RESEARCH ARTICLE   **OPEN ACCESS**

Structural and dielectric properties of Nd Substituted Ni-Co Nanoferrites by autocombustion route

Kokare MK[1]* and Rathod SM[2]

[1]Department of Physics, Tuljaram Chaturchand College, Baramati Pune, [2] Department of Physics, A.G. College, Pune *Email:* kokaremk@gmail.com

ABSTRACT

Neodymium substituted nanocrystalline Ni-Co ferrites which are chemically represented as $Ni_xCo_{1-x}Nd_yFe_{2-y}O_4$ were synthesized by sol-gel autocombustion route. The influence of Nd^{3+} on the structural and dielectric properties of prepared samples was studied in detail. X-ray analysis shows the single phase cubic spinel structure. The crystallite size was observed to be decreasing with increasing Nd content. However the lattice parameter initially decreases gradually and then increases with the substitution of Nd in Ni-Co ferrites. Dielectric parameters were studied for an applied AC field from 50 Hz to 5 MHz range. Dielectric constant and the dielectric tangent loss were observed to be decreasing with increase in frequency.

Keywords: $Ni_xCo_{1-x}Fe_2O_4$, Neodymium, Nanoferrites, Dielectric parameters.

INTRODUCTION

Cobalt spinel ferrite is most useful hard ferromagnetic material with high Curie temperature, high coercivity, high magneto-crystalline anisotropy, moderate saturation magnetization, good mechanical hardness and chemical stability [1]. Spinal ferrite is represented as MFe_2O_4 where M and Fe are divalent and trivalent cations respectively. CFO nanoferrites are useful for development of microwave and spintronic devices, solar cells, magnetostrictive sensors, drug delivery, transducers, actuators, lithium ion batteries, supercapacitors and memorydevices for computers [2].

Due to higher values of magnetostriction CFO ferrites can be used for strain sensor and actuator applications [3]. Currently, nanoparticles and nano-architectures of CFO-based materials are gaining tremendous interest in view of their ability to exhibit tunable electrical and magnetic properties, which could be exploited in numerous technological applications [4-7]. Recently many researchers have concentrated on synthesis of spinel ferrites by substituting trivalent rare earth ions for Fe^{3+}. The doping of rare earth ions into the CFO spinel structure leads to structural distortion which can modulate structural, electrical, magnetic and dielectric properties of ferrites. Specifically, the degree of modification depends on the ionic radius, the electronic configuration of dopant and its site preference (A versus B site) and the extent of distribution at the specific sites within the spinel structure [8-10].

In present work we have synthesized Neodymium substituted Ni-Co nanoferrites by sol-gel autocombustion route. Impact of Nd ion doping on structural and dielectric properties of Ni-Co Nanoferrites have been studied.

METHODOLOGY

Nanoparticles of $Ni_{0.5}Co_{0.5}Nd_xFe_{2-x}O_4$ with (x = 0.025, 0.05, 0.075, 0.1, 0.125) were synthesized by sol-gel autocombustion route. Strochiometric amounts of Analytical Reagent (AR) grade $Co(NO_3)_2H_2O$, $Ni(NO_3)_26H_2O$, $Fe(NO_3)_39H_2O$, $Nd(NO_3)_3H_2O$ (99.99% pure) and citric acid were used as raw precursors. These chemicals were dissolved initially in 100 ml double distilled water. Citric acid was used as a complexing agent to get transparent solution with homogenous distribution of metal ions. The above mixture was stirred for 2 hrs to get homogenous clear solution and then heated with constant stirring upto 50 ^{0}C using a magnetic stirrer with hot plate. Further the pH of solution was adjusted upto 7 by addition of ammonia solution. The resulting solution was evaporated by heating on a hot plate with continuous stirring to form a continuous network of gel. Further heating of the gel, results into fast flameless auto combustion reaction with the evolution of large amount of gases, it gives a burned powder of the resultant product. The burned gel was ground to get a fine ferrite powder by using Agate Mortar and pestle. Finally the ground powders were sintered in air at 560 ^{0}C for 4 hrs and then finally cooled to room temperature.

