Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 1 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Investigation of Structural, Morphological and Optical Properties of Nickel Ferrite Nanoparticles Synthesized via Co-Precipitation

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ABSTRACT

The co-precipitation process was used to create nickel ferrite ($NiFe_2O_4$) nanoparticles, which were then examined to assess their optical, morphological, vibrational, and structural characteristics. X-ray diffraction (XRD) was used to examine the phase development and crystalline structure. The formation of the cubic spinel structure of $NiFe_2O_4$ was confirmed by the XRD pattern, which showed characteristic diffraction peaks at about 30°, 36°, 43°, 57°, and 63°, corresponding to the (220), (311), (400), (511), and (440) planes, respectively. Fourier transform infrared (FTIR) spectroscopy also confirmed the characteristic metal–oxygen vibrational modes of the ferrite lattice, with prominent bands detected around 486.46, 645.53, and 804.61 cm^{-1}. An uneven and heterogeneous surface morphology with notable particle aggregation and rough granular characteristics was discovered by scanning electron microscopy (SEM). Tauc analysis was used to evaluate the optical band gap, and UV–visible spectroscopy was used to examine the optical characteristics. An optical band gap of about 2.5 eV was obtained from the plot of $(\alpha h\nu)^2$ suggesting that the synthesized material is semiconducting. The creation of crystalline $NiFe_2O_4$ nanoparticles with distinctive spinel structure, agglomerated shape, and well-defined optical characteristics is confirmed by the combined XRD, FTIR, SEM, and UV-visible data, indicating their potential for functional nanomaterial applications.

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Keyword: $NiFe_2O_4$, Nanoparticles, Co-Precipitation, XRD; FTIR, SEM; UV–Visible Spectroscopy, Optical Band Gap

Introduction

Ferrites are quite adaptable in producing a wide range of solid-state compositions to modify their properties for a number of uses. They can be prepared in three different crystal systems and different ways of preparation. Ferrites are not suitable in some technological applications where ferromagnetic metals are used but in other applications with lower cost, they can be competitive with metallic materials. Ferrites are electrically non-conductive and act like insulators, however they still have ferromagnetic properties and can be magnetised and even attracted to an external magnetic field.[1]Ferrites are a form of ceramic material composed of iron oxide (Fe_2O_3) and other metal oxides which are commonly used in electronic components due to their magnetic characteristics. The importance of ferrite materials has been known for many centuries, as the Chinese navigational compasses were already using ferrite materials in the early 12th century.[2] With the general chemical formula $NiFe_2O_4$, nickel ferrite is a kind of spinel ferrite, a magnetic ceramic material made of iron (Fe^{3+}) and nickel (Ni^{2+}) ions organized in a cubic spinel crystal structure. It belongs to the family of ferrimagnetic materials that have the mechanical and chemical strength of ceramics and the magnetic characteristics of ferrite.[3]

Numerous techniques, including sol-gel, hydrothermal, combustion, and auto-combustion, can be used to create $NiFeO_4$ nanoparticles. These investigations verify that $NiFe_2O_4$ is routinely revealed by X-ray diffraction (XRD) as a single-phase cubic spinel ferrite, frequently with nanoscale particle size dependent on the production technique.[4]Nickel ferrite ($NiFe_2O_4$) is a material with a considerable ferromagnetic activity, which has an inverted spinel crystal structure. The magnetic properties are due to the antiparallel orientation of the magnetic moment of Ni^{2+} ions at the octahedral (B) positions with that of Fe^{3+} ions at the tetrahedral (A) positions. This gives rise to a net magnetic moment due to the different magnetizations of the sub lattices. Therefore, the magnetic characteristics of the nickel ferrite are primarily influenced by the distribution of the cations inside the spinel lattice as well as by the supra exchange interactions between oxygen ions.[5]Nickel ferrite is an important class of magnetic oxide materials which have received significant research attention because of their excellent magnetic, electrical and optical properties. This is why spinel ferrites are very well suited for applications where high frequency electromagnetic wave propagation is involved. That is why spinel ferrites are used in many technological and industrial applications such as high-density magnetic storage devices, microwave components, telecommunication devices, magnetic fluids, magnetic guided drug delivery systems and gas sensing devices.[6]

Nickel ferrite nanoparticles were manufactured by the chemical co-precipitation method using metal nitrates as predecessors. XRD of the as-prepared powder indicated nickel ferrite along with iron oxide and minor impurity phases, while hotness treatment at 600 °C promoted the formation of an opposite spinel $NiFe_2O_4$ stage with a small fraction of iron oxide remaining. FE-SEM analysis showed that the as-synthesized particles had laminar morphology, whereas the heat-treated sample exhibited irregularly shaped fine particles. Magnetic measurements of the annealed

