

Auto ignition synthesis of Nd³⁺Doped Ni-Zn Spinel Ferrites for high frequency antenna in communication application

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ABSTRACT

With a 1:1 ratio of metal nitrate to citrate, a series of Ni_{0.6}Zn_{0.4}Fe_{2-x}NdxO₄(0x0.10) has been synthesized employing the sol-gel auto combustion approach. Further structural, electrical, morphological, and compositional characteristics of the resulting powders were examined. Single phase with spinel structure was seen in the synthesized samples. The tiny particle nature of the synthetic material was confirmed by DLS analysis. The EDAX investigation showed that the samples had the stoichiometric cation ratios that were predicted. The current sample demonstrates improved electrical conductivity, a high dielectric constant, low dielectric losses, high saturation magnetization, and low coercivity, making it a more promising candidate for high-frequency electronic applications like antennas, microwave absorbers, and inductance/transformer cores.

Keywords: Mixed ferrites, Sol-gel auto combustion, dielectric applications

1. INTRODUCTION

The need for lightweight and miniaturized antennas has developed quickly in response to the fast development of electronic technology in wireless communication devices [1-3]. As a result, efforts to find and create appropriate materials have increased [4]. Materials with strong dielectric responses may be appropriate for miniature antennas. However, the use of such materials may result in concentrated field buildup around the high permittivity area, which might reduce the effectiveness of the antenna and make impedance matching more challenging [5]. Magneto-dielectric ferrite materials have received a lot of interest recently for the purpose of miniaturizing and improving the performance of antennas. [6].

Neodymium (Nd^{3+}) ions are what we want to dope in Ni-Zn ferrite in this work. The 4f orbital of the Nd^{3+} ions contain unpaired electrons and is typically non-magnetic. Additionally, Nd^{3+} ions' greater ionic radii than Fe^{3+} ions may cause cell enlargement and increased permeability. As a result, it is anticipated that adding Nd^{3+} ions to the octahedral site (B) in place of the Fe^{3+} ions will improve the magnetic and electrical characteristics of the nano-spinel-ferrites, making them suitable for use in electronic applications [7]. With the aforementioned information in mind, this study examines the impact of neodymium doping on a Ni-Zn ferrite system created by the sol-gel auto combustion process, with the goal of achieving soft magnetic and thermally stable properties as well as high.

2. Synthesis and characterization

The unique sol-gel auto ignition technique formulated by using citric acid as chelating was employed for synthesis of series of nanoparticles of $\text{Ni}_{0.6}\text{Zn}_{0.4}\text{Fe}_{2-x}\text{Nd}_x\text{O}_4$ ($0 \leq x \leq 0.10$) with ($x = 0.00, 0.02, 0.04, 0.06, 0.08$ and 0.10). In brief, a mixed uniform solution of nitrates of the relevant metal ions viz. Nickel nitrate ($\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$), Zinc nitrate ($\text{Zn}(\text{NO}_3)_2 \cdot 9\text{H}_2\text{O}$), Ferric nitrate ($\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$), Neodymium nitrate ($\text{Nd}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$) and citric acid was set by continuous stirring for the period of 90 mins.

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3. RESULTS AND DISCUSSION

3.1. Elemental analysis: EDAX

Energy dispersive X-ray analysis (EDAX) was used to perform qualitative and quantitative analyses on the NZN samples to verify their stoichiometry and elemental makeup. The identified elements at various energies and the EDAX spectra collected in the 0-10 keV binding energy range are presented systematically in Fig. 1 and Table 1, respectively.

