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Preparation and Study of CdO-CdO_2 Nanoparticles for Solar Cells Applications

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Abstract. In this study, CdO-CdO_2 thin films, which was prepared by chemical method and deposited by drop casting technique on glass and silicon substrates have been studied. The structural, optical and chemical analysis were investigated. X-ray diffraction (XRD) measurements reveal that the CdO-CdO_2 thin film was polycrystalline, cubic structure and there is no trace of the other material. UV-Vis measurements assure that the energy gap of CdO-CdO_2 thin film was found to be 2.5eV. I-V characterization of the solar cell under illumination at $40\mathrm{mW/cm^2}$ fluence was investigated. The open circuit voltage (V_{oc}) was 4.1V and short-circuit current density (I_{sc}) was 1.44 mA. These measurements show that the fill factor (FF) and the conversion efficiency (η), were 36.2% and 6.8% respectively.

Introduction

Cadmium oxide is transparent conducting oxides (TCOs) materials that hold both high electrical conductivity and high optical transparency (>80%) in the visible light region of the electromagnetic spectrum [1]. CdO is a n-type semiconductor with nearly metallic conductivity [2]. It has a direct energy band gap (E_g) of ~2.3 eV and two indirect transitions at lower energies [3].CdO has extensive of applications as solar cells, windows, flat panel display, photo transistors. It was experimentally proven that structural, electrical and optical properties are very sensitive to the film structure and deposition conditions [4,5]. Such transparent conductors are being used comprehensively in thin film solar cells [6] and optoelectronic devices [7].CdO films can be synthesized by many techniques such as sputtering [8], chemical vapor deposition (CVD) [9], spray pyrolysis [10], thermal evaporation [11] sol gel [12], and chemical bath deposition [13] Among various methods, spray pyrolysis is one through which the films can be coated for large area. Yahiya[14] fabricated CdO /Si heterojunction solar cell by vacuum evaporation technique. the fill factor and conversion efficiency of the prepared heteorjunction were 34%, 5.5% respectively. Zaein et al.[15] fabricated a solar cell of CdO/Si by thermal evaporation technique. The fill factor was 68.5 and the conversion efficiency of 5.96%, Mustafa[16] fabricated CdO:In/Si fill factor and conversion efficiency were 66%and 5.2% respectively. In this work, the structural and optical properties of CdO-CdO_2 thin films deposited on glass and silicon wafer are prepared in order to estimate some physical properties of this metal oxides. According to our knowledge this is the first trial to examine the use of CdO-CdO_2 prepared by a simple chemical method for solar cell applications.

Materials and Methodology

In a typical procedure, 1.5g of $Cd(NO_3)_2.H_2O$,(BDH Chemicals Ltd Pool England) was dissolved in 50 ml of PVC (Sigma Aldrich USA) 1WT%. and ethanol (99.9%)was used throughout the experiment. The solution was put into a round-bottom flask with stirring. The color of the mixture was transparent. 25ml of NaOH (1M) was rapidly added to the mixture, and a nanopowder suspension was formed as shown in figure 1.The suspension was kept at 75°C for 1h. After cooling at room temperature, the particles were separated by centrifugation and were washed with ethanol to remove any contaminations.

Fig. 1. CdO freshly colloidal nanoparticles dissolved in PVC.

X-ray diffractometer (XRD-6000, Shimadzu) was used to investigate the structure and crystallinity of nanoparticles. The absorption of the colloidal nanoparticles solution was measured by using UV–Vis (UV -1800, Shimadzu, Japan)

Results and discussion

The XRD diffraction patterns of synthesized CdO-CdO_2 nanoparticles films prepared by quick chemical method were shown in Figure 2.