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sample revealed ferromagnetic behavior with nearly zero reminisce and coercivity, indicating super paramagnetic characteristics with a noticeable saturation magnetization.[7] Because decreasing particle size can alter surface area, magnetic behavior, electrical characteristics, and optical sensitivity, the nano scale form of $NiFe_2O_4$ is very appealing. $NiFe_2O_4$ nanoparticles have therefore been studied for use in energy-related devices, sensors, catalysis, and other functional technologies. Additionally, recent research has shown that synthesis circumstances can significantly affect the size, shape, and optical characteristics of nickel ferrite crystallites.[8]

Materials and Methods

Materials

Nickel Ferrite nanoparticles were synthesized using the following starting materials: Nickel nitrate hex hydrate $Ni(NO_3)_2 \cdot 6H_2O$, Ferric nitrate precursor and sodium hydroxide (NaOH). A solvent of deionized water was used. The choice of nickel and iron precursors was determined by the stoichiometric composition to produce $NiFe_2O_4$.

The overall formation is schematically presented as:

$Ni^{2+} + 2Fe^{3+} + 8OH^- \rightarrow NiFe_2O_4 + 4H_2O$

During the thermal treatment, intermediate hydroxide species could be formed and then dehydrated to give ferrite.

Synthesis by co-precipitation

The required amounts of nickel and iron salts were separately dissolved in deionized water. The two solutions were then combined with stirring to form a uniform solution. The solution was boiled and stirred constantly, and sodium hydroxide solution was used as precipitating agent. The pH of the reaction mixture was kept at about 12, which favored the precipitation of the metal hydroxide precursor species. Under similar alkaline precipitation conditions, the co-precipitation synthesis of nickel ferrite is reported.[9]

The resulting precipitate was separated repeatedly cleaned with deionized water to get rid of any remaining soluble species and then dried. To encourage the production and crystallization of the $NiFe_2O_4$ spinel phase the dried precursor was thermally heated.

Nickel salt + Iron salt → Homogenous Precursor Solution → Addition of NaOH → Hydroxide Precipitation → Washing → Drying → Heat treatment => $NiFe_2O_4$ Nanoparticles.

Materials Characterizations

The crystal structure and the formation of the phase of the resultant nanoparticles was confirmed by X-ray diffraction. The Scherrer equation can be used to estimate the size of the crystallite. The crystallite size D is given by $D = K\lambda / (\beta \cos \theta)$ where λ is the X-ray wavelength, β is the FWHM in radians and K is a constant. The lattice parameter for a cubic spinel structure can be found using $a = d\sqrt{(h^2+k^2+l^2}$.

The structure of the metal-oxygen framework was determined with the help of FTIR spectroscopy and was characterized by the occurrence of unique modes of vibration. Metal–oxygen vibrational zones linked to tetrahedral and octahedral sites are typically

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seen in spinel ferrites. SEM is particularly useful for characterizing the ferrite nanoparticles due to the surface energy and magnetic interactions that could give rise to aggregation of nano scale magnetic particles. The optical band gap was estimated by using the Tauc relationship $(\alpha hv)^1 = A(hv - Eg)$ $(\alpha h\cdot)^2 = A(h - Eg)$. The extrapolated linear section intersects with the photon-energy axis to give the estimated band gap.

Results and Discussion

XRD Analysis

The crystal structure and phase formation of the prepared NiFe2O4 nanoparticles was studied by X-ray diffraction (XRD) technique. The diffraction pattern displayed unique reflections at 2θ values of approximately 30.86°, 36.06°, 43.3°, 54°, 57.84°, and 63.29°. The reflections correspond to the crystallographic planes (220), (311), (400), (511) and (440) characteristic of the cubic spinel structure of $NiFe_2O_4$. The experimental diffraction pattern shows good agreement with previously reported $NiFe_2O_4$ XRD patterns. The presence of individual diffraction peaks suggests that the synthetic material is a crystal. The diffraction peaks at approximately 30°, 36°, 43°, 54°, 57°, and 63° were linked to the crystallographic planes (220), (311), (400), (511), and (440). These characteristic reflections are very similar to the normal cubic spinel $NiFe_2O_4$ diffraction pattern. The strongest reflection was obtained along the (311) plane which is the characteristic dominating peak for $NiFe_2O_4$. The XRD pattern of the synthesized $NiFe_2O_4$ nanoparticles was compared with the standard JCPDS/ICDD card No. 00-044-1485.

