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Structural and Dielectric Studies of Cerium Substituted Nickel Ferrite Nano Particle

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ABSTRACT
Cerium substituted Nickel ferrite nanoparticles with general formula $NiCe_XFe_{2-X}O_4$ (x=0.0, 0.05, 0.1, 0.15) have been synthesized by using sol-gel method. The crystalline structure and grain size of these particles were analyzed by using XRD; the particle size ranged from 12.22nm to 17.60nm.The decrease in value of the lattice parameter with doping suggests that there is shrinkage in unit cell. The single-phase cubic spinal structure was clearly indicated by the XRD patterns of pure $NiFe_2O_4$.The XRD pattern also show that all the samples had formed the cubic single phase spinal structure. Dielectric properties have been studied in the frequency range of 1 kHz to 5 MHz. Permittivity and tangent loss (tanδ) decreases with the substitution of Ce^{3+} in parent crystal structure.

Keywords: *Rare earth ions, XRD, Dielectric properties, Permittivity.*

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I. INTRODUCTION

In the recent years, so much attention has been paid to the nanomagnetic materials that show very interesting magnetic properties. In this material, different properties and applications are appeared as compared to their bulk counterparts. The magnetic properties of nanomaterials are used in medical, electronic, and recording industries that depend on the size, shape, purity and magnetic stability of these materials. In biomedical application, one can use nano magnetic materials as drug carriers inside body where the conventional drug may not work. For this purpose, the nanosize particles should be in the super paramagnetic form with a low blocking temperature. Ferrite nanomaterials are object of intense research because of their proper magnetic properties. It has been reported that when the size of particles reduced to small size or in range of nanomaterials, some of their fundamental properties are affected. nano ferrites are simultaneously good magnetic and dielectric materials. These properties of the nano ferrites are affected by the preparation conditions, chemical composition, sintering temperature and the method of preparation . Several chemical and physical methods such as spray pyrolysis, sol-gel, co-precipitation, combustion technique, high energy milling etc. have been used for the fabrication of stoichiometric and chemically pure nano ferrite materials. Among the available chemical methods, the sol-gel technique is an excellent method to synthesize rare earth substituted nanoparticles with maximum purity. In spite of the development of a variety of synthesis routes, the production of nickel ferrite nanoparticles with desirable size and magnetic properties is still a challenge. This would justify any effort to produce size tuned nickel ferrite nanoparticles with rare earth substitution. In the present paper, the structural and magnetic properties of cerium substituted nickel ferrite and XRD and dielectrical properties were investigated.

II. EXPERIMENTAL

2.1. Synthesis : Nano particles of cerium substituted nickel ferrite were synthesized by the sol-gel combustion method. A stoichiometric ratio of $NiFe_{2-x}Ce_xO_4$ (**x=0.0, 0.05, 0.1, 0.15**) were dissolved in ethylene glycol using a magnetic stirrer. The five sample solutions was then heated at 60 °C for 2 hours until a wet gel of the metal nitrates was obtained. The gel was then dried at 120 ° C. This resulted in the self ignition of the gel producing a highly voluminous and fluffy product. The combustion can be considered as a thermally induced redox reaction of the gel wherein ethylene glycol acts as the reducing agent and the nitrate ion acts as an oxidant. The nitrate ion provides an oxidizing environment for the decomposition of the organic component. The obtained powder of different samples **(x=0.0, 0.05, 0.1, 0.15)** was ground well collected in different packets for the measurements.