For structural determination, powder X-ray diffraction (XRD) patterns were recorded with Rigaku X-ray diffractometer using the Cu (Kα) radiation (λ = 1.5405 A^0). The dielectric parameters were measured by using precision LCR meter.

RESULT AND DISCUSSION

1. XRD analysis

The XRD pattern of $Ni_{0.5}Co_{0.5}Nd_xFe_{2-x}O_4$ with x = 0.025, 0.050, 0.075, 0.1, and 0.125 are shown in Fig.1. The obtained XRD data exactly matches with standard JCPDS data card Number 00-002-1045 and 01-074-2081.The diffraction peaks at (220),(311), (222),(400), (422),(333) and (400) confirms the single phase cubic spinel crystal structure. The lattice constant gradually decreases upto x = 0.100 and then increases with increase in Nd content.
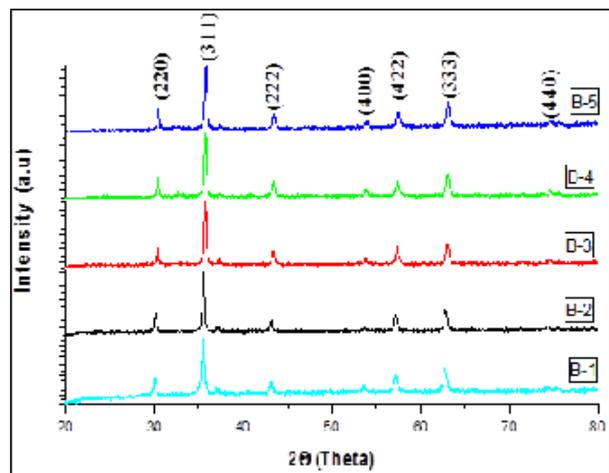

Fig.1. Shows XRD pattern for synthesized $Ni_{0.5}Co_{0.5}Nd_xFe_{2-x}O_4$ samples with varying Nd concentration from B-1) 0.025, B-2) 0.05, B-3) 0.075, B-4) 0.1, and B-5) 0.125.

The calculated crystallite size decreases from 26 nm to 21 nm with increase in Nd content. It reveals that Nd substituted Ni-Co nanoferrites prevents the growth of particles and controls the crystallite size of the

prepared samples. This may attributed to the occupancy of Nd^{3+} ions at octahedral site. Incorporation of Nd^{3+} ions results into compressive stress which leads to decrease in crystallite size. The variation of lattice parameter and crystallite size with Nd concentration is shown in table 1.

Table 1: Variation in Lattice constant and Crystallite Size with increase in Nd concentration

% of Nd doping (x)	Lattice Constant 'a'A^0	Crystallite Size D (nm)
0.025	8.386	26.20
0.050	8.328	25.60
0.075	*8.321*	24.97
0.100	8.311	23.27
0.125	8.371	21.31

2.   Micro-structural Analysis

The FE-SEM micrographs of various $Ni_{0.5}Co_{0.5}Nd_xFe_2O_4$ samples are as shown in Fig.2. Microstructural analysis determines the average grain size of the prepared samples which influence the magnetic properties of the materials. It displays the surface morphology of the prepared samples. It is observed that most of the NiCoNdFeO nanoparticles exhibit the hexagonal crystal structure. The average grain size of the samples decreases with Nd content. SEM image reveals that the grain size decreased with increasing Nd content, which is evident from the XRD analysis.

Fig.2 shows transmission electron micrographs (TEM) of $Ni_{0.5}Co_{0.5}Nd_xFe_2O_4$ ferrite. TEM image reveals the uniform morphology of the ferrite powder with average particle size of 45 nm. These results are well supported by SEM image. The average crystallite size calculated from the XRD data is in the range of 21-26 nm.

