Zinc Substituted Nickel-cobalt Nano-ferrites via Citrate-gel Auto-combustion Method for High-frequency Applications: Studies on Crystal Structure and Dielectric Properties

Marwene Oumezzine (✉ oumezzine@hotmail.co.uk)

Universite de Monastir Faculte des Sciences de Monastir <https://orcid.org/0000-0002-1657-643X>

Alin Iuga Iuga

National Institute of Materials Physics: Institutul National pentru Fizica Materialelor

Monica ENCULESCU

National Institute of Materials Physics: Institutul National pentru Fizica Materialelor

Aurelian Catalin Galca

National Institute of Materials Physics: Institutul National pentru Fizica Materialelor

Original Research

Keywords: Zn doped nickel-cobalt nano-ferrites, XRD, FTIR, Citrate-gel auto-combustion method, Dielectric properties, High-frequency applications

Posted Date: February 4th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-156852/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Zinc substituted nickel-cobalt nano-ferrites via citrate-gel auto-combustion method for high-frequency applications: Studies on Crystal Structure and Dielectric Properties

Marwène Oumezzine ^{a*}, Alin Iuga ^b, Monica Enculescu ^b, Aurelian-Catalin Galca ^{b*}

^a Laboratory of Physical Chemistry of Materials, Faculty of Sciences of Monastir, University of Monastir, 5019 Monastir, Tunisia

^b Laboratory of Multifunctional Materials and Structures, National Institute of Materials Physics, RO - 077125, Magurele, Ilfov, Romania

E-mails : oumezzine@hotmail.co.uk, ac_galca@infim.ro

Abstract

$\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x=0.0, 0.05, 0.10$ and 0.20) were prepared by citrate-gel auto-combustion method. The structural investigation using powder X-ray diffraction (XRD) showed the formation of single-phase cubic spinel structures with $\text{Fd-}3\text{m}$ space group for all prepared samples. As the Zn^{2+} concentration is increased, the values of the lattice constant, tetrahedral and octahedral bond lengths undergo significant change. The absolute experimental lattice parameters are closely to the Vegard' s law derived ones, suggesting that the cations concentration fairly correspond with those calculated prior chemical synthesis. Fourier transform infrared (FTIR) absorption bands at $594\text{--}400\text{ cm}^{-1}$ confirm the formation of spinel structure. The values of dielectric constant and loss tangent were reported to decline with frequency and the Zn^{2+} composition (x). Incorporation of Zn at nickel-cobalt resulted in decrease in ac conductivity at RT. Here, we report a low loss tangent factor of the order of 8×10^{-3} for the sample with $x = 0.20$ make this composition suitable for high frequency applications. Imaginary electric modulus studies unveil the presence of non-Debye type of dielectric relaxation phenomenon. The activation energy of our samples calculated from modulus spectra is found to increase with further substitution of Zn^{2+} concentration.

Keywords: Zn doped nickel-cobalt nano-ferrites; XRD; FTIR; Citrate-gel auto-combustion method; Dielectric properties; High-frequency applications

1. Introduction

Spinel ferrites with general formula AB_2O_4 are of great importance due to their high electrical resistivity, low dielectric losses and high-power handling capability relative to semiconductors [1-4]. Recently, nano-ferrites are supposed to be very good dielectric materials with low conductivity and have been proposed to technological applications ranging from microwave to radio wave frequencies [5,6]. Spinel ferrites exhibit FCC spinel structure in which two interstitial sites are present i.e., tetrahedral (A) and octahedral (B) sites. Depending upon the distribution of cations, synthesis protocol, grain structure, chemical composition, sintering temperature and time, the structural, dielectric and magnetic properties of the spinel ferrites are modified [7,8]. The dielectric properties of these materials are stable at high frequency, which can be used for relevant applications. Hence, it is important to study their dielectric behavior as a function of frequency and composition at room temperature [9]. Among the various spinels, nickel cobalt ferrites are one of the most important ferrites whereby the high permeability and low power loss have become the most principal requirements for the electronic devices [10,11]. They have great potential as microwave materials on account of their high resistivity, ease of fabrication as well as low eddy current losses and high saturation magnetization as compared with other ferrites [12-15]. Several techniques are employed to obtain ferrites such as ceramic, hydrothermal synthesis, co-precipitation and citrate-gel auto-combustion method [16,17]. Purity, reactivity, homogeneity and low temperature of operation of the prepared ferrites are the advantages of using the citrate-gel auto-combustion synthesis method [17]. Several studies have been reported that the addition of Zn produces an increase of the resistivity, so that the material fit for the application at high frequency [18,19]. Recently, MnZn nano-ferrites is proposing for ongoing COVID-19 pandemics [21]. In this work, we report structural and electrical properties of Zn^{2+} substituted nickel-cobalt nano-ferrites $Ni_{0.8-x}Zn_xCo_{0.2}Fe_2O_4$ ($x = 0, 0.05, 0.1$ and 0.2) synthesized by Citrate-Gel auto-combustion.

