Synthesis of Spinel Nanocrystalline ZnFe₂O₄: Structural, Optical, Magnetic and Electrical properties.

Sasirekha Chelladurai (✉ chelladuraisasirekha@gmail.com)

The Gandhigram Rural Institute Deemed University <https://orcid.org/0000-0002-7462-2932>

Raghavan Chandrasekaran

The Gandhigram Rural Institute Deemed University

Sivaraman Murugasen

The Gandhigram Rural Institute Deemed University

Original Research

Keywords: Zinc ferrities, structural studies, FT-IR studies, optical studies, VSM studies, electrical studies

Posted Date: February 12th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-187066/v1>

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

[Read Full License](#)

Abstract

The present paper deals with the synthesis of Zinc Ferrite (ZnFe_2O_4) nanoparticles using simple, low cost co - precipitation method and study the structural, optical, magnetic and electrical properties. The samples have been prepared at two different calcination temperatures of 400°C and 600°C . The XRD studies indicate that the synthesized ZnFe_2O_4 samples exhibit cubic spinel structure and that the grain size increases with calcination temperature. The FTIR spectra demonstrate bands associated with metal – oxygen bonds in the tetrahedral and octahedral sites. Moreover, no unwanted impurity such as nitrate has been detected in the synthesized samples revealing their high purity. The micro structural analysis shows that though most particles are irregular granular ones, some are spherical. The optical band gap energy is found to increase with increasing calcination temperature. The Vibrating Sample Magnetometer (VSM) studies reveal the super paramagnetic behavior of the synthesized samples, even for a high Fe: Zn ratio of 1:2. The electrical resistivity of the samples decreases with increase in calcination temperature. This phenomenon has been explained on the basis of the Verwey-de Boer mechanism.

1. Introduction

In the recent years, many research groups are focusing their attention on magnetic oxide nanomaterials because of their innumerable and innovative applications. Ferrites are a class of magnetic oxide materials which have the structure AB_2O_4 ; in this structure, normally, A occupies tetrahedral, B occupies octahedral cation sites respectively and O occupies the Oxygen anion site [1–3]. Transition metal ferrites have the general molecular formula MFe_2O_4 (where M = Ni, Zn, Mn, Co, Mg etc) and they possess a face-centered cubic (fcc) close packing structure. They are considered as an important group of technological materials because of their properties such as high electrical resistivity, high chemical stability, high saturation magnetization, low eddy current loss, low dielectric loss, ease of preparation, price and performance considerations, good reusability and environmentally friendly nature etc. These properties made them suitable for many applications in magnetic, mechanical, electronic, catalytic and microwave devices [4-8].

Among the transition metal ferrites, the zinc ferrite (ZnFe_2O_4) has been studied extensively due to its different structures composed of normal, inverse and mixed spinel structures and its high electromagnetic performance, excellent chemical stability, mechanical hardness, low coercivity and moderate saturation magnetization, which makes it a good contender for the applications such as soft magnets, low-loss materials at high frequencies, photo catalysis, magnetic resonance imaging(MRI), Li-ion batteries, absorbent materials, biosensors and gas sensors [1,2,9-15]. The zinc ferrite nanoparticles exhibit unique structural, morphological, opto-electrical, magnetic and photocatalytic activities which are quite different from that of their bulk counterparts, due to their smaller particle size and higher surface area[9]. Therefore, controlled synthesis of nanometer sized materials is of great importance for investigating the structure - property relationship of the zinc ferrite nano particles. So far, various methods, such as sol-gel [16,17], co-precipitation [18,19], solution combustion [20,21], thermal

decomposition [22,23], solvothermal [24,25], hydrothermal [26,27], ball milling [28] and ceramic route techniques [29] have been used for synthesizing ZnFe_2O_4 nanoparticles possessing different structures. Among these methods, the co-precipitation method is simple and straight forward, low cost, non toxic, easy control of pH and capable of yielding crystalline nano materials in short time. Hence this method is chosen for preparing the samples. In the present work, it is envisaged to synthesize ZnFe_2O_4 nanoparticles through the co-precipitation method and study their structural, morphological, optical, magnetic and electrical properties.

2. Materials And Methods

2.1 Synthesis of ZnFe_2O_4 nanoparticles

In the present work, zinc ferrite (ZnFe_2O_4) nanoparticle samples have been prepared by co-precipitation method. All the chemicals used for the synthesis of the study samples are Analytical Reagent with 99% purity. For preparing the samples, the molarity ratio of Zn and Fe has been fixed as 1:2. Zinc Nitrate Hexahydrate [$\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$] and Ferric Nitrate nona hydrate [$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$] have been used as the precursors and Cetyl Trimethyl Ammonium Bromide (CTAB) has been used as a surfactant.