The diffraction peak with the greatest intensity at 2θ = 36.06° is indexed to the (311) crystallographic plane of $NiFe_2O_4$. The (311) reflection's prominence is a characteristic of the spinel ferrite structure. The $NiFe_2O_4$ spinel structure was obtained, and no diffraction peaks of secondary crystalline phases were observed in the $NiFe_2O_4$ (excluding the detection limit of XRD data).

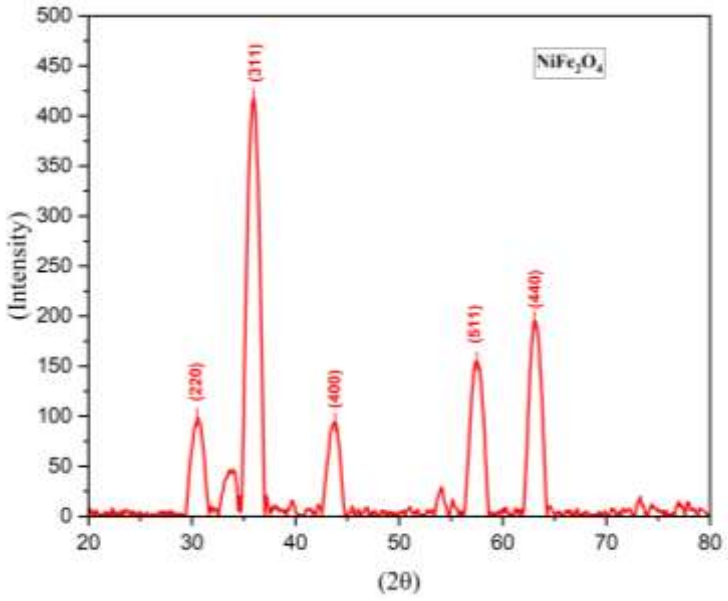


Figure: 1 XRD Patterns of $NiFe_2O_4$

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FTIR Analysis

The FTIR spectra of prepared $NiFe_2O_4$ sample was obtained in the range of 4000–400 cm^{-1} as shown in the figure 2. The spectrum shows the functional groups at the surface of the nanoparticles as well as characteristic vibrations of the metal-oxygen structure of the spinel ferrite.

At about 486 cm^{-1}, there is another significant band in the current spectrum. This band is located in the lower-frequency metal–oxygen vibration region connected to the spinel ferrite structure's octahedral (B) sites. Previous literature provides good support for this assignment.

For instance, an octahedral metal–oxygen vibration at 490 cm^{-1} has been recorded by FTIR analysis of $NiFe_2O_4$, although another study specifically specified 486 cm^{-1} as one of the characteristic vibrational frequencies of nickel ferrite. Consequently, the development of the

$NiFe_2O_4$ spinel structure is consistent with the observed 486 cm^{-1} band. The existence of the two distinctive low-wavenumber bands, which are roughly 645 cm^{-1} and 486 cm^{-1}, provide crucial proof that the metal–oxygen framework of $NiFe_2O_4$ was formed. In spinel ferrites, metal-oxygen extending at tetrahedral sites is often linked to higher-frequency vibrations, while metal-oxygen extending at octahedral sites is linked to lower-frequency vibrations. In the current spectra, a feature can also be seen at 804.6 cm^{-1}. Since the primary spinel ferrite M–O bands are typically found in the 400–650 cm^{-1} area, this band should not be immediately attributed to the distinctive $NiFe_2O_4$ metal–oxygen vibrations. Thus, a surface species, residual precursor/organic species, instrumental or background contribution, or another small vibrational mode could be associated with the band at 804.6 cm^{-1}.

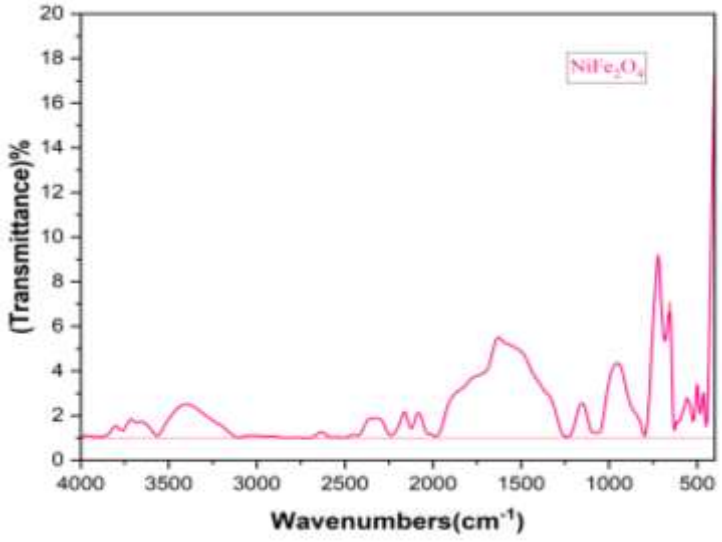


Figure 2: FTIR of of $NiFe_2O_4$

Morphological Analysis (SEM)