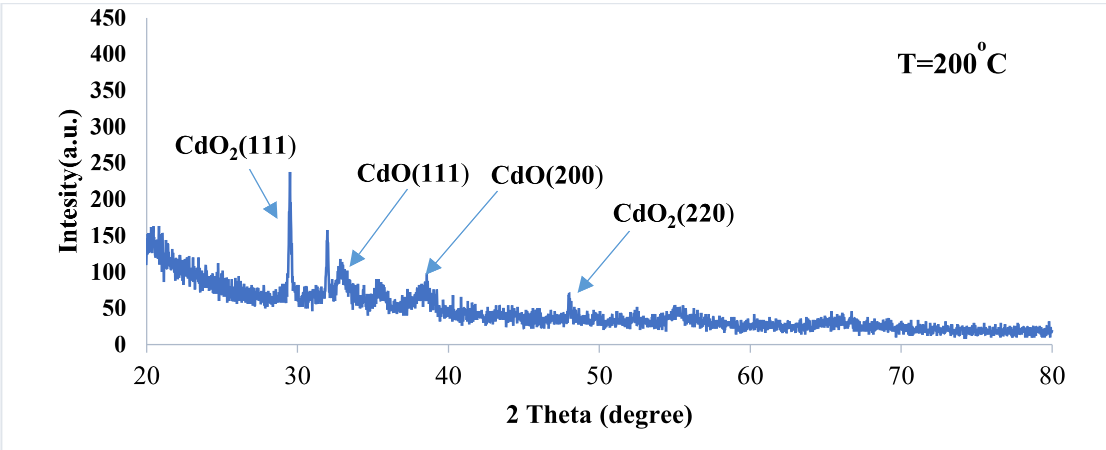

Fig. 2. XRD pattern of CdO-CdO_2 thin films ,which prepared by chemical method and deposited by drop casting technique on glass at Annealing temperature of 200^0C.

Three peaks at $2\theta = 33.18^{\circ}$ and 38.44° corresponds to (111) and (200) planes were observed respectively, which belong to CdO cubic structure (JCPDS card no.05-0640), furthermore, this figure shows another peak which fit with the card (JCPDS 039-1221:CdO_2), The crystallite size (D) was calculated by using Scheerer's formula [17].

$$D = \frac{0.94\,\lambda}{\beta\cos\theta} \quad (1)$$

where λ is the x-ray wavelength of CuKα source (λ= 0.154056 nm), θ is the Bragg's angle and β is the full width at half maximum (FWHM) of the diffraction peak in radians. The dislocation density (δ) and microstrain (γ) values are calculated by using the following relations [18].

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

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

The calculated grain size, microstrain and dislocation density values are presented in Table1.

Table 1. X-Ray characterization for $CdO-CdO_2$ nanoparticles at 200 ^{0}C.

2θ (deg)	(hkI) planes	β (deg)	D (nm)	δ x 10^{14} lines.m^{-2}	γ x10^{-4} Lines^{-2}.m^{-4}
29.51	CdO_2(111)	0.18	47.65	4.40	7.59
33.18	CdO(111)	0.24	36.06	7.69	10.04
38.44	CdO(200)	0.14	62.74	2.54	5.77
47.99	CdO_2(220)	0.14	66.76	2.24	5.42

The values of microstrain and dislocation density of $CdO-CdO_2$ nanostructure films prepared by chemical reaction were listed in Table 1.

Figure 3 shows 3D AFM image and Granularity accumulation distribution chart of $CdO-CdO_2$ nanoparticles prepared by chemical method and deposited on glass substrate at 200^{o}C. AFM images prove that the grains are uniformly distributed within the scanning area (4000×4000) nm with individual columnar grains extending upwards.