3.   Dielectric properties

The dielectric behavior of Nd doped ferrite material is due to the electric dipole moments developed by the charge transfer between the di and trivalent metal cations (ion exchange) within the spinal structure. The dielectric properties of ferrites also depend on the microstructure, method of sample preparation, sintering time, temperature, chemical composition and site occupancy of metal cations among the A and B site [11].
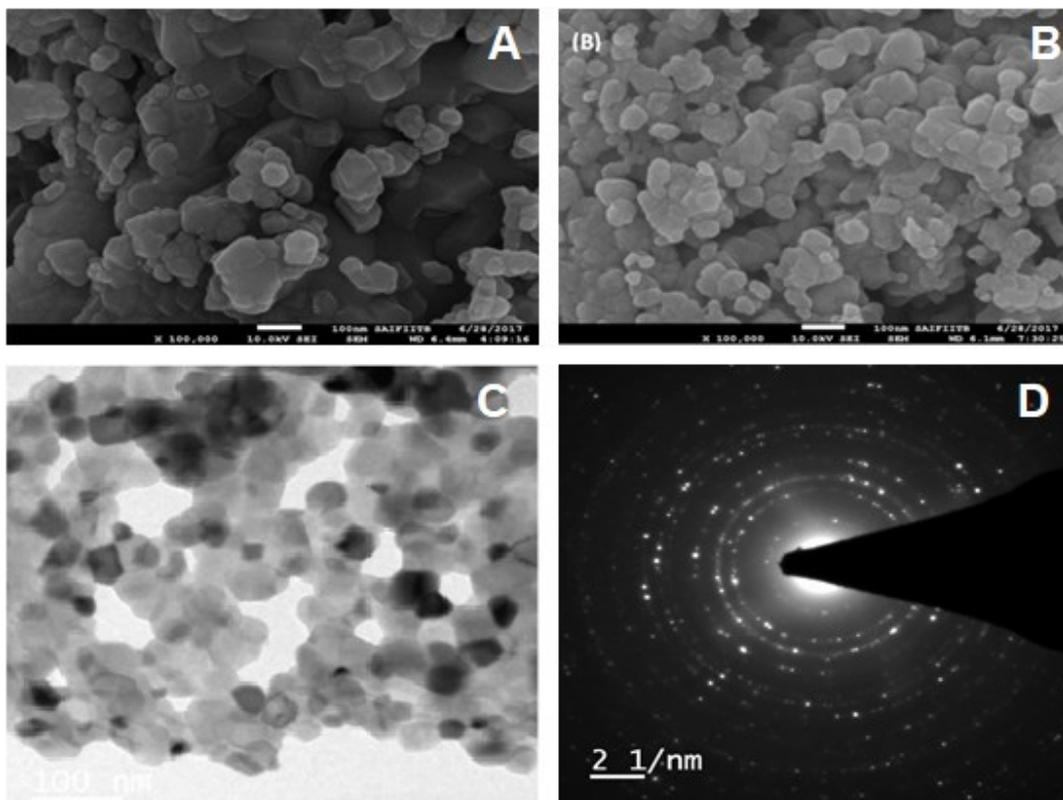

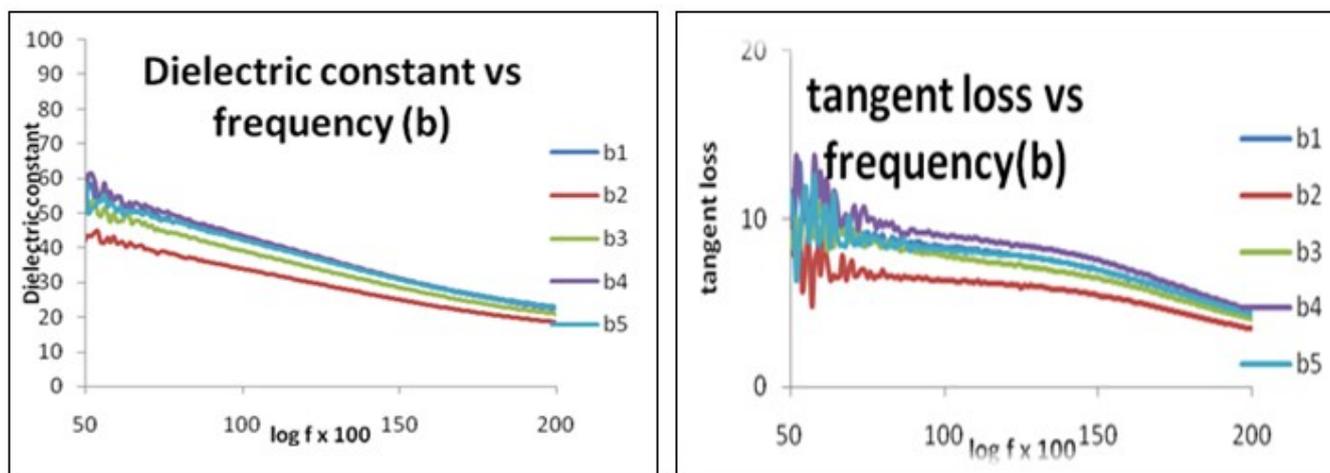**Fig.2. (A) & (B) SEM and (C) & (D) TEM images of sample**