SEM was used to examine and produced NiFe2O4 nanoparticles' surface appearance and particle aggregation behavior. The SEM micrograph primarily displays a highly agglomerated and uneven appearance. Rather of being evenly distributed the particles

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seem to be connected and grouped into sizable clusters. Ferrite nanoparticles frequently exhibit this kind of agglomeration, which is explained by the high surface energy linked to their small particle size, which fosters strong inter particle interactions.

A rough and uneven surface with small granular characteristics dispersed throughout the larger agglomerated areas is also visible in the SEM image. Attached to the surfaces of the bigger aggregates are a number of smaller particles. Interparticle spaces or voids created within the aggregated structure are shown as dark areas in between the particles. The observed morphology indicates that the synthesized $NiFe_2O_4$ powder possesses a heterogeneous surface with considerable particle–particle interaction. The irregular morphology and agglomerated nature observed in the SEM micrograph can also be related to the processing conditions used during synthesis. During precipitation, drying, and subsequent heat treatment, the initially formed particles may come into close contact and form larger aggregates. Therefore, the presence of agglomerates in the SEM micrograph is consistent with the expected morphology of chemically synthesized $NiFe_2O_4$ nanoparticles.

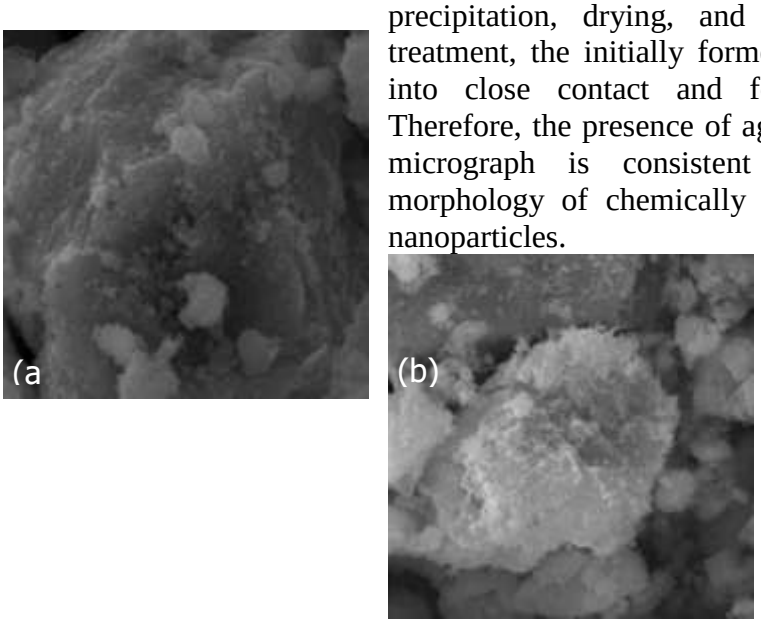


Figure 3: SEM Analysis $NiFe_2O_4$

UV- Vis Analysis.

The synthesized nickel ferrite ($NiFe_2O_4$) nanoparticles were analyzed by UV–Visible spectroscopy to examine the optical properties. The optical band gap (E_g) was estimated by using Tauc relation for the direct allowed electronic transition as $(\alpha h\nu)^2=A(h\nu-E_g)$, where (A) is the slope constant, ($h\nu$) is the photon energy, and (α) is the absorption coefficient. The Tauc plot is a plot of $(\alpha h\nu)^2$ photon energy.

$(\alpha h\nu)^2 = 0$

$0 = A\ (h\nu - E_g)$

$h\nu - E_g = 0$

$E_g = h\nu$ at the x-intercept

Preliminary Value

$E_g = 2.5$ eV

The linear part of the curve was extrapolated to the photon-energy axis to obtain the optical band gap. The value shown on the graph provided is a preliminary value, but the intercept should be revised based on the original UV–Visible data to maintain

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Print ISSN 3007-3189
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consistency with the reported band gap. This optical band gap can be used to discuss the optical response of the synthesized $NiFe_2O_4$ nanoparticles.