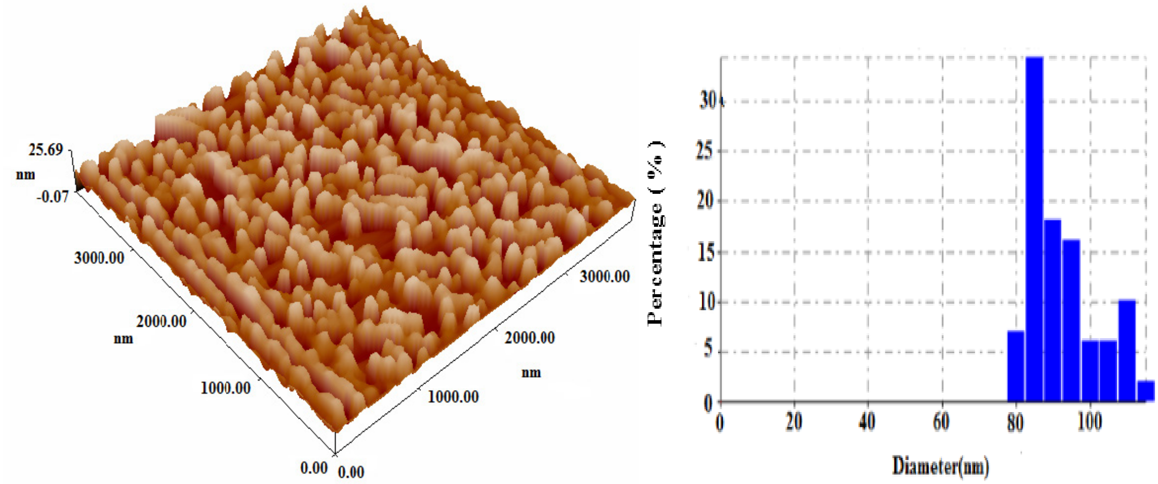

Fig. 3. 3D AFM images of $CdO-CdO_2$ thin film surface and Granularity accumulation distribution chart at Annealing 200^{0}C.

The $CdO-CdO_2$NPs have spherical shaped with good dispensability, homogeneous grains aligned vertically. The estimated values of root mean square (RMS) of surface roughness average and average grain size are listed in Table 2.

Table 2. Average diameter Size, Roughness and root mean square of $CdO-CdO_2$ NPs.

Average Diameter Size (nm)	**Roughness Density (nm)**	**Root Mean Square (nm)**
89.74	3.99	4.58

Figure 4 shows the transmittance spectrum of $CdO-CdO_2$ thin film. The data are corrected for glass transmission in UV region. Also, the figure shows the transmission spectra of the absorption edge is found to be around 430 nm.

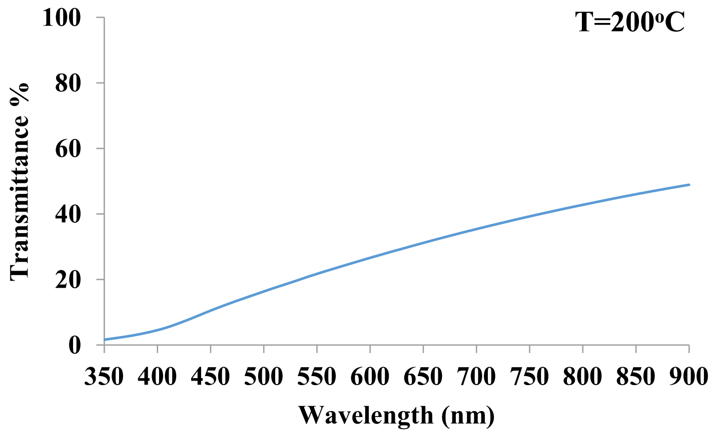

Fig. 4.Transmittance spectrum of CdO-CdO_2 thin films.

The absorbance spectrum shown in Figure 5. It was clearly seen that there was a sharp decrease in absorbance in the wavelength range less than 550 nm, showing a slight decrease after 550 nm

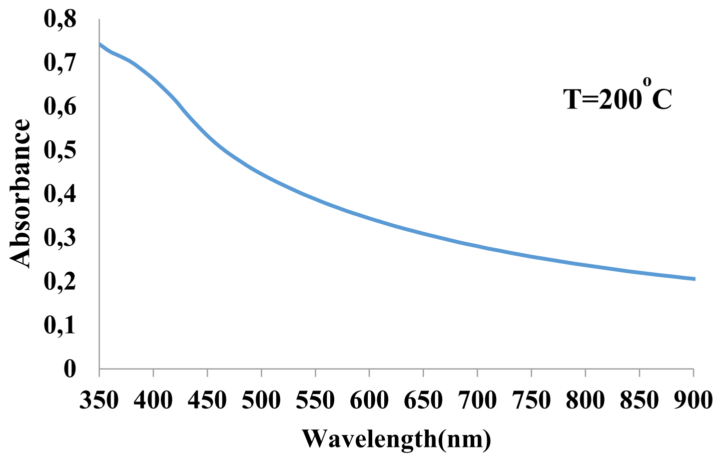

Fig. 5. Absorbane of the as deposited CdO-CdO_2 thin films.

