

# An Investigation on the Synthesis and Characterization of Copper Oxide Doped Nano Particles

M. Sekar<sup>1\*</sup>, K. Saravanan<sup>2</sup>, Bharathi Bernadsha S<sup>3</sup>

<sup>1</sup>Department of Physics, Don Bosco College, Dharmapuri

<sup>2</sup>Sri Venkateshwaraa Arts and Science College, Dharmapuri

<sup>3</sup>Department of Physics, Sacred Heart College (Autonomous), Tirupattur

\* Corresponding author: livyasekar@gmail.com

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## ABSTRACT

Cobalt-doped copper oxide (CuO) nanoparticles, synthesized by hydrothermal method, exhibit enhanced photocatalytic, magnetic, and electrochemical properties, making for energy storage, catalysis, and gas sensing applications. The characterization confirmed successful cobalt doping nanoparticles and material properties. X-ray diffraction (XRD) analysis confirmed the crystalline structure, while field-emission scanning electron microscopy (FESEM) revealed uniform particle morphology and consistent dopant distribution. Optical properties were assessed using UV-Vis diffuse reflectance spectroscopy bandgap energy and Fourier-transform infrared (FTIR) spectroscopy identified characteristic functional groups. These results highlight the potential of cobalt-doped CuO as a multifunctional material for advanced applications.

**Keywords:** Energy storage; catalysis; and gas sensing applications.

## 1. Introduction

Cobalt-doped copper oxide (CuO) nanoparticles have gained significant interest in materials science due to their unique and enhanced properties over pure CuO, expanding their potential applications in fields such as photocatalysis, energy storage, gas sensing, and spintronics. Copper oxide is a p-type semiconductor with a narrow bandgap around 1.2 eV, which limits its light absorption range; however, doping CuO with cobalt introduces additional energy levels within the bandgap, improving light absorption and charge separation efficiency under visible light. This effect is particularly beneficial for Photocatalytic applications and observed enhanced degradation rates of organic pollutants with cobalt-doped CuO nanoparticles under visible light, owing to the material's reduced bandgap and increased surface active sites. In addition to Photocatalysis, cobalt doping in CuO significantly improves its electrochemical performance, making it highly suitable for energy storage applications such as supercapacitors and lithium-ion batteries. copper-substituted cobaltite spinels combine advantageously high stability and activity with low cost and availability. [1,2] report that cobalt-doped CuO exhibits higher specific capacitance, faster charge-discharge rates, and greater cycling stability, attributed to improved electrical conductivity and charge transport in the material. Furthermore, the doping process introduces oxygen vacancies and defects that act as catalytic sites, which are beneficial for both catalytic and sensing applications. These oxygen vacancies enhance gas adsorption and sensitivity, enabling the material to detect gases such as CO and NO<sub>2</sub> more effectively. [3,4] demonstrated that cobalt-doped CuO nanoparticles exhibit enhanced gas sensitivity, lower operating temperatures, and faster response times, making them promising for gas sensors in environmental monitoring Sensors and Actuators. Another interesting property of cobalt-doped CuO nanoparticles is their room-temperature ferromagnetism, which is absent in pure CuO. This magnetic behavior, as studied by Ahmed makes the material potentially useful in spintronics and magnetic data storage applications, where room-temperature ferromagnetism is essential for data integrity and retrieval the nanostructured rare earth



and semiconductor materials like ZrO<sub>2</sub>, ZnO, CuO, TiO<sub>2</sub> and SnO<sub>2</sub> [5,6]. Hydrothermal synthesis is valued for producing highly pure, phase-stable nanoparticles with minimal contamination, making it suitable for applications where particle consistency and stability are essential. The cobalt-doped CuO nanoparticles synthesized method often exhibit enhanced photocatalytic activity, improved electrochemical performance for energy storage, and increased sensitivity in gas sensing applications due to the precise control over their composition and structural characteristics. This makes the hydrothermal method a preferred choice for creating high-quality cobalt-doped CuO nanoparticles for advanced technological applications.

In this work cobalt-doped CuO nanoparticles are an advanced multifunctional material with enhanced photocatalytic, electrochemical, sensing and magnetic properties. Studies have shown the substantial potential of this material, indicating the value of doping as a strategy for developing next-generation materials for sustainable and high-tech applications.