The Stoichiometric proportion of zinc nitrate hexahydrate (0.594 g) and ferric nitrate nonahydrate (1.616 g) have been dissolved in 100 mL of deionized water in two separate beakers. Each solution has been stirred for 30 min at 60°C using a magnetic stirrer to obtain a homogenous solution. These two solutions are labeled as A and B. The solution B is added drop by drop using a burette to the solution A contained in the beaker and the resultant solution is stirred well for 30 min at 60°C . This resultant solution is labeled as C. Similarly, 3.644 g of CTAB has been dissolved in 100 mL of deionized water in a beaker and stirred well at 60°C for 1 h. to get a clear solution. This solution has been labeled as D. The solution D has been added drop by drop using a burette to the solution C contained in a beaker and the resultant solution is stirred well for 30 min at 60°C and this solution has been labeled as E. 0.8M NaOH solution has been prepared using 50 mL deionized water and this solution has been added drop by drop to the solution E simultaneously stirring it until its pH reaches 10. At this stage, brown colored precipitate has been formed in the solution. The solution in the beaker has been left undisturbed until the entire precipitate settles down at the bottom of the beaker. The solution has been drained out and the precipitate is washed 4 times using deionized water. The beaker containing the precipitate has been kept in an oven for 8h. at 80°C for drying. The dried precipitate has been ground in to a fine powder using an agate mortar and pestle. This powder has been calcined at two different temperatures of 400°C and 600°C using a furnace for 2h. in an atmosphere of air.

For the purpose of the present study, the ZnFe_2O_4 samples calcined at 400°C and 600°C are referred to as ZF1 and ZF2 samples.

2.2 Characterization Techniques

The X-ray diffraction (XRD) patterns of the samples have been obtained using the PANalytical X'PERT-PRO X-ray diffractometer with CuK α radiation in the 2 θ angle range of 30° to 75°. The FTIR spectra of the samples have been recorded using the Perkin Elmer SPECTRUM BX II spectrometer in the range of 400 to 4000 cm⁻¹ using potassium bromide (KBr) pellet. The UV-Vis JASCO UV-Vis spectrometer has been used to record the UV-Vis spectra of the samples in the wavelength range of 200 to 900 nm. The morphology of the prepared samples has been analyzed by the scanning electron microscope (SEM)-TESCAN-VEGA3 LMU instrument and the elemental composition of the samples has been made by energy dispersive X-ray analysis (EDAX) spectra using the Bruker Quantax 200 AS instrument in conjunction with the TESCOAN-VEGA3 LMU instrument. The magnetic properties of the samples have been studied using a LDJ9500 vibrating sample magnetometer (VSM) at room temperature with a maximum magnetic field of 15000 G. A Keithley SCS 4200 source meter has been used for the I-V measurements at room temperature.

3. Results And Discussion

3.1 Structural characteristics

The crystal structure of the samples and their purity has been analyzed using X-ray diffraction (XRD) studies. The XRD patterns of the samples ZF1 and ZF2 are displayed in Fig 1.

The figure shows that the reflection peaks are intense and sharp indicating that the samples are well crystallized. The peaks formed at the 2 θ angles of 30.06°, 35.44°, 36.97°, 43.01°, 53.34°, 56.78°, 62.32° and 73.65° correspond to the reflections from (220), (311), (222), (400), (422), (511), (440) and (533) planes of cubic zinc ferrite (ZnFe₂O₄) with spinel structure belonging to the space group *Fd3m* (JCPDS data card number :221012). It can be noted that there are no peaks related to any impurity indicating phase pure nature of the prepared ZnFe₂O₄ samples. From the figure, it can be seen that (311) peak is the most dominant one. Similar results have been obtained by several researchers who have synthesized ZnFe₂O₄ nanoparticles using different methods [1-3, 9,10, 16, 21, 30, 31]. It can be further observed that, when the calcination temperature is increased to 600°C, the peaks become more prominent and sharper which demonstrates the sample crystallization becomes better and the mean grain size has become bigger. The lattice parameter 'a' of a cubic crystal can be calculated using the relation

$$a = d_{hkl} \times (h^2 + k^2 + l^2)^{1/2} \quad (1)$$

where (h k l) are the Miller indices of the reflecting planes and 'd_{hkl}' is the interplanar spacing. The mean value of the lattice parameter 'a' of ZF1 and ZF2 calculated using the above relation are given in Table 1. The mean grain size (D) of the crystallites has been calculated using the Debye Scherrer formula ,

$$D = \frac{K \lambda}{\beta \cos \theta} \quad (2)$$

where λ is the wavelength of the X ray beam, β is the full width of the diffraction peak at half the maximum intensity (FWHM) measured in radian and θ is the Bragg angle. The mean grain sizes (D) of the samples ZF1 and ZF2 evaluated using the relation (2) is given in Table 1.

