

STRUCTURAL, MORPHOLOGICAL AND OPTICAL PROPERTIES OF NICKEL-FERRITE POLYANILINE CONDUCTING NANOCOMPOSITES

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ABSTRACT

Nanocrystalline nickel ferrite (NiFe_2O_4) was formulated by the sol-gel system using ferric nitrate, nickel nitrate and citric acid as a precursors in aqueous solution. Aniline monomer was polymerized in-situ in the presence of prepared ferrites in varying weight percentages (10%, 20%) to create conducting polyaniline nanocomposites ($\text{PANI}/\text{NiFe}_2\text{O}_4$). X-ray diffraction (XRD), Fourier transform infrared (FTIR), transmission electron microscopy (TEM) analysis, and UV-visible spectroscopy were used to demonstrate the presence of NiFe_2O_4 in the nanocomposites. The structural, morphological, and optical characteristics of the $\text{PANI}/\text{NiFe}_2\text{O}_4$ nanocomposites were thoroughly examined in relation to the impact of PANI replacement in nickel ferrite.

Keywords: Nickel Ferrite, Conducting Polymers, Polyaniline, Nanocomposites, Polymerisation.

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INTRODUCTION

Conducting polymers are a desirable material for a range of advanced technologies because they have the flexibility and processability of ordinary polymers while having electrochemical, magnetic and optical properties like metals.¹⁻² Because of their special qualities, including the monomer's low cost, easy processing and exceptional stability. Polyaniline holds a prominent position among the different conducting polymers that are created.³ The proportion of acid and the degree of polymer oxidation determine benzoid and quinoid forms in PANI.⁴ Aqueous acid can protonate it, increasing its conductivity by nearly ten orders of magnitude. The result is a polysemi-quinone radical with a delocalized half-filled broad polar energy band. The creation of conducting polymer nanocomposites with cutting-edge characteristics and a range of uses has drawn increasing attention. An innovative idea in the development of sophisticated systems with functional characteristics arising from the cooperative interaction between PANI and magnetic nanoparticles is conducting polymer-based magnetic nanocomposites. The magnetic capabilities of ferrite nanoparticles can be combined with the superior qualities of conducting polymers, such as their non-corrosiveness, light weight, mechanical robustness and ability to adjust electrical conductivity, to create multifunctional structures.⁵ These days the PANI has been effectively employed in the creation of several nanocomposites.⁶⁻⁹ Because of its high electrical resistivity, chemical stability, and mechanical hardness, spinel nickel ferrites (NiFe_2O_4) have acquired exceptional structural and magnetic qualities among other magnetic materials. Considering the advancements in the synthesis of mixed metal oxides and their nanocomposites in the nano range, current research and studies. The commercial uses of $\text{PANI}/\text{NiFe}_2\text{O}_4$ nanocomposites, such as color imaging, ferrofluids, magnetic refrigeration, information storage, injection-moulded devices, membranes, optical integrated circuits, cars, drug delivery, sensors and medical diagnosis are the reason we synthesized them.

EXPERIMENTAL

Materials and Methods

Analytical grade chemicals were used. Aniline hydrochloride (99.5%), Ferric nitrate [$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$],

and nickel nitrate $[\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}]$ with purity 99.5% were purchased and used as received from Sigma-Aldrich(Merck). All other chemicals, like ammonium peroxydisulfate (APS,98%) and ethanol (99.9%), were bought from Vaishnavi Fine-Chem. Ltd. and used as received without further purification.

Synthesis of NiFe_2O_4 Nanoparticles

The sol-gel method was used for the preparation of NiFe_2O_4 nanoparticles.¹¹ The molar ratio 1:2 of starting materials of metal nitrates and citric acid was taken. De-ionised water was used as the solvent. A magnetic stirrer attached to a hot plate was used for dissolution of precursors. Neutral pH was adjusted with ammonia solution. The solution was kept at a constant temperature of 60°C for three hours. The obtained gel was kept in the hot air oven at the temperature of 80°C for 12 hrs. A mortar and pestle were used for grinding the sample. Calcination was done in a muffle furnace at 600°C for 2 hrs.