## 2. Materials and methods

The hydrothermal method involves dissolving copper and cobalt precursors, such as copper nitrate (Cu(NO<sub>3</sub>)<sub>2</sub>) and cobalt nitrate (Co(NO<sub>3</sub>)<sub>2</sub>), in a solvent, typically water or an aqueous solution. A mineralizing agent, such as NaOH, is then added to adjust the pH. The mixture is transferred into a sealed autoclave, where it is heated at temperature 150°C under autogenous pressure for about 5 hours. These conditions promote the reaction of the precursors, resulting in the formation of well-defined, crystalline CuO nanoparticles doped with cobalt ions.

## 3. Results and Discussion

### 3.1 XRD Analysis

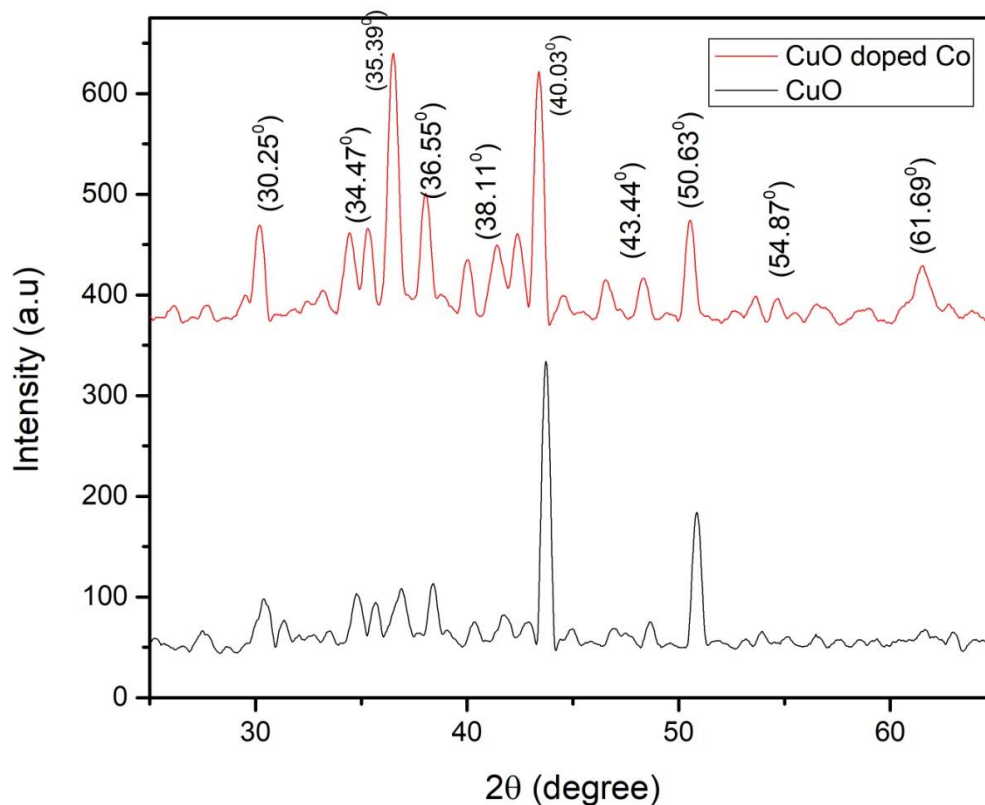


Figure 1: Powder X-Ray Diffraction Patterns of Copper Oxide (CuO)-doped Cobalt

In X-ray diffraction (XRD) analysis of Copper Oxide (CuO) doped cobalt the introduction of Cu into the Co lattice results in observable changes in the XRD pattern, reflecting structural and crystallographic modifications (figure 1). When Cu atoms replace or intercalate within the Co lattice, a shift in diffraction peaks is often observed due to lattice expansion, as Cu has a slightly larger atomic radius than Co. In the diffraction pattern, these shifts typically manifest as lower-angle displacements of peaks for major crystallographic planes, such as the (111), (002), (202), and (020) planes, which are commonly observed for face-centered cubic (fcc) cobalt structures. For a pure Co XRD pattern, the (111) plane might appear around  $43.44^\circ$ , while doping with Cu could shift this peak to a slightly lower angle due to increased lattice spacing. Additionally, Cu doping can broaden the peaks, especially in the high-index planes, due to microstrain and reduction in crystallite size, which is commonly quantified using the Scherrer equation. Broadening is more pronounced in higher-angle reflections like the (220) and (311) planes, indicating lattice distortions induced by Cu incorporation. Comparing the (hkl) values and peak intensities between pure and doped Co allows a quantitative assessment of structural changes, revealing the extent of Cu incorporation, lattice strain, and phase stability in the doped material [7].

