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Optical properties of 0.006 wt. % Cu-Doped Bi_2O_3Nanofilms with various thickness

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Abstract
In this work, thermal evaporation is used to generate (Bi_2O_3) nanofilms doped with Cu nanoparticles (0.006 weight percent) that are coated onto glass substrates at thicknesses of 75, 100, and 125 nm. In the wavelength range of 300-1100 nm, optical measurements of the films are examined using a UV-Visible spectrophotometer. It was found that the transmittance reduced as the film thickness grew, but the absorbance increased. The optical properties are strongly affected by the layer thickness, according to the results of the absorption and extinction coefficients.

Keywords: Cu-Doped Bi_2O_3, optical properties, energy gap

1. Introduction
Bismuth trioxide (Bi_2O_3) is one of the most important V-VI semiconductors due to its unique structural, optical, and electronic properties. It crystallizes in several polymorphs Dopants change semiconductor oxides' morphology, electrical band structure, and optical characteristics. The most researched oxide particles include TiO_2, ZnO, SnO_2, CuO, CeO_2, and Al_2O_3 [1-3],

Due to these properties, Bi_2O_3 has attracted wide interest in multiple fields. It is employed as a photocatalyst for environmental pollutant degradation, CO_2 reduction, and water splitting. In addition, it is widely applied in electronics, sensors [4], solar cells, optical devices, and as a functional additive in glass and ceramics photocatalysts [5,6] dye degradation [7], UV blockers [8]. Furthermore, its high atomic number and strong X-ray absorption make it a promising material for medical imaging and radiation shielding applications

such as the stable monoclinic α-Bi_2O_3 at room temperature, and the high-temperature β (tetragonal) and γ (cubic) phases, in addition to δ, ε, and ω forms that appear under special thermal conditions. Bi_2O_3 is a yellow to greenish solid with a relatively high density (~8.9 g/cm^3), a melting point of ~817 °C, and is insoluble in water but soluble in acids From an electronic point of view [9]

Bi_2O_3 exhibits a wide and direct band gap that varies with its crystalline phase and synthesis route. The α-phase has a band gap of approximately 2.9 eV, while the γ-phase shows a similar value (~2.9 eV), and the β-phase tends to have a narrower band gap (~2.5 eV), enabling stronger absorption in the visible range. In nanoscale form, Bi_2O_3 can reach band gaps of ~3.0-3.1 eV, extending its response into the near-UV region Bi_2O_3 typically behaves as a p-type semiconductor, making it suitable for photocatalytic and optoelectronic applications [10-11]

2. Experimental
Copper (0.006) was combined with 99.99% pure copper (Cu) and zinc oxide (Bi_2O_3). After removing surface impurities with ethanol and distilled water, glass substrates were left to dry fully. The compound was then put in a Molybdenum boat in a thermal evaporation system after the substrate was fastened to a revolving substrate holder (Edward C-306). After sealing the compartment, the pressure was lowered to 1 ×10^{-7} mbar. The films' thicknesses were measured with the Lambda Limf-10 optical thin film measurement device and found to be 75, 100, and 125 nm. The optical properties in the 300-1100 nm range have been examined using a UV-visible spectrophotometer.

3. Results and discussions

Absorbance spectra in the wavelength range of 300-1100 nm are recorded in order to study the topical properties of Cu-doped Bi_2O_3 with Cu-doping (0.006 weight percent) sheets. Through the analysis of the absorbance spectrum, optical parameters including the transmittance (T), absorbance (A) and optical Energy gap (Eg) depend markedly on the films thickness can be found. Figure 4 illustrates the correlation between the wavelength and absorbance spectra of 0.006wt. % Cu-doped Bi_2O_3 films. The graphic makes it clear that as Optical absorbance measurements of the prepared thin films with different thicknesses (50 nm, 75 nm, and 100 nm) are presented in Figure X. All samples exhibit strong absorption in the near-UV region (300-400 nm), which is associated with electronic transitions across the wide and direct band gap of Bi_2O_3. The absorption edge is located around ~350 nm, corresponding to a band gap energy in the range of 3.2-3.5 eV, in good agreement with the reported values for Bi_2O_3 and related V-VI semiconductors.It is evident that the absorbance increases with increasing film thickness. The 100 nm film shows the highest absorbance across the measured spectrum, whereas the 50 nm film exhibits the lowest values. This behavior can be attributed to the larger optical path length in thicker films, which enhances photon-matter interactions and thus increases the probability of absorption.Beyond the absorption edge, a gradual decrease in absorbance is observed, reaching a nearly constant value in the visible to near-infrared region (λ > 600 nm). This residual absorption can be ascribed to defect-related states, oxygen vacancies, or structural disorder within the films, which introduce localized levels inside the band gap. Overall, the results confirm that the optical properties of Bi_2O_3 thin films are strongly dependent on film thickness, and that thicker layers are more suitable for applications requiring enhanced light harvesting, such as photocatalysis, UV photodetectors, and optoelectronic devices.

