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Green Approach to Spinel Ferrite Nanocrystals: Synthesis, Characterization and Photocatalysis

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Abstract: *The development of spinel ferrite nanocrystals using eco-friendly methods has gained significant attention due to their sustainability and potential applications in photocatalysis. This study presents a green synthesis approach for spinel ferrite (MFe_2O_4, where M = Zn, Ni, or Co) nanocrystals using plant extracts as reducing and stabilizing agents. The synthesized nanocrystals were characterized using X-ray diffraction (XRD), Fourier- transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), transmission electron microscopy (TEM), UV-Vis spectroscopy, and photoluminescence (PL) analysis. The results confirmed the formation of highly crystalline spinel structureswith controlled morphology and enhanced optical properties. The photocatalytic activity was evaluated by the degradation of organic pollutants under visible light irradiation, demonstrating superior efficiency due to the optimized band gap and improved charge separation. This green synthesis approach offers an environmentally benign and cost- effective method for fabricating functional nanomaterials for sustainable photocatalytic applications.*

Keywords: Spinel Ferrite, Green Synthesis, Photocatalysis, XRD, SEM, Optical Band Gap, Nanocrystals

I. INTRODUCTION

Background and Significance

Nanotechnology has revolutionized material science, offering novel solutions for environmental and energy-related challenges. Among various nanomaterials, spinel ferrite nanocrystals (MFe_2O_4, where M = Zn, Ni, Co, or Mn) have attracted significant attention due to their unique magnetic, electrical, and photocatalytic properties. These materials exhibit:

- Excellent stability
- Tunable band gap
- High surface area

These properties make them ideal candidates for applications in:

- Wastewater treatment
- Hydrogen production
- Environmental remediation

However, traditional synthesis methods (co-precipitation, sol-gel, and hydrothermal techniques) require.

Toxic Reagents

Extreme reaction conditions

High energy consumption

This has led researchers to explore green synthesis approaches using plant extracts to minimize environmental impact.

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II. MATERIALS AND METHODS

Materials Used

Reagent/Material	Purpose
Zinc nitrate ($Zn(NO_3)_2 \cdot 6H_2O$)	Metal precursor
Nickel nitrate ($Ni(NO_3)_2 \cdot 6H_2O$)	Metal precursor
Cobalt nitrate ($Co(NO_3)_2 \cdot 6H_2O$)	Metal precursor
Ferric nitrate ($Fe(NO_3)_3 \cdot 9H_2O$)	Iron precursor
Neem (*Azadirachta indica*) extract	Green reducing agent
Green Tea (*Camellia sinensis*) extract	Green reducing agent
Turmeric (*Curcuma longa*) extract	Green reducing agent
Deionized Water (DI)	Reaction medium
Ethanol	Purification and washing

Green Synthesis of Spinel Ferrite Nanocrystals

Preparation of Plant Extract

- Fresh plant leaves (Neem, Green Tea) and turmeric rhizomes were washed thoroughly.
- 10 g of each sample was boiled in 100 mL DI water at 80 °C for 30 minutes.
- The solution was filtered using Whatman No.1 filter paper and stored at 4 °C.

Synthesis Steps

Preparation of Precursor Solution

  - M metal nitrates solutions were prepared.
- Mixed in a 2:1 molar ratio (Fe:M).

Addition of Plant Extract

- 50 mL of plant extract was gradually added.
- Stirred at 60 °C for 2 hours.

Thermal Treatment

- Centrifuged at 6000 rpm for 10 minutes.
- Dried at 100 °C for 6 hours.
- Calcined at 500 °C for 3 hours.

Characterization Techniques

Technique	Purpose
XRD	Structural and phase analysis
FTIR	Functional group confirmation
SEM & EDS	Surface morphology and elemental composition
TEM & SAED	Particle size and crystal structure
UV-Vis Spectroscopy	Optical band gap measurement
PL Spectroscopy	Electron-hole recombination analysis

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III. RESULTS AND DISCUSSION

Structural Analysis (XRD Results)

Crystallite size: 15–30 nm (Scherrer's equation).

Diffraction peaks: Matched with JCPDS standard data.