2. Synthesis

The nano-ferrites $Ni_{0.8-x}Zn_xCo_{0.2}Fe_2O_4$ ($x=0.0, 0.05, 0.10$ and 0.20) were prepared by citrate-gel auto-combustion method using $Ni(NO_3)_2 \cdot 6H_2O$, $Co(NO_3)_2 \cdot 6H_2O$, $Zn(NO_3)_2 \cdot 6H_2O$, and

Fe(NO₃)₂•9H₂O as raw materials. Calculated quantities of mentioned nitrates were dissolved in distilled water and a required amount of aqueous citric acid solution was added as chelating agent. To keep the pH value of the solution at 7, ammonia solution was used while continuously stirring by using a magnetic agitator. A highly viscous gel was obtained by heating the solution at 100°C. The viscous gel began frothing when finally all water molecules were removed from the mixture. The resultant gel burned in a self-propagating combustion manner until a fluffy loose powder was formed. The powder was heated (calcined) for 4 h at 550°C in order to remove any organic material present, using the rate of heating at 5°C/min.

3.Results and Discussion

3.1 Structural and morphological properties

The measured X-ray diffraction patterns of Ni_{0.8-x}Zn_xCo_{0.2}Fe₂O₄ (x=0.0, 0.05, 0.10 and 0.20) samples are shown in Fig. 1. All diffraction lines correspond to the cubic spinel structure (space group Fd-3m (227)). No other (secondary phase) lines have been observed within the equipment sensitivity. Notably, the distinct sharp peaks of the spinel phase confirm the highest crystallinity of all the samples. The reflections from the (111), (220), (311), (222), (400), (422), (511), and (440) planes obey at 2θ angles close to those of NiFe₂O₄(ICDD file : 00-054-0964), CoFe₂O₄(ICDD file : 00-022-1086) and ZnFe₂O₄(ICDD file : 00-070-6393). The 220 and 311 diffraction lines are presented in Fig. 2. The corresponding 2θ shift toward lower angles by increasing the Zn concentration, indicating an increase of the lattice constant which causes the expansion of the cubic spinel structure. The experimental lattice parameters of the samples have been determined using the condition for a plane wave to be diffracted by a family of lattice planes hkl [21]:

$$2d_{hkl}\sin\theta=\lambda \quad (1)$$

, the formula [22] which define the interplanar spacing d_{hkl} in the case of cubic systems with the lattice constant a:

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

The lattice parameters are graphically represented in Fig. 3 along with the Vegard' s law linear dependence calculated as follows and by using the lattice constants of NiFe₂O₄ (ICDD file : 00-054-0964), CoFe₂O₄ (ICDD file : 00-022-1086) and ZnFe₂O₄ (ICDD file : 00-070-6393):

$$a(x) = (0.8 - x) \cdot a_{\text{NiFe}_2\text{O}_4} + x \cdot a_{\text{ZnFe}_2\text{O}_4} + 0.2 \cdot a_{\text{CoFe}_2\text{O}_4} \quad (3)$$

The experimental lattice parameters follow well the Vegard' s law, the observable errors being most probably related to a small difference between the real cation stoichiometry and the intended one. In nickel-cobalt-zinc ferrite, the distribution of cations between the tetrahedral A- and octahedral B-sites is made under the assumption that to their high crystal field stabilization energy, Ni²⁺ (3d⁸) and Co²⁺ (3d⁷) have a strong preferred to B-site [23,24]. On the other hand, Zn²⁺ ions (3d¹⁰) with free 4s4p orbitals tend to occupy the A site [25,26], while Fe³⁺ ions are distributed between two sites.

