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Green Synthesis and Electrical Characterization of Copper Ferrite Nanomaterials using Egg White as fuel

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ABSTRACT

Cubic spinel ferrites are essential magnetic metal oxide materials with applications in data storage, adsorption, sensors, and innovative technologies. Among them, nano zinc ferrite is particularly valuable owing to its strong photo-induced catalytic activity, low saturation magnetization, increased resistivity, and consistent properties. In this study, $CuFe_2O_4$ *nanoparticles were produced by means of a green solution combustion technique with egg white as a bio-template fuel. The produced nanoparticles were evaluated for their structural and electrical properties. XRD analysis confirmed the development of copper ferrite with reduced crystallite size, while FTIR spectroscopy identified the chemical bonds within the nanomaterial. Dielectric analysis was conducted to assess the electrical characteristics by measuring dielectric permittivity and loss over a broad frequency range. This analysis is crucial for understanding polarization processes, conductivity, relaxation mechanisms, and molecular dynamics. Electrical characterization techniques are widely applied in electronics, material science, and research for comprehensive material evaluation.*
Keywords: *conductivity, dielectric, ferrite, FTIR, XRD*

1. Introduction

Magnetic nanoparticles are small particles, typically on the nanoscale (1-100 nanometers in size), that exhibit magnetic properties. They have been extensively researched for their unique magnetic, electrical, optical properties [1] and potential applications such as biomedical Imaging [2], Drug Delivery [3], cancer therapy [3], environmental remediation [4], catalyst [5], and biotechnology [6]. They are frequently made from materials like iron, nickel, cobalt, or their alloys. Spinel ferrite nanoparticles hold significant importance in the realm of magnetic nanoparticles due to their distinct characteristics and versatile applications. Spinel ferrite is a specific class of ferrite materials that have a crystal structure known as spinel. This structure is characterized by an arrangement of metal cations (ions with a positive charge) in a pattern where they reside at specific locations within the crystal lattice. The typical chemical formula for a spinel ferrite is represented as $M^{2+}Fe_2^{3+}O_4$ where M^{2+}

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represents a divalent metal cation such as zinc (Zn), copper (Cu), or magnesium (Mg). Fe^{3+} denotes two trivalent metal cations denoting two trivalent metal cations. O_4 stands for four oxide ions that complete the crystal structure. The M^{2+} and Fe^{3+} cations will be dispersed among the tetrahedral and octahedral crystal sites of the spinal structure [7]. In our work $CuFe_20_4$ is produced by combining egg white (albumen) with the nitrates of iron and copper. Being magnetic materials, copper ferrite nanoparticles can display superparamagnetic behavior, rendering them useful for various applications like targeted drug delivery and magnetic resonance imaging (MRI). These nanoparticles find use in various fields, including electronics, materials science, medicine, and environmental science, showcasing their versatility.

After a thorough analysis of solid-state reactions, this approach was selected. Nanoparticle synthesis employs a range of techniques, including chemical reduction, sol-gel processes, precipitation, and physical means such as laser ablation or milling. These methods are utilized to create particles with specific properties, sizes, and shapes, catering to diverse applications in fields like medicine, electronics, catalysis, and more. Green synthesis offers numerous advantages compared to traditional synthesis methods. It is more environmental friendly and operates at a low reaction temperature, reducing the use of toxic chemicals, energy, and generating less waste. This approach aims to reduce the aid of harmful chemicals and energy in the mixture process, making it more eco-friendly. It's gaining attention due to its reduced environmental impact and potential for diverse applications in various industries. It often utilizes natural, renewable materials like plant extracts, animal byproducts, microorganisms such as fungi and bacteria, or other sustainable resources [8]. Santi Maensiri et al. initially documented the albumen-enriched egg white for the synthesis of ferrites substituted for transition metal [9]. The ultimate goal of the present work is to examine the physical, chemical and electrical characteristics of copper ferrite.

2. Experimental details

Copper ferrite nanoparticles were prepared using highly pure ferric nitrate nonahydrate, cupric nitrate hexahydrate, and freshly processed egg white. Egg white is noted for its foaming and emulsification capabilities and being water-soluble, making it easy to interact with metal ions [9,10]. Egg white is also a binding agent and gel for material shaping.