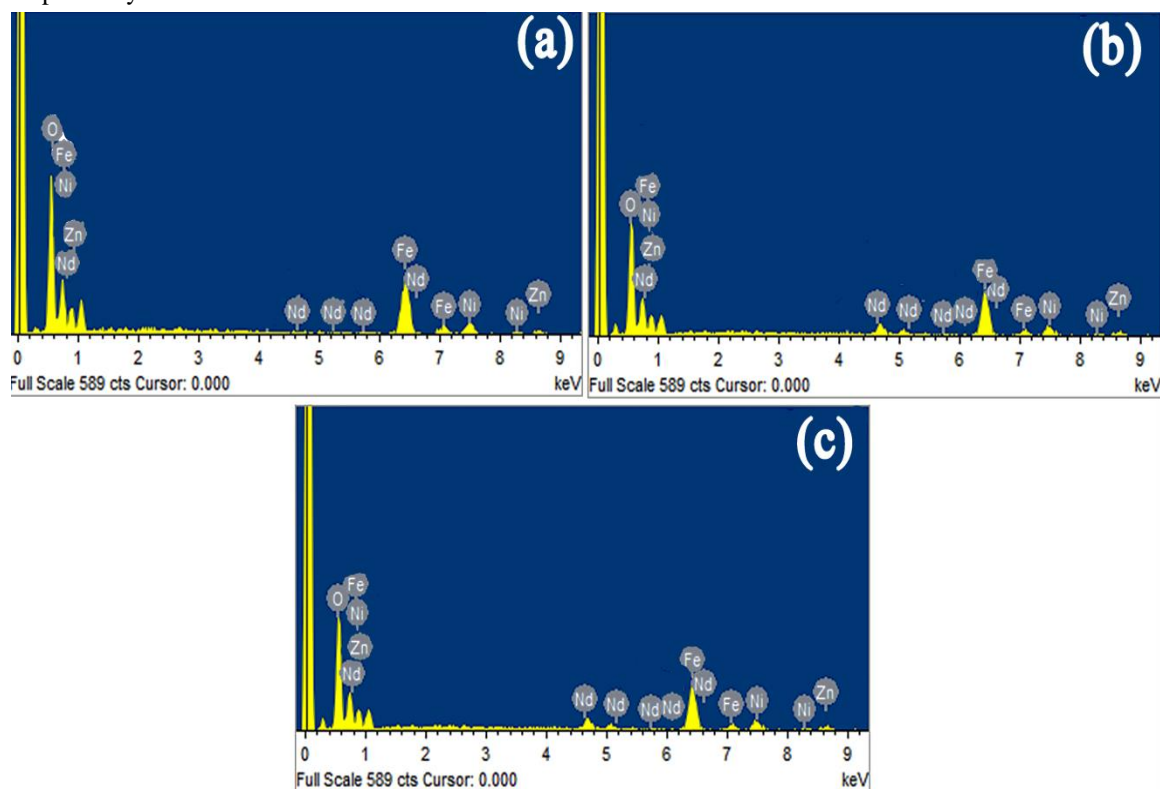


Fig. 1 EDAX spectra of $Ni_{0.6}Zn_{0.4}Fe_{2-x}Nd_xO_4$ samples with $x = 0.02, 0.06, \text{ and } 0.10$

Table 1 Elemental analysis of $Ni_{0.6}Zn_{0.4}Fe_{2-x}Nd_xO_4$ by EDAX

Composition x	Ni	Zn	Fe	Nd	O
0.02	6.5714	6.7143	29.2857	0.2857	57.1429
0.04	9.5714	7.7143	26	0.5714	56.1429
0.06	9.214	6.132	28.704	0.8071	55.1429
0.08	7.5714	6.7143	28.426	1.1424	56.1459
0.10	8.5714	5.7143	27.1429	1.4286	57.1428

The existence of the constituent elements Zn, Fe, Ni, and Nd is verified by intensity peaks that are provided at various energies, and the presence of the principal component of oxygen is also confirmed in the required proportion of the chemical composition.

3.2. Particle size distribution analysis (DLS):

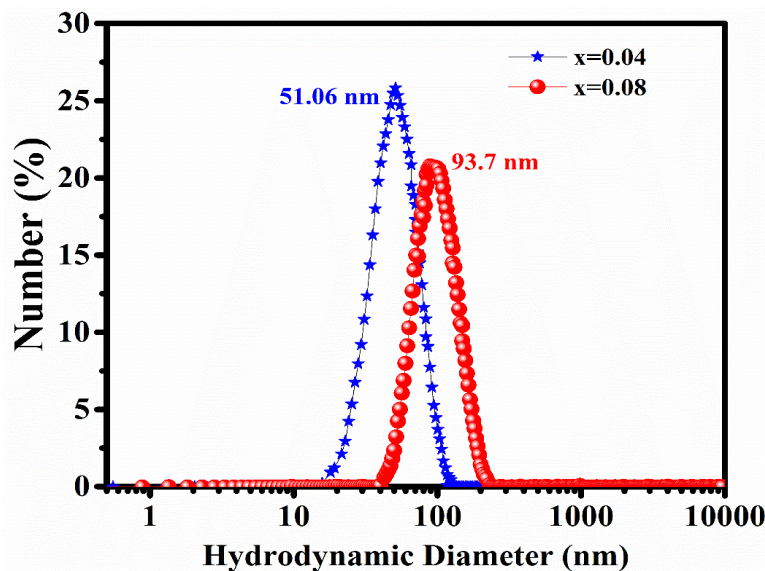


Fig. 2 Size distribution curves obtained from DLS data of $Ni_{0.6}Zn_{0.4}Fe_{2-x}Nd_xO_4$ samples with $x = 0.04, \text{ and } 0.08$