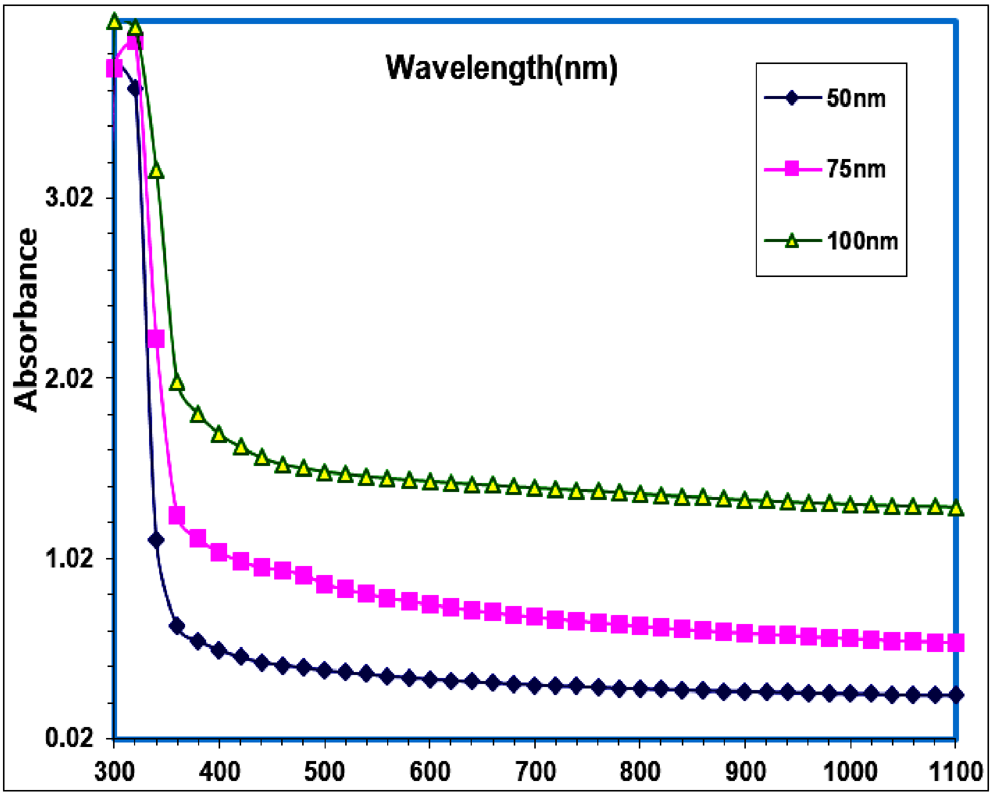

Fig 1: Shows the absorbance spectra of Bi_2O_3:0.006wt. % Cu films with different thicknesses as a function of wavelength.

The transmittance spectra of the Bi_2O_3 thin films with thicknesses of 50 nm, 75 nm, and 100 nm are shown in Figure Y. A sharp decrease in transmittance is observed in the near-UV region (300-400 nm),

The effect of thickness is clearly demonstrated in the spectra: the 100 nm film exhibits the highest transmittance across the visible to near-infrared range (λ > 400 nm), while the 50 nm film shows the lowest transmittance. This behavior is opposite to the absorbance trend, confirming the complementary relationship between absorption and transmission according to the Beer-Lambert law. Thicker films absorb more photons, resulting in lower transmitted intensity. At longer wavelengths (λ > 600 nm), the transmittance becomes nearly constant for all samples, which suggests that photon energies in this region are insufficient to excite electrons across the band gap. The slight residual absorption can be associated with defect states, oxygen vacancies, or scattering processes within the thin films. These results demonstrate that film thickness strongly influences the optical transparency of Bi_2O_3 thin films, making the 100 nm samples more suitable for applications requiring higher optical transmission, such as optoelectronic devices and transparent conducting layers, while thinner films are advantageous for applications demanding stronger light absorption.