In the synthesis process, 45 mL of egg white was mixed with 5 mL of distilled water and stirred thoroughly using a magnetic stirrer for approximately 30 minutes. Copper nitrate and ferric nitrate are mixed in a stoichiometric ratio of 1:2 with distilled water to prepare a 50 ml solution. This mixture is stirred using a magnetic stirrer until a clear solution is achieved. After preparing the metal nitrate solution, it is added dropwise to the egg white solution while stirring continuously until froth forms, ensuring proper binding. The combined solution is then heated on a hot plate, which ignites a spark and initiates combustion, resulting in a fluffy product. Finally, the obtained product is calcined in a muffle furnace at 600°C for about 3.5 hours to achieve the desired material. Further, the synthesised material is subjected to various studies such as powder XRD, FTIR and dielectric studies.

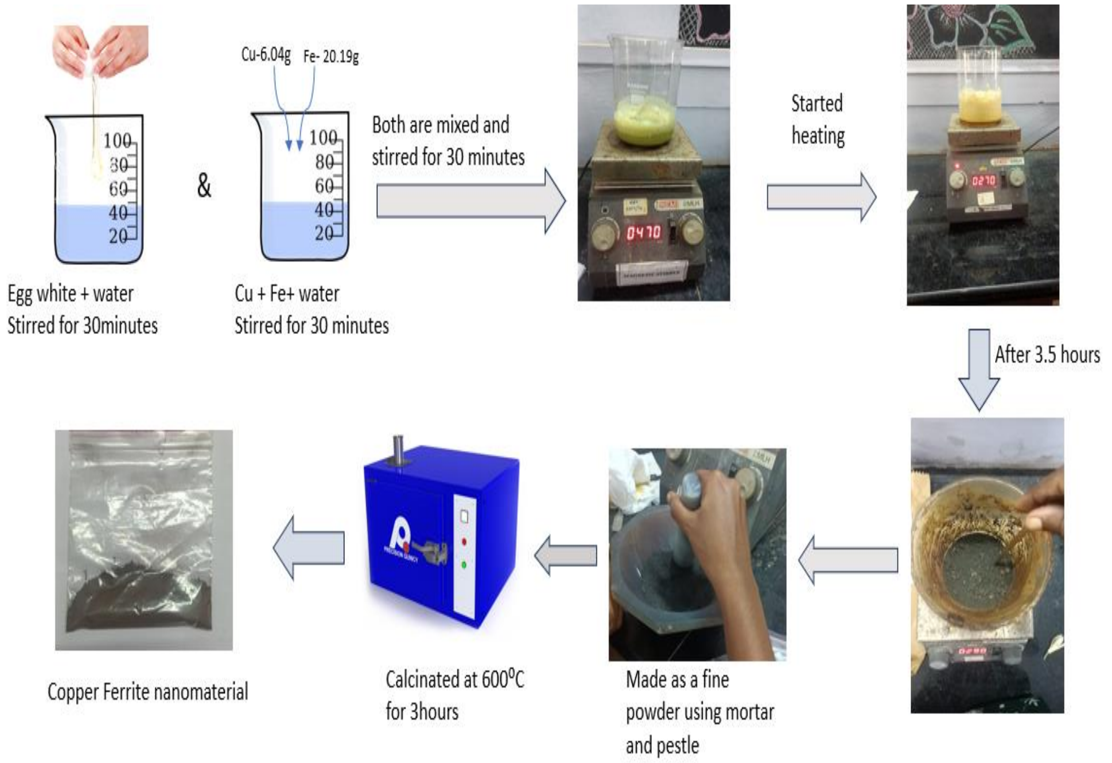

Fig. 1. Schematic representation of synthesis of copper ferrite nanoparticles

3. Results and Discussion

3.1. XRD Analysis

The synthesized copper ferrite nanoparticle was calcinated at 600ºC for three hours and subjected to XRD analysis. The PXRD pattern of the prepared particles is shown in the figure. They exhibit typical reflection planes (2 2 0), (3 1 1), (4 0 0), (5 1 1), and (4 4 0) that are indicators of the presence of cubic spinel structure [11]. These diffraction planes serve as clear evidence of the formation of copper ferrite nanoparticles. All the diffraction peaks align closely with the expected values. (JCPDS file No: 25-0283). The mean particle size of $CuFe_2O_4$ nanoparticle is found to be 50.17631 nm using Scherrer equation. $D = K\lambda/\beta\cos(\theta)$, where: D is the crystallite size, K is shape factor (typically around 0.9), β is the FWHM of the peak in radians, λ is the X-ray wavelength and θ is the Bragg angle. The lattice parameter of $CuFe_2O_4$ nanoparticle is calculated to be 8.4009Å using the below formula [12, 13]

