

# Structural Properties of Neodymium Substituted Cobalt Ferrite Synthesized by Standard Ceramic Technique

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**Abstract:** Neodymium substituted Cobalt ferrite having molecular formula  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  where ( $x = 0.00, 0.05$  and  $0.10$ ) samples have been prepared by standard ceramic technique. The structural properties were investigated by X-ray diffraction technique. X-ray diffraction data shows single phase cubic spinel structure for  $x=0.00$  sample and extra peak of neodymium is observed in substituted cobalt ferrite sample where  $x= 0.05$  and  $x=0.10$ . The structural parameters lattice constant  $a$  (Å), crystallite size  $t$  (nm) and X-ray density decreases and porosity increases with substitution of Neodymium in cobalt ferrite. The values of the tetrahedral and octahedral bondlength ( $d_{AX}$  and  $d_{BX}$ ), the tetrahedral edge ( $d_{AXE}$ ), and the shared and unshared octahedral edge ( $d_{BEX}$  and  $d_{BXEU}$ ) and Hopping length ( $L_A, L_B$ ) values are depend on the lattice parameter so, the lattice parameter decreases so the Hopping length ( $L_A, L_B$ ) also decreases with increasing neodymium ( $\text{Nd}^{3+}$ ) substitution content in cobalt ferrite  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x = 0.00, 0.05$  and  $0.10$ ).

**Keywords:** Cobalt ferrite, rare earth, X-ray diffraction

## 1. Introduction

Magnetic materials play very important roles in a daily life [1]. Among different magnetic materials, the ceramic materials received special attention due to the chemical stability, ease of synthesis and a high electrical resistivity value. One of the important magnetic spinel material, cobalt ferrite ( $\text{CoFe}_2\text{O}_4$ ) is a unique ferrite having inverse spinel structure. Cobalt ferrite is a hard magnetic material possessing high magneto anisotropy, high Curie temperature, high corecivity and moderate saturation magnetization along with the chemical stability and mechanical hardness [2]. Several researchers have studied pure and substituted cobalt ferrite with a view to understand their basic properties [3-5]. These studies revealed that substitution of nonmagnetic cations in cobalt ferrite predominantly affects the magnetic as well as electrical properties compared to magnetic cations. Recent research shows by introducing rare earth ions into the spinel lattice, can lead to small changes in the structural, magnetization and Curie temperature of the spinel ferrite. A small amount of rare earth element substitution in cobalt ferrites can affect the magnetic property as well as magnetic coercivity which make it suitable for different applications like hyperthermia treatment [6, 7]. Due to the localized nature of 4f electrons, rare earth elements possess large magnetic moments, large value of magneto crystalline anisotropy and high magnetostriction at low temperature. Since Nd has large ionic radii (0.0983nm), the substitution of Neodymium in the spinel structure leads to distortion of crystal structure [8] and change in coercivity [9]. In the present work we have focused to correlate the understandings between structural properties of Neodymium substituted cobalt ferrites having molecular formula  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x = 0.00, 0.05$  and  $0.10$ ).

## 2. Experimental Details

Polycrystalline specimens of  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x = 0.00, 0.05$  and  $0.10$ ) were prepared by standard ceramic technique using analytical reagent grade oxides compounds were accurately weighed in molecular weight percentage with a single pan microbalance. The mixed powders were wet ground and pre-sintered at  $950^\circ\text{C}$  for 24 hours. The sintered powder is again re-ground and pelletized. Polyvinyl alcohol was used as a binder in making circular pellets of 10mm diameter and 2–3mm thickness. The pellets were finally sintered in muffle furnace for  $1180^\circ\text{C}$  for 24 hours and then slowly cooled to the room temperature [10]. X-Ray diffraction patterns were taken at room temperature to confirm the crystal structure of the prepared samples. The XRD patterns were recorded in the  $2\theta$  range from  $20^\circ$  to  $80^\circ$  using  $\text{Cu-K}\alpha$  radiation ( $\lambda = 1.5406 \text{ \AA}$ ) with scanning rate  $1^\circ$  per/m.

## 3. Result and Discussion

**Structural Analysis:** Room temperature X-ray powder diffraction patterns (XRD) for series having molecular formula  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x=0.00, 0.05$  and  $0.10$ ) synthesized by standard ceramic method are shown in Figure 1. The X-ray diffraction patterns show the formation of cubic spinel structures  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  where ( $x=0.00$ ), with the appearance of characteristic peaks representing rare earth Neodymium based secondary phases structure in the ( $x=0.05$  and  $x=0.10$ ) compositions with of Neodymium in cobalt ferrite.