Table 1: Mean lattice parameter (a) and mean grain size (D) of the ZnFe₂O₄ Samples

Sl.No	Sample	Calcination Temperature °C	'a' (nm)	D (nm)
1	ZF1	400	0.8392	14.2
2	ZF2	600	0.8412	17.4

The lattice parameter values obtained for the samples ZF1 and ZF2 (Table 1) are close to the standard value of 0.8441 nm for ZnFe₂O₄ given in the JCPDS data card. The table indicates that, as the calcination temperature increases, the mean grain size also increases. The same conclusion has also been arrived at by other researchers who have studied Zn Fe₂O₄ synthesized using different methods [10, 30,31].

3.2 FTIR studies

The FTIR spectroscopy is a powerful tool to identify the presence of functional groups in the samples. The FITR spectra of the samples ZF1 and ZF2 are presented in Fig.2. It is evident from the figure that, both the samples give rise to absorption bands in the range of 4000 to 400 cm⁻¹ and that the samples exhibit bands of the same frequencies.

The band assignments of the FTIR spectra are given below. The broad band centered at 3443 cm⁻¹ can be attributed to the stretching vibrations of O-H functional group. The medium intensity sharp band at 1647 cm⁻¹ can be associated with the bending vibrations of O-H functional group. The existence of these two bands confirms the presence of water molecules adsorbed from the environment on the surface of the nanomaterial due to their high specific surface areas [21,32]. The sharp and medium intensity bands at 2926 cm⁻¹ and 2858 cm⁻¹ can be assigned to C-H stretching bonds. These bands invariably appear in the FTIR spectra of samples and they are seldom considered important in determining the structure [21]. The sharp medium intensity bands occurring at 1745 cm⁻¹ and 1740 cm⁻¹ may be associated with C=O stretching vibrations. These bands may arise due to the presence of traces of adsorbed or atmospheric CO₂ [10]. In cubic spinel ferrites, the metal ions are present in the tetrahedral and octahedral sub lattices and consequently would exhibit two different vibrational bands in the range of 600 - 400 cm⁻¹. The higher frequency band at 556 cm⁻¹ can be assigned to stretching vibrations of the

metal - oxygen (M - O) bonds in the tetrahedral site while the lower frequency band at 418 cm^{-1} can be ascribed to the bending vibrations of metal - oxygen (M - O) bonds in octahedral site [21,33-35].

3.3 Morphological characteristics

The surface morphological features of the samples have been assessed using scanning electron microscope (SEM). Fig 3 illustrates the SEM micrographs obtained for the samples ZF1 and ZF2. The micrograph for the sample ZF1 (fig 3a) reveals that, though most particles are irregular granular ones, the presence of spherical particles in a few regions of the micrograph can be noticed and that there are some small pores primarily in the spherical particle regions. The particle distribution is rather non-uniform; the particles are agglomerated in certain locations in the micrograph. The micrograph of ZF2 (fig 3b) shows that the morphological features of this sample is in no way different from the features exhibited by the sample ZF1.

The Energy Dispersive X-ray Analysis (EDAX) has been used to identify the elemental composition of the samples. The EDAX spectra of samples ZF1 and ZF2 are depicted in Fig 4. They show the presence of Zinc (Zn), Iron (Fe) and Oxygen (O) in the samples studied without any impurity being present in them.

3.4 Optical characteristics

Fig 5 gives the UV-Vis spectra of the samples ZF1 and ZF2 obtained at room temperature. It can be observed from the figure that there are absorption bands in the UV as well as in the visible region of the spectrum and that the ZF2 sample exhibits a blue shift of spectral response with respect to ZF1 sample. The basic process of absorption of light is related to the electronic structures of materials. In such a case, the estimation of band gap energy assumes significance.

