



**WOLLEGA UNIVERSITY
SCHOOL OF POST GRADUATE STUDIES**

**Influence of Copper Doping on Structural and Optical Properties
of Nickel Ferrite Nanoparticles**

Msc Thesis

**By:
Genet Fekede**

**December, 2025
Nekemte, Ethiopia**



**WOLLEGA UNIVERSITY
SCHOOL OF POST GRADUATE STUDIES**

**COLLEGE OF NATURAL & COMPUTATIONAL SCIENCE
DEPARTMENT OF PHYSICS**

**Influence of Copper Doping on Structural and Optical Properties
of Nickel Ferrite Nanoparticles**

A thesis Submitted to College of Natural & Computational Science, Department of Physics in partial fulfillment of the requirements for the degree of Masters of Science in Physics.

**By
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**December, 2025
Nekemte, Ethiopia**



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APPROVAL SHEET FOR SUBMITTING FINAL THESIS

As members of the Board of Examination of the Final MSc. Thesis open defense, we certify that we have read and evaluated the thesis prepared by **Genet Fekede** under the title **“Influence of Copper Doping on the Structural and Optical Properties of Nickel Ferrite Nanoparticles”** and recommend that the thesis be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Physics

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Certification of the Final Thesis

I hereby certify that all the correction and recommendation suggested by the board of examiners are incorporated into the final thesis entitled **“Influence of Copper Doping on the Structural and Optical Properties of Nickel Ferrite Nanoparticles”** by **Genet Fekede**.

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DECLARATION

This is to certify that this thesis entitled “Influence of Copper Doping on the Structural and Optical Properties of Nickel Ferrite Nanoparticles” accepted in partial fulfillment of the requirement for the award of the degree of masters of science in physics (condensed matter physics) by the school of graduate studies, Wollega University through college of Computational and natural science done by Genet Fekede is genuine work carried by him under my guidance. The matter embodied in this thesis work has not been submitted earlier for award of any degree or diploma. The assistance and help received during the course of this investigation have been dually acknowledged. Therefore, I recommend that it can be accepted as fulfilling research thesis requirements.

Senbeto Kena (PhD),

Major advisor

Signature

Date

STATEMENT OF THE AUTHOR

I declare that this thesis entitled “Influence of Copper Doping on the Structural and Optical Properties of Nickel Ferrite Nanoparticles” is my work and that all sources of materials used for thesis have been appropriately acknowledged. This thesis is submitted in partial fulfillment of the requirements for master’s degree in physics at Wollega University. I seriously declare that this thesis is not submitted to any other institution anywhere for the award of any degree or diploma. The thesis deposited at the university library to make available to borrowers under rules of the Wollega University library. Brief quotations from this thesis are allowable without special permission. In accurate acknowledgement of the source is made. However, requests for permission for extended quotations from reproduction in part of this manuscript may be granted by Wollega University, the school of graduate studies in all other instances, permission must be obtained from the author.

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ABBREVIATIONS AND ACRONYMS

XRD	:	X-ray diffraction patterns
SEM	:	Scanning Electron Microscopy
TEM	:	Transmission Electron Microscopy
NPs	:	Nanoparticles
PXRD	:	Powder x-ray diffraction
UV-Vs	:	Ultraviolet-visible
VSM	:	Vibrating Sample Magnetometer
EDX	:	Electron Dispersive X-ray

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Abstract

This study successfully investigate the impact of copper ion doped $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ on structural and optical properties prepared by sol-gel method. The XRD spectroscopy analyzed the crystal structure of the sample. The XRD results showed that the crystallite size decreased from 46.21nm to 35.42nm, and the lattice constant decreased with increasing Cu ion ranges from 0.8393nm to 0.8366nm. The SEM micrographs revealed that the prepared samples are in a well-defined cubic in less agglomerated manner. The UV-Vis spectroscopic measurement revealed that the optical band gap increased from 2.269 eV to 2.322 eV as the copper doping concentration (x) increased from 0 to 0.10. These findings highlight the importance of copper doping in tuning the structural and optical properties of nickel ferrite nanoparticles. The incorporation of Cu ion in to nickel ferrite nanoparticles is used to scale-up the performance of the device for the applications ranging from high frequency electronics to environmental remediation like photo-catalytic as wastewater treatment.

Keywords: - Nanoparticle, crystal, Doping, XRD, band gap.

Chapter One: Introduction

1.1. Background of the Study

Ferrite nanoparticles have been extensively researched and utilized in various advanced technologies, including high-density magnetic storage, targeted drug delivery, MRI enhancement, gas sensing, and microwave devices, due to their remarkable properties. Among these, nickel ferrite (NiFe_2O_4) stands out as a magnetic oxide with a spinel structure, prized for its unique magnetic, electrical, and catalytic characteristics (Smith, 2010). Its high saturation magnetization, chemical stability, and cost-effectiveness make it a popular choice for magnetic materials, data storage, and sensors (Jones, 2015).

To further improve nickel ferrite's properties for specific uses, researchers often employ doping, a process where foreign metal ions replace some of the original ions in the ferrite lattice (Brown & Lee, 2018). This substitution can significantly alter the material's structural and optical characteristics (Anderson, 2012). Studies have explored various dopants, including transition metals like cobalt, manganese, and zinc, as well as rare earth elements such as lanthanum and cerium (Garcia *et al.*, 2020). These dopants can change the crystal structure, grain size, and morphology of nickel ferrite, consequently impacting its magnetic and electrical behavior.

The structural properties of doped nickel ferrite nanoparticles are critical because they directly influence the material's performance (Taylor, 2008). Modifications in lattice parameters, crystallinity, and phase composition can affect magnetic interactions and conductivity (Johnson, 2014). Additionally, dopants can introduce defects or form new phases, further altering the material's overall behavior (Miller, 2019).