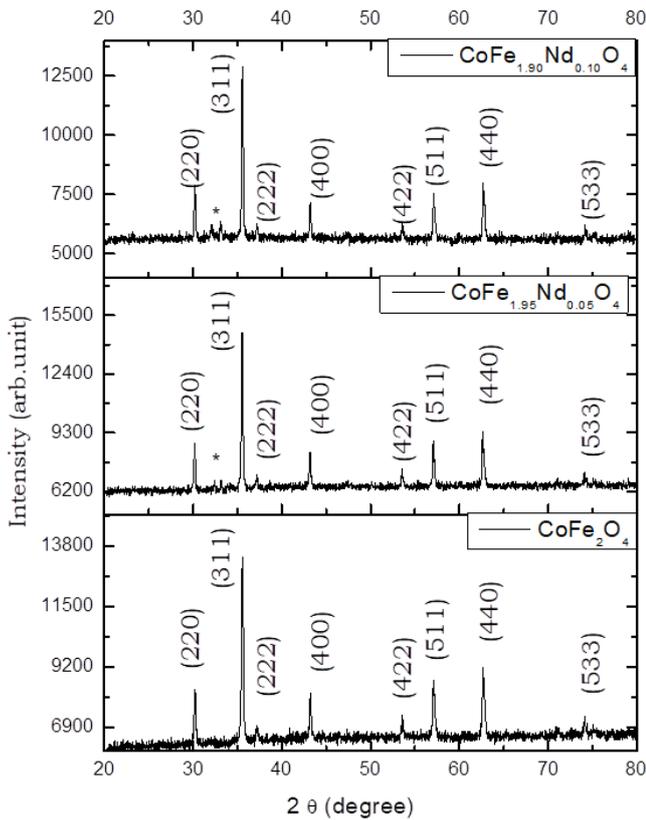


Figure 1: XRD patterns of  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$ . ( $x = 0.00, 0.05$  and  $0.10$ )

The value of lattice parameter for the substituted and unsubstituted Neodymium in cobalt ferrite samples was computed using the d spacing values and the respective hkl parameters and the lattice constant values decreases with increasing the contentment of neodymium substituted cobalt ferrite as shown in Figure 2. The decrease in lattice constant is due to replacement of larger ionic radii of  $\text{Nd}^{+3}$  ( $0.983 \text{ \AA}$ ) by smaller ionic radii of  $\text{Fe}^{+3}$  ( $0.64 \text{ \AA}$ ) at octahedral site. The Figure 2. shows the variation of crystallite size with  $\text{Nd}^{+3}$  substituted, the crystallite size is found to decrease with increase in neodymium ( $\text{Nd}^{+3}$ ) substituted cobalt ferrite in the range from 36 nm to 18 nm.

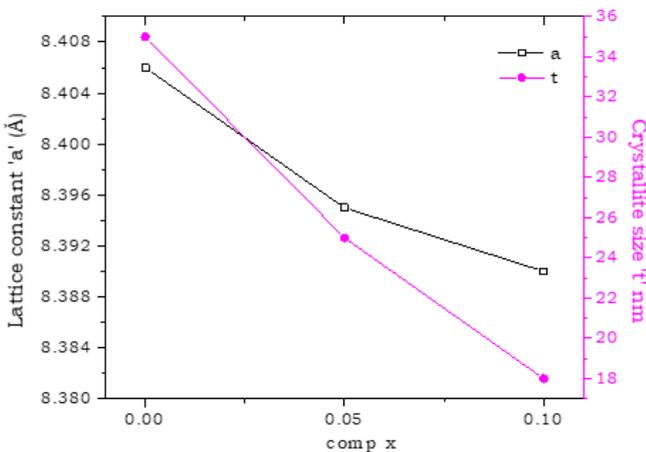


Figure 2: Lattice constant and crystallite size of  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$ . ( $x = 0.00, 0.05$  and  $0.10$ )

The Figure 3. shows that x-ray density increases with neodymium substituted in cobalt ferrite because the atomic weight of  $\text{Nd}^{+3}$  is 144.24 gm, which is greater than that of  $\text{Fe}^{3+}$  (55.845 gm). This behavior of enhancement in the X-ray density with increase in  $\text{Nd}^{+3}$  substituted also supports effective incorporation of  $\text{Nd}^{+3}$  into  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x = 0.00, 0.05$  and  $0.10$ ) samples. The enhanced value of X-ray density may be also due to the improved molecular weight of the samples with neodymium ions. When neodymium ( $\text{Nd}^{+3}$ ) is substituted into cobalt ferrites ( $\text{CoFe}_2\text{O}_4$ ), it can lead to changes in the physical properties of the material, including its density.

Figure 3. shows mass density ' $\rho_M$ ' increases with neodymium substituted in cobalt ferrite. The mass density of ferrites can vary depending on specific dopants and its concentrations. The mass density is typically expressed in units of grams per cubic centimeter ( $\text{gm/cm}^3$ ) and porosity decrease with increasing neodymium ( $\text{Nd}^{+3}$ ) substitution content in cobalt ferrite  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x = 0.00, 0.05$  and  $0.10$ ).