The band gap energy (E_g) has been calculated using Tauc's formula which shows the relationship between the absorption coefficient (α) and the incident photon energy ($h\nu$) and can be written as:

$$\alpha h\nu = A(h\nu - E_g)^n \quad (3)$$

where 'A' is a constant independent of energy and 'n' depends on the type of transition having values $1/2$, 2 , $3/2$ and 3 corresponding to the allowed direct, allowed indirect, forbidden direct and forbidden indirect transitions [36]. Since, ZnFe_2O_4 is a direct band gap material, n takes the value of ' $1/2$ ' for the allowed transitions. So, Tauc's formula for this case becomes,

$$\alpha h\nu = A(h\nu - E_g)^{1/2} \quad (4)$$

The $(\alpha h\nu)^2$ versus $(h\nu)$ plots (Tauc plot) for the samples ZF1 and ZF2 are given in Fig 6. Both the plots are found to be linear in the higher energy region. The intercept made by the extrapolated linear portion of the Tauc plot on the ' $h\nu$ ' axis corresponding to $(\alpha h\nu)^2 = 0$ gives the band gap energy (E_g) of the material.

The band gap energy (E_g) value of the sample ZF1 has been found to be 2.3 eV, which is blue shifted when compared with the bulk ZnFe_2O_4 (1.9 eV), which may be due to the presence of nano size particles in the study sample. At this juncture, it is pertinent to mention that band gap energy values ranging from 2.1 to 2.4 eV have been reported for ZnFe_2O_4 nanoparticles by other research groups [9, 37-39]; however,

Ahmad Reza Abbalian and MadhiShafiee Afrani [21] have reported a higher E_g value of 4.5 eV for ZnFe_2O_4 nanoparticles prepared by one- step solution compusion method. The band gap energy value of ZF2 sample has been found to be 2.6 eV. This shows that the band gap energy increases with increasing calcination temperature. Similar results have been reported by K. Kombaiah et.al [40] from their studies on CuFe_2O_4 nanoparticles.

3.5 Magnetic characterization

The magnetic properties of the samples ZF1 and ZF2 at room temperature have been investigated using the VSM technique by sweeping the magnetic field (H) between -15 000 G and + 15 000 G. The samples get magnetized with the applied field and when the field is increased the magnetization also increases and vice-versa. Fig 7 displays the magnetic field dependence of magnetization (M-H) of the samples ZF1 and ZF2. As shown in the inset of Fig 7, the samples exhibit very small hysteresis loop on the expanded scale. It is evident from the inset of Fig 7 that the coercivity (H_c) of the samples are almost negligible, revealing the super paramagnetic nature of the samples. Such a conclusion is consistent with the conclusions arrived at by the other investigators also [2,10, 41]. The particle size is a key factor influencing the magnetic properties of the sample. The super paramagnetic behaviour of the samples may be attributed to the nano sized particles [2,8,42].

The bulk ZnFe_2O_4 has a normal spinel structure with Zn^{2+} ions in the A (tetrahedral) site and Fe^{3+} ions in the B (octahedral) site. In contrast to the bulk materials, which exhibits normal spinel structure, nanocrystalline ZnFe_2O_4 material shows a mixed spinel structure in which Zn^{2+} and Fe^{3+} ions are distributed over both the A and B sites. This cationic rearrangement (cationic inversion) leads to the formation of two magnetic sub-lattices, which is responsible for the enhanced magnetization of the ZnFe_2O_4 nanoparticle material [1,43,44]. Since there is no cationic rearrangement in bulk ZnFe_2O_4 , it would exhibit paramagnetic behaviour. On the other hand, ZnFe_2O_4 nanocrystals could show super paramagnetic behaviour due to cationic inversion.

From Fig 7, it can also be noted that when the calcination temperature increases from 400°C to 600°C, the saturation magnetization increases from 3.15 emu/g to 4.25 emu/g (i.e the increase is about 35%). Sasanka Deka and Joy [45] have also observed similar increase in magnetization when the calcination temperature is increased from 600 K to 873K. The small increase in the magnetization above 400°C is likely to be due to the growth of the particles during the heating run [45].

3.6 Electrical Properties

The DC electrical resistivity is one of the most important properties of ferrites; usually high resistivity is prerequisite for most electronic applications that require negligible eddy currents which degrade the ferrite performance. So, the current – voltage (I-V) characteristics of the pellets prepared using the samples ZF1 and ZF2 have been studied by sweeping the applied voltage between – 10V and +10 V. The I – V characteristics obtained for the pellets are presented in fig 8.

The fig. reveals that, for both the pellets, when the voltage increases, the current also increases proportionally and the I-V plot is a slanting straight line in the first quadrant, the slope of which gives the conductance of the pellet; when the applied voltage is reversed, the current also reverses and the I – V plot is a straight line in the third quadrant, having the same slope as that in the first quadrant; when the applied voltage is swept between -10 V and +10 V, the I – V plot traces the same straight line path. The fig. further shows that, the I – V plots of the pellets are similar and symmetric and that the pellets exhibit Ohmic behaviour.