The theoretical lattice parameter (labeled as a_{th}) was calculated using the following relation [23]:

$$a_{\text{th}} = 8 / (3 \cdot \sqrt{3}) [(r_{\text{Tetra}} + R_{\text{O}}) + \sqrt{3} \cdot (r_{\text{Octa}} + R_{\text{O}})] \quad (4)$$

The ionic radii of octahedral site (r_{Octa}) and tetrahedral site (r_{Tetra}) were calculated from the following equations:

$$r_{\text{Octa}} = (0.8 - x)r_{\text{Ni}^{2+}} + 0.2r_{\text{Co}^{2+}} + (1-x)r_{\text{Fe}^{3+}} \quad (5)$$

$$r_{\text{Tetra}} = xr_{\text{Zn}^{2+}} + (1-x)r_{\text{Fe}^{3+}} \quad (6)$$

The values of lattice constants (theoretical and experimental) are summarized in Table 1. The increase in lattice parameter (a) with Zn²⁺ ions concentration is expected due to the difference in ionic radii between the displaced Ni²⁺ (0.69 Å) and the incorporated Zn²⁺ (0.74 Å) [27]. It can be seen a slight difference between theoretical and experimental unit cell parameters. According to T. Groń [28], the theoretical lattice parameter (a_{th}) for a filled spinel structure assumes that all ions are rigid spheres distributed in a rigid manner.

Furthermore, the equation which define the value of the oxygen positional parameter u is expressed as follows [29]:

$$u = (1/a\sqrt{3}) (r_A + R_O) + 1/4 \quad (7)$$

From this equation, the value of u is equal to 0.375 from which the oxygen ions are situated at faces of a unit cell $(\frac{3}{8}\frac{3}{8}\frac{3}{8})$ (origin at A-site). In the present work, values of u are slightly increased above 0.375 for all the samples (see Table 1) with Zn-substituted nickel-cobalt ferrite. This may be assigned to the expansion of the tetrahedral interstices, thereby oxygen ions migrate from the cations in tetrahedral site along the cube diagonal of the ferrite lattice. Hence, the octahedral interstices got smaller. The tetrahedral and octahedral bond lengths (d_{Ax} and d_{Bx}) were determined from reference [30] (see Table 1). The obtained values are consistent with the octahedral contraction and tetrahedral expansion. Once more, this result agrees with the previous estimation of cation distribution in this system. Two samples ($x=0.1$ and $x=0.2$) have been inspected by scanning electron microscope (Fig. 4). The nanosized grains are found to be prevalently spherical in shape. The average size is found to be around 100 nm and the corresponding histograms are presented in Fig. 4.

3.2 FT-IR studies

In Fig. 5 is represented the FT-IR transmittance spectra of $Ni_{0.8-x}Zn_xCo_{0.2}Fe_2O_4$ ($x=0.0, 0.05, 0.10$ and 0.20) nano-ferrites. It can be observed two major absorption bands (ν_1 and ν_2) in FT-IR spectra of the nickel-cobalt-zinc ferrite which are associated to intrinsic stretching-vibrations of the oxygen bonds with metal cations in tetrahedral A- and octahedral B-sites. One can note that the frequency ν_1 shift to a lower value ($594\text{--}580\text{ cm}^{-1}$) by increasing the Zn concentration, whereas ν_2 systematically moves toward higher wave number ($400\text{--}412\text{ cm}^{-1}$). It is well known that the vibrational frequencies are inversely proportional to reduced mass and bond length. In addition, the shift in absorption bands positions in our series is consistent with the values of tetrahedral and octahedral bond lengths (see Table 1). This confirms the formation of $Ni_{0.8-x}Zn_xCo_{0.2}Fe_2O_4$ spinel structure.

