RESEARCH PAPER

Synthesis and Characterization of Indium-doped CdO Nanostructured Thin Films: a Study on Optical, Morphological, and Structural Properties

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ABSTRACT

In this study, the doping impact of indium (In) on the actual properties of CdO at different content of (1, 2, and 3 wt% In) was discussed. The samples were prepared utilizing the spray pyrolysis method. The structural, topographical, and optical properties were characterized X-ray diffraction (XRD) analysis, UV-Vis, and atomic force microscope (AFM). The surface topography was discussed by utilizing AFM analysis. Results display that the average diameter appears to be dependent on the indium content. The particle size was decreased from 78.05 to 65.77 nm when In content was increased from 0% to 3%. It is found that the roughness of the film was decreased to 3.03 nm via increasing In content to 3%. Also, the band gap of prepared samples were studied and compared. Results revealed that the value of band gap is decreasing via doping indium. The band gap of bare CdO, 1%In-CdO, and 3%In-CdO were determined 2.63, 2.54, and 2.46 respectively.

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INTRODUCTION

Nanotechnology has been extremely applied as a superior technique entailing the design and preparation of nanostructures [1]. Many studies in this issue are considered to be challenging thought in various fields such as medicine, material science, sensors, manufacturing, nanoelectronics, etc. [2, 3]. Transparent conducting oxide (ZnO, SnO_2, Co_3O_4, MnO_2, etc.) are largely exploited recently owing to their physicochemical attributes [4], low resistivity [5], and high optical transmittance [6, 7].

Among them, the cadmium oxide (CdO) nanoparticles is a favorable material to be utilized as a straightforward n-type semi-conveyor because of its high electrical conductivity and optical conveyance in the obvious district of the sun oriented range [8, 9]. Besides, the CdO nanoparticles are played a considerable role in a broad range of applications: gas sensors [10], photo-transistors [11], solar cells [12], heat mirrors, and thin-film resistors [13-15].

Numerous strategies are utilized to plan unadulterated CdO and doped CdO films on various substrates, for instance, shower pyrolysis

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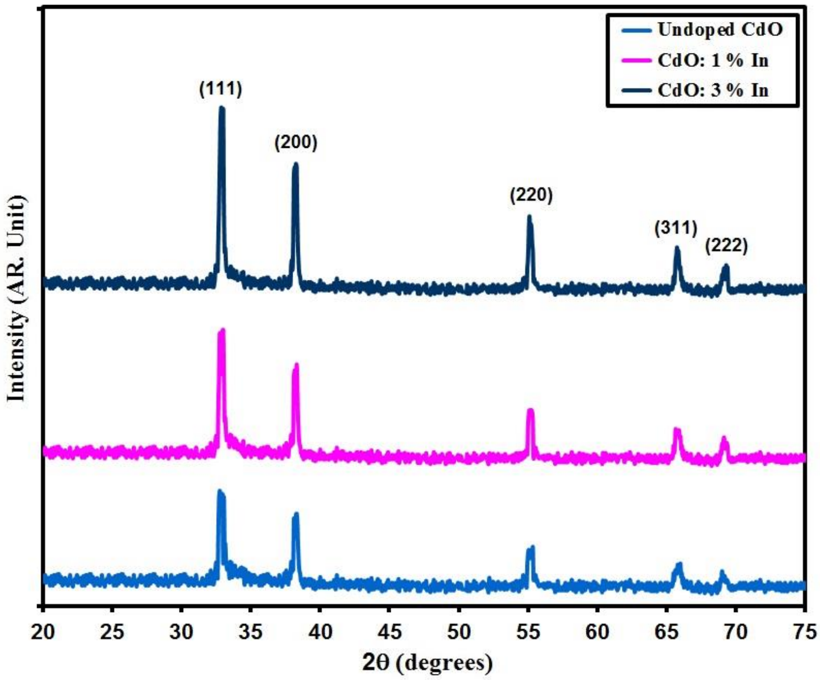

Fig. 1. XRD-patterns crystalline size of the prepared films.

[16, 17], metal natural compound fume statement [18], receptive vanishing [19, 20], RF magnetron faltering [21], beat laser affidavit [22, 23], sol-gel (SG) turn covering procedure [24, 25], and chemical spray pyrolysis [26, 27].