Preparation of $\text{PANI}/\text{NiFe}_2\text{O}_4$ Nanocomposites

$\text{PANI}/\text{NiFe}_2\text{O}_4$ nanocomposites with different ferrite compositions were produced at a constant temperature of 60°C by using APS as an oxidant during the in situ chemical oxidation polymerization of aniline in the presence of NiFe_2O_4 nanoparticles at room temperature in air for three hours. Typically, 10% of sonicated NiFe_2O_4 nanoparticles were combined with 0.1M of aniline hydrochloride diluted in 100 mL of water and stirred for 30 minutes. For two hours, the suspension mixture was treated dropwise with 0.1 M of the oxidizing agent $(\text{NH}_4)_2\text{S}_2\text{O}_8$. After three hours, the color shifted from blue to blackish green, suggesting a high level of polymerization. The solution was then left overnight. To obtain $\text{PANI}/\text{NiFe}_2\text{O}_4$ nanocomposite powder the reaction precipitate was filtered off and vacuum-dried for a whole day. The $\text{PANI}/\text{NiFe}_2\text{O}_4$ nanocomposite preparation process is shown schematically in Fig.-1.

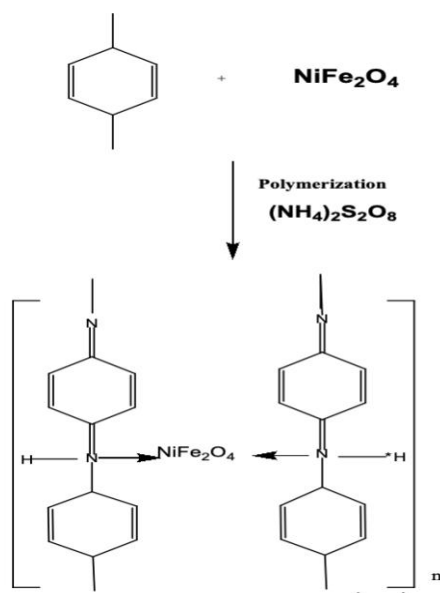
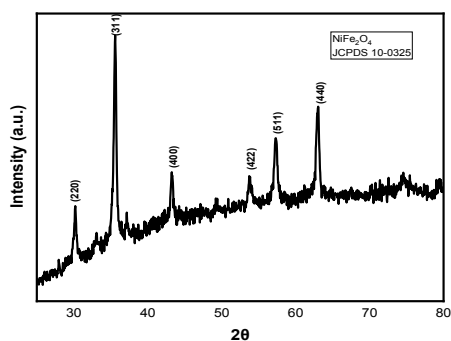
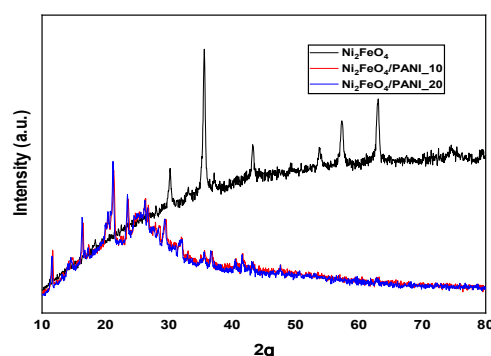


Fig.-1: Schematic Reaction Showing Encapsulation of NiFe_2O_4 Nanoparticles on Polyaniline Matrix

RESULTS AND DISCUSSION

Structural Analysis

The XRD spectra of $\text{PANI}/\text{NiFe}_2\text{O}_4$ nanocomposites and NiFe_2O_4 nanoparticles calcined at 600°C are displayed in Figs.-2(A) and Fig.-2(B). According to JCPDS data 10-0325, the XRD pattern of NiFe_2O_4 reveals that every peak corresponds to the spinel ferrite phase with a face-centered cubic crystal structure. The crystallite size and lattice parameter of synthesized NiFe_2O_4 were determined to be 24.2 nm and $8.40\text{\AA}$, respectively, based on the widening of the peak. The spinel ferrite reflections (311) were responsible for the maximum intensity peak at $2\theta = 35.57^\circ$. Tetrahedral sites A and octahedral sites B make up NiFe_2O_4 , which has the structural formula $\text{Fe}^{3+}[\text{Ni}^{2+}\text{Fe}^{3+}]\text{O}_4$.

