THE IMPACT OF Cd DOPING ON THE STRUCTURAL AND OPTICAL PROPERTIES OF SnO_2 NANORODS

Ravi S. Kawale[1*]

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Abstract

This research paper investigates the structural and optical effects of cadmium (Cd) doping in tin oxide (SnO_2) nanorods. The study aims to understand the changes induced by Cd doping and their potential impact on the material's properties for applications in optoelectronic devices, sensors, and catalysis. The synthesis process involves incorporating Cd chloride into the precursor solution, followed by gelation, aging, and calcination. X-ray diffraction (XRD) analysis reveals changes in the crystalline structure and size of the nanorods due to Cd doping. Fourier Transform Infrared (FTIR) analysis shows the presence of hydroxyl groups and distinctive features in the doped sample, indicating the influence of Cd on the material's chemical structure. Scanning electron microscopy (SEM) analysis confirms that the overall morphology of the nanorods is not significantly affected by Cd doping. UV-visible absorption spectroscopy demonstrates that Cd-doped SnO_2 exhibits higher UV light absorption and a slightly reduced bandgap compared to pure SnO_2, indicating changes in the electronic band structure influenced by Cd doping. Overall, this research provides valuable insights into the structural and optical effects of Cd doping in SnO_2 nanorods, paving the way for tailored material design and improved performance in various technological applications.

[1*]Dept. Of Electronics, D.S.M. College, Jintur, Dist. Parbhani-431509, Maharashtra India.
Email: ravi.kawale 1972@gmail.com

***Corresponding Author:** Ravi S. Kawale
*Email: ravi.kawale1972@gmail.com

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1. Introduction

The introduction of Cd doping in SnO_2 nanorods has garnered significant interest due to its potential impact on the structural and optical properties of the material[1]. By incorporating cadmium into tin oxide nanorods, researchers aim to explore the resulting changes in the material's crystalline structure and optical behaviour. This is crucial for potential applications in optoelectronic devices, sensors, and catalysis [2], [3]. In this study, we aim to investigate the structural and optical effects of Cd doping in SnO_2 nanorods, shedding light on the potential for tailored material properties and improved performance in various technological applications[4]. Doping is a common strategy to modify the properties of materials for specific applications. In the case of Cd doping in SnO_2 nanorods, the ability to control the structural and optical characteristics opens up opportunities for enhancing the performance of optoelectronic devices, sensors, and catalysts[5]. Understanding the impact of Cd doping on the structural and optical properties of SnO_2 nanorods is essential for harnessing the full potential of this material in practical applications. In this study, we delve into the structural and optical intricacies of Cd-doped SnO_2 nanorods to unravel the underlying mechanisms and pave the way for future advancements in material design and engineering. Doping semiconductor nanomaterials like SnO_2 with Cd has been shown to have a significant influence on their properties[6 - 8]. The introduction of Cd into SnO_2 nanorods can lead to changes in their crystalline structure and optical behavior, which are critical for their potential applications in various fields such as optoelectronic devices, sensors, and catalysis.

In this paper, it is essential to delve into a detailed analysis of the structural and optical impacts of Cd doping in SnO_2 nanorods. This study aims to provide a comprehensive understanding of how the addition of Cd influences the material's properties, paving the way for tailored material design and improved performance in practical applications[9]. By exploring the structural and optical effects of Cd doping in SnO_2 nanorods, we can uncover valuable insights that may contribute to further advancements in material engineering and design [10]. Understanding the intricate mechanisms behind these modifications is crucial for harnessing the full potential of Cd-doped SnO_2 nanorods in a wide range of technological applications. The study of Cd doping in SnO_2 nanorods presents an exciting opportunity to explore the impact of dopant atoms on the material's properties. As the demand for high-performance materials in various technological fields continues to grow, the ability to tailor the structural and optical characteristics of nanomaterials like SnO_2 becomes increasingly significant [11].

In this study, we embark on a thorough investigation of the structural and optical impacts of Cd doping in SnO_2 nanorods. By delving into the intricacies of these modifications, we aim to contribute valuable insights that could pave the way for enhanced material design and improved performance in practical applications. The potential applications of Cd-doped SnO_2 nanorods in optoelectronic devices, sensors, and catalysis make it imperative to thoroughly understand the changes induced by Cd doping. By shedding light on the interplay between the dopant atoms and the host material, we strive to uncover fundamental principles that could drive advancements in material engineering and design[12].