### 3.2 UV- Analysis

In the analysis of CuO-doped cobalt using UV-Vis spectroscopy, the optical properties of the material reveal significant insights into electronic structure modifications, particularly the band gap energy (Figure 2). CuO doping can lead to changes in the absorbance spectrum of cobalt, typically shifting the absorption edge toward longer wavelengths (redshift), which corresponds to an increase in the band gap energy. This redshift arises due to the introduction of CuO atoms, which affect the electronic band structure by creating impurity states or altering the conduction and valence bands. For undoped cobalt oxide typically shows a band gap around 4.37 eV CuO doping might increase this band gap to values 4.79 eV, This reduction in the band gap allows Cu-doped cobalt to absorb visible light more effectively, which is advantageous in photocatalysis and photo electrochemical applications. The UV-Vis absorbance spectrum of CuO-doped cobalt will show a distinct absorption onset that corresponds to the modified band gap, enabling precise calculation through the Tauc plot method.

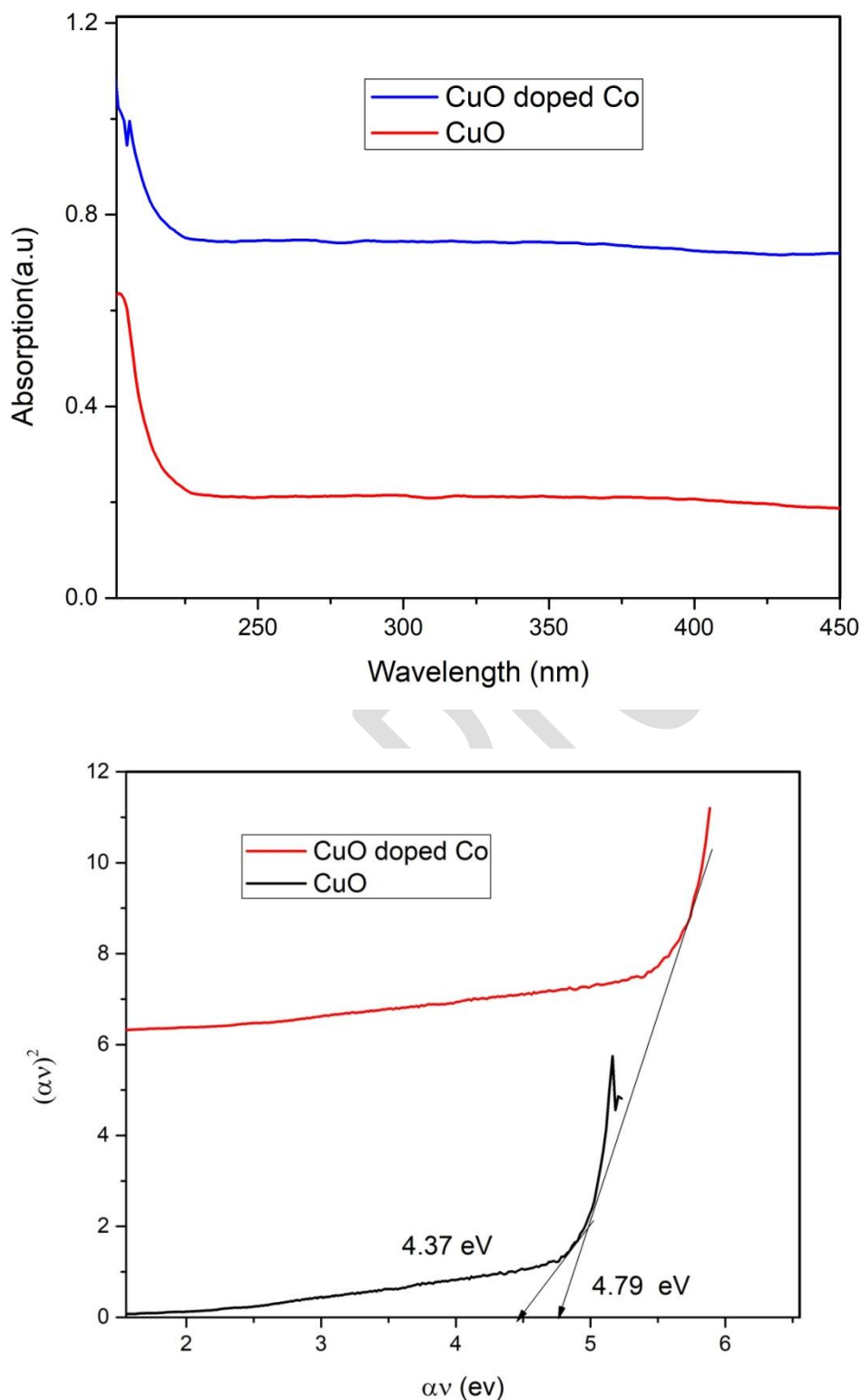
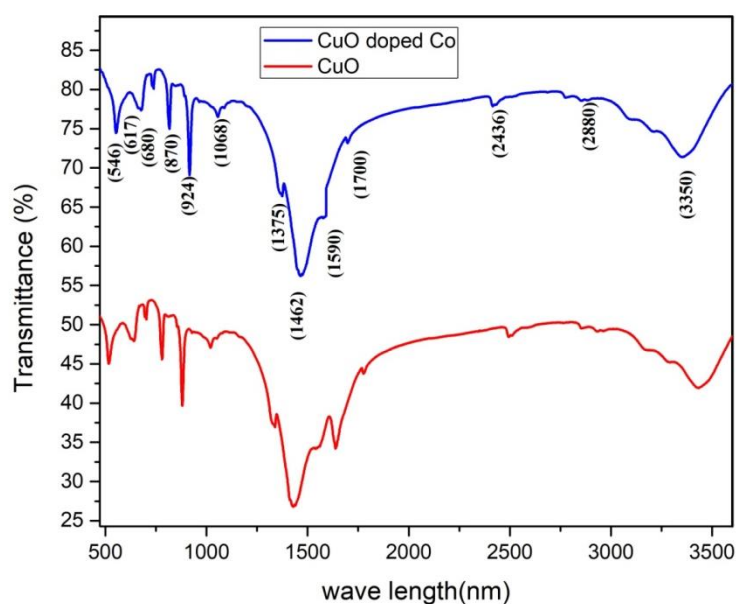


