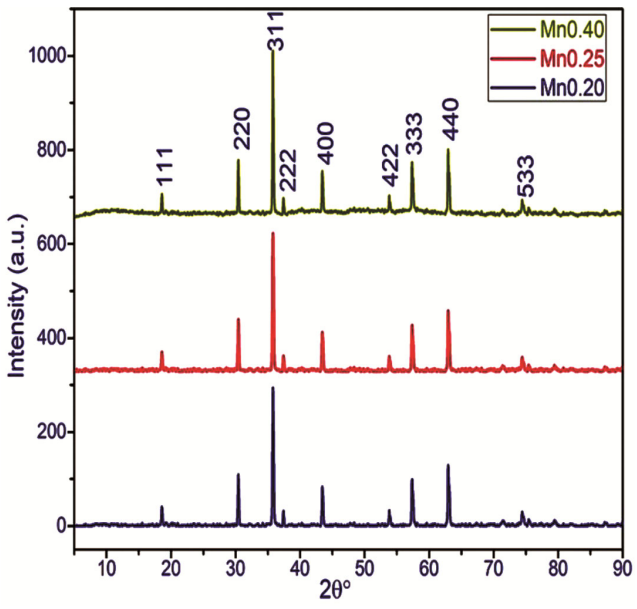

Fig. 1 — X-ray diffraction patterns of the samples.

3.2 Magnetic Properties

Figure 2 shown M-H loop of three samples were measured at room temperature, all samples exhibit ferromagnetic behavior. The data derived from M-H loop: saturation magnetization (M_s), residual magnetization (M_r) coercivity field (H_c), remanance ratio (R) = M_r/M_s and Magnetic moment calculated using the following equation[27].

$$\mu_B = \frac{M*M_S}{5585} \quad \ldots (5)$$

Where M is molecular weight of composition and M_s is saturation magnetization. Anisotropy constant (K) calculated from this equation[28].

$$H_c = \frac{0.96K}{M_S} \quad \ldots (6)$$

In Table 2 all calculated and experimental magnetic parameters are reported. Saturation magnetization was found 55 emu/g to 42.19 emu/g,

Table 1 — X-ray diffraction parameters of $Mn_xCo_xNi_{1-2x}Fe_2O_4$

x	Crystallite Size D (nm) (±0.1)	X-ray density (ρ_x) (g/cm^3)	S (cm^2/g)	a (Å) (±0.001)
0.20	36.42	5.39	30.56	8.321
0.25	36.14	5.37	30.92	8.328
0.40	35.56	5.36	31.48	8.329

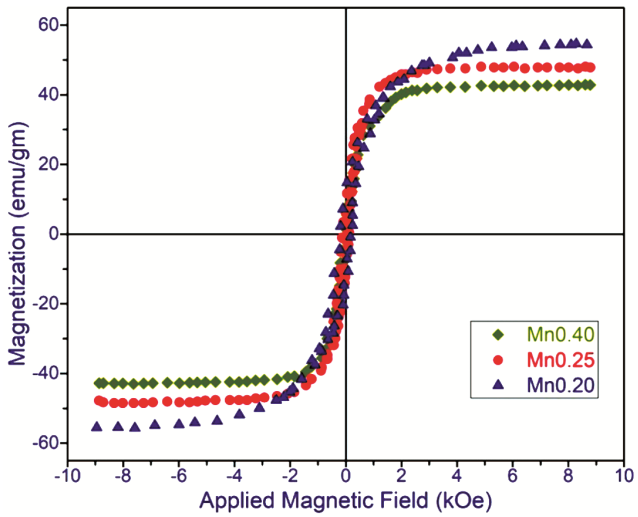

Fig. 2 — M-H plots for three samples at RT.