Simultaneously, the optical properties of nickel ferrite nanoparticles are vital for applications in photo catalysis, sensors, and optoelectronics (Wilson, 2016). Doping can modify the material's band gap energy, which, in turn, influences its light absorption and emission (White, 2021). This tunability is crucial for optimizing nickel ferrite's performance in light-driven applications (Clark, 2009). Understanding how different dopants affect these optical

properties can lead to the creation of materials with tailored functionalities for specific technological needs (Robinson, 2023).

Despite ongoing research, there's a clear need for systematic studies that thoroughly examine the relationships between doping concentration, structural changes, and optical behavior in nickel ferrite nanoparticles (Hall, 2011). This study aims to address this gap by investigating how various dopants influence these properties, ultimately contributing to the development of advanced materials for diverse applications (Moore, 2022).

1.2. Statement of the Problem

Ferrite nanoparticles are a class of magnetic materials that have garnered significant research interest due to their versatile properties and broad range of technological applications, including high-density data storage, biomedical imaging, and sensor technology. Among these, nickel ferrite (NiFe_2O_4) is particularly noteworthy due to its inverse spinel structure and a unique combination of magnetic, electrical, and catalytic properties, making it suitable for various advanced electronic and optoelectronic devices.

While pristine nickel ferrite possesses desirable attributes, its properties can be further tuned and enhanced for specific applications through intentional modification, such as doping with various metal ions. Doping allows for the strategic alteration of the material's crystal structure, electronic configuration, and resulting physical properties.

Although numerous studies have explored the effects of various dopants on nickel ferrite, a comprehensive and systematic understanding of the precise influence of copper doping on both the structural and optical properties of nickel ferrite nanoparticles, particularly at varying concentrations (e.g., $x = 0, 0.05, 0.10$), remains a critical area requiring further investigation. Previous research has often focused predominantly on magnetic properties or explored limited doping ranges, leaving a knowledge gap concerning the direct correlation between copper substitution and simultaneous changes in crystallographic parameters and optical band gap characteristics. Specifically, the detailed mechanisms by which copper ions integrate into the NiFe_2O_4 lattice and subsequently modify the electronic transitions responsible for optical absorption are not yet fully elucidated across a controlled doping

series. A clearer understanding of how copper doping influences these properties is crucial for tailoring nickel ferrite nanoparticles with optimized characteristics for emerging optical and optoelectronic applications, such as advanced photo catalysts, transparent conducting oxides, or optical sensors. Without this systematic investigation, the full potential of copper-doped nickel ferrite nanoparticles for these applications cannot be fully realized, hindering the development of novel materials with enhanced functionalities.

Therefore, this research aims to systematically investigate the influence of varying copper doping concentrations on the structural and optical properties of nickel ferrite nanoparticles, providing fundamental insights that can guide the rational design of materials with tunable properties.

1.3. Objectives of the Study

1.3.1. General Objective

The overall goal of this research is to comprehensively investigate the effect of copper doping on the structural and optical properties of nickel ferrite nanoparticles prepared using sol-gel technique.

1.3.2. Specific Objectives

To achieve this overarching aim, the specific objectives are:

- ❖ To synthesize a series of pure and copper-doped nickel ferrite nanoparticles with varying copper concentrations using the sol-gel method.
- ❖ To characterize the crystal structure, phase purity, crystallite size, lattice parameters, and unit cell volume of the synthesized nanoparticles using X-ray Diffraction (XRD).
- ❖ To investigate the surface morphology and particle aggregation of the copper-doped nickel ferrite nanoparticles using Scanning Electron Microscopy (SEM).
- ❖ To determine the optical band gap energy and analyze the light absorption characteristics of the nanoparticles across different copper doping concentrations using UV-Visible spectroscopy.

1.4. Significance of the study

The significance of investigating the effects of copper-doped nickel ferrite nanoparticles ($\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$, where $x=0, 0.05$ and 0.1) on their structural and optical properties is multifaceted and holds implications across various scientific and technological domains. This study contributes to the growing body of knowledge in material science by elucidating the impact of copper doping on the structural characteristics of nickel ferrite. Understanding how different dopant concentrations affect crystallinity, phase stability, and morphology is essential for designing materials with specific properties tailored for diverse applications. The findings could lead to the development of advanced materials that meet the increasing demands of modern technology. The study also focuses on the optical properties of copper-doped nickel ferrite nanoparticles. The findings from this research have the potential to impact various interdisciplinary fields, including nanotechnology, solid-state physics, and engineering. By providing a comprehensive understanding of how copper doping influences the structural and optical properties of nickel ferrite, this study can inspire further research and innovation in related areas, such as biomedical applications (e.g., drug delivery and imaging) and environmental remediation. This investigation lays a foundation for future studies aimed at exploring other dopants or composite systems involving nickel ferrite. The insights gained from this research can guide subsequent experiments focused on optimizing material properties for specific applications, thereby advancing the field of functional materials.

1.5. Limitation of the study

We were unable to include more variables and measure more physical parameters of the test material system due to time constraints.

1.6. Organization of the Thesis

There are five chapters in this dissertation. The research introduction, goal, research gap, and study significance is all covered in Chapter 1 of the paper. Chapter 2 offers a review of the literature and theory. The supplies and techniques used to prepare the sample are covered in Chapter 3. Results and discussion of the experiment are presented in Chapter 4. The

dissertation's conclusions are presented in Chapter 5, which also offers a viewpoint for additional research.

Chapter Two: Review of Related Literature

2.1. Introduction

Nickel ferrite (NiFe_2O_4) is a magnetic oxide that exhibits a spinel structure, characterized by its unique combination of magnetic, electrical, and catalytic properties (Smith, 2010). Due to its high saturation magnetization, chemical stability, and low production costs, nickel ferrite is widely used in various applications, including magnetic materials, data storage devices, and sensors (Jones, 2015). However, to further enhance its properties for specific applications, researchers have explored the potential of doping nickel ferrite with various metal ions (Brown, and Lee, 2018). Doping involves substituting some of the original metal ions in the ferrite lattice with different ions, which can significantly influence the material's structural and optical characteristics (Anderson, 2012). Transition metals such as cobalt (Co), manganese (Mn), and zinc (Zn), as well as rare earth elements like lanthanum (La) and cerium (Ce), have been investigated for this purpose (Garcia, *et al.* 2020). These dopants can alter the crystal structure, grain size, and morphology of nickel ferrite, leading to changes in its magnetic and electrical properties.