According to various approaches, it is found that the spray pyrolysis route has outstanding features, such as simplicity, low-cost, safety, ease of adding various doping materials, and simple of the supplies and raw materials [28-30]. Therefore, in this research, indium-doped CdO nanoparticle (In-CdO NPs) thin films have been fabricated via spray pyrolysis route and the effects of indium doping on optical, morphological, and structural attributes were investigated.

MATERIALS AND METHODS

Chemicals

All chemicals were purchased from Sigma-Aldrich (German) without any purification. Powder X-ray diffraction (XRD) was performed with monochromatized Cu Kα radiation (λ = 0.15406 nm) with a filter point of 2θ = 20-60o (Shimadzu, model 6000, Japan). Absorbance was obtained by UV-Visible spectrophotometer (Shimadzu Company Japan) in the frequency range (3000-900 nm). AFM was utilized to measure the outside of the films.

Synthesis of In-CdO NPs thin films

The nano-sized CdO thin films were synthesized from 0.1 *M* of $CdCl_2$ (in deionized water and ethanol in a 1:1 ratio) as a precursor. The indium trichloride was separately dissolved in 10 ml of deionized water and then HCl (12 *M*) was added dropwise to the solution to get a clear solution. Next, the $In^{3+}_{(aq)}$ was added to the Cd-based solution as a doping reagent. Finally, the prepared solution was subjected to spray pyrolysis conditions. The conditions were set as: substrate temperature 350 °C, spraying period 8 s endured by 60 s to abstain from cooling, shower rate was 4ml/min, the separation between the nozzle and the substrate was 28 cm. Also, nitrogen gas was used as a carrier gas.

RESULTS AND DISCUSSIONS

The XRD analysis of the deposited films reveal in Fig. 1. The presence of (111), (200), (220), (311), and (222) planes were confirmed the polycrystalline structure of CdO thin films. The XRD analysis were confirmed formation of samples with no impurity. All the diffraction peak were recorded by coordinating with the standard information (JCPDS card No. 05-0640). The crystallite size (*D*) was calculated utilizing Scherrer's equation [31]

Table 1. Grain size, optical band gap, and structural parameters of the prepared films.

Samples	(hkl) Plane	2θ (°)	FWHM (°)	Grain size (nm)	Optical band gap (eV)	Dislocations density ($\times 10^{15}$)(lines/m^2)	Strain ($\times 10^{-3}$)
Undoped CdO	111	33.28	0.79	10.49	2.63	9.08	3.30
CdO: 1% In	111	33.00	0.74	11.20	2.54	7.97	3.09
CdO: 3% In	111	32.66	0.69	12.00	2.46	6.94	2.80