Table 2 — Magnetic and UV-Visible parameters of $Mn_xCo_xNi_{1-2x}Fe_2O_4$.

x	M_s (emu/g)	M_r (emu/g)	H_c (Oe)	$R = M_r/M_s$	μ_B	K (erg/Oe)	λ_{max} (nm)	E_g (eV)
0.20	55	15	165	0.27	2.30	9453.12	213	3.32
0.25	47.65	11.32	127	0.23	1.99	6303.69	215	3.46
0.40	42.19	5.39	88	0.12	1.75	3867.41	222	3.96

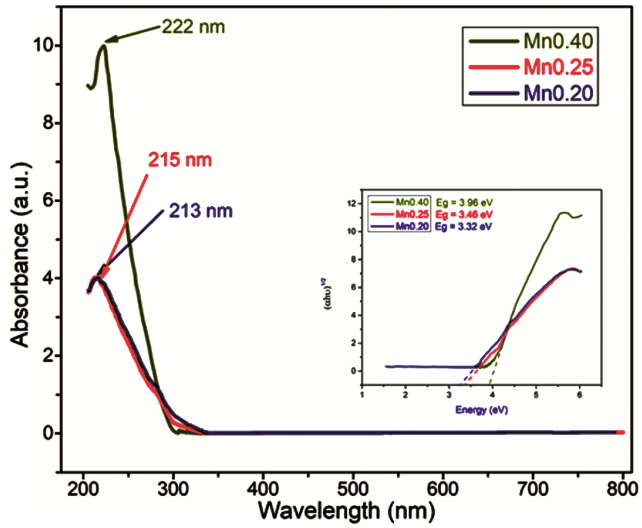

Fig. 3 — UV-Vis spectra and optical Band Gap graph of all three specimens.

residual magnetization found 15 emu/g to 5.39 emu/g, Coercivity field was found 165 Oe to 88 Oe, Remanence ratio was found 0.27 to 0.12, Magnetic moment was calculated 2.30 μ_B to 1.75 μ_B and anisotropy constant (K) was calculated 9453.12 erg/Oe to 3867.41 erg/Oe. Similar decreasing behaviour in magnetic moment has been observed in Ref. [2] for $Ni_{0.5}Co_{0.5}Gd_yFe_{2-y}O_4$ ferrites. Cation distribution dominates the resulting magnetic moments in the spinel ferrites systems[29,30].

3.3 UV-Visible studies

The optical properties of all three specimens were measured by UV –Visible spectroscopy in the wavelength range of 200 – 800 nm as shown in Fig. 3. The absorbance depends on so many factors such as band gap, grain size, lattice parameter, surface roughness and impurity[30].

In Fig. 3 revels that there is no visible absorption measured. These spectra show the higher absorption peaks λ_{max} at 213 nm to 222 nm towards lower wavelength. The optical direct band gap is calculated 3.32 eV to 3.96 eV. The absorption coefficient α is calculated by given equation[31] these parameters have been given in Table 2.

$$\alpha = \frac{2.303\,A}{t} \quad \ldots (7)$$

where A is absorbance and t is thickness of the sample.

The direct optical band gap was calculated by Tauc relation[32].

$$\alpha h\nu = A\left(h\nu - E_g\right)^{1/2} \quad \ldots (8)$$

where hν is photon energy and E_g is optical band gap.

4 Conclusion

All three samples have been successfully prepared by solid state reaction method. Structural parameters, crystalline size, and lattice parameter supported the considerable variations in values of magnetic parameters with doping of Mn/Co ions. Magnetization curve revels soft magnetic material with saturation magnetization 55 emu/g to 42.19 emu/g and magnetic moment is 2.30 Bohr magnetron to 1.75 Bohr magnetron. The UV-Visible studies revels the maximum absorption peaks λ_{max} at 213 nm to 222 nm and the direct optical band gap is calculated 3.32 eV to 3.96 eV. Magnetic behavior is observed to be strongly dependent on cation distribution and the variation in anisotropy constant is in accordance with the change in coercivity.

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Author contribution statement

Vijay Sharma: conceptualization, methodology, formal analysis, investigation, writing − original draft.

Anjali Oudhia: validation, resources, writing − review & editing, supervision, project administration.

M P Sharma: Methodology, validation, resources, writing − review & editing.

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