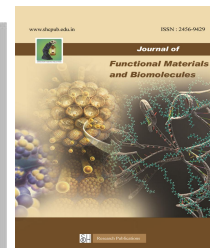




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SYNTHESIS, CHARACTERIZATION, AND OPTICAL PROPERTIES OF COPPER OXIDE (CuO) NANOPARTICLES USING THE CO-PRECIPIATION

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Abstract

Copper oxide (CuO) nanoparticles were successfully synthesized using the co-precipitation method. The resulting products were calcined at 400°C and subsequently analyzed using X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and UV-Vis absorption spectroscopy. The findings confirmed the formation of CuO nanoparticles during the co-precipitation process. XRD patterns revealed the monoclinic crystal structure of CuO nanoparticles with a preferred orientation along the (111) plane. The FTIR spectra exhibited distinct absorption peaks at approximately 605 cm⁻¹, corresponding to the stretching vibrations of the Cu-O bond. The UV-Vis absorption spectrum demonstrated a prominent absorption peak at 254 nm, with the optical band gap energy calculated as 1.8 eV using the Tauc plot. These results highlight the potential of CuO nanoparticles for applications in photocatalysis, sensing, and energy storage.

Keywords: Copper oxide, co-precipitation synthesis, X-ray diffraction, FTIR spectra, UV-Vis spectroscopy.

1 Introduction

Nanoparticles have garnered significant attention, particularly in research, due to their unique optical, magnetic, chemical, and physical properties, which significantly differ from their bulk counterparts. Among nanoparticles, metal oxide nanostructures have emerged as materials of interest because of their versatility and broad range of applications, including their use as

catalysts [1], sensors [2], and in antimicrobial treatments [3]. One of the most prominent and extensively studied metal oxides is copper oxide (CuO), which is well known for its remarkable antimicrobial and biocidal properties. Furthermore, CuO is considered an excellent semiconductor material due to its distinctive electrical, magnetic, and optical properties [4]. These properties have made CuO an essential material in the development of various sensors used for air quality monitoring, security, defense, and healthcare applications [5].

In addition to its use in sensors, CuO has demonstrated therapeutic potential, particularly in glucose and dopa-mine sensing applications. Its excellent optical and magnetic properties, combined with its high stability and low toxicity, make it a versatile material for applications ranging from energy storage to environmental remediation [6]. The small size and high surface area of CuO nanoparticles (NPs) have enabled their incorporation into numerous commercial and industrial applications. Among the common synthesis methods for CuO nanoparticles, precipitation techniques are often preferred for their simplicity and efficiency.

In recent years, there has been a significant increase in research focused on semiconductor metal oxide nanostructures, particularly copper oxide (CuO), owing to their distinctive electronic, optical, mechanical, magnetic, and chemical characteristics. CuO nanostructures can be produced in various forms, including nanorods,

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nanoflowers, nanowires, nano dendrites, and nanosheets, among others. These diverse morphologies are highly advantageous for customizing the material properties for particular applications. CuO is an inorganic, non-flammable, and water-insoluble substance with a wide bandgap energy of approximately 3.3 eV and a high excitation energy of 60 eV [7]. It also demonstrates remarkable transparency, elevated electron mobility, photochemical stability, and high breakdown field strength, which are essential for applications in electronics, optoelectronics, and photocatalysis.

CuO nanostructures hold immense potential in environmental applications, particularly in water treatment. They have been extensively studied as heterogeneous photocatalysts, a key component of advanced oxidation processes (AOPs) [8-9]. These photocatalysts are highly effective in degrading toxic pollutants in industrial wastewater, converting them into safer by-products such as CO₂, H₂O, and mineral acids. Additionally, CuO nanostructures are employed in energy devices, batteries, and fuel cells, owing to their excellent electron mobility and stability under operating conditions [10].

Several conventional methods have been explored for synthesizing CuO nanostructures, including chemical vapor deposition, laser ablation, solvothermal synthesis, thermal decomposition, and the sol-gel method. However, in this study, a simple co-precipitation method was employed to synthesize uniform and pristine CuO nanoflakes, using copper nitrate as a metal precursor and ammonium hydroxide as a precipitating agent. This approach offers the advantages of simplicity, cost-effectiveness, and scalability while maintaining high product quality [11-14].

The co-precipitation method was chosen over sol-gel and hydrothermal methods due to its simplicity, cost-effectiveness, scalability, and environmental friendliness. Unlike the sol-gel method, which requires complex chemical reactions and specialized conditions, co-precipitation is straightforward and operates under mild

reaction conditions [15-17]. Similarly, compared to the hydrothermal method, which involves high pressure and temperature, co-precipitation avoids the need for sophisticated equipment and energy-intensive processes, making it a more practical choice for large-scale synthesis.