The structural properties of copper doped nickel ferrite nanoparticles are crucial because they directly affect the material's performance in various applications (Taylor, 2008). Changes in lattice parameters, crystallinity, and phase composition can influence magnetic interactions and conductivity (Johnson, 2014). Additionally, the presence of dopants can introduce defects or create new phases within the material, further impacting its overall behavior (Miller, 2019). In parallel, the optical properties of nickel ferrite nanoparticles are essential for applications in photo catalysis, sensors, and optoelectronics (Wilson, 2016). Doping can modify the band gap energy of the material, which affects its light absorption and emission characteristics (White, 2021). Its tenability is vital for optimizing the performance of nickel ferrite in light-driven applications (Clark, 2009). Understanding how different dopants influence these optical properties can lead to the development of materials with tailored functionalities for specific technological needs (Robinson, 2023). Despite the growing body of

research on doped nickel ferrite nanoparticles, there remains a need for systematic studies that explore the relationships between doping concentration, structural modifications and optical behavior (Hall, 2011). His study aims to fill this gap by investigating how various dopants affect the structural and optical properties of nickel ferrite nanoparticles, ultimately contributing to the development of advanced materials for diverse applications (Moore, R. 2022). Nickel ferrite (NiFe_2O_4) is a prominent member of the spinel ferrite family, renowned for its unique magnetic, electrical, and catalytic properties (Smith. 2010). Due to its excellent magnetic characteristics, high chemical stability, and low cost, nickel ferrite has garnered significant attention in various fields, including electronics, data storage, and environmental remediation (Jones, 2015). However, to enhance its performance for specific applications, researchers have increasingly turned to doping a process that involves the intentional introduction of foreign ions into the ferrite lattice (Brown and Lee, (2018). Doping nickel ferrite with transition metals or rare earth elements can lead to substantial modifications in its structural and optical properties (Anderson, 2012).

The optical properties of doped nickel ferrite nanoparticles are equally critical, as they influence their applicability in areas such as photo catalysis and sensor technology. Doping can modify the band gap energy, leading to changes in light absorption and emission characteristics (White, 2021). This tenability is essential for optimizing the material's performance in various applications (Clark, 2009). This study aims to systematically investigate the effects of doping on the structural and optical properties of nickel ferrite nanoparticles. By understanding these effects, we can better harness the potential of doped nickel ferrite in advanced technological applications, paving the way for innovative solutions in materials science and engineering (Moore, 2022).

2.2. Synthesis method of (NiFe_2O_4) nanoparticles

2.2.1 Sol-Gel Method

Sol-gel is one of a wet chemical synthesis method to preparation of ceramic powders, specifically, oxides (Majid *et al.*, 2015). This method is mostly used in preparation of ferrite nanoparticles. Due to it's quickly reaction rate, low synthesis temperature, and product of small particle (Shirsath *et al.*, n.d.). A sol and a gel are the two steps in the sol-gel process.

It has been demonstrated that the sol-gel technique offers many advantages like better mixing of the initial materials and homogeneity of the chemicals in the final result (Ibrahim *et al.*, 2017). The methods are based on mixing solutions that enable reactions for the formation of distinct particles. Typically, this involves forming citrate complexes of the metals, followed by the addition of ethylene glycol, which undergoes a condensation reaction with the citric acid, to form a homogeneous mixture. Sol-gel synthesis method is a cost-effective synthesis process due to its capability to be synthesized at low temperatures (Wani *et al.*, 2020). The most important advantage of sol-gel method is the ability of mixing of precursors, to form compounds. This provides a decrease in diffusion length in molecular level. Moreover, sol-gel process is more controllable technique for synthesizing different materials (D. Wang *et al.*, 2015). Typically, there are two kinds of sol-gel methods: particulate sol-gel method (or non-alkoxide method) and polymeric sol-gel method, which is also called alkoxide method. In the particulate sol-gel method, the precursors are initially converted to a dispersible oxide on addition to dilute acid or distilled water in a chemical process, which forms a colloidal dispersion (sol). By removing of the solvents from the sol, a stiff gel is produced. Calcinations of the gel lead to a final product after decomposition of the constituents. The second sol-gel technique includes hydrolysis of metal-organic compounds particularly metal alkoxides. To prepare ceramic oxides, metal alkoxide is mixed with alcohol and the hydrolysis is carried out under controlled conditions resulting in a solid monolithic gel.

2.2.2 Hydrothermal method

Hydrothermal is another type of preparation route which employs heat and pressure to initiate reactions of reagents dissolved in water, or organic solvent (Katlakunta *et al.*, 2015). It takes place in a sealed autoclave at temperatures higher than the boiling point of the solvent and at increased pressures (Govind Mallan *et al.*, 2014). This method allows for preparation of pure phase nano-sized materials with unique nano-morphologies at low temperatures compared to solid state reaction (SSR) method. In this synthesis route particles size and morphology are controlled through the factors such as; the temperature, pH and concentration of the reactants. Generation of autogenously pressure, due to the evolution of gases during the reaction creates unique reaction conditions. Sometimes a mineralizer, such

as an inorganic salt is required to enhance solubility of particular reagents (Ozdilek & Ozenbas, 2020).

Chapter Three: Materials and Methods

3.1. Introduction

This chapter examines, chemicals (precursors) were used, apparatus, synthesis method, experimental producer and characterization techniques.

3.2. Chemicals used (Precursors)

To prepared copper doped Nickel ferrite nanoparticles: Nickel Nitrate $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$, Ferric Nitrate $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$, Copper Nitrate $\text{Cu}(\text{NO}_3)_2 \cdot 3\text{H}_2\text{O}$, were used as starting chemicals and citric acid, anhydrate ($\text{C}_6\text{H}_8\text{O}_7$) was used as chelating agent, 25% Ammonium solution (NH_3) was used to regulate the PH value of the acidic solution to neutral, Doubly deionized water and Acetone.