If T is the transmittance and A is the absorbance of the CdO-CdO_2 thin film. The reflectance of the film has been found by using relationship:

$$T+A+R=1 \tag{4}$$

The reflectance of the CdO-CdO_2 thin film increases with increasing the wavelength above 430 nm. After that there is about 0.1 as shown in figure 6 due to increase in transmittance .

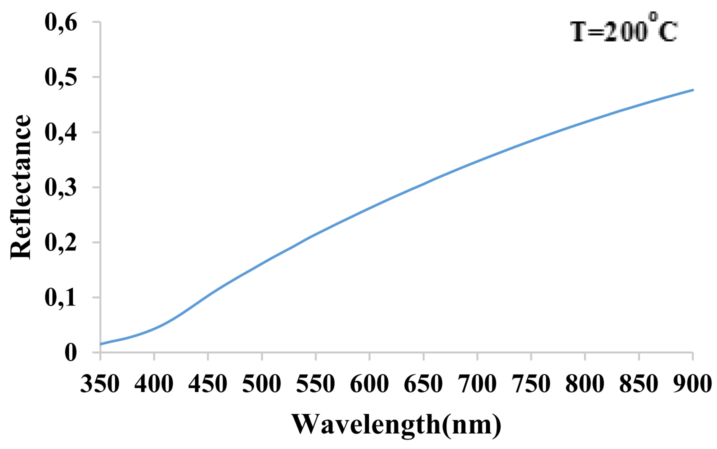

Fig. 6. Reflectance spectrum of CdO-CdO_2 thin films.

The optical absorption coefficient α was evaluated by Tauc relation $\alpha h\nu = A\left(h\nu - E_g\right)^n$ Where $\alpha = 2.303\ \frac{A}{t}$ and t is the film thickness, $h\upsilon$ is the photon energy, $E_g = \frac{1240}{\lambda(nm)}$ and $n = 0.5$ for direct allowed transition. Plotting the graph between $(\alpha h\upsilon)^2$ versus photon energy (hυ) gives the value of direct band gap. The extrapolation of the straight line to $(\alpha h\upsilon)^2 = 0$, gives the value of band gap, as shown in figure 7 the optical band gap was equal to 2.5 eV, in other word, the exciting wavelength ~ 496 nm. This result is very important to judge if this film can be used in a solar cell device.

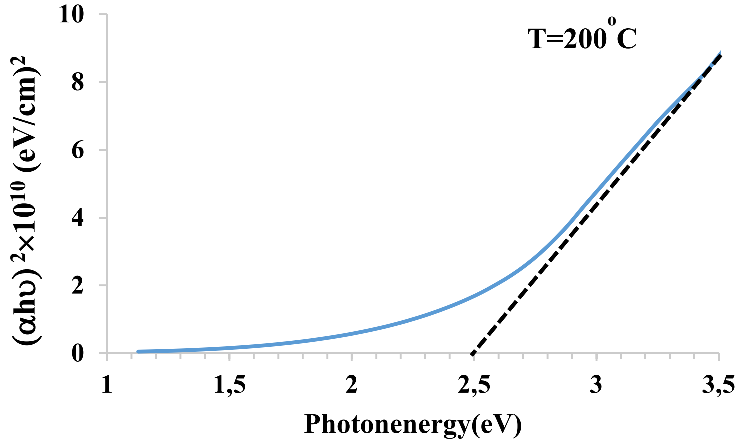

Fig.7: $(\alpha h\upsilon)^2$ versus photon energy plot of CdO-CdO_2 thin films.

From the reflectance R of the thin film, the refractive index can be calculated from the following relationship[19]:

$$n = \frac{1+\sqrt{R}}{1-\sqrt{R}} \tag{5}$$

The refractive index (n) of the prepared CdO-CdO_2 films has been calculated using equation 5, for a range of wavelength of 350 nm to 900 nm. The plot of n versus wavelength was shown in Fig. 8. The refractive index of the film remains almost equal through the visible region 350 nm to 430 nm with the value of 1.3, then the refraction index was slightly increased above that.