2.2. Characterization : The cerium doped nickel ferrite samples were characterized by an X-ray powder diffract meter (XRD, Bruker AXS D8 Advance) using radiation (*wavelength*= 1.5406 A°) at 40 kV and 35 mA. Lattice parameter was calculated. The crystal structure, crystallite size and X-ray density were determined. Electrical studies conducted using RF material analyzer (AGILENT E4991A)

III. RESULTS AND DISCUSSION

3.1. Structural Analysis

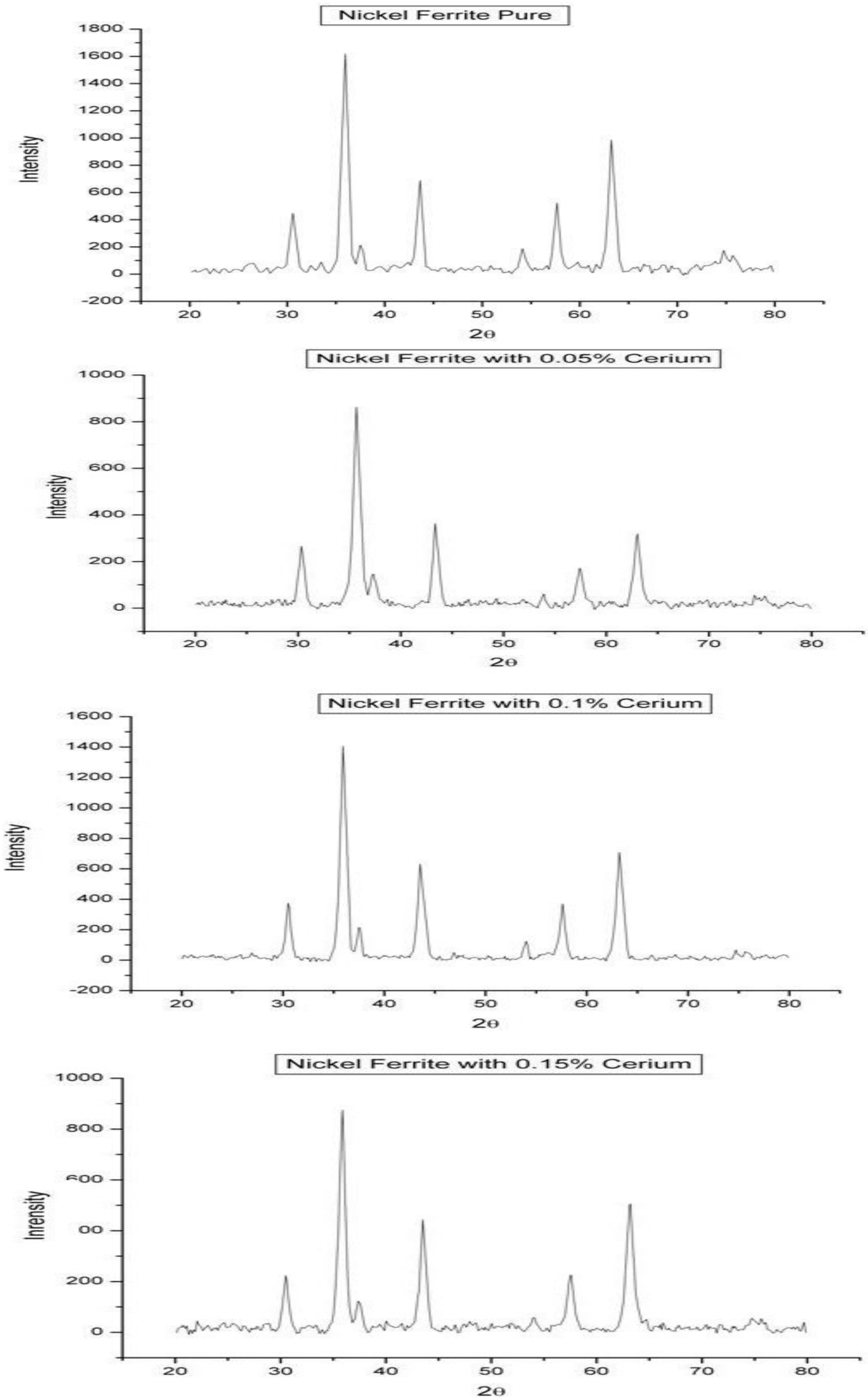


Fig.1. XRD patterns of $NiFe_{2-x}Ce_xO_4$ (x=0.0, 0.05, 0.1, 0.15)