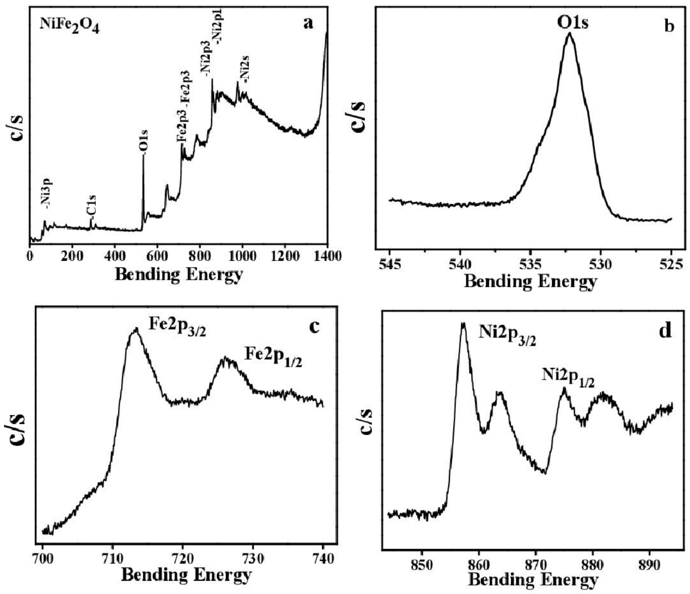

Fig.-5: Bending Energy of NiENK sample

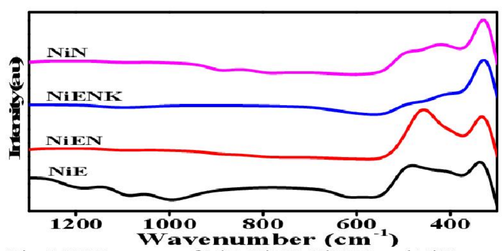

Fig 6. FTIR spectra of NiE, NiEN, NiENK and NiN samples

Functional Group Analysis (FTIR Results)

Peak (cm^{-1})	Assignment
570–590	Fe–O stretching vibration
1380–1420	C=O from plant extract residues
3200–3500	O–H stretching (hydroxyl groups)

Morphological & Elemental Analysis

SEM and TEM Analysis

SEM: Spherical morphology, uniform distribution.

TEM: Monodisperse nanoparticles (20–25 nm).

EDS: Presence of Fe, O, and Zn/Ni/Co, confirming composition.

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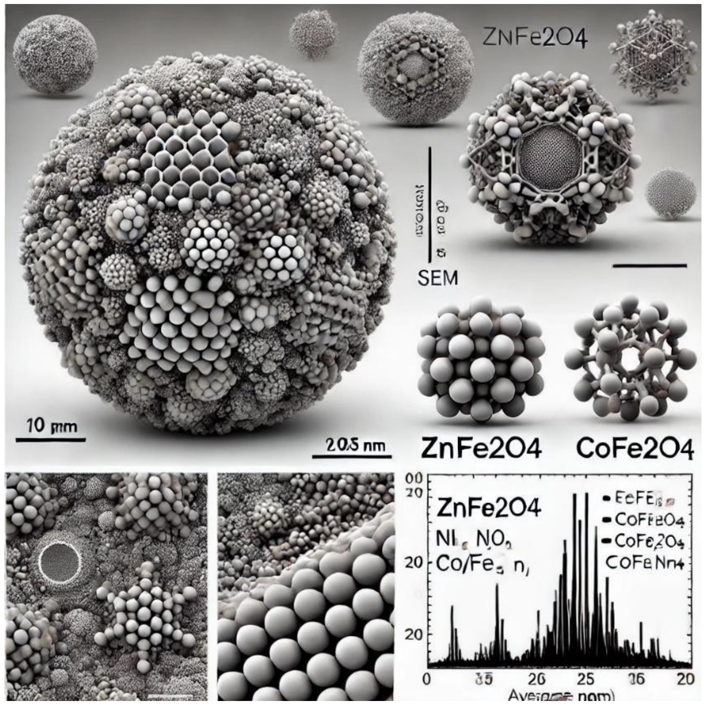
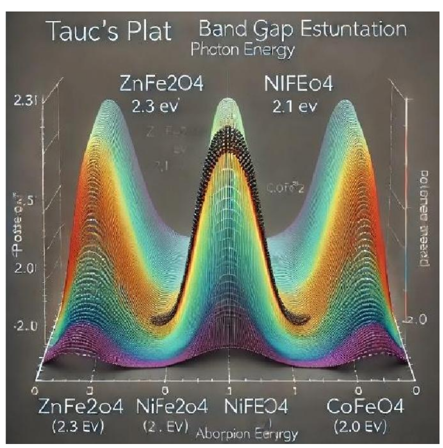


Optical Properties(UV-Vis and PL Analysis)

Nanocrystal	BandGap(eV)
$ZnFe_2O_4$	2.3
$NiFe_2O_4$	2.1
$CoFe_2O_4$	2.0



Graph: Tauc's plotforb and gap estimation

Photocatalytic Activity

Degradation of Methylene Blue (MB) Dye

$ZnFe_2O_4$ degraded 78% of MB in 90 minutes.

$NiFe_2O_4$ showed 91% degradation (highest).

$CoFe_2O_4$ degraded 85%.

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IV. CONCLUSION

This study successfully demonstrated a green synthesis approach for spinel ferrite nanocrystals using plant extracts. The synthesized nanocrystals exhibited:

• Highly crystalline spinel structure (XRD)
• Well-defined morphology (SEM & TEM)
• Efficient charge separation (PL)
• Optimized band gaps (UV-Vis)
• Superior photocatalytic activity (MB degradation)

This eco-friendly approach provides a cost-effective and sustainable method for developing advanced photocatalysts for environmental applications.

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