$$a = d\sqrt{h^2 + k^2 + l^2}$$

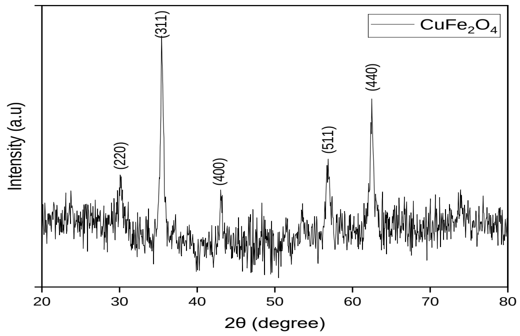

Fig. 2. XRD pattern of $CuFe_2O_4$ nanoparticle

3.2. FTIR Analysis

The FTIR bands of copper ferrite nanoparticles were analysed in two ranges of the absorption bands, 4000 - 1000 cm^{-1} and 1000-400 cm^{-1} and shown in Figure. In the range of 4000 - 1000 cm^{-1}, vibrations of CO, NO and moisture were observed. The intense broad band around 3436 cm^{-1} and the less intense band near 1617 cm^{-1} are attributed to O-H stretching vibrations interacting through hydrogen bonds. The ν (C=O) stretching vibration of the carboxylate group (CO_2) appears around 1383 cm^{-1}, while the band at approximately 1096 cm^{-1} corresponds to traces of nitrate ions [14-16].

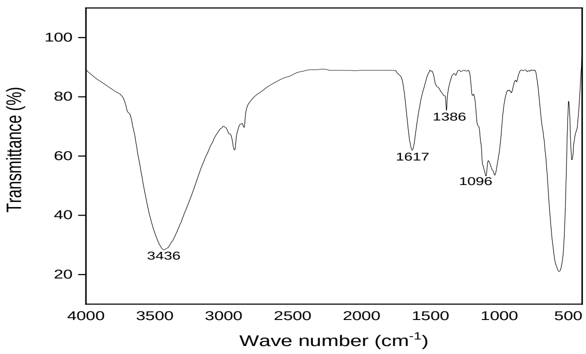

Fig. 3. FTIR spectra of $CuFe_2O_4$ nanoparticle

3.3. Dielectric Analysis

The dielectric constant (ε_r) of $CuFe_2O_4$ was determined through dielectric analysis. The capacitance of a parallel plate capacitor, formed by electrodes with the sample as the dielectric medium, was measured. The capacitance variation was observed across a frequency range of 100 Hz - 1 MHz at temperatures between 40°C and 150°C. The dielectric constant (ε_r) of the material was calculated at diverse temperatures using the measured capacitance values. It was determined using the following equation. [17]

$$\varepsilon_r = \frac{tC_p}{A\varepsilon_0}$$

Here, *t* represents the thickness of the sample, C_p is the measured capacitance, ε_0 is the permittivity of free space, and *A* denotes the sample's area. The variation of the dielectric constant with frequency at different temperatures for $CuFe_2O_4$ nanoparticles is illustrated in Fig. 4. It is evident from Fig. 4 that the dielectric constant decreases as the temperature increases. [18-20]