The XRD patterns of $NiFe_{2-x}Ce_xO_4$ nanoparticles**(x=0.0, 0.05, 0.1, 0.15)** are depicted in Fig.1 and are typical of spinel structure. Comparing the XRD pattern with the standard data, the sample with cerium concentration zero shows highest peak and concentration 0.15 shows lowest.The diffraction peaks are broad because of the nanometer size of the crystallite. The crystallite size 'D' of the samples has been estimated from the broadening of XRD peaks using the Scherrer equation.

$$D = \frac{K\lambda}{\beta \cos\theta}$$

Lattice parameter 'a' for all the samples has been calculated by interplanar spacing (dhkl) and 2-theta values using the standard relation,

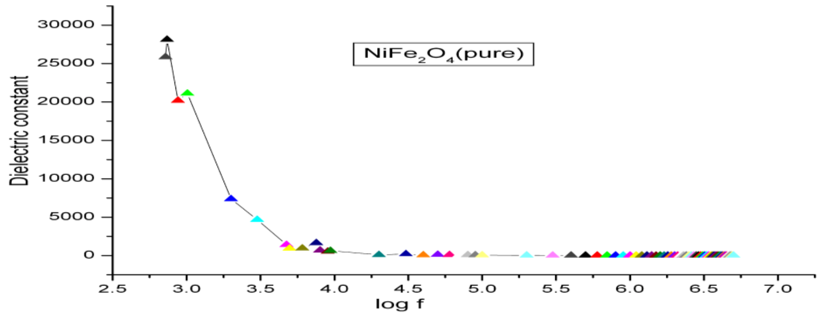
$$a = d_{hkl}\sqrt{h^2 + k^2 + l^2}$$

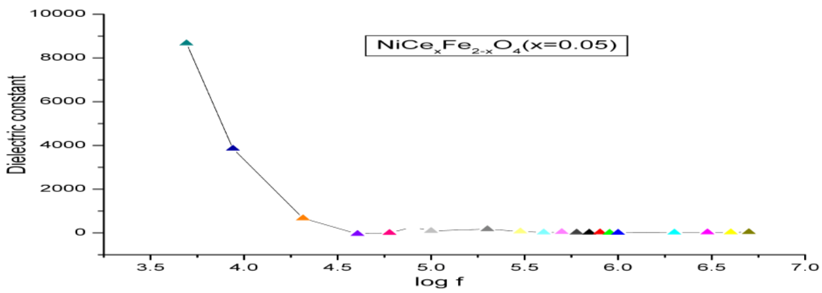
Composition (x)	Lattice parameter a (Å)	Crystallite size(nm)	X-ray density(g/cm^3)
0.0	8.331	17.60	5.502
0.05	8.327	15.78	5.387
0.10	8.297	16.19	5.449
0.15	8.293	15.26	5.434

Table.1.Structural Parameters of $NiCe_XFe_{2-X}O_4$ system

Value of lattice constant for x=0.0 comes out to be 8.331Å, well in agreement with reported value. The decrease in value of the lattice parameter with doping suggests that there is shrinkage in unit cell. The single-phase cubic spinal structure was clearly indicated by the XRD patterns of pure $NiFe_2O_4$.The XRD pattern also show that all the samples had formed the cubic single phase spinal structure

3.2. Dielectric study : Dielectric behavior of nano spinel ferrites mainly depends upon the nature and distribution of metal cations on A-sites and B-sites in the spinel lattice. Spinel nickel ferrites are considered good dielectric materials and the high frequency dielectric behavior is mainly dependent upon the particle size and method of synthesis of nano particles. Different studies have been provided relating the dielectricparameters of Ce^{3+} doped ferrites. Dielectric parameters (relative permittivity, dielectric loss tangent) for the prepared series of $NiCe_xFe_{2-x}O_4$ (x=0.0 to x=0.15) have been studied in the frequency range 1 MHz to 1GHz at room temperature. Figs.2 shows the variation of relative permittivity with frequency at room temperature. It can be observed from the figure that relative permittivity for all the samples decreases with increase in frequency and ultimately becomes constant at higher frequencies. This decrease in permittivity is more rapid in the low frequency region and becomes sluggish as the applied frequency increases. This behaviour is subjected to dielectric polarization under the application of AC field.