The resistivity (ρ) of the material of the pellet (i.e the resistivity of the material of the sample) has been determined using the relation

$$\rho = R \times \left(\frac{A}{d} \right) \quad (5)$$

Where R is the resistance of the pellet, found from the relation $R = V / I$

(where V is the applied voltage and I is the measured current), 'd' is the thickness of the pellet and A is the area of cross section of the pellet. The resistivities of the samples ZF1 and ZF2 have been evaluated using the relation 5 and the values obtained are 3.96×10^{-6} and $3.13 \times 10^{-6} \Omega \text{ cm}$ respectively. It can be seen that the electrical resistivity of the samples decreases with increase in calcination temperature indicating the semiconducting nature of the samples. This decrease in resistivity can be explained as a consequence of micro structural and structural changes introduced by the increased calcination temperature. It can be noted that the mean grain size of the samples increases with increase in calcination temperature [section 3.1] which may cause a decrease in resistivity of the sample. The electric conductivity in ferrites can be explained by the Verwey-de Boer mechanism in which electron hopping takes place between ions of the same element present in more than one valence state, which are distributed randomly over crystallographically equivalent lattice sites. In ferrites, the charge carriers are localized at the magnetic ions and the electronic hopping between Fe^{2+} and Fe^{3+} ions located on octahedral sites is the primary mechanism which allows electrical transport. Obviously, the more the Fe^{2+} iron content the higher the conductivity and hence lower the resistivity. The decrease in DC resistivity with the increase in calcination temperature can be attributed to the presence of increase in Fe^{2+} content [46-50]. So, it can be concluded that, the above mentioned factors may be the cause for the observed drop in resistivity with increase in calcination temperature.

4. Conclusions

ZnFe₂O₄ (Zinc ferrite) nanoparticles, at two different calcination temperatures of 400°C and 600°C, have been successfully synthesized using the simple, low cost co - precipitation method. Studies made on the synthesized samples reveal that ZnFe₂O₄ with cubic spinel structure has been formed, the mean crystallite size increases with calcination temperature, no unwanted impurity such as nitrate has been detected in the synthesized samples indicating their high purity, particles are of irregular granular shape with a sprinkling of spherical particles, the optical band gap energy increases with increasing calcination temperature, the samples exhibit super paramagnetic behaviour and the saturation magnetization of the samples increases with calcination temperature. The studies further reveal that the electrical resistivity of the samples decreases with increasing calcination temperature and this phenomenon can be explained by Verwey-de Boer mechanism.

References

1. Yan Xu, Yantian Liang, Lijuan Jiang, Huarui Wu, Hongzhi Zhao, and Desheng Xue, Preparation and Magnetic Properties of ZnFe₂O₄ Nanotubes, *J.Nanomate*, 5, **(2011)**, Article ID 525967.
2. M. Maria Angelin Sinthiya K. Ramamurthi S. Mathuri T. Manimozhi, N. Kumaresan, Mudaliar Mahesh Margoni and PC. Karthika, Synthesis of Zinc Ferrite (ZnFe₂O₄) Nanoparticles with Different Capping Agents, *Int.J. ChemTech Res.*, 7 **(2015)**, 2144-2149.
3. M. Deraz, Omar H and Abd-Elkader, *Fabrication and Characterization of ZnFe₂O₄ / ZnO Based Anticorrosion Pigments*, *Int. J. Electrochem. Sci.*, 10, **(2015)**, 7103 - 7110,
4. Pardavi-Horvath, M. *Microwave applications of soft ferrites. Journal of Magnetism and Magnetic Materials*, 215-216, (2000), 171–183
5. Fan, H. M., Yi, J. B., Kho, K. W., Tan, H. R., Shen, Z. X., Ding, J., Sun, X. W., Olivo, M. C., and Feng, Y. P., Single- crystalline M Fe₂O₄ nanotubes/nanorings synthesized by thermal transformation, *J.ACS nano*, 3, **(2009)**, 2798-2808.
6. A Sutka, R Parna, J Kleperis, T Kaambre, I Pavlovskas, V Korsaks, K Malnieks, L Grinberga and V Kisand, Photocatalytic activity of non-stoichiometric ZnFe₂O₄ under visible light irradiation, *J. Phys. Scr.*, 89 **(2014)**, 044011-044019.
7. Radga .C. Sripriya, Arasi Ezhil, J Madhavan and Antony Raj Victor. Synthesis and Characterization studies of ZnFe₂O₄ nanoparticles, *J.MMSE.*, 9, **(2017)** , ISSN 2412-5954.
8. Teena James, Tomlal Jose E, Subin P John and Jacob Mathew, Structural, Thermal and Magnetic Properties of PMMA-ZnFe₂O₄ Nanocomposite Thin Films, *IJRASET*, 7, **(2019)**, 869-874.
9. N. Deraz and A. Alarifi, Microstructure and magnetic studies of zinc ferrite nano-particles. *Int. J. Electrochem. Sci.*, 7, **(2012)**, 6501–6511.