2. Synthesis

The synthesis of pure SnO_2 nanorods involved a multi-step process. Firstly, a precursor solution was prepared by dissolving tin chloride in an ethanol solvent with the addition of a stabilizing agent, creating a sol. Subsequently, the sol underwent hydrolysis and condensation, leading to gelation. The gel was then subjected to aging, facilitating the growth of nanocrystals and the formation of nanorods. Finally, the gel was calcined at a specific temperature to eliminate organic residuals and induce crystallization, ultimately yielding pure SnO_2 nanorods. In the synthesis of Cd-doped SnO_2 nanorods, the process mirrored that of pure SnO_2 with some modifications. Specifically, cadmium doping was introduced by incorporating a predetermined amount of cadmium chloride into the precursor solution during the sol preparation stage. The subsequent steps, including gelation, aging, and calcination, were carried out similarly to the process for pure SnO_2 nanorods. This comprehensive procedure resulted in the successful synthesis of Cd-doped SnO_2 nanorods with the desired properties

3. Results and Discussion

3.1 XRD Analysis

The X-ray diffraction (XRD) analysis was performed on SnO_2 and Cd-doped SnO_2 nanostructures synthesized via the hydrothermal technique, as illustrated in Figure 1. The diffraction pattern signifies the crystalline nature of both samples. The observed diffraction peaks at angles 26.4°, 33.7°, 37.8°, 51.4°, and 64.7° correspond to (110), (101), (200), (211), and (112) planes, respectively. An increase in Cd doping concentration results in a decrease in observed diffraction peak intensity, and the broadening of

peaks indicates crystallite size in the nanometer range [13], [14].

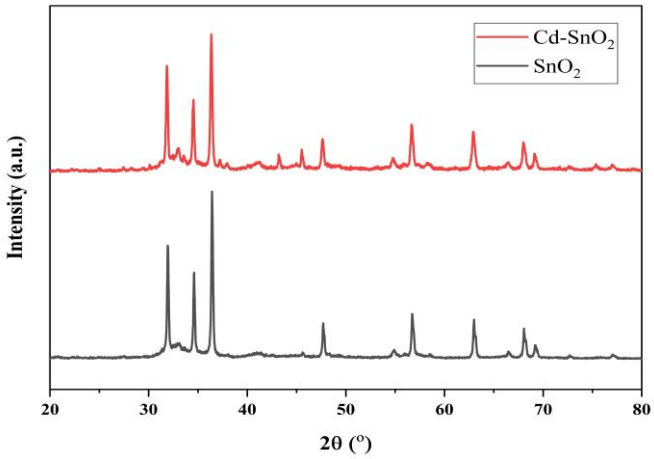

Figure 1: *X-ray Diffraction (XRD) Patterns of Pure SnO2 and Cd-doped SnO_2 Nanorods*

All diffraction peaks are associated with the tetragonal rutile crystalline phases of SnO_2 nanostructures, aligning with the standard file (JCPDS no. 77-0452) [14]. The crystallite size, calculated using Scherrer's formula (1), reveals an average size of 8.86 nm for SnO_2 and 9.10 nm for Cd-doped SnO_2. The increase in crystallite size in the Cd-doped sample suggests the influence of cadmium on the nanostructure of SnO_2. The lattice parameters of the tetragonal SnO_2 nanostructure were estimated using equation (2) based on crystalline (110) and (101) planes. The lattice parameters for pure SnO_2 nanostructures are a = 4.760 Å and c = 3.232 Å. For Cd-doped SnO_2, the lattice parameters are (a=4.7412 Å, c=3.216 Å). Changes in lattice parameters, compared to pure SnO_2 nanostructures, are attributed to the larger ionic radius of Cd^{2+} (0.97 Å) compared to Sn^{4+} (0.71 Å), indicating the nanostructural modification of SnO_2 tetragonal nanostructures due to Cd doping.

3.2 FTIR Analysis

The Fourier Transform Infrared (FTIR) analysis of Cd-doped SnO_2 reveals distinctive features at specific wavenumbers[15]. The observed bands at 3968 cm^{-1} and 3174 cm^{-1} suggest the presence of hydroxyl groups or water molecules, indicating the potential involvement of surface functionalities. The wavenumber at 2285 cm^{-1} appears unusually high and may require further investigation, as it is not typically associated with common functional groups. The band at 1522 cm^{-1} is indicative of stretching vibrations, possibly related to N-H or C=C groups, suggesting additional molecular components in the doped SnO_2. The lower wavenumber at 60_2 cm^{-1} is associated with metal-oxygen (Cd-O) stretching vibrations, supporting the incorporation of cadmium into the SnO_2 lattice[16].