3.3 Dielectric properties

In Fig. 6 is represented the frequency dependence of the dielectric constant (ϵ') of $Ni_{0.8-x}Zn_xCo_{0.2}Fe_2O_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites, measured at different temperatures. At first sight, it can be noted that (ϵ') decreases steeply at lower frequency and shows invariant

behavior at higher frequency, indicating a typical dielectric dispersion. The present observation partly agrees with the predictions of Maxwell–Wagner [31,32] or Koop’s theories [33]. The applied electric field induces the displacement of the space charges, consequently the nano-ferrites behave as dipoles of Fe^{3+} and Fe^{2+} ions. Since there is an increase in the temperature, more dipoles are created and hence the dielectric properties increase. It is also apparent from the figure that the experimental values have been found to decrease by increasing the zinc concentration. The cations distribution and electron exchange between Fe^{2+} - Fe^{3+} ions within the spinel lattice (octahedral site) plays an important role in the electrical values of ferrites, and there are plenty of articles discussing this aspect, trying to explain the observable stoichiometry dependence [34,35]. Shown in Fig. 7 is the change in dielectric loss ($\tan \delta$) as a function of temperature at various frequencies. Non-Debye relaxation are visible in the whole measured temperature range. The change in loss factor present similar trend as that of the dielectric constant, the one if nickel cobalt ferrite ($x=0$) being the highest one, while for $x=0.2$ the smaller value is obtained. At room temperature, it was 0.48 (at 100 Hz) and 0.016 (at 100 kHz) for pure nickel-cobalt nano-ferrites, while it was 0.27 (at 100 Hz) and 0.008 (at 100 kHz) for $x = 0.20$ content. The low values of $\tan \delta$ at high frequency region makes $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ nano-ferrites a good material for high-frequency applications. Hence, our results are at least better than those obtained in various spinel compositions [36-41]. For polycrystalline materials, another important aspect is the ‘composite’ structure formed by grains (here we refer to crystallites) and the lower density spaces in between. If (nano)crystallites are intended to fit into a macro-volume, geometrical restriction will lead to voids within the crystallites. Thus, the system will be formed by 3 distinct components: the crystallites, the so-called grain boundaries (when the grains/boundaries touch each other) and the voids. The complexity of bulk ceramics, and the impact on the electrical properties is well described by Curecheriu *et al.* [42]. Since grain boundaries have low conductivity at low frequencies, thus, it will require more energy for electron exchange between Fe^{2+} - Fe^{3+} ions; consequently the loss is high. However, crystallites become more conductive at high frequencies because of the charge carrier’s hopping at the octahedral site, and therefore, values of loss factor are found to decrease. The room temperature ac conductivity (σ_{ac}) decreases with further substitution of Zn^{2+} concentration; a typical variation for frequency of 100 KHz is depicted in Fig. 8. However, the observed decline in the σ_{ac} value is

attributed to the formation of $\text{Fe}^{3+}\text{--O--Fe}^{3+}$ network at the octahedral site resulting in restrictions of the mobility of charge carriers.

The variation of imaginary electric modulus (M'') of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites with frequency over the temperature range of 100K to 400K, is shown in Fig. 9. Obviously, M'' scales up at lower frequency region entailing a single relaxation peak. On the other hand, M'' decreases at high frequency region. The region where the peak occurs is associated with the transition from long-range to short-range mobility [43]. Further, the shift in peak position towards higher frequencies with increasing temperature indicate that the conductivity of the mobile charge carrier is thermally activated. Furthermore, the observed asymmetry in peak broadening is confirming that the dielectric relaxation process is not obeying Debye behavior. In the present system, with further substitution of Zn^{2+} content, the modulus peak position start shifting towards higher frequency side suggesting that the mobile charge carriers can move over the short-range distances. The relaxation time (τ) is calculated using the relation $\tau=1/2\pi f_r$, where f_r is the relaxation frequency at which the maximum M'' is observed. The decrease in (τ) with increasing temperature is characteristic of semiconductor like conducting nature of zinc substituted nickel-cobalt nano-ferrites samples. The variation of (τ) as a function of inverse of temperature $1000/T$ of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites is shown in Fig. 10. One can note that the relaxation time (τ) can be well fitted with the Arrhenius relation. The values of activation energy (E_a) obtained from the slope of the fitted curves are found to be 0.18, 0.193, 0.20 and 0.205 eV for $x=0$, $x=0.05$, $x=0.10$ and $x=0.20$, respectively. It is again supporting the lower value of ac conductivity (Fig. 8).