Fig.-2(A) XRD of NiFe₂O₄Fig.-2(B) XRD of NiFe₂O₄ & its PANI Nanocomposites

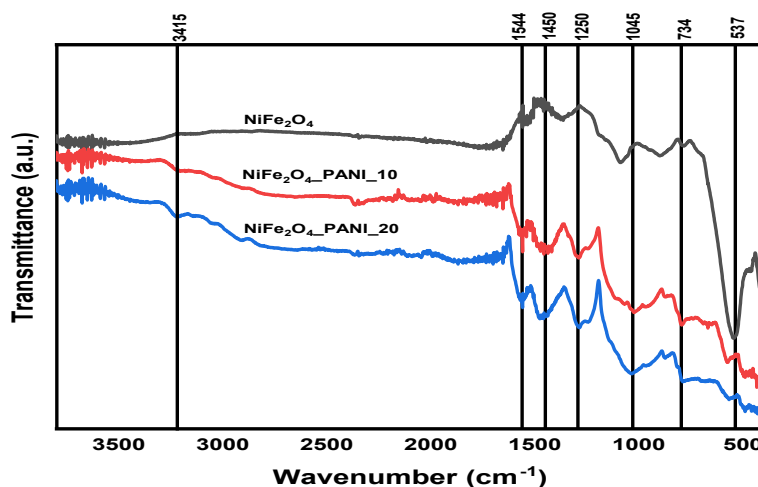
The nickel ions Ni²⁺ and half of the iron ions Fe³⁺ are located in the B site, while the remaining half of the iron ions are located in the A site. The XRD pattern of PANI/NiFe₂O₄ nanocomposites shows two peaks at $2\theta = 20^\circ$ and 25° , which clearly indicates that the sample is semi-crystalline. According to the Debye-Scherrer formula, the average crystallite size of PANI/NiFe₂O₄ nanocomposites decreases as we increase the content of NiFe₂O₄ in PANI. XRD pattern of the nanocomposite with 20% weight concentration of NiFe₂O₄ shows a crystalline phase with an average grain size of 10.5 nm comparable with that found for the 10 % weight concentration NiFe₂O₄ (21.9 nm). This signifies that there is strong interaction between NiFe₂O₄ and the PANI Matrix. As we embedded NiFe₂O₄ nanoparticles with weight percentages of 10% and 20%, there is dominance of diffraction peaks of NiFe₂O₄ and only peaks of PANI. Properties and crystallite size of synthesised NiFe₂O₄ and PANI/NiFe₂O₄ nanocomposites are shown in Table-1.

Table-1: XRD of NiFe₂O₄ and PANI

Materials	2 θ (Degree)	FWHM(Degree)	d- spacing (Å ^o)	Crystallite Size(nm)
NiFe ₂ O ₄	35.578	0.360	2.521	24.2
NiFe ₂ O ₄ ¹³	35.78	0.369	2.509	60
NiFe ₂ O ₄ /PANI ¹⁴	25.23	0.792	3.52	30
NiFe ₂ O ₄ /PANI (20%)	24.86	0.801	3.578	10.5
NiFe ₂ O ₄ /PANI (10%)	24.709	0.392	3.602	21.9