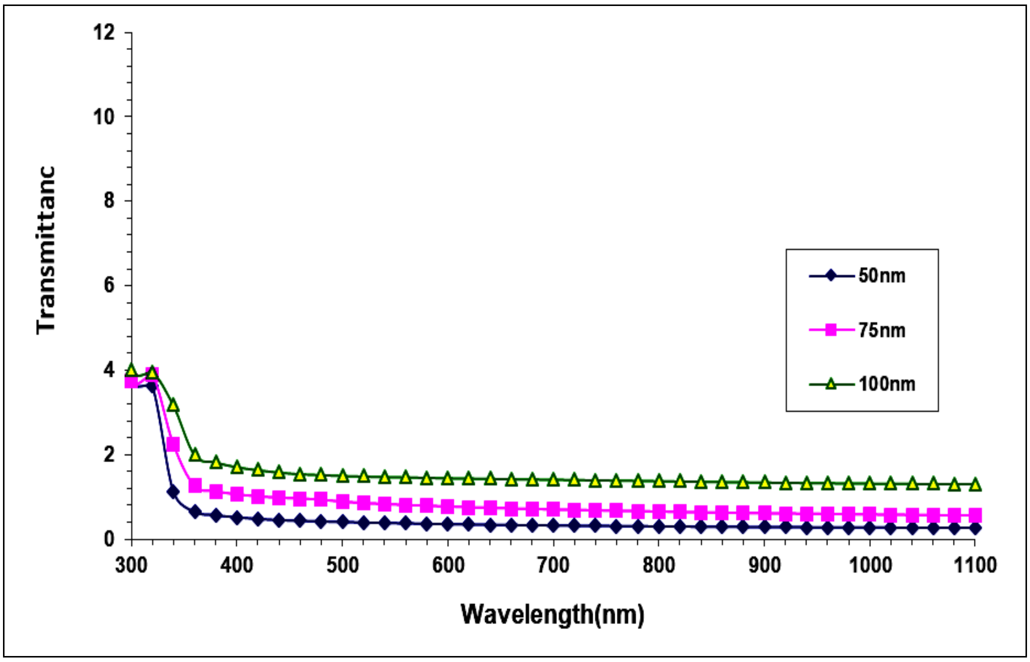

Fig 2: Transmittance spectra as a function of wavelength of Bi_2O_3: Cu filmsat different thickness.

To get the absorbance coefficient (α) of Bi_2O_3: Cunanofilms, utilize the following formula [12]:

$$\alpha = 2.303\ A/t \qquad (1)$$

The optical absorption coefficient was studied as a function of photon energy for thin films with different thicknesses (50, 75, and 100 nm). The results show that the absorption coefficient increases with increasing film thickness, which is attributed to the longer optical path and enhanced light-matter interaction inside the material. At low photon energies (1-2.5 eV), the absorption is relatively weak, indicating that the photons do not possess sufficient energy to induce strong electronic transitions. A sharp increase in absorption is observed around 3.0-3.8 eV, which corresponds to the fundamental optical band gap of the material. Beyond this region, the absorption coefficient reaches high values due to strong interband electronic transitions. These results confirm that film thickness plays a crucial role in tailoring the optical absorption properties, while the position of the absorption edge provides an estimate of the band gap energy.