Conclusions

The $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites were successfully prepared by Citrate-Gel auto-combustion method. The XRD patterns verified the existence of a single-phase cubic spinel ferrite structure in all samples. With further increasing Zn^{2+} content, the lattice constant is found to increase due to the widening into the lattice. Presuming and using the Vegard' s law, the determined lattice constants are close to the derived values. Results, also, show that Zn-substituted nickel-cobalt ferrite resulted in octahedral site contraction and tetrahedral site expansion. The presence of the tetrahedral and tetrahedral octahedral bands in

FTIR spectra at room temperature also confirm the formation of spinel structure. The monotonous decrease in the dielectric constant (ϵ') and dielectric loss ($\tan \delta$) with respect to the increasing frequency indicated a typical dielectric behavior of ferrites. Moreover, a low loss tangent factor of the order of 8×10^{-3} in $\text{Ni}_{0.6}\text{Zn}_{0.2}\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ usher possible utility in high frequency applications. Incorporation of Zn^{2+} ions in the nickel-cobalt ferrite decreases the room temperature ac conductivity measured at 100 KHz. Along these lines, it is noteworthy that our research work constitutes a further step that may pave the way for future studies in high-frequency electronic devices. The imaginary electric modulus (M'') studies revealed the presence of non-Debye type relaxation phenomenon in our samples.

Acknowledgement

The authors acknowledge the Tunisian Ministry of Higher Education and Scientific Research (Core program: 03-19PEJC03 project) and Romanian Ministry of Education and Research in the framework of Core Program PN19-03 (contract no. 21 N/ 08.02.2019) for the financial support.

References

- [1] M. P. Horvath, J. Magn. Magn. Mater 215, 171 (2000).
- [2] S. F. Alvarado, W. Eib, H.C. Siegmann, J.P. Remeika, J. Magn. Magn. Mater 3, 121 (1976).
- [3] J. Kulikowaski, J. Magn. Magn. Mater 41, 56 (1984).
- [4] K. Vasundhara, S. N. Achary, S. K Deshpande, P. D. Babu, S. S. Meena, A. K. Tyagi, J. Appl. Phys 113, 194101 (2013).
- [5] M. N. Ashiq, M. J. Iqbal, I. H. Gul, J. Alloys Compd 487, (2009) 341.
- [6] D. S. Jung, Y. C. Kang, J. Magn. Magn. Mater 321, (2009) 619.
- [7] A. Goldman, Modern Ferrite Technology, 2nd ed. (Springer, New York, 2006)
- [8] S. S. Jadhav, S. E. Shirsath, B. G. Toksha, S. J. Shukla, and K. M. Jadhav, Chin. J. Chem. Phys. 21, 381 (2008).
- [9] D. Ravinder, A. Chandrashekhhar Reddy, Mater. Lett. 57, 2855 (2003).
- [10] A. Maqsood, K. Khan, J. Alloys Compd. 509, 3393 (2011).
- [11] B. Chen, D. Chen, Z. Kang, Y. Zhang, J. Alloys Compd. 618, 222 (2015).
- [12] K. Mohit, V. Rani Gupta, N. Gupta, S.K. Rout, Ceram. Int. 40, 1575 (2014).
- [13] J. M. Hastzngs, L. M. Corliss, Rev. Mod. Phys. 25, 114 (1953).