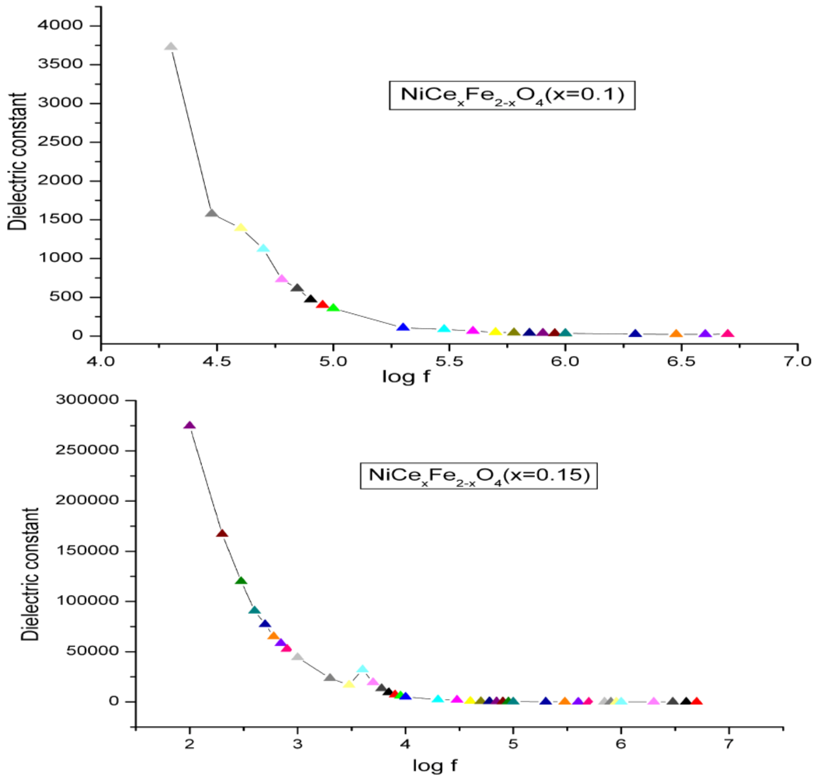
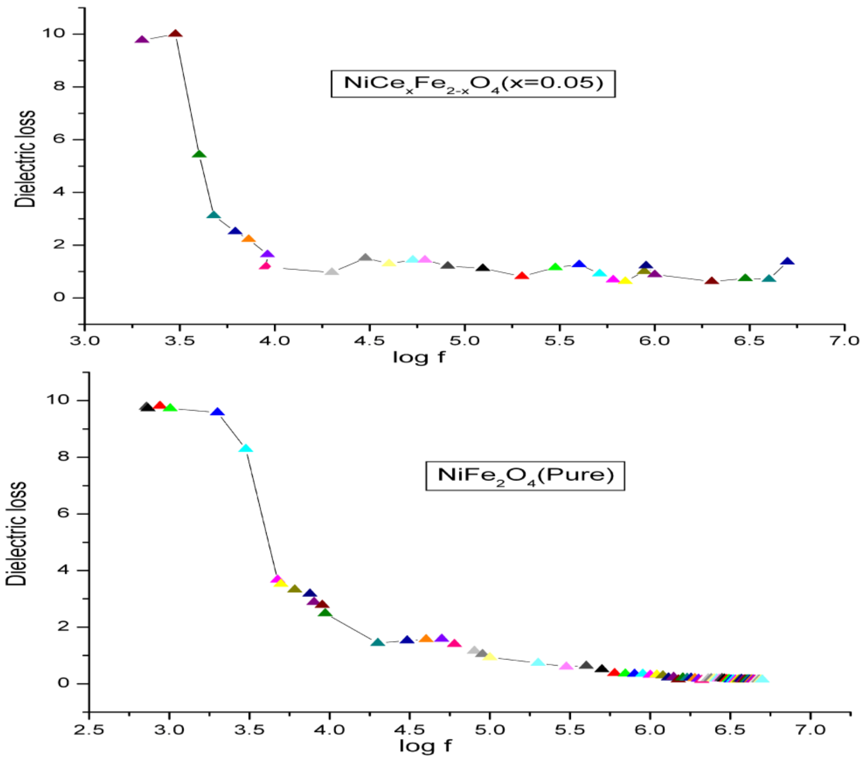


