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Assessing Optical Behavior and Antibacterial Potency of $Mg_{0.91}Cu_{0.09}O$ Nanoparticles

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ABSTRACT

This study investigates the synthesis, optical properties, and antibacterial activity of $Mg_{0.91}Cu_{0.09}O$ nanoparticles (NPs), fabricated via the sol-gel method. The influence of copper (Cu) doping on the structural, optical, and antibacterial properties of magnesium oxide (MgO) was analyzed. The NPs were characterized using Fourier Transform Infrared (FTIR) spectroscopy, ultraviolet-visible (UV-Vis) spectroscopy, and antibacterial tests against Escherichia coli (E. coli). FTIR analysis revealed characteristic absorption peaks corresponding to the metal-oxygen stretching vibrations, indicating the successful formation of $Mg_xCu_{1-x}O$ structure. The optical bandgap (Eg) of the nanoparticles was determined to be 2.18 eV, suggesting their potential in optoelectronic and photocatalytic applications. Antibacterial testing demonstrated significant inhibition of E. coli growth with a zone of inhibition (ZOI) of 27 mm, highlighting the promising antibacterial efficacy of the synthesized NPs. These findings indicate that $Mg_{0.91}Cu_{0.09}O$ nanoparticles exhibit a combination of favorable optical properties and strong antibacterial activity, making them suitable candidates for applications in biomedical and environmental fields.

Keywords: $Mg_{0.91}Cu_{0.09}O$ nanoparticles, sol-gel method, optical properties, antibacterial activity, FTIR, UV-Vis, E. coli, zone of inhibition, nanomaterials, doping

INTRODUCTION

Magnesium oxide (MgO) nanoparticles have garnered significant attention in recent years due to their excellent biocompatibility, non-toxicity, and versatile applications in various fields, such as catalysis, drug delivery, and antibacterial agents [1-10]. The incorporation of metal dopants, such as copper (Cu), into MgO has been shown to enhance its physical and chemical properties, including optical characteristics, antibacterial activity, and catalytic performance [11-15]. Cu doping in MgO nanoparticles can induce structural and electronic modifications that improve their antimicrobial properties by generating reactive oxygen species (ROS), which damage bacterial cells [16-20].

The antibacterial efficacy of MgO nanoparticles has been widely studied, particularly for their ability to inhibit the growth of pathogenic bacteria such as *Escherichia coli* and *Staphylococcus aureus* [21-25]. However, the enhancement of these properties

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via doping remains an area of active research [26-30]. The sol-gel method is one of the most commonly employed techniques for synthesizing metal-doped oxide nanoparticles due to its simplicity, cost-effectiveness, and ability to produce high-purity materials with controllable size and morphology [31-35].

In this study, we focus on the synthesis and characterization of $Mg_{0.91}Cu_{0.09}O$ nanoparticles. By analyzing their optical properties, including bandgap determination, and evaluating their antibacterial activity against *E. coli*, we aim to explore the effects of Cu doping on the material's performance. This work seeks to contribute to the growing body of knowledge on metal-doped MgO nanoparticles and their potential applications in biomedical and environmental fields.

EXPERIMENTAL AND METHODS

SYNTHESIS of $Mg_xCu_{1-x}O$ NANOPARTICLES

$Mg_xCu_{1-x}O$ nanoparticles were synthesized using the sol-gel method. Magnesium nitrate ($Mg(NO_3)_2 \cdot 6H_2O$) and copper nitrate ($Cu(NO_3)_2 \cdot 3H_2O$) were used as precursors. The stoichiometric amounts of magnesium and copper salts were dissolved in distilled water and mixed with a suitable amount of citric acid as a chelating agent. The mixture was stirred continuously at room temperature to obtain a homogeneous solution. The pH of the solution was adjusted to 7 using ammonia solution. The solution was then heated at 80°C to form a gel. After the gel formation, the temperature was gradually increased to 400°C for calcination to ensure the complete conversion of the gel into nanoparticles. The obtained $Mg_xCu_{1-x}O$ nanoparticles were then cooled and washed with ethanol to remove any impurities. Finally, the product was dried in an oven at 60°C for 12 hours. The resulting nanoparticles were characterized for their structural, optical, and antibacterial properties (Figure 1).