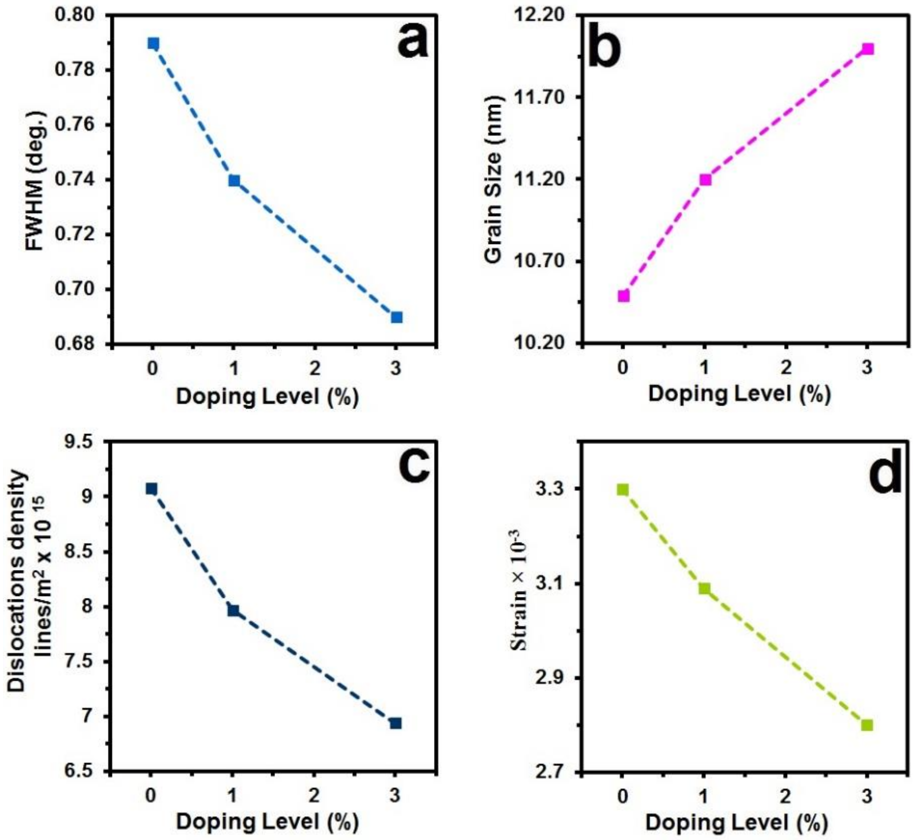

Fig. 2. FWHM (a), Grain size (b), Dislocation (c), and Strain (d) of the prepared films.

$$D = \frac{0.9\lambda}{\beta cos\theta} \quad (1)$$

Where β is (FWHM) and λ is the X-ray wavelength. The outcomes are displayed in Table 1, which shows that for high-dosage of dopant (3%) *D* is higher than lower-dosage dopant and bare CdO. It is found that *D* changes from 10.49 nm to 12 nm via In-doping up to 3%. The dislocation density (δ) was determined utilizing the equation [32, 33]:

$$\delta = \frac{1}{D^2} \quad (2)$$

The strain (ε) of the thin films were estimated utilizing the following relation [34, 35]:

$$\varepsilon = \frac{\beta cos\theta}{4} \quad (3)$$

Furthermore, the determined parameters are given in Table 1. The strain and dislocation density esteem that decreased with increasing In as a dopant in thin films. The lower 'δ' for 3% confirms decreasing of defects and improving crystalline quality in the CdO thin films. The same as dislocation density, the minimum strain of prepared thin films attributed to 3% of In-doped CdO thin films. Fig. 2 shows correlation between FWHM, Grain size, dislocation density, and Strain and different dosage of indium clearly.