3.3. Apparatus

To prepare the sample of copper doped Nickel ferrite, the following equipment was required: Beaker, Spoon, Spatula, Cotton, filter paper, Tunnel, Electric balance, (chemical mass measurement), Magnetic stirrer, Magnetic bead, Evaporating dish, Hot oven, Agate mortar with pestle, Alumina crucible, Temperature programmed, Electric furnace, Litmus paper.

3.4. Synthesis methods

There are two distinct approaches commonly used in the synthesis of nanoparticles. Namely top down and bottom-up approaches. Top-down synthesis involves the fabrication of nanoparticles by reducing the size of a bulk material through mechanical or physical methods. One common top-down method is milling, where larger particles are ground down to nano scale dimensions using mechanical forces. Another approach is lithography, which utilizes techniques such as electron beam lithography or photolithography to pattern and etch nanoscale features on a substrate. Top-down methods offer control over the size, shape, and composition of nanoparticles, but they may have limitations in terms of scalability and the ability to produce mono-disperse nanoparticles. On the other hand, bottom-up synthesis

involves the assembly or growth of nanoparticles from smaller building blocks or precursor materials. Chemical synthesis methods, such as chemical precipitation or sol-gel methods, fall under the bottom-up category. In chemical precipitation, nanoparticles are formed by the controlled precipitation of precursor materials from a solution. Sol-gel methods involve the hydrolysis and condensation of precursor compounds to form a gel, which is then processed to obtain nanoparticles. Bottom-up methods provide excellent control over the size, shape, and composition of nanoparticles and can produce mono-disperse particles. They are often used for the synthesis of complex nanoparticles with tailored properties. For this present study, the sample was prepared using sol-gel synthesis method. The sol-gel synthesis method is favored the primary approach for preparing copper doped nickel ferrite nanoparticles due to it numerous advantages such as:

- ✓ Control over particle size
- ✓ Homogeneous composition
- ✓ Purity and chemical homogeneity
- ✓ Tailoring of properties
- ✓ Versatility and scalability
- ✓ Low-temperature processing

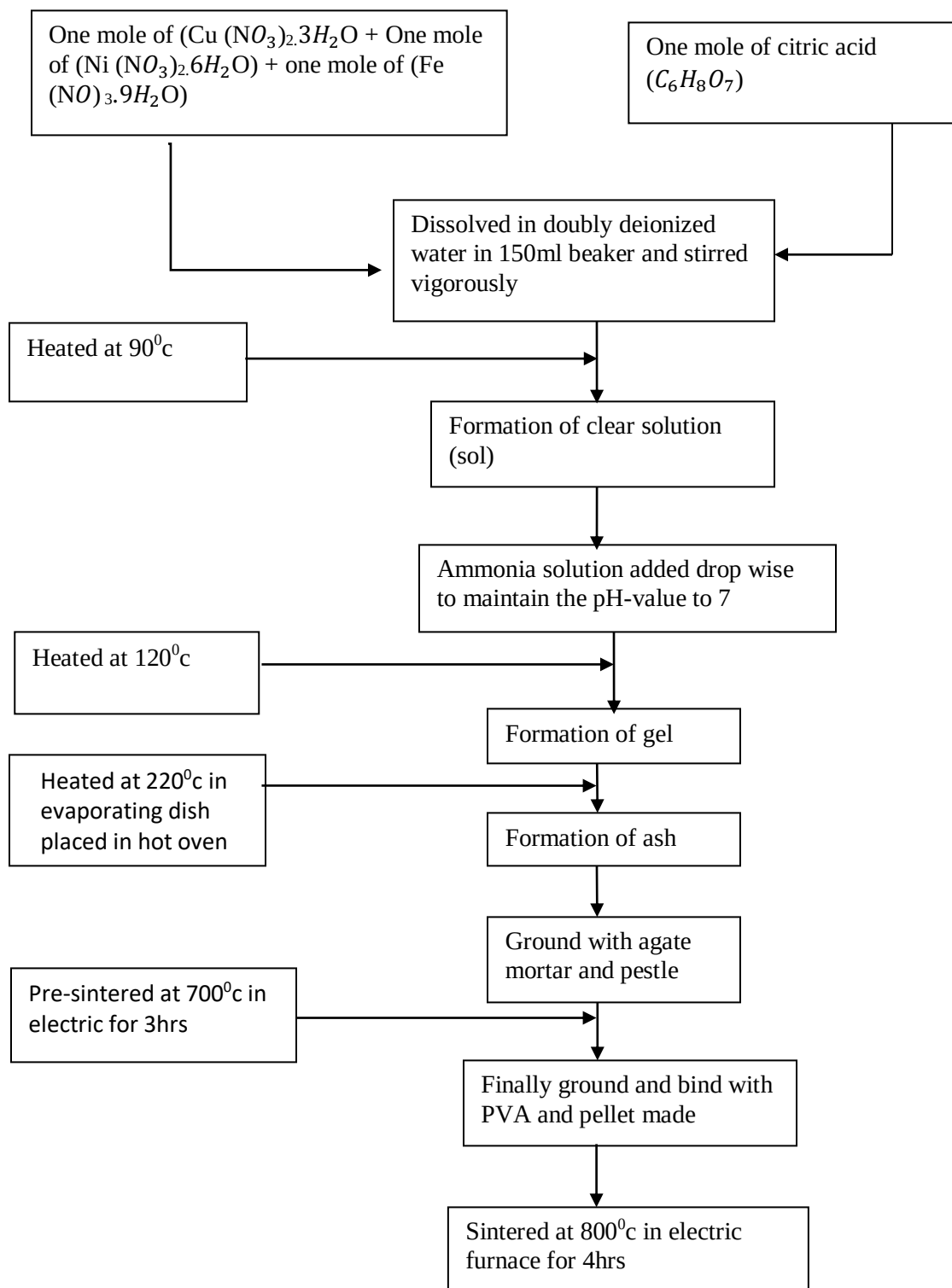
3.5. Experimental Procedure

Synthesis of high quality materials with desired properties is utmost important in the experimental condensed matter physics research. To prepare copper doped nickel ferrite nanoparticle, the following experimental procedures were employed:

- ❖ Stoichiometry amount of Nitrates $Fe(NO_3)_3 \cdot 9H_2O$, $Ni(NO_3)_2 \cdot 6H_2O$ and $Cu(NO_3)_2 \cdot 3H_2O$ are mixed in a beaker containing an amount of doubly deionized water.
- ❖ Equal mole of anhydrous citric acid ($C_6H_8O_7$) with total mole of metal nitrates was added to the solution as chelating agent (to facilitate chemical reaction).
- ❖ The solution were placed on hot plate and stirred using magnetic stirrer with spell to homogenize the mixture The homogenized form clear solution called `sol`.
- ❖ Which the magnetic stirrer is on the ammonia solution was added drop wise to the solution to neutralize the acidic solution to the PH-7.

- ❖ As time goes on the structural net worked `gel` was formed.
- ❖ The gel were poured in to evaporating dish and was loaded in hot over at 2200⁰c to remove moistures until its gel to burnt ash.
- ❖ After temperature of the over drop to room temperature, the burnt ash was grounded finely using agate mortar.
- ❖ The finely grounded powder was held in aluminum crucible and was loaded electric furnace at 650°C 3hrs to remove impurities and organic substances (calcinations) then the calcined powder was grounded finely several times.
- ❖ The finely grounded powder was sent to characterization and measurements.

3.6. The flow chart (chemical synthesis route)



3.7. Characterization Techniques

3.7.1. X-ray diffraction (XRD)

X-ray diffraction (XRD analysis) is unique method in determination of crystallinity of a compound. This technique is primarily used for phase identification of a crystalline material and can provide information on unit cell dimensions. In XRD, X-rays scattered by the atoms of a crystal produce constructive interference effect, so the diffraction pattern gives information on the structure of the crystal or the identity of a crystal in substance. Monochromatic X-rays are impinged on powdered crystalline sample, which is called powdered crystallography. X-ray diffractometer consists of three basic elements: an X-ray tube, a sample holder, and an X-ray detector. X-rays are generated in a X-ray tube by heating filament to produce electrons, accelerating the electrons toward a target by applying a voltage, and bombarding the target material with electrons. Copper is the most common target material to produce X-ray.

The structural parameters like inter planar distance (d), crystallite size (D), lattice constant (a), and volume of unit cell (V) can be calculated using the following equations:
The Bragg's equation

$$2d_{hkl}\sin\theta = n\lambda \quad (3.1)$$

For cubic crystal, the lattice constant can be

$$a = d_{hkl}\sqrt{h^2 + k^2 + l^2} \quad (3.2)$$

(Where “d” is the interplanar distance and h, k, and l are the miller indices).

The volume of the cubic crystal structure

$$V = a^3 \quad (3.3)$$

The crystallite size D will be calculated using the Debye-Scherrer formula (Hashimet al.,2018).

$$D = \frac{k\lambda}{\beta\cos\theta} \quad (3.4)$$

Where,

$K=0.89$ = Scherer constant, $\lambda=0.15406$ nm= wavelength of x-ray used, β is full width at half maximum (FWHM) of the diffraction peak in radian.

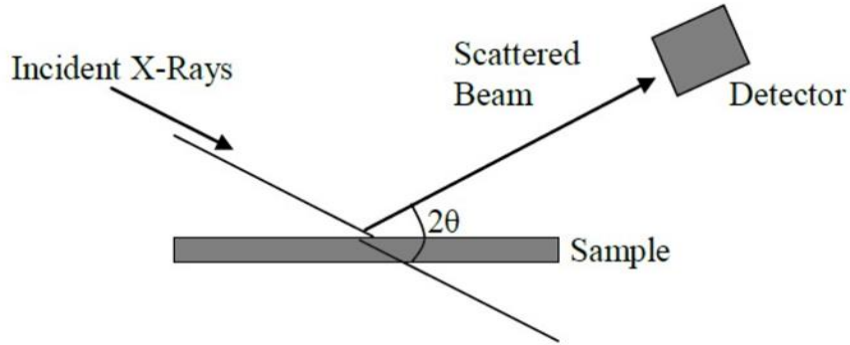


Figure 3. 1. X-ray diffraction from Crystal

The x-ray density which is considered as theoretical density of the sample can be calculated as:

$$\rho_{x-ray} = \frac{8M}{N_a V} \quad (3.5)$$

3.7.2. Scanning electron microscopy (SEM)

When the incident electrons hit the sample, they cause the sample's own electrons (secondary electrons) to be emitted. The angle and speed of these secondary electrons provide information about the sample's surface structure. A detector captures these secondary electrons, converts them into an electronic signal, amplifies it, and then transforms it into a video image displayed on a monitor.

The SEM scans this focused electron beam across the sample in a raster pattern. By combining the beam's position with the intensity of the detected signals, the SEM constructs an image. This process allows for high-resolution imaging, typically with a resolution of 2 nanometers (2nm), making it ideal for studying the topography (surface features) and morphology (shape and structure) of materials. The interaction of the electron beam with the sample's atoms also provides information about the sample's composition.

SEM analysis is frequently used to examine changes in the crystalline and surface morphology of materials, such as copper-doped Nickel ferrite nanoparticles with varying metal concentrations. When the electron beam strikes a crystalline specimen (whether powder or pellet), it undergoes complex interactions with the nuclei and electrons of the atoms within the sample.



Figure3. 2. SEM machine

3.7.3. UV-Vis spectroscopy

The optical properties of copper-doped nickel ferrite nanoparticles are mainly studied using UV-Vis spectroscopy. This method helps us understand how these nanoparticles absorb ultraviolet and visible light, which gives us important information about their electronic transitions.

The UV-Vis spectrum typically shows specific absorption peaks. These peaks represent where electrons within the material are moving to different energy levels. When copper ions are added, these electronic transitions can change. This often results in the absorption peaks shifting their positions or changing in intensity compared to pure nickel ferrite.