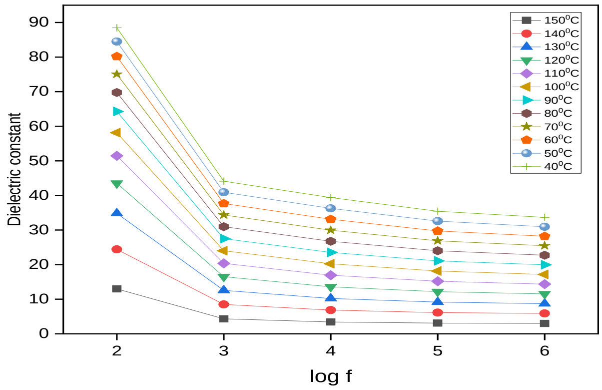

Fig. 4. log f Vs Dielectric constant

The AC Conductivity is calculated using the given relation.

$$\sigma_{ac} = \omega\varepsilon_0\varepsilon' tan\delta$$

Where, σ_{ac} is the AC Conductivity, ε_0 is the permittivity of free space, ω is the angular frequency and δ is the loss factor. The plot depicting the discrepancy of AC conductivity with frequency is shown in Fig 5. It is detected that the AC conductivity increases with both the applied frequency and temperature [21]. The rise in AC conductivity can be ascribed to enhanced polarization effects, which is due to the increased mobility of free charges as the temperature increases.

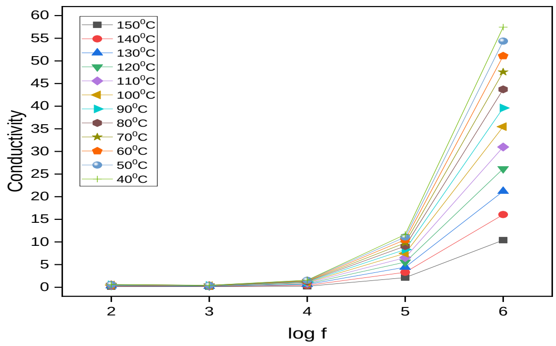

Fig. 5. log f Vs AC Conductivity

The plot illustrating the discrepancy of dielectric loss versus frequency is presented in Fig. 6. The dielectric loss declines as the frequency increases; however, it shows an cumulative trend with a rise in temperature [22,23].

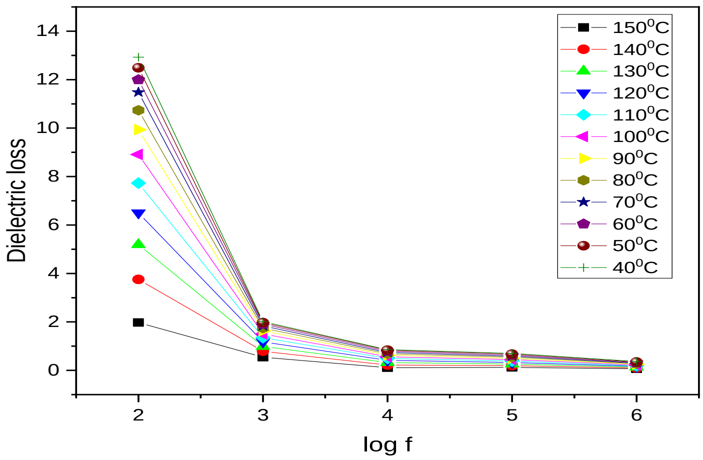

Fig. 6. log f Vs Dielectric loss

4. Conclusion

The present work focuses on the synthesis of Copper Ferrite nanoparticles in green synthesis route using egg white as an eco-friendly precursor. The egg white protein albumen served as a fuel in the auto combustion method. Characterization techniques such as PXRD, FTIR, and dielectric measurements were conducted to investigate the structural, elemental, and dielectric properties of the materials. PXRD analysis confirmed the formation of copper ferrite ($CuFe_2O_4$) nanoparticles with a cubic spinel structure and an average particle size of 50.176 nm. The FTIR spectra displayed absorption peaks at 466 cm^{-1} and 567 cm^{-1}, indicative of metal-oxygen vibrations. Dielectric studies revealed that both the dielectric constant and dielectric loss decrease with increasing frequency of the applied signal, while the AC conductivity increases with frequency. These synthesized copper ferrite nanoparticles exhibit potential applications in electronics and energy storage.

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