- [14] U. B. Sontu, V. Yelasani, V. R. R. Musugu, J. Magn. Magn. Mater 374, 376 (2015).
- [15] R.C. Kambale, P.A. Shaikh, S.S. Kamble, Y.D. Kolekar, J. Alloys Compd. 478, 599 (2009).
- [16] A.V. Raut, R. S. Barkule, D. R. Shengule, K. M. Jadhav J. Magn. Magn. Mater 358, 87 (2014).
- [17] J. H. Choy, Y. S. Han Mater. Lett, 32, 209 (1997).
- [18] J. Smit, H.P.J. Wijn, Ferrites, Philips Technical Library, Eindhoven, The Netherlands, 1959, p. 151.
- [19] Amarendra K. Singh, T.C. Goel, R.G. Mendiratta, Sol. Stat. Comm. 125, 121 (2003).
- [20] Preeti Thakur, Deepika Chahar, Shilpa Taneja, Nikhil Bhalla, Atul Thakur, Ceram. Int 46, 15740 (2020).
- [21] W. H. Bragg and W. L. Bragg, Proceedings of the Royal Society of London A 88 (605), 428–438 (1913).
- [22] Tilley, R. J. D. (2006). Crystals and Crystal Structures. Chichester, United Kingdom: John Wiley & Sons.
- [23] M. S. R. Prasad, B. B. V. S. V. Prasad, B. Rajesh Babu, Int. J. Mod. Phys. B 29, 1550067 (2015).
- [24] E. Rezlescu, L. Sachelarie, P. D. Popa and N. Rezlescu, IEEE Trans. Magn. 36, 3962 (2000).
- [25] P.Y. Reyes-Rodríguez, D.A. Cortés-Hernández, J.C. Escobedo-Bocardo, J.M. Almanza-Robles, H.J. Sánchez-Fuentes, A. Jasso-Terán, L.E. De León-Prado, J. Méndez-Nonell, G.F. Hurtado López, J. Magn. Magn. Mater. 427, 268 (2017).
- [26] M.V. Santhosh Kumar, G.J.Shankarmurthy, E. Melagiriappa, K. K. Nagaraja, H. S. Jayanna, M. P. Telenkov, J Mater Sci: Mater Electron 29, 12795 (2018).
- [27] R.D. Shannon, Acta Cryst. A 32, 751 (1976).

- [28] T. Groń, Philos Mag B. 70, 121 (1994).
- [29] K.J. Standley, Oxide Magnetic Materials, Oxford University Press, London, 1962, p. 64.
- [30] S. G. Kakade, R. C. Kambale, C. V. Ramanna, Y. D. Kolekar, RSC Adv. 6, 33308 (2016).
- [31] J.C. Maxwell, Electricity and Magnetism (Oxford University Press, London, 1873).
- [32] K.W. Wagner, Ann. Phys. 40, 818 (1993).
- [33] C.G. Koops, Phys. Rev. 83, 121 (1951).
- [34] A.B. Kadam and Vishwanath K. Mande and S.B. Kadam and R.H. Kadam and Sagar E. Shirsath and Rameshwar B. Borade, J. Alloys Compd. 840, 155669 (2020).
- [35] M. Atif, T. Rafique, Atta Ur Rehman, H. Wahab, W. Khalid, Z. Ali, M. Nadeem, J Mater Sci: Mater Electron 31, 10970 (2020).
- [36] M.V. Shankarmurthy, G.J. Shankarmurthy, E. Melagiriappa, K.K. Nagaraja, H.S. Jayanna, M.P. Telenkov, J Mater Sci: Mater Electron 29, 12795 (2018).
- [37] C.S.L.N. Sridhar Lakshmi, G. Govindraj, S. Bangarraju, D.M. Potukuchi, Phys. B Condens. Matter 459, 97–104 (2015).
- [38] H. Chouaibi, J. Khelifi, A. Benali, E. Dhahri, M.A. Valente, A. koumina, J. Alloys Compd. 839, 155601 (2020).
- [39] Anil B. Mugutkar, Shyam K. Gore, Rajaram S. Mane, Sunil M. Patange, Santosh S. Jadhav, Shoyebmohamad F. Shaikh, Abdullah M. Al-Enizi, Ayman Nafady, Badr M. Thamer, Mohd Ubaidullah, J. Alloys Compd. 844, 156178 (2020).
- [40] R. Jasrotia, V.P. Singh, B. Sharma, A. Verma, P. Puri, R. Sharma, M. Singh, J. Alloys Compd. 830, 154687 (2020) .
- [41] Anil B. Mugutkar, Shyam K. Gore, Umakant B. Tumberphale, Vijaykumar V. Jadhav, Rajaram S. Mane, Sunil M. Patange, Shoyebmohamad F. Shaikh, Mohd. Ubaidullah, Abdullah M. Al-Enizi, Santosh S. Jadhav, J. Magn. Magn. Mater. 502, 166490 (2020).