Figure 1 presents the schematic representation of the preparation process for $Mg_xCu_{1-x}O$ nanoparticles via the sol-gel method

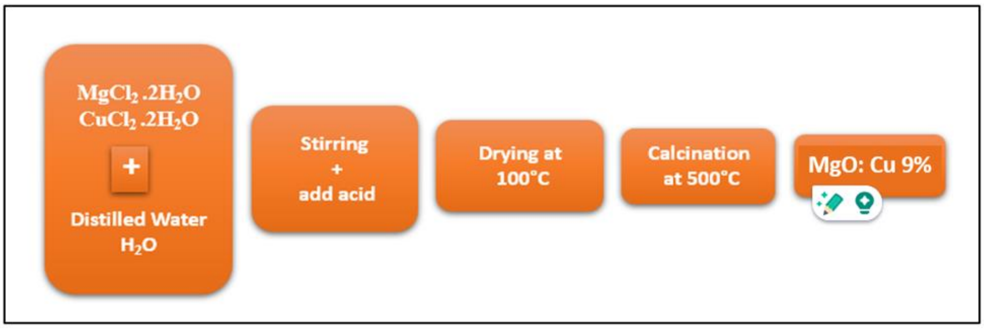

Figure 1: The schematic representation of the preparation process for $Mg_xCu_{1-x}O$ nanoparticles via the sol-gel method

CHARACTERIZATION

- The synthesized $Mg_xCu_{1-x}O$ nanoparticles were characterized using various techniques to assess their structural, optical, and antibacterial properties. Fourier Transform Infrared (FTIR) spectroscopy was used to determine the functional groups and confirm the presence of metal-oxygen bonds in the nanoparticles. UV-Vis spectroscopy was employed to study the optical properties, including the absorption spectrum and bandgap determination. The antibacterial activity was evaluated using the agar well diffusion method, testing the inhibition zone (ZOI) against *Escherichia coli*.

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RESULTS AND DISCUSSION

FTIR ANALYSIS

FTIR analysis was performed to identify the functional groups and confirm the formation of $Mg_xCu_{1-x}O$ nanoparticles [36-40]. The spectra exhibited characteristic peaks at 420.48, 443.63, 536.21, 852.54, 1423.47, 1647.21, and 3441.01 cm^{-1}, which correspond to the metal-oxygen (Mg-O and Cu-O) stretching vibrations and the stretching vibrations of hydroxyl groups (OH) [41-45]. The peak at 420.48 cm^{-1} is attributed to the bending mode of the metal-oxygen bond, indicating the successful formation of the metal oxide structure [46-50]. The absorption band near 3441.01 cm^{-1} corresponds to the O-H stretching vibration, which may arise from the adsorption of moisture or surface hydroxyl groups on the nanoparticle surface [51-55]. The presence of these peaks further confirms the successful doping of Cu into the MgO lattice and the formation of $Mg_xCu_{1-x}O$ nanoparticles (Figure 2) [56-60].

