# Performance-related structural, optical, and electrical characteristics of 2 μm the CdTe-CdSe absorption layer of solar cell

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The current work attempts to develop the most efficient compositions of 1 m between  $CdTe_{1,x}Se_x$  thin films as absorptive layer in solar cell applications (with x = 0 to 1, step 0.1 wt.%). Mechanical alloying was used to create the  $CdTe_{1-x}Se_x$  powdered materials, and thermal evaporation was used to create the thin film versions of these compositions. Swanepoel's approach was used to measure the films' thicknesses, and the spectroscopic ellipsometry technique was used to calibrate the results. The analyzed films' structural, electrical, and optical characteristics have been studied. It was determined that CdTe<sub>0.7</sub>Se<sub>0.3</sub> at had the highest crystalize size and the lowest lattice strain, which contributed to the reduction in imperfection in this sample since XRD revealed the nanostructures nature of these films. Additionally, it was discovered that CdTe<sub>0.7</sub>Se<sub>0.3</sub> had the lowest energy gap and the highest refractive index, which was responsible for this composition's largest crystalline size. CdTe<sub>0.7</sub>Se<sub>0.3</sub> possessed low resistivity, high conductivity, a high carrier concentration, and high carrier mobility, according to the Hall effect studies of these films. Two different types of solar cells were created: n-CdS/p-CdTe and n-CdS/p-CdTe/ CdTe<sub>0.7</sub>Se<sub>0.3</sub>. The power conversion efficiency of these two solar cells was determined to be 17.71 for CdS/CdTe and 18.92 for CdS/CdTe/ CdTe<sub>0.7</sub>Se<sub>0.3</sub>. Se should be doped in CdTe1-xSex thin films at an ideal level of 0.3%, making CdTe<sub>0.7</sub>Se<sub>0.3</sub> thin film a suitable choice for solar cell applications.

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## 1. Introduction

The greenhouse effect, which is brought on by burning fossil fuels, is what contributes to the amount of ecological imbalance. Despite this, because fossil fuels have a finite shelf life, researchers are seeking for other sources of energy. Solar cells are a type of technology that convert solar energy into electrical energy for use in practical applications by utilizing the photovoltaic effect. This non-conventional energy source should be taken into account for the future energy requirements of the current society because it is practical, eco-friendly, clean, and abundant [1-3]. It is generally known that the usage of solar cells contributes significantly to the global need for sustainable renewable energy [4]. II-VI group semiconductor materials are currently attracting increased attention in the realm of solar cell technology because of their intriguing physical and chemical features and applications [5, 6]. Due to its close to optimal and direct optical energy bandgap, high electron affinity, large absorption coefficient, suitable lattice parameters, and low negative formation enthalpy, cadmium telluride (CdTe) is a well-known II-VI semiconductor material for producing significant amounts of terrestrial electricity [7, 8]. It has the most stable crystal phase and melts consistently, making it possible to develop CdTe thin films

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using a range of fabrication methods and to manufacture stoichiometric CdTe films with little difficulty [9]. It is challenging to achieve low resistance and Ohmic electrical contact with the surface of CdTe thin films, nevertheless, due to its greater electron affinities [10]. Doping in CdTe semiconductors has been widely exploited by researchers from across the world to optimize the structural, optical, electrical, and other features for a variety of optoelectronic appliances [11-13]. It has been discovered that the presence of a third element modifies the chemical and physical properties of CdTe films. The effects of Bi [3], Se [11, 13–18], Mg [19], Sb, Sn, and Cu [20] doping on the properties of CdTe films have been studied. Of these dopants, selenium (Se), an element in the periodic table's VI group, is the most effective. Selenium, which is commonly alloyed into the CdTe absorber layer (CST alloy), is the most widely used component for thin-film solar cell technology [14]. It is a substance that has the ability to raise the short circuit current density (Jsc) of CdTe-based thin-film solar cells [15]. By forming alloys at the cation and anion sites, it is widely employed to change the optical energy bandgap of CdTe. The bandgap changes as a result of alloying with selenium, grading from 1.45 eV (for CdTe) to 1.37 eV (for CdSeTe) [17, 18]. The lower bandgap, which boosts current collection and increases open circuit voltage, accounts for the greater wavelength light absorption [16, 17]. Selenium incorporation into the CdTe absorber layer passivates grain boundaries (GBs) and significantly lengthens minority carrier lifetimes there [18]. The typical time-resolved photoluminescence (PL) tail lifetime of a pure CdTe absorber is a few nanoseconds, whereas CdSeTe alone and CdSeTe/CdTe bilayer absorbers exhibit increased lifetimes of up to 20–25 nanoseconds and microseconds, respectively [21-23]. In the present work, the powdered materials of  $CdTe_{(1-x)}Se_x$  was synthesized via mechanical alloying technique, the high quality of 2 µm films forms of these compositions was prepared according to the thermal evaporation technique. The structural, electrical and optical properties of  $CdTe_{(1-x)}Se_x$ films (with x = 0 to 1, step 0.1) were studied. The best composition of the films can be identified in terms of structrural, optical and electrical characteristics for solar cells.