Copper doping can either boost or lower the optical absorption of nickel ferrite. As noted by Senbeto and Elangovan (2023), the light transmitted after passing through the sample can be calculated using Beer- Lambert's law

$$I = I_0 e^{-\alpha L} \quad (3.6)$$

Where, I is the transmitted intensity of light after moving through a sample having sample holder (Cuvette) thickness 'L', I_0 is intensity of incident light arrived at the edge of the sample, α is the absorption coefficient of the sample,

The absorbance (A) and the absorption coefficient (α) can be related using;

$$\alpha = 2.303 \frac{A}{L} \quad (3.7)$$

For appropriate measurement the thickness of the sample holder must be 1mm=1cm

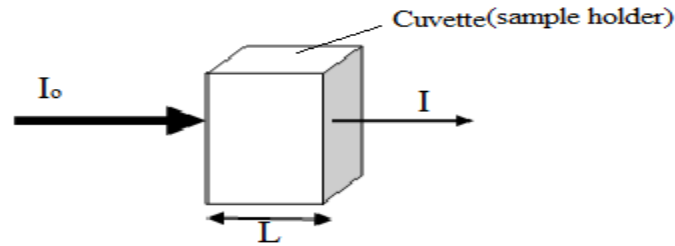


Figure 3. 3. Schematic diagram of Light transmission

The optical direct band gap energy can be estimated by transforming the absorption UV-Vis spectral data using Tauc relation:

$$(\alpha h\nu)^2 = B(h\nu - E_g) \quad (3.8)$$

$h\nu$ is the energy of the photon incident on the sample, h is plank's constant, ν is the frequency of the photon, E_g is the band gap energy between the bottom of the conduction band and the top of the valence band.

Chapter Four: Result and Discussions

4.1. Introduction

This chapter is dedicated to the presentation and in-depth analysis of the experimental findings concerning the influence of copper doping on the structural and optical properties of nickel ferrite nanoparticles. The results obtained from various characterization techniques, including XRD, SEM, and UV-Vis spectroscopy, will be systematically presented. For each set of data, a detailed discussion will follow, interpreting the observed changes in crystallite size, lattice parameters, surface morphology, and optical absorption characteristics as a function of copper concentration.

4.1. XRD Analysis

Figure 4.1 displays the X-ray Diffraction (XRD) patterns for $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ nanoparticles, where x represents copper concentrations of 0, 0.05, and 0.10. These nanoparticles were synthesized using the sol-gel method at room temperature. The XRD patterns for all samples confirm a single-phase cubic spinel ferrite structure with no observable impurity peaks. Distinct and intense peaks are clearly indexed at approximate Bragg angles 2θ of 19.7° , 31° , 35° , 36° , 44.6° , 54.6° , 57° , and 64.8° , corresponding to the (111), (220), (311), (222), (400), (422), (511), and (440) crystallographic planes, respectively.

The Crystal lattice parameters (a), the interplanar distance(d), crystallite size(D) for the prominent intense peak at (311) plane can be found using equations (3.1-3.4) and the results are summarized in Table 4.1.

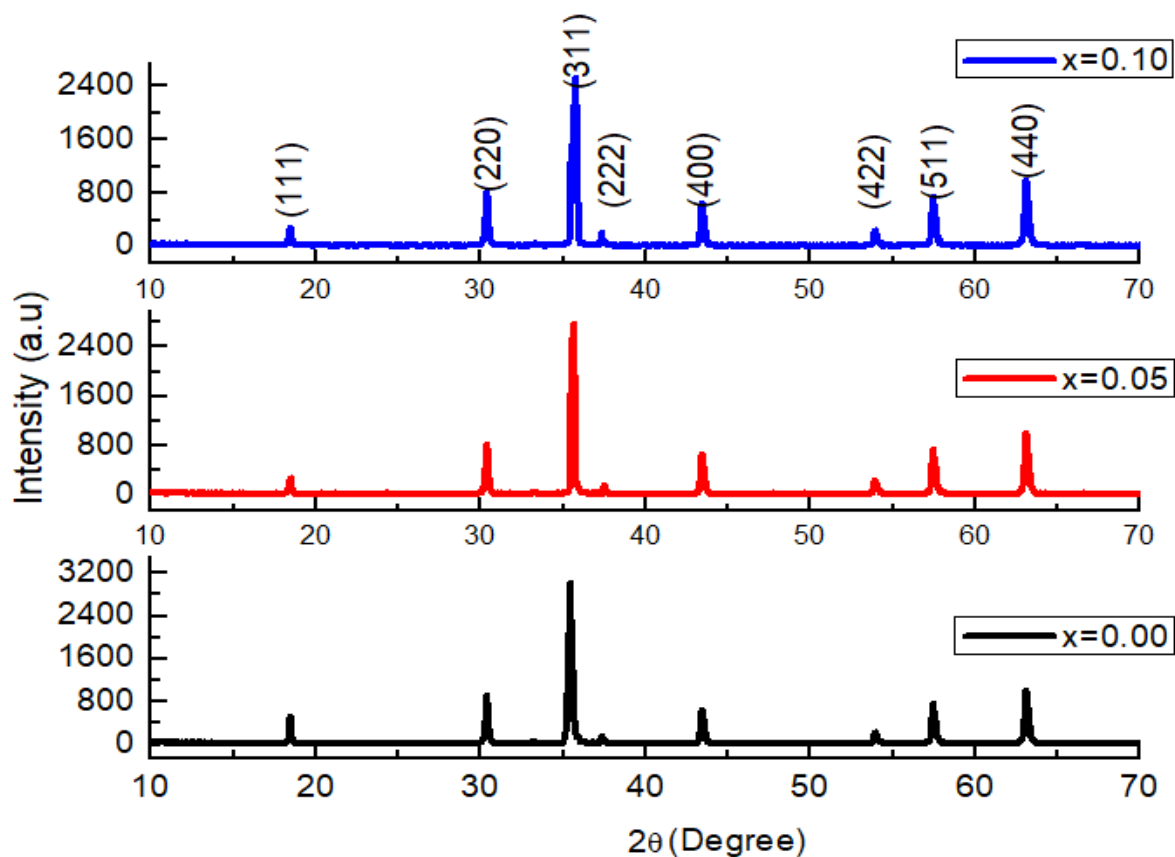


Figure 4. 1.X-ray diffraction patterns of $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ sample ($x=0,0.05,0.10$)

Table 4. 1. Crystallite size, d -spacing, Lattice parameter and intense peak.