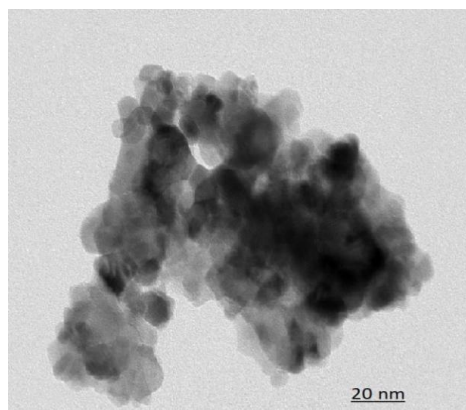
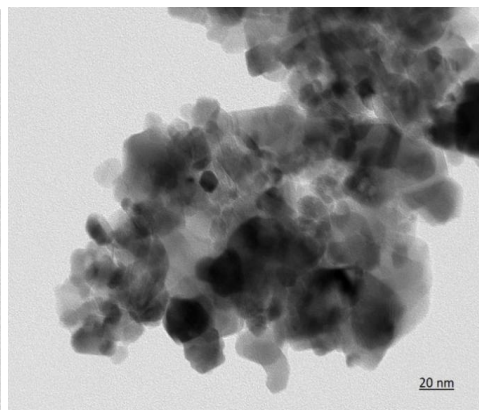
Functional Analysis

FTIR spectroscopy offers important insights into the type of functional groups found in PANI/NiFe₂O₄ nanocomposites and nickel ferrite nanoparticles. Figure-3 shows that the O-H stretching vibration interaction with H bonds is responsible for the intense band at 3114 cm⁻¹ and the less intense band at 1544 cm⁻¹ for NiFe₂O₄. Stretching vibrations of antisymmetric NO originating from the nitrate group that is present as a residue in the samples are indicated by the band around 1045 cm⁻¹. The stretching vibration of ferrite's tetrahedral and octahedral groups is responsible for the absorption bands ν_1 and ν_2 at about 734cm⁻¹ and 537 cm⁻¹, respectively. PANI/NiFe₂O₄ nanocomposites FTIR spectra reveal that the aromatic C-H vibration is responsible for the vibration band between 1490 and 1290 cm⁻¹. The vibration band at 848-853 cm⁻¹ is assigned to the C-H vibration band of the para-linked phenyl ring, confirming the prevalence of para coupling in aniline polymerization, whereas the vibration band at 1064-1070 cm⁻¹ shows protonation due to the presence of a C-N double bond. The characteristic bands of NiFe₂O₄ in PANI/NiFe₂O₄ nanocomposites are found around 850 cm⁻¹ and 734 cm⁻¹, further demonstrating the effective encapsulation of NiFe₂O₄ particles within PANI. In PANI/NiFe₂O₄ nanocomposites, the corresponding peaks at 1539 cm⁻¹, 1444 cm⁻¹, 1253 cm⁻¹, and 1132 cm⁻¹ migrated to lower wavenumbers of 1532 cm⁻¹, 1434 cm⁻¹, 1238 cm⁻¹, and 1064 cm⁻¹. Findings indicate that the PANI matrix and NiFe₂O₄ nanoparticles interact in some way.

Fig.-3: FTIR Spectra of NiFe_2O_4 and PANI/ NiFe_2O_4

Morphological Analysis

TEM images of NiFe_2O_4 and PANI/ NiFe_2O_4 nanocomposite (20%) are shown in Figs.-4(A) and 4(B), respectively. The produced NiFe_2O_4 nanoparticles typically exhibit a spherical or irregular form. Agglomeration, which is typical of magnetic nanoparticles because of dipole-dipole interactions, is also observed. The form and contrast imply that the aggregated structure contains crystalline domains. Darker areas are probably denser or thicker agglomerates; contrast variations (dark vs. bright areas) indicate variances in particle thickness or stacking. The presence of a transition metal oxide with a moderate electron density, such as nickel ferrite, is supported by the comparatively high contrast. The effective production of nanoscale NiFe_2O_4 particles is confirmed by the TEM image. Particles form aggregated clusters are mostly less than 20 nm. TEM image of PANI/ NiFe_2O_4 confirms the successful formation of PANI/ NiFe_2O_4 nanocomposites. The image shows a heterogeneous and somewhat diffuse structure compared to pure nickel ferrite. Nickel ferrite nanoparticles are still present as dark, high-contrast spots, while the lighter diffuse regions suggest the presence of the polyaniline matrix. This indicates successful encapsulation or embedding of the NiFe_2O_4 nanoparticles within or around the polymer matrix. The NiFe_2O_4 nanoparticles remain within the nanometre scale and are embedded or coated with the polyaniline matrix.¹⁶ The composite structure may offer improved properties such as enhanced electrical conductivity, magnetic behaviour or stability due to the polymer support. The lighter grey areas or halos surrounding the nanoparticles are indicative of an amorphous or less electron-dense phase consistent with the polyaniline polymer. These areas are not as sharply defined, supporting the idea that the PANI matrix has a coating or encapsulating effect on the magnetic particles.