#### 2. Experimental details

Different composition of ternary polycrystalline  $CdTe_{(1-x)}Se_x$  alloys (with x = 0 to 1, step 0.1) were taken in molecular stoichiometric proportional weight of high purity (99.999% produced by Aldrich) analytical grade of CdSe and CdTe powders according to the following relation:

$$xCdSe + (1-x)CdTe \rightarrow CdTe(1-x)Se_x$$
 (1)

At room temperature, the powders were mixed together in a mechanical ball mortar for about 1 hour. After that, the mixed powders were then pressed into a circular disk shape pellet. Such pellets were used as the starting materials from which the thin film will be prepared. The different sets of samples of varying compositions of  $CdTe_{1-x}Se_x$  were deposited via evaporation of the compound in vacuum higher than  $10^{-6}$  Pa under controlled growth conditions of various compositions onto the precleaned glass substrates at the temperature of 373 K), using a conventional coating unit (Edward 306A).

The rate of evaporation thickness of the film thickness were controlled using a quartz crystal DTM 100 monitor. The deposition rate was maintained 20 Å/s constant throughout the sample preparations and the film thickness was 2 microns for all films. The structure of the prepared samples were studied by XRD analysis (Philips X-ray diffractometry (1710)) with Ni-filtered Cu K<sub>a</sub> radiation with  $\lambda = 0.15418$  nm). The intensity data were collected using the step scanning mode with a small interval ( $2\theta = 0.05^{\circ}$ ) with a period of 10 s at each fixed value to yield reasonable number of counts at each peak maximum. The compositional analysis of the obtained films was done by energy dispersive X-ray spectrometer. (EDXS) unit interfaced to scanning electron microscope (SEM) (JEOL JSM-6360LA, Japan) operating at an accelerating voltage of 30 kV. The relative error of determining the indicated elements does not exceed 2 %. The dual-beam spectrophotometer (UV-Vis-NIR JASCO-670) was used to measure the transmission of the films. The SE parameters ( $\psi$  and  $\Delta$ ) for CdTe<sub>1-x</sub>Se<sub>x</sub> films were measured with a rotating-compensator instrument (J.A. Woollam, M-2000) in the wavelength range 400–1100 nm. The data were

acquired at angle of incidence of 70°, at room temperature. The electrical characteristics of CdTe<sub>1</sub>,  $_xSe_x$  thin films were evaluated with van der Pauw method using Hall effect experiment (HMS-5000; ECOPIA). 1 cm<sup>2</sup> glass substrates of CdTe<sub>1-x</sub>Se<sub>x</sub> thin films were made to measure the resistivity, the mobility, and the carrier concentration. Then Keithley's 2400 power source meter was utilized for Solar Simulator 1.5 Worldwide Spectrum under AM 1.5 conditions to measure the current density versus the voltage (J-V) characteristics of solar cells.