Sample	Crystallite size D(nm)	d- spacing	Lattice constant, a(nm)	Volume of unit cell, $V(\text{nm})^3$	X-ray density(g/cm^3)
NiFe_2O_4	46.21	0.2531	0.8393	0.5913	5.266
$\text{Ni}_{0.95}\text{Cu}_{0.05}\text{Fe}_2\text{O}_4$	40.35	0.2526	0.8379	0.5884	5.297
$\text{Ni}_{0.90}\text{Cu}_{0.10}\text{Fe}_2\text{O}_4$	35.42	0.2522	0.8366	0.5855	5.329

Table 4.1, shows the decreased in the crystallite size and lattice constant with increasing concentration of Copper ion which influenced by the ionic property of the dopant and synthesis condition. The ionic radius of Cu^{2+} (0.73 Å) is slightly larger than that of Ni^{2+} (0.69 Å), that inhibited the grain growth and can act as the impurities which segregate the grain boundaries that physically impede its movement. These effects might lead to the distortion of the formed crystal causing less average of its parameters. The x-ray density increased with increasing concentration of

copper ion in the pristine which is attributed to the decrease in lattice constant of sample cubic crystal,

4.2. SEM Analysis

Figure 4.2 shows the SEM micrographs of $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ ($x=0.0, 0.05, 0.10$) nanoparticles prepared using sol-gel method at room temperature. The result revealed that the prepared sample in well defined manner but less agglomerated at optimum value of the dopant concentration. There are certain reasons for the occurrence of the structure: One possible reason is the variation of in atomic arrangement and bonding characteristics resulting from the substitution. This can lead to changes in surface morphology. According to recent study by Smith et al. (2021), the substitution of different elements in nanoparticles can have significant affect their morphology.

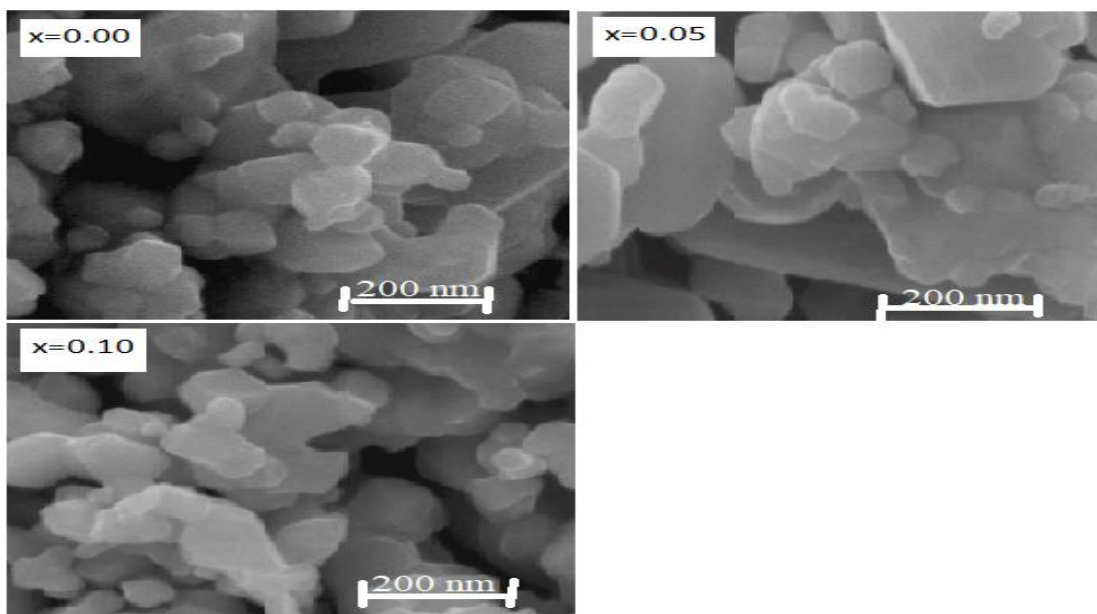


Figure 4. 2.SEM Micrograph of $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ sample ($x=0,0.05,0.10$)

4.3. Optical Studies

Figure 4.3 shows the optical properties (absorbance) of $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ ($x = 0, 0.05, 0.1$) samples were measured at room temperature in the wavelength range 480 to 640 nm.

As seen in figure 4.4, the optical band gap energy increased from 2.269 eV to 2.322 eV with increasing of the concentration of Cu ion which resulted from the Quantum confinement effect that explains size dependent effect of E_g . The widening the energy band require the electronic transition to shift the lower energy state to the valence band.