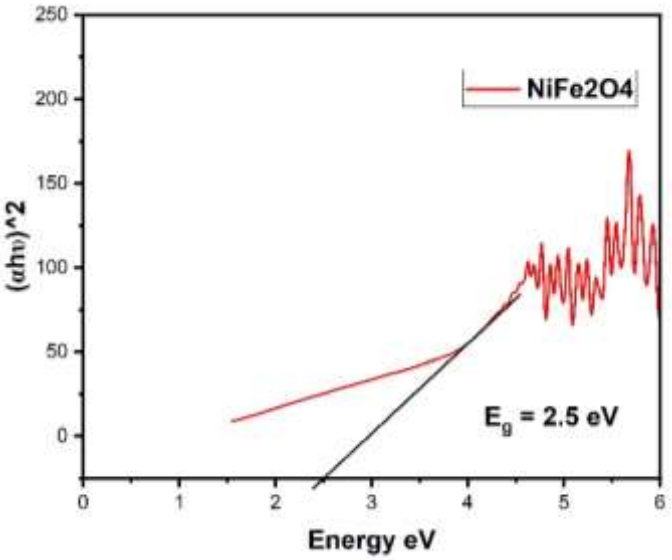


Figure:4 Tauc plots of $NiFe_2O_4$

Conclusion

The $NiFe_2O_4$ nanoparticles were successfully synthesized by co-precipitation method and characterized by XRD, FTIR, SEM and UV–Visible spectroscopy. The XRD studies showed the presence of characteristic cubic spinel ferrite structure with the major plane reflections as (220), (311), (400), (511) and (440). FTIR results indicated that metal–oxygen vibrational features were observed that were consistent with the spinel ferrite framework. This band is commonly observed around 500–600 cm^{-1} and is generally associated with metal–oxygen stretching vibrations at tetrahedral sites. Band is commonly observed around 350–450 cm^{-1} and is generally associated with metal–oxygen vibrations at octahedral sites. The nano scale particulate morphology was confirmed by SEM which also showed significant aggregation, typical of ferrite nanoparticles' interactions due to surface energy and magnetic interaction. The optical band gap for the sample under investigation was found to be about 2.5 eV from the UV–Visible analysis, using Tauc approach. Overall, the results show that the co-precipitation process is useful for the synthesis of $NiFe_2O_4$ nanoparticles with well-defined structural, vibrational, morphological and optical properties. The synthesized material has been found to be a promising material for further study in various functional applications such as optical, sensing, catalytic, etc.

References

1. Carlson, J.B., *Lodestone compass: Chinese or Olmec primacy? Multidisciplinary analysis of an Olmec hematite artifact from San Lorenzo, Veracruz, Mexico.* Science, 1975. **189**(4205): p. 753-760.
2. Mills, A.A., *The lodestone: History, physics, and formation.* Annals of Science, 2004. **61**(3): p. 273-319.
3. Patra, J. and V. Verma, *Nickel ferrite: Advances in the synthesis methods,*

Online ISSN 3007-3197
Print ISSN 3007-3189

properties and its applications. Nano-Structures & Nano-Objects, 2025. **42**: p. 101458.

4. Majid, F., et al., *Synthesis and characterization of NiFe2O4 ferrite: Sol–gel and hydrothermal synthesis routes effect on magnetic, structural and dielectric characteristics.* Materials Chemistry and Physics, 2021. **258**: p. 123888.
5. Gupta, N., et al., *Current development in synthesis and characterization of nickel ferrite nanoparticle.* Materials Today: Proceedings, 2017. **4**(2): p. 342-349.
6. Joshi, S., et al., *Structural, magnetic, dielectric and optical properties of nickel ferrite nanoparticles synthesized by co-precipitation method.* Journal of Molecular structure, 2014. **1076**: p. 55-62.
7. Ansari, A., V. Kumar Chakradhary, and M. Akhtar, *Synthesis of nickel ferrite nanoparticles via chemical co-precipitation method.* Advanced Materials Proceedings, 2017. **2**(1): p. 32-34.
8. Kazi, S., et al., *Simple Co-precipitation synthesis and characterization of magnetic spinel NiFe2O4 nanoparticles.* Materials Today: Proceedings, 2023. **73**: p. 448-454.
9. Maaz, K., et al., *Synthesis and magnetic characterization of nickel ferrite nanoparticles prepared by co-precipitation route.* Journal of Magnetism and Magnetic Materials, 2009. **321**(12): p. 1838-1842.