Figure 2 : a)UV Visible Spectroscopy Spectrum b) Energy Band gap

### 3.3 FTIR analysis

In Fourier Transform Infrared (FTIR) spectroscopy analysis, CuO-doped cobalt materials exhibit characteristic absorption bands that provide information about their chemical bonding, functional groups,

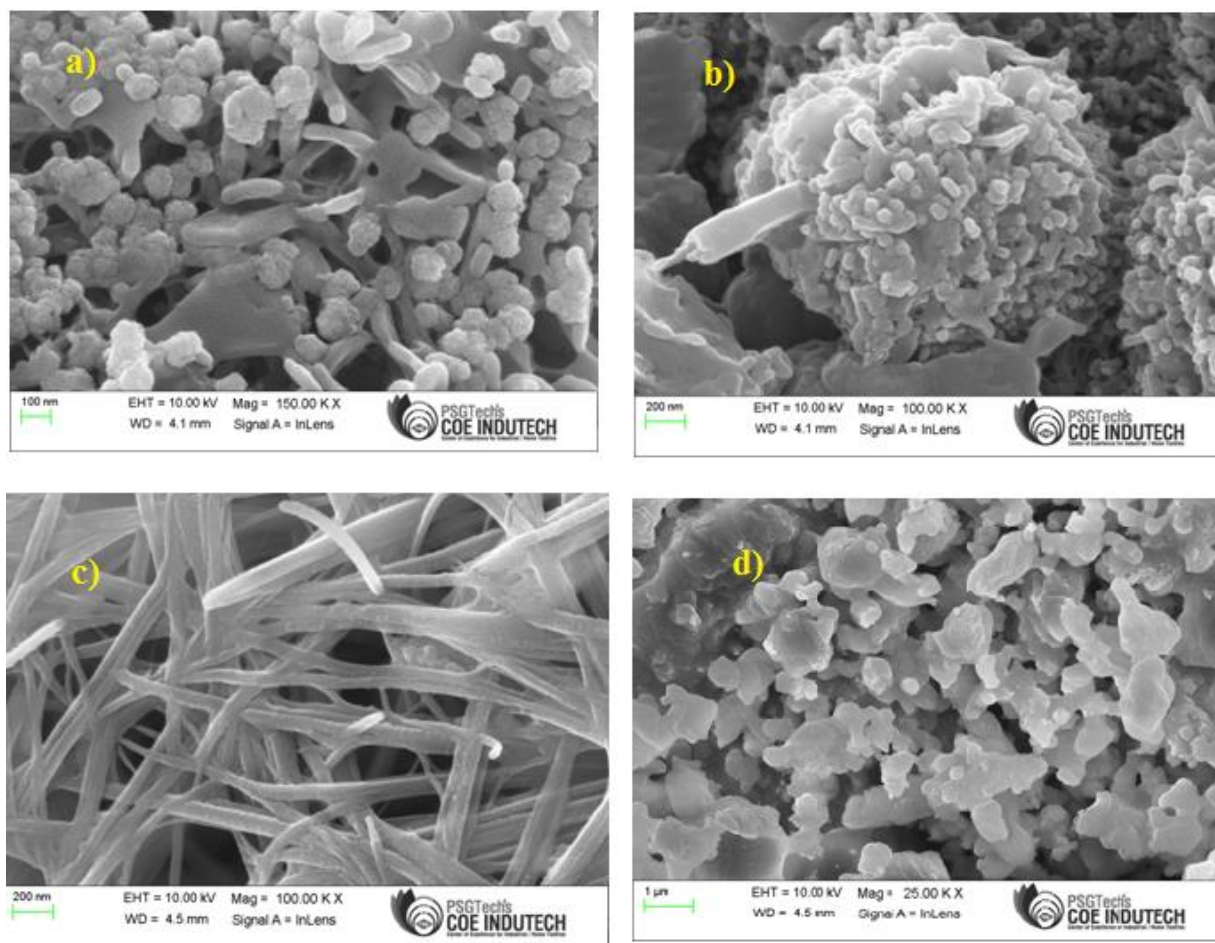
and lattice vibrations. The FTIR spectrum for CuO-doped cobalt typically includes prominent absorption peaks associated with metal-oxygen (M-O) bonds, often observed in the range of 560–700  $\text{cm}^{-1}$  corresponding to the stretching vibrations of Co-O and Cu-O bonds within the lattice (figure 3). Doping cobalt with Cu slightly shifts these vibrational frequencies, reflecting changes in bond strength and lattice structure due to Cu incorporation. For a pure cobalt oxide sample, Co-O stretching vibrations are typically observed around 570–590  $\text{cm}^{-1}$ . Upon CuO doping, these peaks may shift and broaden slightly, with additional weak peaks potentially appearing due to Cu-O vibrations. FTIR analysis may also reveal hydroxyl (O-H) stretching vibrations near 3350  $\text{cm}^{-1}$  often due to adsorbed water or hydroxyl groups on the sample surface, as well as weak peaks near 1462  $\text{cm}^{-1}$  for O-H bending, which can affect surface properties and reactivity.



**Figure 3:** FTIR Spectra Copper Oxide (CuO)-doped cobalt

### 3.4 FESEM

FESEM images of copper oxide-doped cobalt materials morphological details show (fig 4a-4d) doping influences their properties. Copper oxide doping tends to create finer, more uniformly distributed particles within the cobalt matrix, enhancing the surface area. FESEM images show distinct morphologies, including nanorods, and