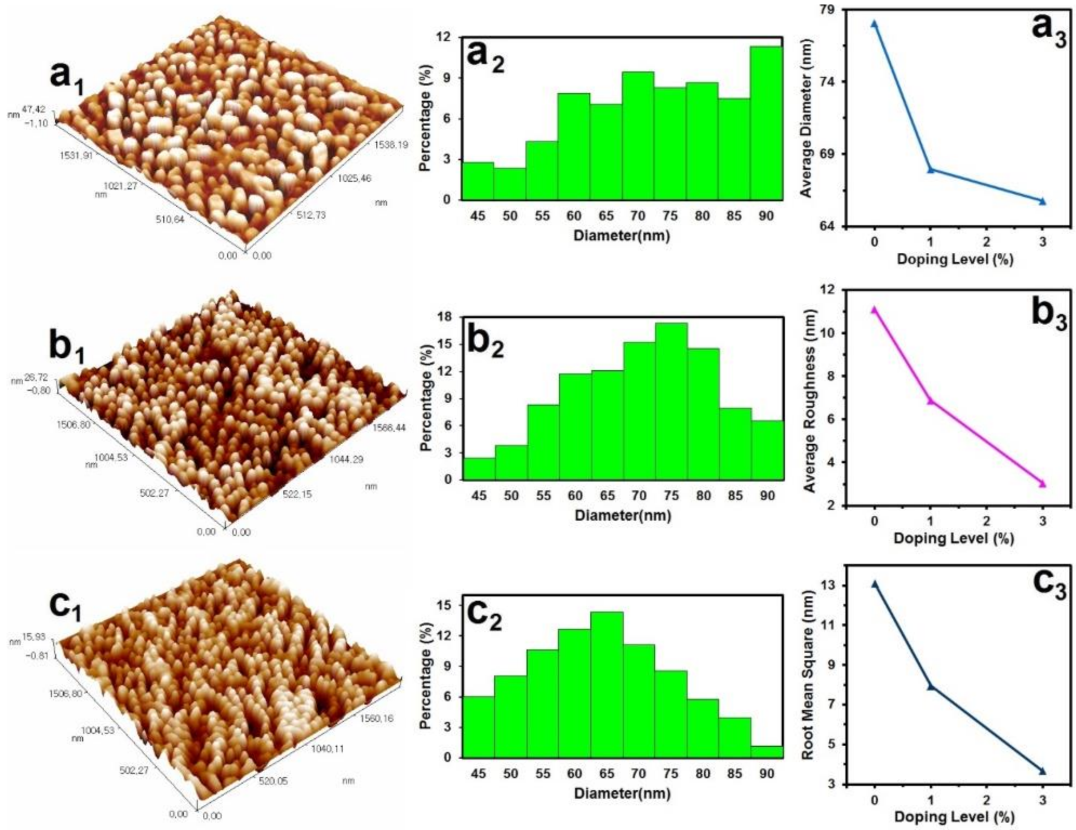

Fig. 3. AFM images of the prepared films (a_1, b_1, and c_1), granularly distributed (a_2, b_2, and c_2), and variation of AFM parameters via doping (a_3, b_3, and c_3).

Table 2. AFM parameters of the deposited films.

Samples	Average Particle size nm	Roughness Average (nm)	R. M. S. (nm)
Undoped CdO	78.05	11.10	13.10
CdO: 1% In	67.95	6.88	7.94
CdO: 3% In	65.77	3.03	3.76

The surface topographical investigation for CdO and In-CdO was performed via atomic force microscopy (AFM) analysis. Fig. 3 shows the AFM images of CdO and In-CdO films for the various content of In as a dopant (0, 1, and 3 %). The nanostructure size and surface roughness of the grown films are presented in Table 2. Results display that the average diameter appears to be dependent on the In content. From Table 2, the particle size decreased from 78.05 to 65.77 nm when In content was increased from 0% to 3%. It is found that the roughness of the film was decreased to 3.03 nm via increasing In content to 3%.

Fig. 4 demonstrated the transmittance spectra of the deposited films. The nano-sized CdO film displays transparency of 80 % which enhances to 95 % for 3 % doped-In. The absorption coefficient (α) of films was specified by equation [36]:

$$\alpha = (2.303\times A)/t \quad (4)$$

Where (t) is film thickness, and A is a constant. Fig. 5 shows the absorption coefficient α (cm^{-1}) versus photon energy for prepared films. It is clear that the absorption coefficient is the smallest at a low energy. This reveal that the possibility of electron transition is little because the energy of

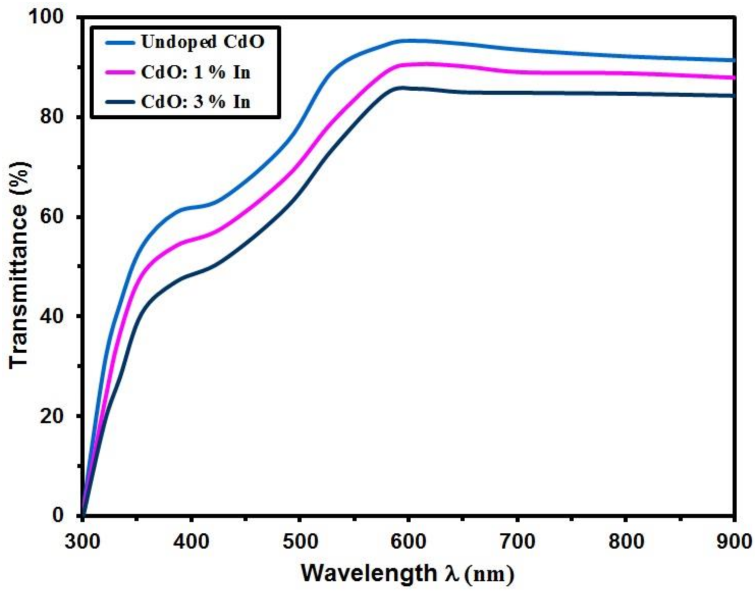

Fig. 4. Transmittance for grown films.