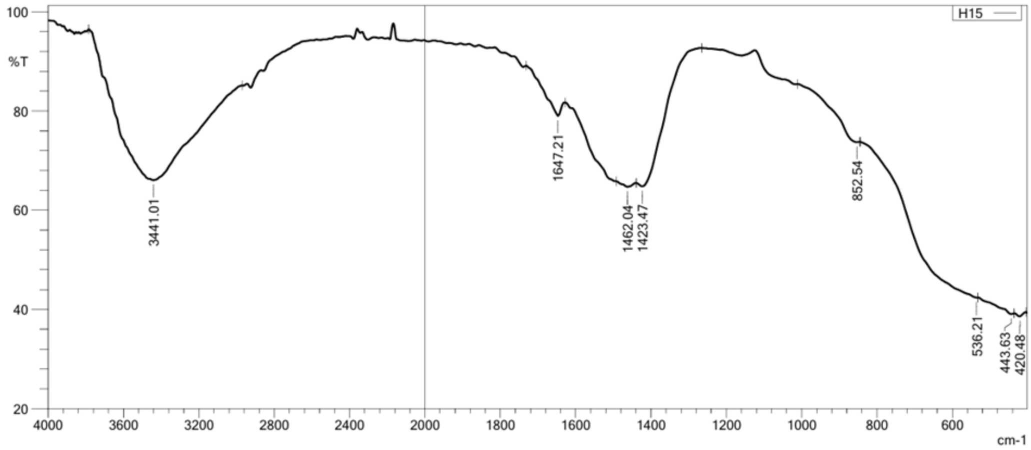

Figure 2: The FTIR analysis for $Mg_{0.91}Cu_{0.09}O$ NPs

Table 1 presents the FTIR peak assignments for the synthesized $Mg_xCu_{1-x}O$ nanoparticles.

Table 1: The FTIR peak assignments for the synthesized $Mg_xCu_{1-x}O$ NPs

Wavenumber (cm^{-1})	Peak Assignment
420.48	Metal-Oxygen Stretching (Mg-O, Cu-O bonds)
443.63	Metal-Oxygen Stretching (Mg-O, Cu-O bonds)
536.21	Vibrational Mode of Metal-Oxygen (Mg/Cu-O)
852.54	Possible Metal-Oxygen-Metal (M-O-M) Vibrations
1423.47	Symmetric and Asymmetric Stretching of Carbonates (CO_3^{2-} groups)
1647.21	Adsorbed Water (H-O-H bending)
3441.01	O-H Stretching from Hydroxyl Groups or Adsorbed Water

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OPTICAL PROPERTIES

The optical properties of $Mg_{0.91}Cu_{0.09}O$ nanoparticles were investigated using UV-Vis absorption spectroscopy. The absorption spectrum exhibited a distinct absorption edge in the UV region, indicating the semiconducting nature of the nanoparticles [61-65]. The bandgap energy (Eg) was calculated using the Tauc plot method, yielding a value of 2.18 eV, which is in the range suitable for photocatalytic and optoelectronic applications [66-70]. The reduction in the bandgap compared to pure MgO can be attributed to the copper doping, which introduces localized states within the bandgap, facilitating electronic transitions at lower energies [71-75]. This characteristic makes the $Mg_{0.91}Cu_{0.09}O$ nanoparticles a potential candidate for various applications, including photocatalysis and solar energy conversion [76]. The shift in the absorption edge and the optical bandgap are important factors for determining the suitability of these nanoparticles for environmental and energy-related applications. Figure 3 presents the absorption curve and Eg value for $Mg_{0.91}Cu_{0.09}O$ nanoparticles [77].