2.1 Materials

Copper (II) nitrate trihydrate [Cu(NO₃)₂·3H₂O] and sodium hydroxide [NaOH] were obtained from Merck, and deionized water was used for solution preparation. The final product was washed with absolute ethanol to ensure purity.

2.2 Experimental Method

In a typical experiment for synthesizing copper oxide (CuO) nanoparticles, a 1 M aqueous solution of copper (II) nitrate trihydrate [Cu(NO₃)₂·3H₂O] and a 1 M aqueous solution of sodium hydroxide [NaOH] were prepared separately in distilled water. The NaOH solution was heated to approximately 80°C, and the Cu(NO₃)₂·3H₂O solution was added drop wise to the heated solution while stirring continuously at high speed for 2 hours. The resulting blue solution was left undisturbed for 2 hours, after which the blue precipitate was filtered and washed thoroughly with deionized water and ethanol to remove impurities. The washed material was dried in a hot air oven at 100°C for 5 hours. The dried material was then calcined at 600°C for 4 hours, resulting in a black powder.

3. Results and Discussion

3.1 Powder X-Ray Diffraction Analysis.

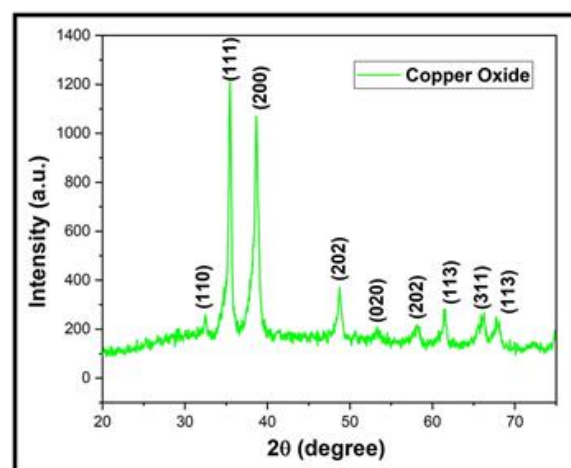


Figure 1: XRD pattern of CuO Nanoparticles.

The XRD studies were conducted to characterize the phase purity and crystallinity of the synthesized sample. Figure 1 illustrates the XRD pattern of the CuO nanoparticles.

peaks were observed at angles (2θ) of 32.54° , 35.56° , 38.78° , 48.96° , 53.76° , 58.33° , 61.67° , 66.16° , and 68.23° , corresponding to the (110), (111), (200), (202), (020), (202), (113), (311), and (113) planes, respectively. These peaks are in strong agreement with the monoclinic crystal structure of CuO (JCPDS Card No: 45-0937). The grain size of the crystallites in the synthesized product was determined using the Debye-Scherrer formula

In this case, λ denotes the wavelength of the X-ray used (0.15418 nm), β represents the full width at half-maximum of the radiation peak, and θ represents the Bragg angle of the X-ray diffraction peak [18]. The average crystallite size of the synthesized CuO nanoparticles was found to be approximately 20 nm. These results confirm that the CuO nanoparticles are well-crystallized with nanoscale dimensions.

3.2 FT-IR Spectra

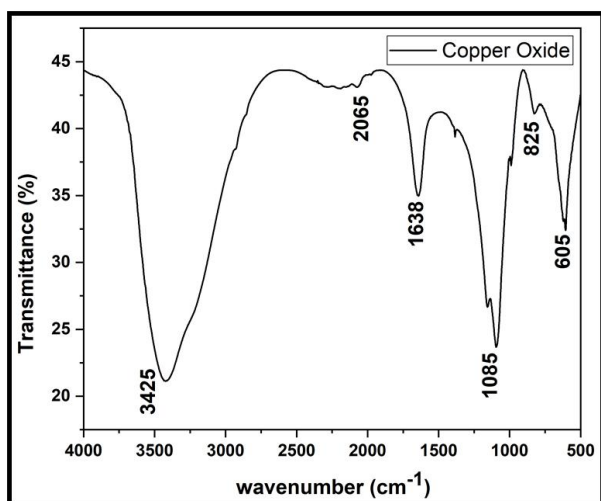


Figure 2: FTIR spectrum of CuO nanoparticles

The FTIR spectrum of CuO nanoparticles is presented in Figure 2, showcasing the functional groups and chemical bonds present in the sample. A prominent absorption band at 3425 cm^{-1} is attributed to the O-H stretching vibrations, indicating the presence of adsorbed water molecules or hydroxyl groups on the nanoparticle surface [19]. The

peak observed at 1638 cm^{-1} corresponds to the O-H bending vibration, further confirming the presence of water or hydroxyl groups [20]. A band around 2065 cm^{-1} can be attributed to carbon-related vibrations, possibly arising from atmospheric CO_2 or organic impurities [21]. The absorption band at 1085 cm^{-1} is associated with C-O stretching vibrations [22]. Peaks at 825 cm^{-1} and 605 cm^{-1} are characteristic of Cu-O stretching vibrations, confirming the formation of CuO nanoparticles [23-24]. These peaks are in agreement with the reported FTIR spectra of CuO, indicating the successful synthesis of copper oxide nanoparticles and confirming the presence of metal-oxygen bonds.