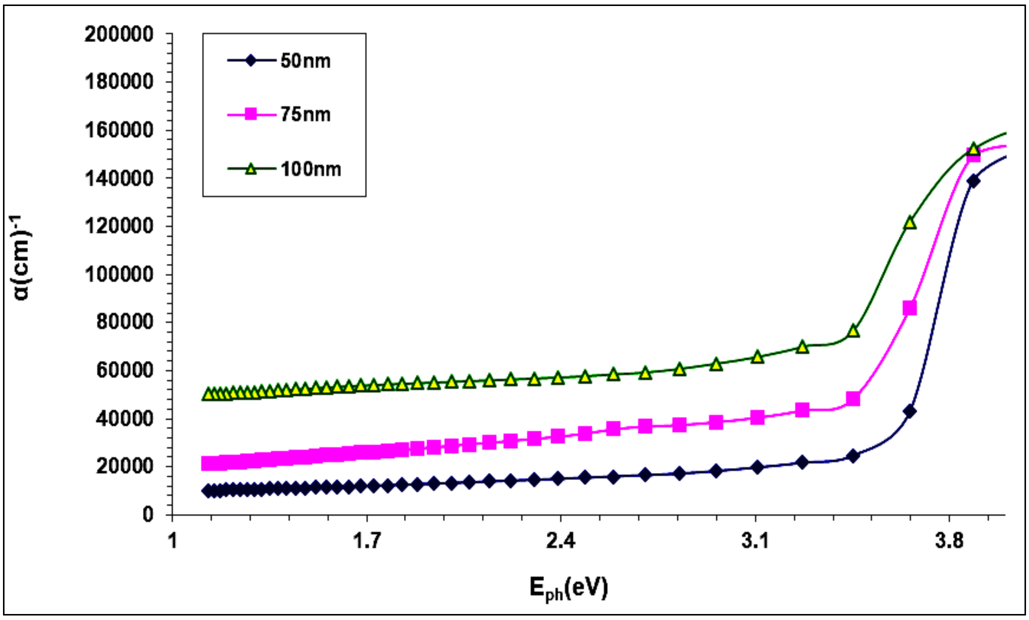

Fig 3: The Bi_2O_3: Cuthin films at varying thicknesses and their absorption coefficient spectra as a function of wavelength.

The optical band gap values obtained from the Tauc plots were about 3.*45* eV (50 nm), 3.*35* eV (75 nm), and 3.*3* eV (100 nm). The slight reduction of the band gap with increasing film thickness is mainly related to reduced quantum confinement, improved crystallite growth, and the presence of structural disorder that introduces localized states in the band structure.

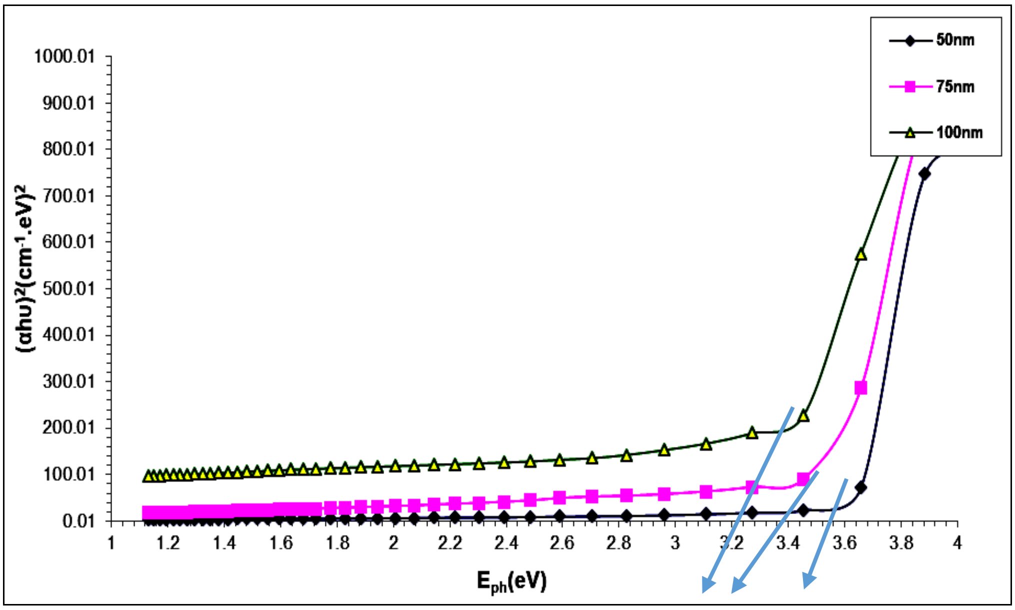

Fig 4: A plots of $(\alpha h\nu)^2$ versus photon energy (hυ) of Bi_2O_3 filmsat different thickness.