Figure 3A: Variation of dielectric constant with frequency. **Figure 3B:** Variation of tangent loss with frequency.

The dielectric behavior of ferrite material as a function of frequency provide valuable information about the localized electric charge carriers and better understanding of the mechanism of dielectric polarization in ferrites.

The variation of dielectric constant and dielectric tangent loss of Nd doped Ni-Co ferrite with frequency is shown in Fig.3A and 3B. The dielectric constant decreases slowly with increase in frequency. The variation of dielectric constant with frequency may be explained on the basis of space-charge polarization phenomena. Low dielectric loss of Nd doped Ni-Co nanoferrites are useful for high frequency applications like microwave devices, high density magnetic recording.

CONCLUSION

Neodymium substituted Ni-Co nanoferrites were successfully synthesized by sol gel auto combustion route. The prepared samples were investigated by XRD, SEM, TEM and dielectric measurements. XRD confirmed the single phase cubic spinel structure. The lattice constant initially decreased and then increased with the increase in Nd^{3+} content. The crystallite size decreased from 26 nm to 21 nm. Dielectric parameters were studied for an applied AC field from 50 HZ to 5 MHZ frequency range. Both dielectric constant and the tangent loss were decreased with increases in frequency. Low tangent loss at high frequency

indicates the potential application of Nd doped Ni-Co nanoferrites in high frequency microwave devices.

REFERENCES

1. Kakade SG, Yuan-Ron Ma, Devan RS, Kolekar YD and Ramana CV, *J. Phys. Chem. C* 2016**,** 120:5682-5693.

2. Orozco C, Melendez A, Manadhar S, Singamaneni SR, Reddy KM, Gandha K, Niebedim I, Ramana CV, *J. Phys. Chem.* 2017; 121 (46): 25623-26140.

3. Chaa F, Liao C, Kuana J, Z. Xu, C. Yan, L. Chen, H. Zhed, Z.liu, *J. Appl. Phys*. 1999;85: 2782.

4. Kakade SG, Kamble RC, Kolekar YD, Ramana CV, *J. Phys. Chem. C* 2016; 113: 9070-9076.

5. Dmazario E, Menendez N, Herrasti P, Canete M, Connord V, *J. Phys.Chem. C* 2013;117: 11405-11411.

6. Mukherjee D, Hordagoda M, Hyde R, Bingham N, Hariharan S, Witanachchi S, ACS Appl. Mater. Interfaces. 2013; 5:7450-7457.

7. Mikalauskaite A, Kondrotas R, Niaura G, Jagminas A. *J. Phys. Chem. C.*2015;119:17398-17407.

8. Mahalakshimi S, Srinivasa MK, Nithiyanantham S. *J. Supercond. Nov. Magn.* 2014; 27: 2083- 2088.

9. Dascalu G, Popescu T, Feder M, Caltun OF, *J. Magn. Magn. Mater.* 2013; 333: 69-74.

10. Bharathi K, Ramanaa CV, *J. Mater. Res.* 2011; 26:584-591.

11. Ramana CV, Kolekar YD, Bharathi KK , Sinha B, Ghosh K. *J. Appl. Phys.* 2013; 114: 18s3907.