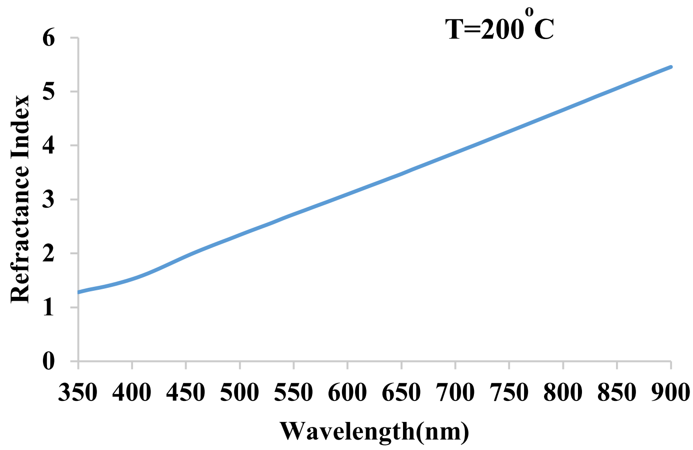

Fig.8: Refractive index spectrum of CdO-CdO_2 thin films

Figure 9 shows the I-V dark characteristics in forward and reverse direction of n-CdO-CdO_2/P-Si solar cell..

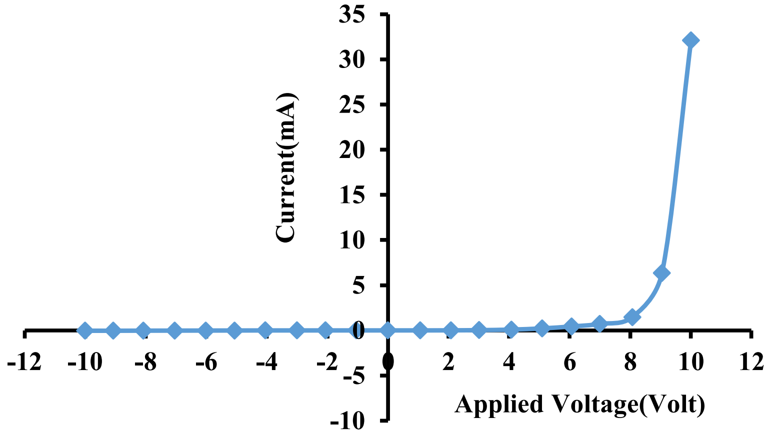

Fig. 9. I-V characteristic under forward and reverse bias of n-CdO-CdO_2/P- Si at 100 ^{0}C.

Figure 9 and 10 shows that the reversed current voltage characteristics of the device measured in dark and the photocurrent under 40 mW/cm^2 tungsten lamp illuminations. It can be seen that the reverse current value of a given voltage for n-CdO-CdO_2/P-Si solar cell under illumination is higher than that in the dark and it can be seen from these figures that the current value of a given voltage for heterojunction under illumination is higher than that in dark, this indicate that the light generated carrier contributing photocurrent due to the production of electron – hole as a result of the light absorption. This behavior yield useful information on the electron-hole pairs, which are effectively generated in the junction by incident photons[20].