Table1: Optical Band Gap Values for Different Film Thicknesses

Thickness (nm)	Optical Band Gap (eV)
50	3.45
75	3.35
100	3.3

The extinction coefficient (k) for Bi_2O_3: Cu thin films is determined by using equation [13, 14]:

$$k = \frac{\alpha\lambda}{4\pi} \quad (2)$$

The optical characterization of the thin films reveals a strong dependence of the extinction coefficient (k) on both wavelength and film thickness. In the ultraviolet region (300-400 nm), a pronounced absorption peak is observed, which is attributed to interband electronic transitions from the valence to the conduction band. This indicates that the material strongly absorbs high-energy photons in this range. As the wavelength increases into the visible region (400-700 nm), the extinction coefficient drops significantly and then stabilizes, suggesting that the films exhibit relatively high transparency in the visible spectrum. In the near-infrared region (700-1100 nm), a gradual increase in the extinction coefficient is recorded, particularly for the thicker films (100 nm). This behavior can be explained by free carrier absorption and possible plasmonic effects, which become more significant as the optical path length within the film increases. Furthermore, the results clearly demonstrate that film thickness plays a crucial role in the optical response: thicker films absorb more strongly at longer wavelengths due to the extended interaction between the incident light and the material. Overall, these findings confirm that the prepared thin films exhibit strong UV absorption, moderate transparency in the visible range, and enhanced infrared absorption with increasing thickness. Such tunable optical properties make them promising candidates for applications in photovoltaics (solar cells), optical coatings (antireflection and filtering layers), and sensing devices, where controlled absorption and transparency are essential.

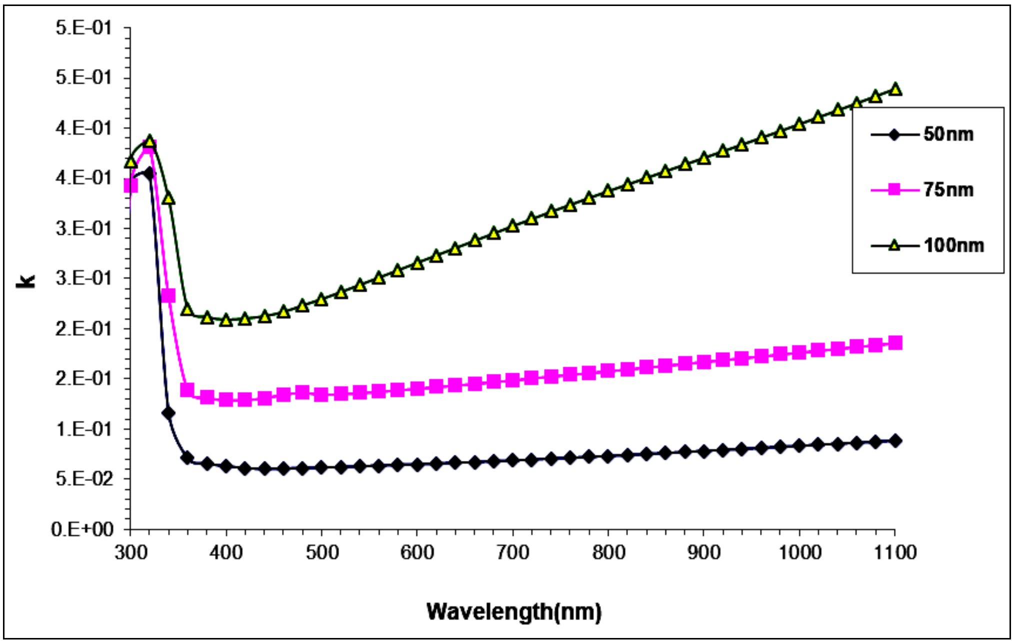

Fig 5: Extinction coefficient variation with wavelength of b Bi_2O_3: Thin films at varying thicknesses

4. Conclusions

In a thermal evaporation chamber at 1 $\times 10^{-7}$ mbar, Bi_2O_3 films containing 0.006 weight percent Cu were effectively created. The optical characteristics investigation revealed that while the manufactured films' absorbance grew with increasing thickness, their transmittance decreased. Films that are appropriate for the production of solar cells are identified by their optical

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