#### 3. Results and discussion

#### 3.1. Structural and morphological characterizations of the CdTe<sub>1-x</sub>Se<sub>x</sub> thin films:

The XRD pattern of CdTe<sub>1-x</sub>Se<sub>x</sub> thin films at doping concentrations of (x=0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1 wt. %) is illustrated in Fig.1. When x=0 in CdSe<sub>x</sub>Te<sub>1-x</sub> thin film, cadmium telluride (CdTe) was formed with peaks positioned at  $2\theta$ = 24.08°, 39.7° and 46.94° belonging to the (111), (220) and (311) miller planes of the cubic zinc blende structure according to the XRD card (ICDD: 00-015-0770). And at x = 1, cadmium selenide (CdSe) was made with peaks at  $2\theta$ = 23.84°,25.34°, 26.92°, 35.12°, 41.92°,45.7° and 49.52° corresponding to the (100), (002), (101), (102), (110), (103) and (112) planes of the hexagonal wurtzite structure according to the XRD card (ICDD: 00-008-0459). For thin films at x=0.1 and 0.2 both the cubic and the hexagonal structures are found in the thin film with the orientations (1 1 1), (2 2 0) and (3 1 1) for cubic structure and only the plan (100) for the hexagonal structure. Additionally thin films with compositions from x = 0.3 to x = 0.9 showed both the hexagonal and cubic phases as seen in Fig.1.



*Fig. 1. XRD pattern of CdSe<sub>x</sub>Te<sub>1-x</sub> thin films at doping concentrations of* (*x*=0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1 wt. %).

The prominent peaks representing the cubic structure of CdTe, would be found with higher concentration of tellurium; while the prominent peaks defining the hexagonal structure of CdSe, would be found with higher concentration of selenium.

The lattice parameters, *a* for the cubic structure and (a & c) for the hexagonal structure for all CdTe<sub>1-x</sub>Se<sub>x</sub> compositions are displayed in Table 1 and their values are roughly equivalent to the standard lattice parameters (*a*=6.481Å for cubic phase, *a*=4.299Å & *c*=7.01Å for hexagonal phase).

Se (at. %)	a(Cubic) (Å)	a(Hex) (Å)	c(Hex) (Å)	Crystallize Size (nm)		Lattice Strain (x10 <sup>-3</sup> )	
× ,		~ /		Hex.	Cub.	Hex.	Cub.
0	6.773				44.52		1.91
0.1	6.699				40.28		4.959
0.2	6.636				34.98		8.778
0.3	6.584	4.544	7.394	65.72	67.84	0.9476	0.836
0.4	6.531	4.538	7.374	60.42	62.54	1.246	1.121
0.5	6.489	4.532	7.363	53	56.18	3.358	3.477
0.6	6.447	4.529	7.353	46.64	50.88	5.377	4.883
0.7		4.523	7.342	41.34	46.64	6.726	6.859
0.8		4.519	7.332	32.86		8.92	-
0.9		4.512	7.322	39.22		9.373	
1		4.507	7.311	45.58		10.35	

Table 1. Microstructure parameters and lattice parameters of  $CdSe_xTe_{l-x}$  thin films.

The crystallize size D was evaluated using Scherrer's equation [24] in eq.2; while the microstrain ( $\epsilon$ ) formed by the crystal imperfections and distortion, was estimated using Stokes–Wilson equation [25] given in eq.3 as given in the following equations:

$$D = \frac{0.89\lambda}{\beta\cos\theta} \tag{2}$$

$$\varepsilon = \frac{\beta \cos\theta}{4} \tag{3}$$

where  $\beta$  is the full width at half maximum (FWHM in radians),  $\theta$  is the diffraction angle and  $\lambda$  is the of Cu-K<sub>a</sub> radiation wavelength (1.54056 Å)).

The crystallize sizes (D) values increase with increasing the Se percent until Se equals 0.3% that D=64nm, then their values decrease as indicated in table 1. The lattice strain also increases with increasing the Se percent, then sharply decreases to 0.88 at Se equals 0.3%, after that their values increase as before. From this table, it is concluded that the highest crystallize size and the lowest lattice strain was found at Se equals 0.3% in the CdTe<sub>1-x</sub>Se<sub>x</sub> thin films. The recognized high crystallize size and low lattice strain is attributed to the lowering in imperfection in the CdTe<sub>1-x</sub>Se<sub>x</sub> thin films when x equals 0.3 percent.

Figure 2 depicts the SEM of thin films with  $CdTe_{1-x}Se_x$  concentrations of x = 0 at.% (a) and x = 0.3 at.% (b) correspondingly. It can be seen that the doping of Se results in a clear rising in grain size. The images showed that the particle size of  $CdTe_{0.7}Se_{0.3}$  films is greater than the particle size of CdTe film, indicating gradual improvement in the sample's crystal quality. The average grain size of CdTe and  $CdTe_{0.7}Se_{0.3}$  films is around 39 nm and 61 nm, respectively, with a slightly wider grain size distribution for the former, ranging from 20 nm to 60 nm, and for the latter, from 30 nm to 80 nm. The values of grain size are in a good agreement with the values obtained by XRD. A growing in average grain size leads to enhance crystalline quality and an reduce in the overall grain boundary fraction in the films.