3.3 UV-Visible Absorption Spectrum and Band Gap Analysis of CuO Nanoparticles

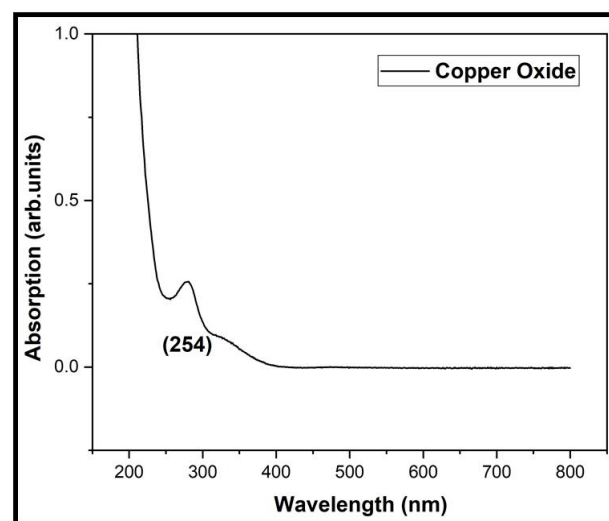


Figure 3 (a): UV-Visible Spectrum of CuO Nanoparticles

Figure 3(a) illustrates the UV-visible absorption spectrum of CuO nanoparticles, which were ultrasonically dispersed in water. A prominent absorption peak is observed at 254 nm, corresponding to the intrinsic band-gap absorption of CuO. This absorption peak signifies the strong interaction between incident photons and the CuO nanoparticles, demonstrating their semiconducting nature. The absorption in this region can be attributed to the electronic transitions from the valence band to the

conduction band, primarily involving copper 3d and oxygen 2p orbitals.

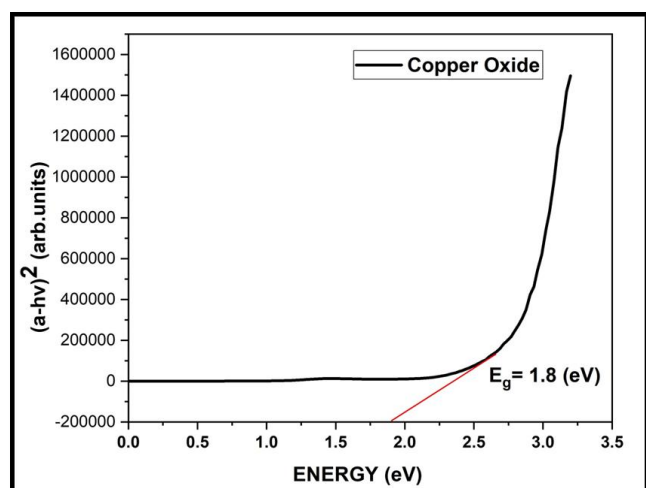


Figure 3 (b): Band Spectrum of CuO Nanoparticles

Figure 3(b) displays the Tauc plot for CuO nanoparticles, used to determine the optical band gap energy. The energy band gap of CuO was calculated using the Tauc relation [25]

$$(\alpha h\nu)^n = A (h\nu - E_g)$$

Here, α represents the absorption coefficient, $h\nu$ denotes photon energy, A signifies absorbance, E_g represents the optical band gap, and n characterizes the nature of the transition process; $n = 2$ for direct transition and $n = 1/2$ for indirect transition. The optical band gap energy for CuO nanoparticles was calculated to be approximately 1.8 eV. This band gap value is consistent with CuO semiconducting nature, further confirming its potential use in optoelectronic devices, sensors, and photocatalytic applications [26]

4 Conclusions

CuO nanoparticles were successfully synthesized using the co-precipitation method, utilizing copper nitrate as the precursor and ammonium hydroxide as the precipitating agent. XRD analysis confirmed the formation of nanocrystalline CuO, revealing a crystallite size of approximately 20 nm at a calcination temperature of 400°C. The FTIR spectrum further validated the presence

of CuO nanoparticles, with characteristic peaks corresponding to Cu–O stretching vibrations. The UV-visible absorption spectrum exhibited a prominent absorption peak at 254 nm, and the optical band gap energy, calculated using the Tauc plot, was determined to be 1.8 eV. These findings demonstrate that CuO nanoparticles possess significant potential for applications in photocatalysis, optoelectronics, and sensing technologies.

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