Fig.-4(A): NiFe_2O_4 TEMFig.-4(B): PANI/ NiFe_2O_4 TEM

TEM images of NiFe_2O_4 and PANI/ NiFe_2O_4 nanocomposite (20%) are shown in Figs.-4(A) and 4(B), respectively. The optical band gap is determined by the electron's transition from the valence band to the conduction band during photoexcitation. The exciton transition from benzenoid to quinoid rings ($\pi-\pi^*$) is

linked to two absorption peaks seen in the spectra of PANI/NiFe₂O₄ nanocomposites around 310–330 nm.¹⁷ The absorption peaks shift slightly to the red (longer wavelength) when the ferrite content in the PANI matrix increases. The PANI/NiFe₂O₄ core-shell development results in energy confinement from the surface plasmon-excitation interaction, which raises the nanocomposite's absorption level. This process demonstrates that excitons and plasmons interact strongly. This results from charge changes from the highest occupied molecular orbital in the benzenoid ring to the lowest empty molecular orbital in the quinoid ring.

The optical direct and indirect band gaps were calculated using the Tauc equation, which is expressed as:

$$(ah\nu)^n = (h\nu - E_g)$$

Where E_g is the optical band gap, h is Planck's constant, B is a constant that depends on the transition probability and theoretically the index n should be 1/2 for indirect permitted transitions and 2 for direct permitted transitions. For each composite, the direct and indirect optical band gap values are computed using this relationship.¹⁸ Table-2 and Fig.5 displays the matching band gap energies of NiFe₂O₄ and PANI/NiFe₂O₄ nanocomposites at various wavelengths. Due to the vacancies in the intergranular areas creating new energy levels to lower the band gap energy, the corresponding band gap energy increases when we add the concentration of NiFe₂O₄ to the PANI matrix while the particle size decreases.

Table-2: Band Gap Energy Value at Maximum Absorbing Wavelength

Product	$\lambda_{\max}$ (nm)		Band Gap (eV)	
NiFe ₂ O ₄	331	680	3.75	1.82
NiFe ₂ O ₄ /PANI (10%)	-	643	-	1.93
NiFe ₂ O ₄ /PANI (20%)	-	620	-	2.00

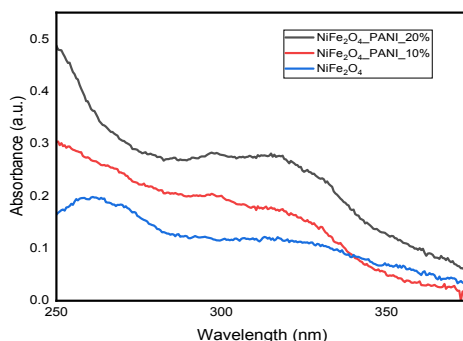


Fig.-5: UV-Visible Spectra of NiFe₂O₄ and PANI/NiFe₂O₄ Nanocomposites

CONCLUSION

Sol-gel has been successfully used to create nanocrystalline nickel ferrite, and in situ chemical oxidation polymerization has been successfully used to create PANI/NiFe₂O₄ nanocomposites. Good interactions between PANI and the synthesized nickel ferrite nanoparticles were revealed by FTIR, XRD and TEM studies. It was found that the inclusion of varying concentrations of NiFe₂O₄ in the PANI matrix had a significant impact on optical characteristics.