The "Dynamic Light Scattering (DLS)" experiment was designed to map out the range of particle sizes and look at how Nd doping affects the size of NZN samples. In DLS characterization, the hydrodynamic diameter of the nanoparticle colloidal solution is determined [8–10]. In Fig. 2, the size distribution by volume of the usual compositions with $x = 0.04$ and $x = 0.08$ is shown. All of the compositions' Z-average values were discovered to fall between 51 and 125 nm. Due to the powder sample's insolubility and aggregation in water, the greater particle

size that was determined from the DLS data. According to Sivagurunathan et al. [11], the co-precipitation approach used to create NiFe₂O₄ nanoparticles had a similar outcome.

3.3. Magnetic properties

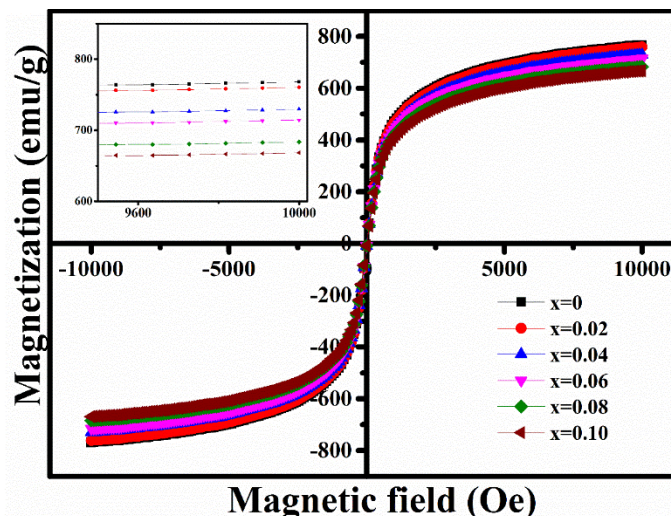


Fig. 3 The magnetization hysteresis loops (M-H) of Ni_{0.6}Zn_{0.4}Fe_{2-x}Nd_xO₄ ferrites at room temperature

The magnetic characteristics of the NZN samples were examined using VSM analysis. Ni_{0.6}Zn_{0.4}Fe₂xNd_xO₄'s magnetization hysteresis loops (MH) are depicted in Fig. 9 for x=0.0, 0.02, 0.04, 0.06, 0.08, and 0.10. The magnetic characteristics are controlled by the synthesis process, crystallite size, cation distribution, and crystal anisotropy [12]. The Nd-Fe interaction is strengthened by the addition of Nd³⁺ ions, changing the measured magnetization [13].

The magnetization curve makes it evident that all of the samples have ferromagnetic M-H loops with very low coercive fields (20 Oe), which exhibit soft magnetic behaviour. The Inset of Fig. 3 shows an expanded view. The inset clearly shows that when the concentration of Nd³⁺ ions in Ni_{0.6}Zn_{0.4}Fe₂xNd_xO₄ increases, the magnetization at 10k Oe drops. Additionally, it is evident that the saturation magnetization linearly declines as the Nd³⁺ concentration rises, from 76.8 emu/g at x=0 to 66.81 emu/g at x=0.10. The findings are much in line with the published literature [14].

4. CONCLUSIONS

The sol-gel auto combustion method was used to produce single-phase cubic spinel nano-structured rare-earth doping with the chemical formula Ni_{0.6}Zn_{0.4}Fe_{2-x}Nd_xO₄ (0x0.10). The unit cell length parameter rose due to the Nd³⁺ substitution, going from 8.405 to 8.438 along with the values of specific surface area. The samples' density progressively rose as the porosity decreased. The creation of nano-regime crystallites was established by the methodical investigation of structural and morphological pictures. With the replacement of Nd³⁺, the crystallite dimensional values increased from 22 to 45 nm. The cation distribution study allowed to deduce that Fe³⁺ inhabited both crystallographic sites, whereas Zn²⁺ occupied the A site and Ni²⁺, Nd³⁺ filled the B site. With the

replacement of Nd³⁺, the force constants and Debye temperatures rose. Notably, the coercivity values below 20 Oe, the magnetization dropped as concentration of Nd³⁺ doping increased, exhibiting soft magnetic behavior. It is suitable as filler material in PCBs and high-frequency antenna devices because to the alteration in the structural and magnetic characteristics caused by the little amount of rare-earth metal dopant.

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