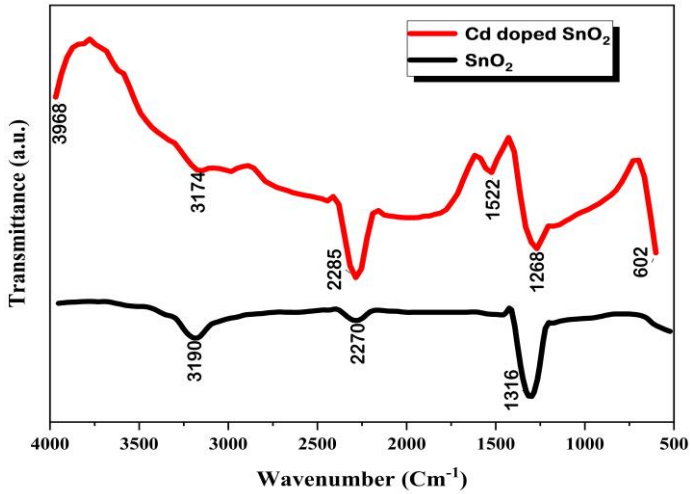

Figure 2*: FTIR Spectra of Pure SnO2 and Cd-doped SnO_2 Nanorods*

On the other hand, the FTIR analysis of SnO_2 exhibits characteristic features at 3190 cm^{-1}, indicative of O-H stretching vibrations and the presence of hydroxyl groups. The wavenumber at 2270 cm^{-1}, not commonly associated with known functional groups, requires further investigation to understand its significance. The band at 1316 cm^{-1} suggests bending vibrations of O-H groups or the presence of water molecules in the SnO_2 structure. The FTIR spectra for Cd-doped SnO_2 and SnO_2 highlight the presence of common functional groups such as hydroxyl groups, with distinctive features in the doped sample suggesting the influence of cadmium on the material's chemical structure[17]. The specific wavenumbers identified provide valuable insights into the molecular composition and structural modifications induced by cadmium doping in SnO_2.

3.3 SEM Analysis

The morphological features of SnO_2 and SnO_2 nanorods doped with Cd using scanning electron microscopy (SEM). When examining pure SnO_2, the SEM images displayed nanorods that were well-defined and uniform, showcasing a clear aspect ratio. The surfaces seemed smooth, suggesting a well-regulated and orderly growth process during synthesis. After incorporating cadmium doping (Cd) into the SnO_2 nanorods, there were significant alterations observed in the nanostructure as observed through SEM analysis. The aspect ratio of the Cd-doped SnO_2 nanorods remained similar to their pure counterparts, indicating that the overall morphology was not significantly affected by the doping process. Upon further examination, it became apparent that there were slight differences in the surface characteristics, suggesting the potential presence of cadmium within the nanorod structure[18], [19].

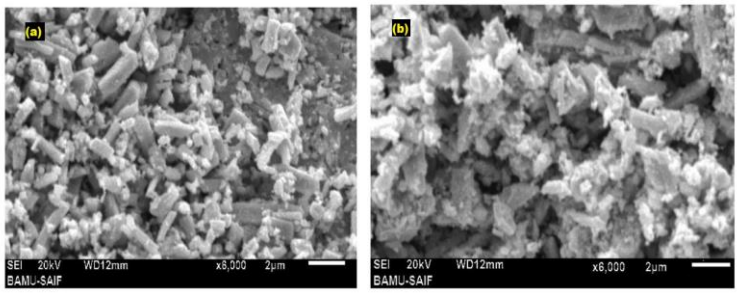

Figure 3: *SEM Images of Pure SnO2 and Cd-doped SnO_2 Nanorods*

3.4 UV Analysis

The optical properties of pure SnO_2 and Cd-doped SnO_2 nanostructures were studied using UV-visible absorption spectroscopy, as shown in Figures 5(a) and 5(b). Notably, the UV light absorption in the Cd-doped SnO_2 was higher compared to that of pure SnO_2. The absorption spectrum of Cd-doped SnO_2 exhibited a broader profile and a shift towards longer wavelengths, indicating changes in the electronic band structure due to the addition of cadmium[20], [21].

The UV-visible spectrum of pure SnO_2 displayed a distinct absorption edge corresponding to a bandgap energy of 3.56 eV. This bandgap signifies the minimum energy required for electronic transitions from the valence band to the conduction band with direct allowed transitions. In contrast, the UV-visible absorption spectrum of Cd-doped SnO_2 revealed a comparable but slightly blue-shifted absorption edge leading to a reduced bandgap measuring at 3.48 eV instead of its original value in pure SnO_2.