10. Goodarz Naseri M., Saion E. B and Kamali A. An Overview on Nanocrystalline ZnFe_2O_4 , MnFe_2O_4 , and CoFe_2O_4 Synthesized by a Thermal Treatment Method. *ISRN Nanotechnology*, **(2012)**, 1–11.
11. X. Zhou X. Li H. Sun P. Sun X. Liang F. Liu X. Hu and G. Lu, Nanosheet-assembled ZnFe_2O_4 hollow microspheres for high sensitive acetone sensor, *J.ACS Appl. Mater. Interfaces*, **7**, **(2015)**, 15414–15421.
12. H. Xu X. Chen L. Chen L.E. Li L. Xu J. Yang and Y. Qian, A comparative study of nanoparticles and nano spheres ZnFe_2O_4 as anode material for lithium ion batteries. *Int. J. Electrochem. Sci.*, **7**, **(2012)**, 7976–7983.
13. M.K. Lima-Tenório, E.T. Tenório-Neto, A.A.W. Hechenleitner H. Fessi and E.A.G. Pineda, CoFe_2O_4 and ZnFe_2O_4 nanoparticles: an overview about structure, properties, synthesis and biomedical applications. *Colloid Sci. Biotechnol.*, **5**, **(2016)**, 45–54.
14. P. Suppuraj, G. Thirunarayanan, M. Swaminathan and I. Muthuvel, Facile synthesis of spinel nanocrystalline ZnFe_2O_4 : enhanced photocatalytic and microbial applications, *J. Mater. Sci. Appl. Chem.* **34**, **(2017)**, 5-11.
15. Wang, M. Ai, Z. H. and Zhang, L. Z. Generalized Preparation of Porous Nanocrystalline ZnFe_2O_4 Superstructures from Zinc Ferrioxalate Precursor and Its Super paramagnetic Property. *J. Phys. Chem. C*, **112**, **(2008)**, 13163–13170.
16. F. Iqbal, M.I.A. Mutalib, M.S. Shaharun, M. Khan and B. Abdullah, Synthesis of ZnFe_2O_4 using sol–gel method: effect of different calcination parameters, *Proc. Eng.*, **148**, **(2016)**, 787–794.
17. M. Atif, S. K. Hasanain, and M. Nadeem, “Magnetization of sol-gel prepared zinc ferrite nanoparticles: effects of inversion and particle size,” *Solid State Commun.*, **138**, **(2006)**, 416–421.
18. Ebrahim M, Raeisi Shahraki R, Seyyed Ebrahimi S.A. and Masoudpanah S.M. Magnetic Properties of Zinc Ferrite Nanoparticles Synthesized by Co precipitation Method., *J. Supercond Nov Magn*, **27**, **(2014)**, 1587–1592.
19. A. Vinosha, L.A. Mely, J.E. Jeronsia, S. Krishnan and S.J. Das, Synthesis and properties of spinel ZnFe_2O_4 nanoparticles by facile co-precipitation route, *J. Optik.*, **134**, **(2017)**, 99–108.
20. A. Manikandan, S.A. Antony, R. Sridhar, S. Ramakrishna and M. Bououdina, A simple combustion synthesis and optical studies of magnetic $\text{Zn}_{1-x}\text{Ni}_x\text{Fe}_2\text{O}_4$ nanostructures for photoelectrochemical applications, *J. Nanosci. Nanotechnol.*, **15**, **(2015)**, 4948–4960.
21. Ahmad Reza Abbasian and Mahdi Shafiee Afarani, One step solution combustion synthesis and characterization of ZnFe_2O_4 and $\text{ZnFe}_{1.6}\text{O}_4$ nanoparticles, *J. Appl. Phys. A*. **125**, **(2019)**, 1-12.