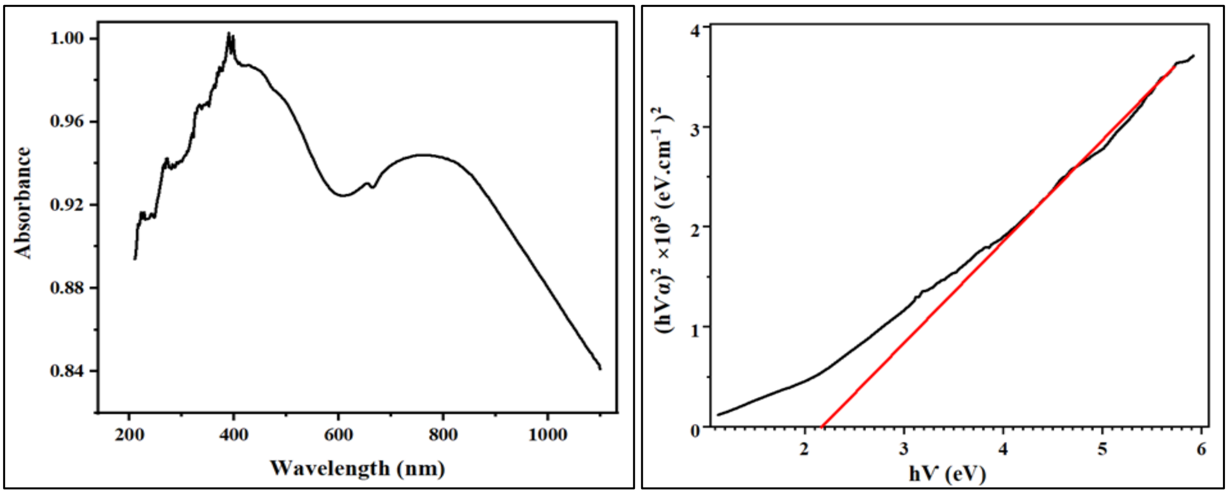

Fig. 3: The absorption curve and Eg value for $Mg_{0.91}Cu_{0.09}O$ NPs

ANTIBACTERIAL ACTIVITY

The antibacterial activity of the synthesized $Mg_{0.91}Cu_{0.09}O$ nanoparticles was tested against *Escherichia coli* (E. coli) using the agar well diffusion method [78]. The zone of inhibition (ZOI) was measured to assess the antimicrobial efficacy. The results showed that the nanoparticles exhibited significant antibacterial activity, with a ZOI of 27 mm against E. coli [79]. The antibacterial activity can be attributed to the production of reactive oxygen species (ROS) by the nanoparticles, which induce oxidative stress in bacterial cells, leading to their death [80]. The presence of Cu in the MgO lattice is believed to enhance the antibacterial effect, as Cu ions can leach out from the nanoparticles and disrupt bacterial cell membranes. The $Mg_{0.91}Cu_{0.09}O$ nanoparticles showed promising antibacterial efficacy, suggesting their potential as antimicrobial agents for applications in medicine and environmental sanitation (Figure 4).

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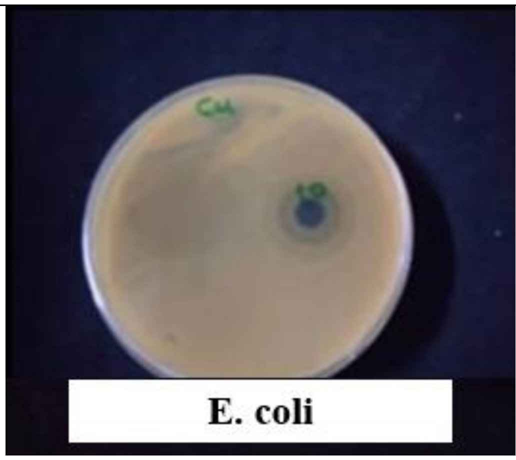

ZOI (mm)	27

Fig. 4: The antibacterial activity for $Mg_{0.91}Cu_{0.09}O$ nanoparticles against *E. coli*, showing a ZOI of 27 mm

CONCLUSION

In this study, $Mg_{0.91}Cu_{0.09}O$ nanoparticles were successfully synthesized via the sol-gel method and characterized for their structural, optical, and antibacterial properties. The FTIR analysis confirmed the successful doping of Cu into the MgO lattice, while the UV-Vis spectroscopy revealed a bandgap of 2.18 eV, indicating the semiconducting nature of the nanoparticles. The antibacterial tests demonstrated significant antibacterial activity against *Escherichia coli*, with a zone of inhibition of 27 mm, highlighting the potential of these nanoparticles as antimicrobial agents. The doping of copper played a crucial role in enhancing the antibacterial performance, possibly due to the release of Cu ions and the generation of reactive oxygen species. These findings suggest that $Mg_{0.91}Cu_{0.09}O$ nanoparticles have promising applications in biomedical, environmental, and optoelectronic fields. Future studies can explore the optimization of synthesis conditions and further investigate the long-term stability and potential toxicity of these nanoparticles for practical applications.

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CONFLICTS OF INTEREST

There is no conflict of interest among the authors.

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