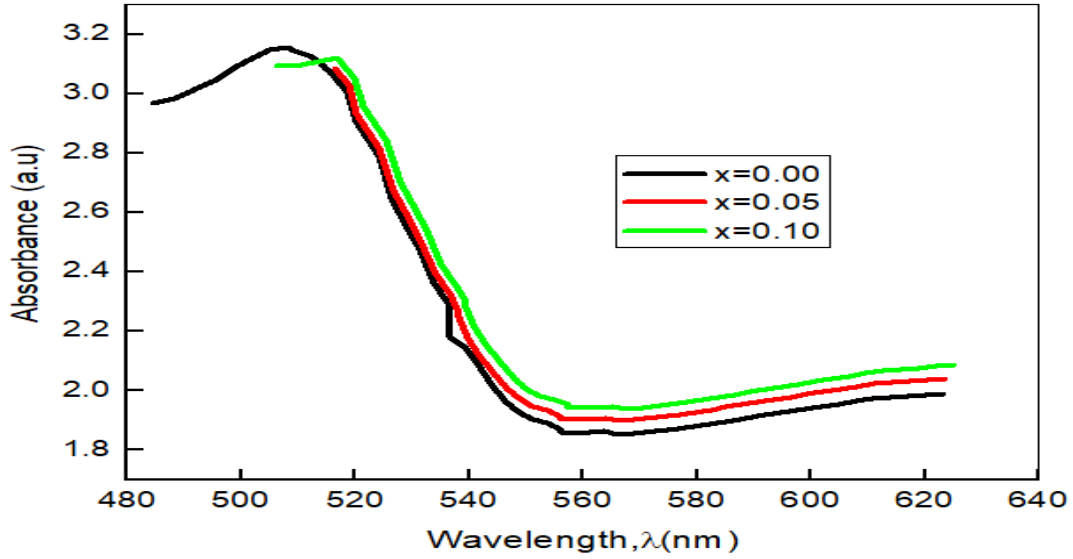


Figure 4. 3. Optical studies of $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ sample ($x=0,0.05,0.10$)

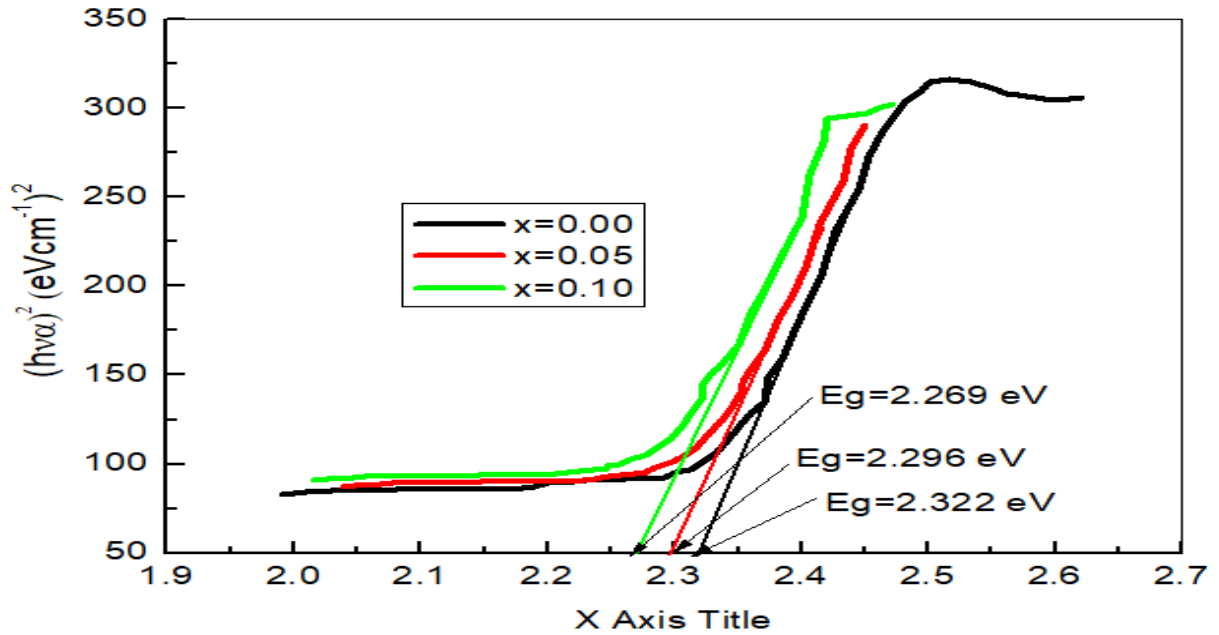


Figure 4. 4: Optical studies of $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ sample ($x=0,0.05,0.10$)

Table 4. 2. Band gap Energy of $\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$ sample ($x=0,0.05,0.10$)

Sample	Band gap (eV)
NiFe₂O₄	2.322
Ni_{0.95}Cu_{0.05}Fe₂O₄	2.296
Ni_{0.90}Cu_{0.10}Fe₂O₄	2.269

Chapter Five: Conclusion and Recommendation

5.1. Conclusion

Nickel ferrite nanoparticles doped with copper ($\text{Ni}_{1-x}\text{Cu}_x\text{Fe}_2\text{O}_4$), $x = 0, 0.05, 0.10$) were successfully synthesized by the sol-gel method. In this study we prepared pure and copper doped nickel ferrite nanoparticles using sol-gel method. After preparing the sample, the crystal structure and its phase was characterized by using XRD. Lattice parameters were found to $a=3.10\text{\AA}$, $b= 2.70\text{\AA}$ and $c=2.38\text{\AA}$ respectively. In this study we prepared pure and copper doped nickel ferrite nanoparticles using sol-gel method. After preparing the sample, the crystal structure and its phase was characterized by using XRD. The XRD data showed that the crystallite size, lattice constants, and unit cell volume increased with increasing concentration of copper ions. The surface morphology was characterized using SEM. In order to confirm the formation of ($x=0.0, 0.05, 0.10$) nanoparticles EDX analysis was performed.

5.2. Recommendation for future work

This study has several strengths and limitations that should be addressed to study the effects of copper doped nickel ferrite nanoparticle on structural and optical properties. Moreover, the synthesized method, amount of substituted elements, and types of characterization technique has their own contributions to the limitations. Therefore, to describe the effects of copper doped nickel ferrite nanoparticle on structural and optical properties, a more systematic study (similar research) that can address the point in limitations; still there are no enough literatures. Based on the findings of this study, the following recommendations are provided:

- ✚ The effect of varying copper concentration on the structural and optical properties should be explored to optimize the doping level of copper.

- ✚ Investigation of other transitional elements dopants on structural and optical properties of nanoparticles can provide insights into the potential for further enhancement.
- ✚ Application oriented investigation such as in data storage or spintronics should be explored to assess their practical viability.
- ✚ The stability of the doped nanoparticles over the time should be investigated to ensure their suitability for long-term applications.

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