22. Kalpana devi Kalimuthu, Sinduja C. Rangasamy and Manimekalai Rakkiya samy, Characterization of ZnFe_2O_4 nanoparticles obtained by the thermal decomposition of $\text{ZnFe}_2(\text{cin})_3(\text{N}_2\text{H}_4)_3$, *J. Acta Chim. Slov.*, 60, **(2013)**, 896– 900.
23. U. Kurtan, H. Erdemi, A. Baykal and H. Güngüneş, Synthesis and magneto-electrical properties of MFe_2O_4 (Co, Zn) nanoparticles by oleylamine route. *J. Ceram. Int.*, 42, **(2016)**, 13350–13358 .
24. P. Guo, M. Lv, G. Han, C. Wen, Q. Wang, H. Li and X. Zhao, Solvothermal synthesis of hierarchical colloidal nano crystal assemblies of ZnFe_2O_4 and their application in water treatment. *J. Materials.*, 9, **(2016)**, 1-10.
25. R. Liu M. Lv Q. Wang H. Li P. Guo and X.S. Zhao, Solvothermal synthesis of size-tunable ZnFe_2O_4 colloidal nanocrystal assemblies and their electro catalytic activity towards hydrogen peroxide. *J. Magn. Mater.*, 424, **(2017)**, 155–160.
26. Rameshbabu R, Ramesh R, Kanagesan S, Karthigeyan A and Ponnusamy S, Synthesis and study of structural, morphological and magnetic properties of ZnFe_2O_4 nanoparticles, *J. supercond Nov Magn.*, 27, **(2014)**, 1499-1502 .
27. J. Zhang, J.M. Song, H.L. Niu, C.J. Mao, S.Y. Zhang and Y.H. Shen, ZnFe_2O_4 nanoparticles: synthesis, characterization, and enhanced gas sensing property for acetone. *J. Sens. Actuators B, Chem.* 221, **(2015)**, 55–62.
28. Mozaffari M and Masoudi H, Zinc Ferrite nanoparticles: New preparation method and magnetic properties, *J. Supercond Nov Magn*, 27, **(2014)**, 2563–2567.
29. Mohammad Niyafar, Effect of preparation on structure and magnetic properties of ZnFe_2O_4 , *Journal of Magnetism*, 19, **(2014)**, 101-105.
30. S. AbediniKhorramia, G. Mahmoudzadeha , S. S. Madania and F. Gharibb Effect of calcination temperature on the particle sizes of zinc ferrite prepared by a combination of sol-gel auto combustion and ultrasonic irradiation techniques, *J. Ceram Process Res.* 12, **(2011)**, 504~508.
31. Samarjit Singh, Gaurav Goswami and Abhishek Kumar, Influence of pH and Calcination temperature on magnetic properties of nanosized Zn-ferrite synthesized by sol–gel citrate method, *IJRET: (International Journal of Research in Engineering and Technology)*, 6, **(2017)**, 23-29.
32. Palusamy Suppuraj, Ganesamoorthy Thirunarayanan, Meenakshisundaram Swaminathan and Inbasekaran Muthuvel, Facile Synthesis of Spinel Nanocrystalline ZnFe_2O_4 : Enhanced Photocatalytic and Microbial Applications, *J. Mater Sci Technol*, 34, **(2017)**, 5-11.
33. P. Annie Vinosha, L. Ansel Mely, J. EmimaJeronsia, S. Krishnan and S. Jerome Das, Synthesis and properties of spinel ZnFe_2O_4 nanoparticles by facile co-precipitation route, *J. Optik.*, 134, **(2017)**, 99-108.