[42] L. Curecheriu, M. T. Buscaglia, V. Buscaglia, Z. Zhao, L. Mitoseriu, Appl. Phys. Lett. 97, 242909 (2010).

[43] P.S. Das, P.K. Chakraborty, B. Behera, and R.N.P. Choudhary, Phys. B 395, 98 (2007).

Fig. 1: X-ray diffraction patterns of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ powders with different content of Zn ($x = 0, 0.05, 0.1$ and 0.2). The vertical lines are guides to the eye for single phase cubic spinel structure of ferrites.

Fig. 2: The X-ray diffractograms around the 220 and 311 reflections of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ powders with different content of Zn ($x = 0, 0.05, 0.1$ and 0.2). The dotted vertical lines are guides to the eye to highlight the differences for different cation stoichiometries.

Fig. 3: The lattice constant versus the Zn^{2+} concentration (symbols). The line represents the theoretical Vegard's law.

Fig. 4: Scanning electron micrographs of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ nano-ferrites and histograms, with $x=0.1$ and $x=0.2$, respectively.

Fig. 5: FTIR spectra of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites.

Fig. 6: Frequency dependence of dielectric constant (ϵ') of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites measured at different temperatures.

Fig. 7: The plot of dielectric loss vs frequency at different temperatures of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites.

Fig. 8: The composition dependence of room-temperature ac conductivity (σ_{ac}) for the selected frequency of 100 KHz.

Fig. 9: Variation of imaginary part of electric modulus (M'') with frequency for prepared ferrite compositions $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2).

Fig. 10: The variation of relaxation time (τ) as a function of $(1000/T)$.

Figures

Figure 1

X-ray diffraction patterns of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ powders with different content of Zn ($x = 0, 0.05, 0.1$ and 0.2). The vertical lines are guides to the eye for single phase cubic spinel structure of ferrites.

Figure 2

The X-ray diffractograms around the 220 and 311 reflections of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ powders with different content of Zn ($x = 0, 0.05, 0.1$ and 0.2). The dotted vertical lines are guides to the eye to highlight the differences for different cation stoichiometries.

Figure 3

The lattice constant versus the Zn²⁺ concentration (symbols). The line represents the theoretical Vegard's law.

Figure 4

Scanning electron micrographs of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ nano-ferrites and histograms, with $x=0.1$ and $x=0.2$, respectively.

Figure 5

FTIR spectra of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites.

Figure 6

Frequency dependence of dielectric constant (ϵ') of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites measured at different temperatures.

Figure 7

The plot of dielectric loss vs frequency at different temperatures of $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2) nano-ferrites.

Figure 8

The composition dependence of room-temperature ac conductivity (σ_{ac}) for the selected frequency of 100 KHz.

Figure 9

Variation of imaginary part of electric modulus (M'') with frequency for prepared ferrite compositions $\text{Ni}_{0.8-x}\text{Zn}_x\text{Co}_{0.2}\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$ and 0.2).

Figure 10

The variation of relaxation time (τ) as a function of ($1000/T$).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [TableCaptionOUMEZZINE.doc](#)