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CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS

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REFERENCES

1. M. A. Rahman, P. Kumar, D. S. Park, Y. B. Shim, *Sensors*, **8**, 118(2008), <https://doi.org/10.3390/s8010118>
2. K. Gurunathan, A.V. Murugan, R. Marimuthu, U.P. Mulik, D.P., *Materials Chemistry and Physics*, **61**, 173(1999), [https://doi.org/10.1016/S0254-0584\(99\)00081-4](https://doi.org/10.1016/S0254-0584(99)00081-4)
3. S. N. Bhadani, M. K. Gupta, S. K. Gupta, *Journal of Applied Polymer Science*, **49**, 397(1993), <https://doi.org/10.1002/app.1993.070490304>
4. A.G. MacDiarmid, A.J. Epstein, *Chemical Society*, **88**, 317(1989), <https://doi.org/10.1039/DC9898800317>
5. J.C.Aphesteguy, P.G. Bercoff, S.E. Jacobo, *Physica B: Condensed Matter*, **398(2)**, 200(2007), <https://doi.org/10.1016/j.physb.2007.04.018>
6. B.I.Nandapure, S.B. Kondawar, M.Y. Salunkhe, A.I. Nandapure, *Journal of Composite Materials*, **47**, 559 (2012), <https://doi.org/10.1177/0021998312442559>
7. A. Parveen, A.S. Roy, *Advanced Materials Letters*, **4(9)**, 696(2013), <https://doi.org/10.5185/amlett.2012.12481>
8. B.I.Nandapure, S.B. Kondawar, M.Y.Salunkhe, A.I., *Advanced Materials Letters*, **4(2)**, 134(2013), <https://doi.org/10.5185/amlett.2012.5348>
9. S.B. Kondawar, S.P. Agrawal, S.H. Nimkar, H.J. Sharma, P.T. Patil, *Advanced Materials Letters*, **3(5)**, 393(2012), <https://doi.org/10.5185/amlett.2012.6361>
10. N.E. Kazantseva, Yu. I. Bespyatykh, I. Sapurina, J. Stejskal, J. Vilcakova, P.Saha, *Journal of Magnetism and Magnetic Materials*, **301**, 155(2006), <https://doi.org/10.1016/j.jmmm.2005.06.015>
11. R.Kesavamoorathi, A.N. Vigneshwaran, V. Sanyal, C.R. Raja, *Journal of Chemical and Pharmaceutical Sciences*, **9(1)**, 160(2015), <https://doi.org/10.1016/j.matpr.2015.07.165>
12. K.R. Reddy, W. Park, B.C. Sin, J. Noh, Y. Lee, *Journal of Colloid and Interface Science*, **335**, 34(2009), <https://doi.org/10.1016/j.jcis.2009.02.068>
13. A.I. Nandapure, S.B. Kondawar, P.S. Sawadh, B.I. Nandapure, *Physica B: Condensed Matter*, **407**, 1104(2012), <https://doi.org/10.1016/j.physb.2012.01.081>
14. B. Kaur, A. Arora, A. Shankar, A.K. Srivastava, R.P. Pant, *Advanced Materials Letters*, **3(5)**, 399(2012), <https://doi.org/10.5185/amlett.2012.7288>
15. A.I. Nandapure, S.B. Kondawar, B.I. Nandapure, M.M. Chaudhari, *Advanced Materials Proceedings*, **2(7)**, 463(2017), <https://doi.org/10.5185/amp.2017/713>
16. M Khairy, et. Al., *Synthetic Metals*, **189**, 34(2014), <https://doi.org/10.1016/j.synthmet.2013.12.022>
17. K. Daideche, L. Hasniou, D. Lerari, *Chemistry Proceedings*, **3(110)**, 1(2021), <https://doi.org/10.3390/ecsoc-24-08328>
18. C Kumari, H Dubey, F Naaz, P Lahiri, *Phase Transitions*, **93**, 1(2020), <https://doi.org/10.1080/01411594.2019.1709120>

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