34. Jessyamma Kurian and M. Jacob Mathew. Structural, optical and magnetic studies of CuFe_2O_4 , MgFe_2O_4 and ZnFe_2O_4 nanoparticles prepared by hydrothermal / solvothermal method, *J. Magn. Magn.*, 451, **(2018)**, 121-130.
35. A. Pradeep and G. Chandrasekaran, FTIR study of Ni, Cu and Zn substituted nano- particles of MgFe_2O_4 , *Mater. Lett.*, 60, **(2006)**, 371 – 374.
36. Manish Mittal, Manoj Sharma, O.P. Pandey, UV–Visible light induced photocatalytic studies of Cu doped ZnO nanoparticles prepared by co -precipitation method, *J. Sol. Energy.*, 110, **(2014)**, 386–397.
37. K. Shetty, L. Renuka, H.P. Nagaswarupa, H. Nagabhushana, K.S. Anantharaju, D. Rangappa, S.C. Prashantha and K. Ashwini, A comparative study on CuFe_2O_4 , ZnFe_2O_4 and NiFe_2O_4 : morphology, impedance and photocatalytic studies. *J. Mater. Today. Proc.*, 4, **(2017)**, 11806–11815.
38. G. Raja, S. Gopinath and K. Sivakumar, Effect of glycine and L-arginin as processing fuels in the synthesis of ZnFe_2O_4 nanostructures prepared via a facile microwave combustion method, *J. Ceram. Int.*, 42, **(2016)**, 8763–8768.
39. R. Rachna, N.B. Singh and A. Agarwal, Preparation, characterization, properties and applications of nano zinc ferrite. *J. Mater. Today Proc.*, 5, **(2018)**, 9148–9155.
40. K. Kombaiah, J. Judith Vijaya, L. John Kennedy, M. Bououdina and Basma ANajarc, Conventional and microwave combustion synthesis of opto magnetic CuFe_2O_4 nanoparticles for hyperthermia studies, *J. Phys. Chem. Solids.*, 115, **(2018)**, 162-171.
41. C. Sambathkumar, S. EzhilArasi, B. Natarajan, A. Arivarasan and P. Devendran, Examination of Structural, Morphological and Magnetic Behaviour of ZnFe_2O_4 Nanoparticle Synthesized by Co-Precipitation Method, *J. IJEAT*, 9, **(2019)**, 1085-1088.
42. Mahmoud Goodarzi Naseri and Elias B. Saion, , Crystalization in Spinel Ferrite Nanoparticles, *Advances in Crystallization Processes*, 14, **(2012)**, 349-380.
43. V. Sepelak, M. Zatroch, K. Tkacova, P. Petrovic, S. Wibmann and K. D. Becker, Structure and properties of the ball-milled spinel ferrites, *J. Mat sci Eng A*, 22, **(1997)**, 226–228.
44. B. Jeyadevan, K. Tohji, and K. Nakatsuka, Structure analysis of co-precipitated ZnFe_2O_4 by extended X-ray-absorption fine structure, *J. Appl. Phys.*, 76, **(1994)**, 6325–6327.
45. Sasanka Deka and P. A. Joy, Super paramagnetic Nanocrystalline ZnFe_2O_4 with a Very High Curie Temperature, *J. Nanosci. Nanotechnol.*, 8, **(2008)**, 3955–3958.

46. Dalibor L. Sekulic, Zorica Z. Lazarevic, Miljko V. Sataric, Cedomir D Jovalekic and Nebojsa Z. Romcevic, Temperature - dependent complex impedance, electrical conductivity and dielectric studies of MFe_2O_4 ($M = Mn, Ni, Zn$) ferrites prepared by sintering of mechanochemical synthesized nanopowders, *J. Mater Sci: Mater Electron*, 26, **(2015)**, 1291–1303.
47. Li ZY, Liu BG, Zhou KC, Zhang D and Zhang L, Microstructure and DC Electrical Conductivity of Spinel Nickel Ferrite Sintered in Air and Nitrogen Atmospheres, *J. Mater. Res. Bull.*, 45, **(2010)**, 1668-1671.
48. Mahalakshmi S and Manja KS., AC electrical conductivity and dielectric behavior of nanophase nickel ferrites, *J. Alloys Compd.*, 457, **(2008)**, 522-525.
49. Fabio Luis Zabotto, Alexandre José Gualdi, Jose Antonio Eiras, Adilson Jesus Aparecido de Oliveira and Ducinei Garcia, Influence of the Sintering Temperature on the Magnetic and Electric Properties of $NiFe_2O_4$ Ferrites, *J. Mater. Res.*, 15, **(2012)**, 428-433.
50. M.S. Khandekar, R.C. Kambale, J.Y. Patil, Y.D. Kolekar and S.S. Suryavanshia, Effect of calcination temperature on the structural and electrical properties of cobalt ferrite synthesized by combustion method, *J. Alloys Compd.*, 509, **(2011)**, 1861–1865.

Figures

Figure 1

XRD patterns of (a) ZF1 and (b) ZF2 samples

Figure 2

FTIR spectra of (a) ZF1 and (b) ZF2 samples

Figure 3

SEM micrographs of (a) ZF1 and (b) ZF2 samples.

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
Fe	26	K-series	73.28	64.88	63.59	1.95
Zn	30	K-series	36.61	32.41	27.13	1.05
O	8	K-series	3.06	2.71	9.28	1.19
Total:			112.96	100.00	100.00

El	AN	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (1 Sigma) [wt.%]
O	8	K-series	18.94	18.99	46.29	4.17
Fe	26	K-series	52.83	52.97	36.99	1.45
Zn	30	K-series	27.96	28.04	16.72	0.87
Total:			99.74	100.00	100.00	

Figure 4

EDAX spectra of (a) ZF1 and (b) ZF2 samples

Figure 5

UV-Vis Spectra of (a) ZF1 and (b) ZF2 samples.

Figure 6

Tauc plots for (a) ZF1 and (b) ZF2 samples

Figure 7

The M-H curves of (a) ZF1 and (b) ZF2 samples.

Figure 8

I – V characteristics of (a) ZF1 and (b) ZF2 samples