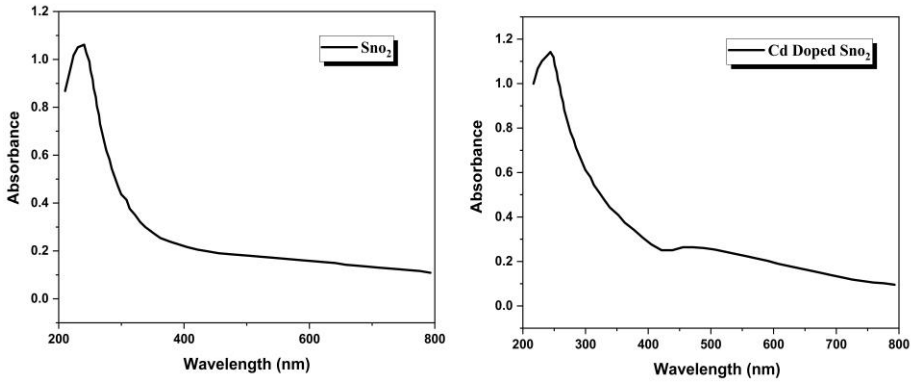

Figure 4: *UV-Visible Absorption Spectra of Pure SnO2 and Cd-doped SnO_2 Nanorods*

These findings suggest that doped-SnO_2 exhibits altered optical properties compared to its undoped counterpart, demonstrating shifted spectral characteristics and modified bandgap energies influenced by cadmium doping. Understanding these optical changes is crucial for utilizing SbN15within optoelectronic devices [22], thus further investigation into specific transitions and features is necessary for comprehensive insights into their optical behavior.

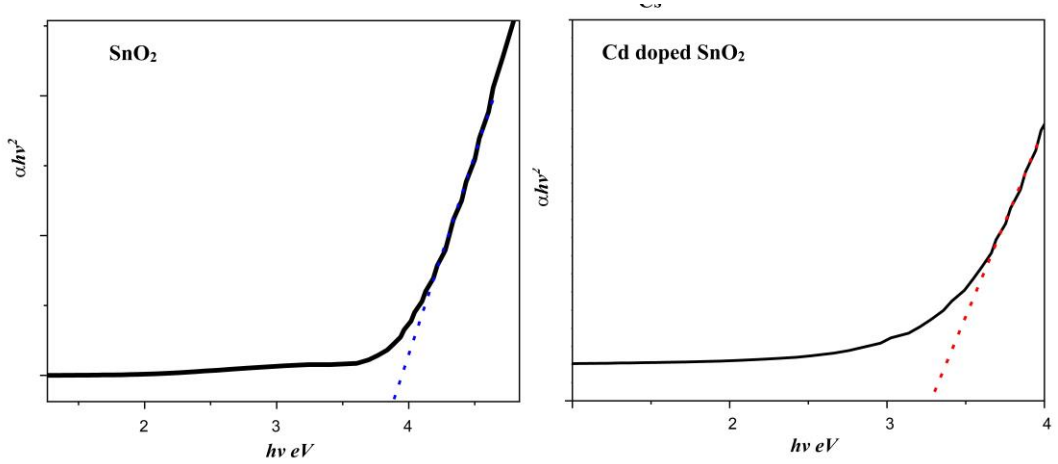

Figure 5: *Tauc Plot Analysis for Band Gap Estimation of Pure SnO2 and Cd-doped SnO_2 Nanorods*

Conclusion

In conclusion, the research paper explores the impact of Cd doping on the structural and optical properties of SnO_2 nanorods. The study aims to understand the changes induced by Cd doping in order to enhance material design and improve performance in practical applications such as optoelectronic devices, sensors, and catalysis. The synthesis process involves incorporating cadmium chloride into the precursor solution during the sol preparation stage, followed by gelation, aging, and calcination. XRD analysis reveals that Cd doping leads to a decrease in diffraction peak intensity and an increase in crystallite size, indicating the influence of cadmium on the nanostructure of SnO_2. FTIR analysis shows the presence of hydroxyl groups and distinctive features in the doped sample, suggesting the influence of cadmium on the material's chemical structure. SEM analysis confirms that the overall morphology of the nanorods is not significantly affected by Cd doping. UV analysis demonstrates that Cd-doped SnO_2 exhibits higher UV light absorption and a slightly reduced bandgap compared to pure SnO_2, indicating changes in the electronic band structure influenced by cadmium doping. Overall, the research provides valuable insights into the structural and optical effects of Cd doping in SnO_2 nanorods, paving the way for tailored material design and improved performance in various technological applications.

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