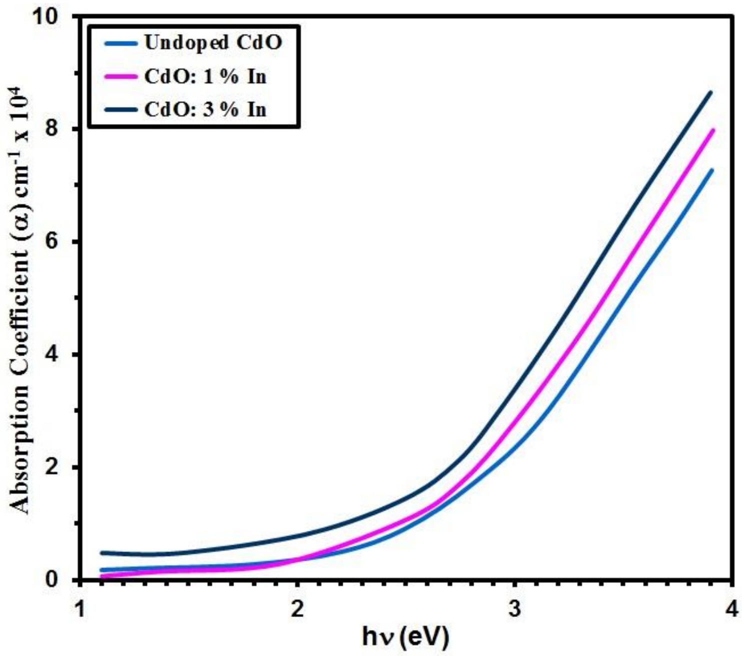

Fig. 5. α against hν of grown films.

the incident photon is not appropriate to move electron from valance to conduction band. At higher energy, this movement has been done. It should be noticed that the value of α is less than 10^4 cm^{-1} which attributes to indirect electron transition.

The optical absorption edge was analyzed with Tauc equation [37]:

$$\left(\alpha h\nu\right) = A\left(h\nu - E_g\right)^{\frac{1}{2}} \tag{5}$$

Where A is an optical constant. The band gap can be calculated via plotting $(\alpha h\nu)^2$ versus hν.

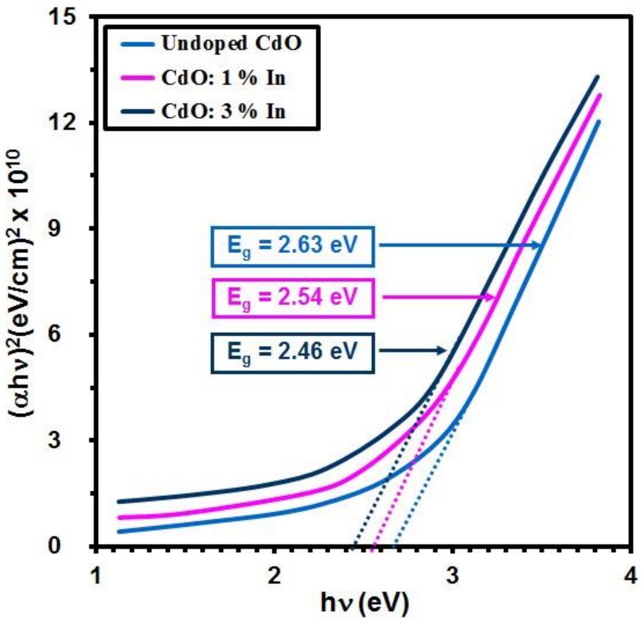

Fig. 6. $(\alpha h\nu)^2$ against hν of the prepared thin films.

From Fig. 6, the E_g of doped and bare CdO films were determined. As can be seen, the band gap of CdO was calculated 2.63eV. Results revealed that the value of band gap is decreasing via doping indium. The band gap of 1%In-CdO and 3%In-CdO were obtained 2.54 and 2.46 eV respectively.

CONCLUSION

The CdO and indium-doped CdO thin films were synthesized by a simple and fast spray pyrolysis method. XRD, and AFM analysis were applied for investigation of structural and morphological properties of prepared samples. The results showed that properties of prepared samples was affected via content of indium as a dopant. The XRD analysis were confirmed formation of samples with no impurity. AFM analysis reveals that the particle size was decreased from 78.05 to 65.77 nm when In content was increased from 0% to 3%. The roughness of the films were decreased via increasing In content. Investigation optical properties of samples confirmed that the value of band gap is decreasing via doping indium.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript.

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