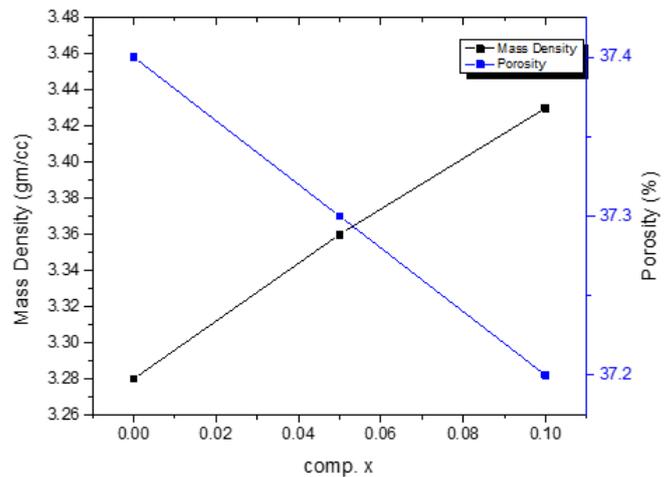


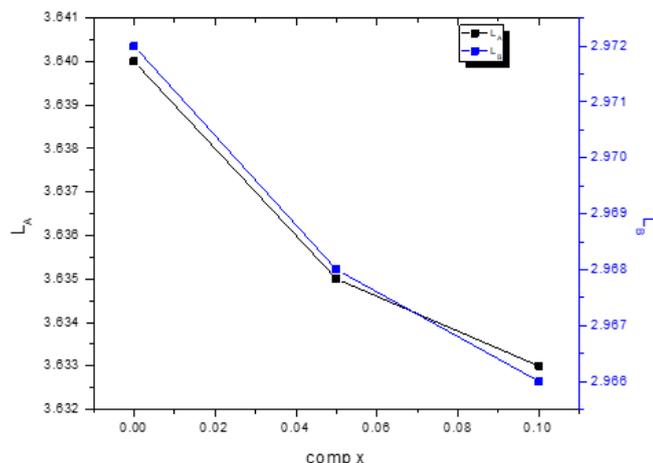
Figure 3: Mass Density and Porosity of  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$ . ( $x = 0.00, 0.05$  and  $0.10$ )

The values of the tetrahedral and octahedral bondlength ( $d_{AX}$  and  $d_{BX}$ ), the tetrahedral edge ( $d_{AXE}$ ), and the shared and unshared octahedral edge ( $d_{BEX}$  and  $d_{BXE}$ ) can be calculated [11]. Using the value of the lattice parameter 'a' ( $\text{\AA}$ ) and the oxygen position parameter 'u' ( $u=0.381 \text{ \AA}$ ). The value of the bondlength of the tetrahedral and octahedral sites are shown in Table 1, It is seen that the all values are depend on the lattice parameter so, the lattice parameter decreases, then the edge and the bondlength of the tetrahedral and octahedral sites are also decreases with increasing neodymium ( $\text{Nd}^{+3}$ ) substitution content in cobalt ferrite  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x = 0.00, 0.05$  and  $0.10$ ).

Table 1. Tetrahedral bond ( $d_{AX}$ ), octahedral bond ( $d_{BX}$ ), tetra edge ( $d_{AXE}$ ) and octa edge ( $d_{BXC}$ ) of  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$ .

Comp X	$d_{AX}$ ( $\text{\AA}$ )	$d_{BX}$ ( $\text{\AA}$ )	$d_{AXE}$ ( $\text{\AA}$ )	$D_{BXC}$ ( $\text{\AA}$ )	
				(Shared)	(Unshared)
0.00	1.907	2.052	3.115	2.829	2.974
0.05	1.905	2.050	3.111	2.826	2.970
0.10	1.904	2.048	3.109	2.824	2.968

The distance between magnetic ions (hopping length) in the tetrahedral sites as shown in Figure 4.



**Figure 4** Hopping Length ( $L_A$ ,  $L_B$ ) of  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$ . ( $x = 0.00, 0.05$  and  $0.10$ )

where 'a' is the lattice constant, the value Hopping length ( $L_A$ ,  $L_B$ ) are shown in Figure 4, Hopping length ( $L_A$ ,  $L_B$ ) values are depend on the lattice parameter so, the lattice parameter decreases so the Hopping length ( $L_A$ ,  $L_B$ ) also decreases.

#### 4. Conclusions

The XRD pattern shows the formation of disordered cubic spinel structure as concentration of rare earth  $\text{Nd}^{3+}$  substitution in cobalt ferrite matrix. The lattice parameter, crystallite size and X-ray density decreases and porosity increases with substitution of  $\text{Nd}^{3+}$  in cobalt ferrite. The values of the tetrahedral and octahedral bondlength ( $d_{AX}$  and  $d_{BX}$ ), the tetrahedral edge ( $d_{AXE}$ ), and the shared and unshared octahedral edge ( $d_{BEX}$  and  $d_{BXEU}$ ) and Hopping length ( $L_A$ ,  $L_B$ ) values are depend on the lattice parameter so, the lattice parameter decreases so the Hopping length ( $L_A$ ,  $L_B$ ) also decreases with increasing neodymium ( $\text{Nd}^{3+}$ ) substitution content in cobalt ferrite  $\text{CoFe}_{2-x}\text{Nd}_x\text{O}_4$  ( $x = 0.00, 0.05$  and  $0.10$ ).

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