Fig.2. Variation of permittivity as a function of frequency

It can be seen fig.3. that dielectric loss tangent has the same trend as permittivity losses. It decreases with increase in frequency and becomes constant up to 1GHz due to decreased polarization at high AC fields. At x=0.15 shows a low loss dielectric behaviour which allows its use in high frequency data reading/writing in electronic structures.



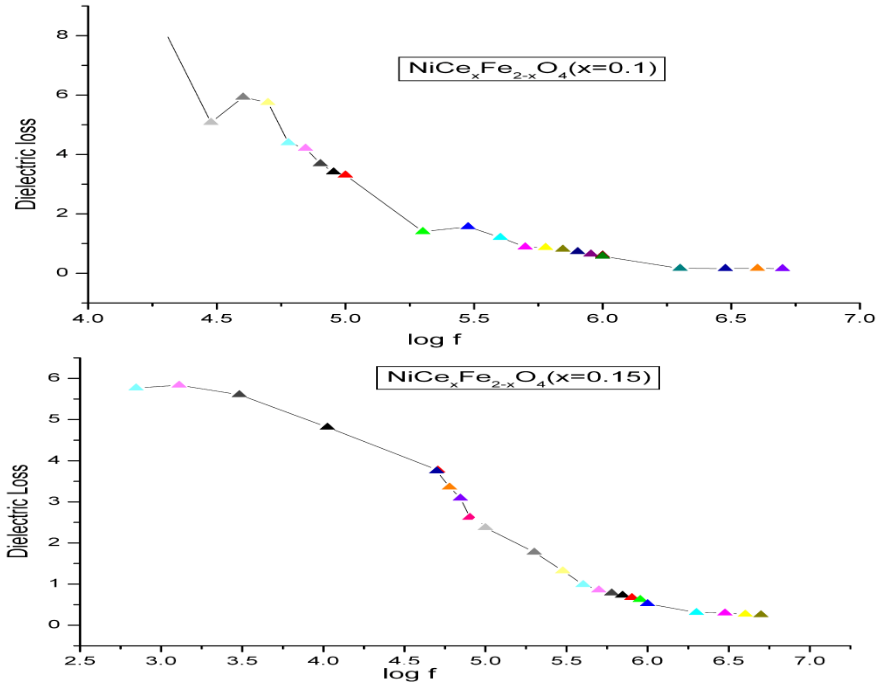


Fig.3. Variation of dielectric loss as a function of frequency

IV. CONCLUSIONS

Nano spinal $NiFe_{2-x}Ce_xO_4$ with x in step increment has been synthesized by sol-gel Combustion method. All the studied samples are pure cubic spinel phase ferrites without any impurity metal oxides. Lattice constant and crystallite size decreases with increase in Ce^{3+} concentration, due to doping there is shrinkage in unit cell. Dielectric constant and loss tangent decreases with increase in the dopant concentration showing that the material with x=0.15 is a low loss dielectric.

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