porous or flower-like structures. Flower-like or porous structures increase active sites and electron pathways, enhancing catalytic activity and charge storage. The dopant-induced morphological changes lead to improved mechanical stability, electron transfer, and chemical reactivity, which are essential for applications in batteries and supercapacitors.



**Figure 4:** FESEM Images of (a-b) Copper Oxide (CuO)-doped cobalt (b) Copper Oxide pure

#### 4 Conclusion

The integration of CuO into the cobalt lattice induces lattice expansion, structural phase transitions, and the introduction of defects, as highlighted by XRD analysis. These changes indicate an increase in lattice spacing and strain, which can alter electronic and magnetic behaviors. FTIR analysis further shows shifts in metal-oxygen (Co-O and Cu-O) bond vibrations, confirming alterations in the bonding environment due to CuO addition, while UV-Vis spectroscopy reveals a reduction in the band gap, allowing for enhanced absorption in the visible light range, which is crucial for applications in photocatalysis and optoelectronics. FESEM analysis provides insights into the microstructure, showing that CuO doping results in flower like and nano road structure more uniform particle dispersion within the cobalt matrix, which increases surface area, reduces agglomeration, and promotes enhanced catalytic activity. These combined structural and electronic modifications not only enhance cobalt's catalytic and photocatalytic activity but also improve its electrochemical stability.

#### 5 Declarations

##### 5.1 Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## 5.2 Acknowledgements

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