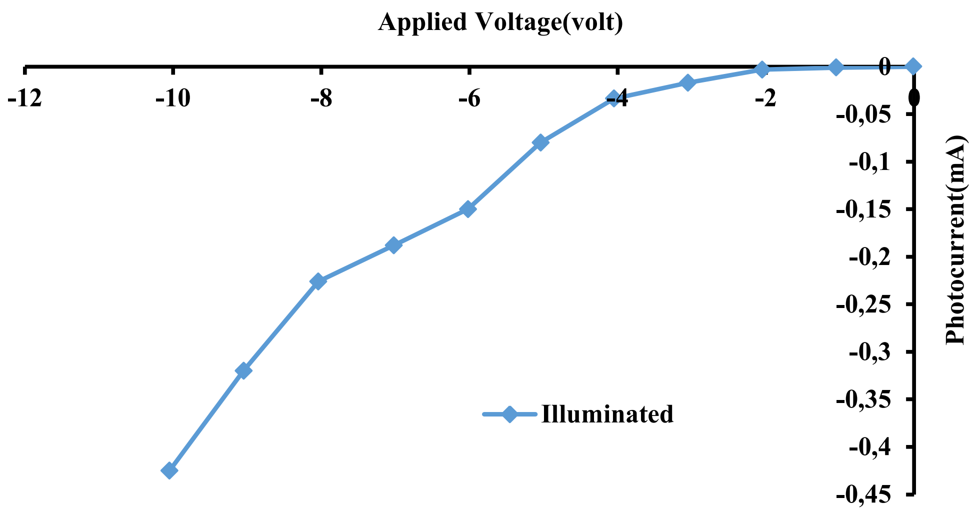

Fig.10: Illuminated (I-V) chara-cteristic of n-CdO-CdO_2/P-Si solar cell at 100 ^{0}C.

Figure. 11 shows the I–V characteristics of the solar cell under a 40 mW/cm^2 illumination condition

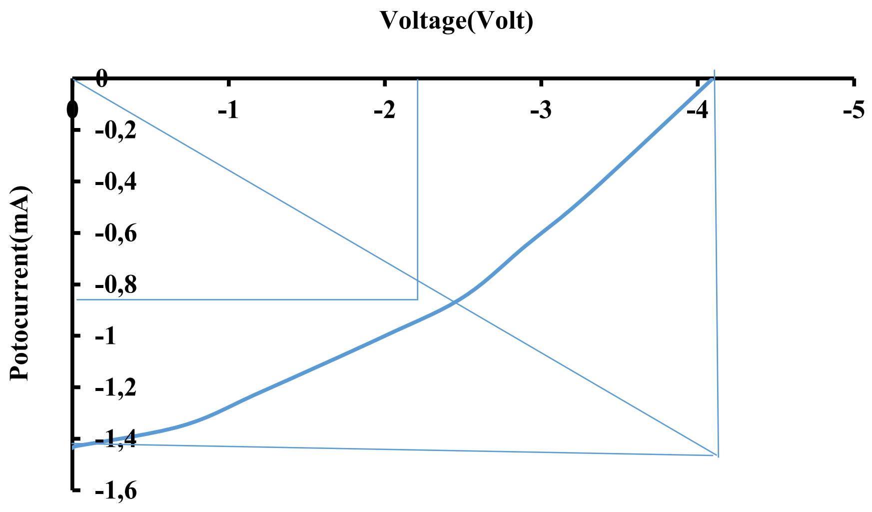

Fig11. I-V characteristics (n-CdO-CdO_2/p-Si) solar cell at 100 ^{0}C.

In the present study, the n-CdO-CdO_2/P-Si solar cell has an open-circuit voltage (V_{oc}) of 4.1V, a short circuit current (I_{sc}) of 1.44mA, a maximum voltage (V_{max}) of 2.4V, and a maximum current(I_{max}) of 0.89mA.

The fill factor (FF) was calculated as follows[21].

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} \times 100\% \tag{6}$$

FF was calculated to be 36.2%.

Cell energy conversion efficiency (η), was calculated using equation(7)

$$\eta = \frac{Pmax}{P_{in} \times A} \text{ x } 100\% \tag{7}$$

Where P_{in} is the power input to the cell defined as the total radiant energy incident on the surface of the cell in mW/cm^2, A is the surface area of the solar cell in cm^2 and $P_{max}= V_{max}I_{max}$ [18].

The efficiency of the (n-CdO-CdO_2/p-Si) solar cell was 6.8% using chemical reaction.

Conclusions

CdO-CdO_2 thin films were prepared successfully by chemical method. Bandgap value of 2.5 eV was estimated from optical characterization. X-ray diffraction (XRD) patterns approved that the CdO-CdO_2 are polycrystalline. The characteristics of n-CdO-CdO_2/p-Si shows good results which assure the sutitabibilty of using this device of solar cell applications.

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