Fig. 2. SEM image (a) CdTe and (b) CdTe<sub>0.7</sub>Se<sub>0.3</sub> films.

#### 3.2. Optical characterization of the CdTe<sub>1-x</sub>Se<sub>x</sub> thin films

Fig. 3 shows the deposit films' transmittance (T) (Fig. 3 (a)) and reflection (R) (Fig. 3 (b)) as a function of wavelength. The homogeneity and smoothness of the deposited films are indicated by the interference fringes in the transmittance spectra at wavelengths (800–2000 nm) that are "non-shrinking" in amplitude (fringes of equal chromatic order, FECO). Additionally for more illustration as shown in Fig.4 which represents the variation of T with  $\lambda$  in the strong absorption region, as the Se content in the CdTe<sub>1-x</sub>Se<sub>x</sub> system rises from 0 to 0.6, the absorption edge shifts towards the lower photon energy, but at 0.3 it reaches to the lowest photon energy.



Fig. 3. (a)The transmittance (T) and Reflection (R) spectra of  $2 \mu m CdSe_xTe_{1-x}$  films.



Fig. 4. The variation of transmittance wavelength in the strong absorption region.

While the Se contents varies between 0.7 and 1, the absorption edge moves towards the higher photon energies. This is considered because of the two different manners of energy gap variation: firstly, the energy gap decreases due to the substitution of Se for Te atoms in the doping range (0-0.6), hence the lowest energy gap is expected at 0.3 doping rate, secondly the energy gap increases in the doping range (0.7-1). Swanepoel have introduced a method for analyzing a first, approximative value of the refractive index of the film n and film thickness, d in the spectral region of medium and weak absorption, according to the expression [26]:

$$\begin{split} n &= \left[ N + \left( N^2 - s^2 \right)^{1/2} \right]^{1/2} \\ N &= 2s \frac{T_M - T_m}{T_M T_m} + \frac{s^2 + 1}{2} \\ d &= \frac{A}{2} \cdot (\lambda_1 \lambda_2) \cdot [\lambda_1 n_2 - \lambda_2 n_1]^{-1} \end{split}$$
(4)where, And

Here T<sub>M</sub> and T<sub>m</sub>, are the transmission maximum and the corresponding minimum at a certain wavelength. This method is based on creating the upper and lower envelopes of interference fringes [26]. Furthermore, if  $n_1$  and  $n_2$  have refractive indices at the adjacent maximum (or minimum) at 1 and 2. All the details of Swanepoel' method have been clearly seen in references [28-30].

The values of *n* extrapolated across the entire wavelength dependence of the refractive index by fitting them to a reasonable dispersion function, such as the two-term Cauchy function,  $n(\lambda) = B + \frac{A}{\lambda^2}$ , as shown in Fig. 5 for different CdTe<sub>1-x</sub>Se<sub>x</sub> ( $0 \le x \le 1$ ) thin films. Over the entire spectral range under investigation, Fig.5 demonstrates that the refractive index rises as the Se content rises from 0 to 0.6, having the higher values at 0.3 Se doping. While n decreases at 0.7 -1 doping rates. Which is expected according to the variations of absorption edge.



Fig. 5. The variation of refractive index n as a function of wavelength  $\lambda$  for different  $CdTe_{1-x}Se_x$  ( $0 \le x \le 1$ ) thin films.

According to the following expression [26], the experimentally measured values of R and T can be used to calculate the absorption coefficient in the strong absorption region.

$$\alpha = \frac{1}{d} ln \left[ \frac{(1-R)^2 + \left[ (1-R)^4 + 4R^2 T^2 \right]^{1/2}}{2T} \right]$$
(5)

where *d* stands for the sample thickness. The absorption coefficient for the various compositions is depicted as a function of photon energy in Fig.6.



Fig. 6. The absorption coefficient for the various tested compositions as a function of photon energy.

Fig. 7 represents the absorption coefficient of the tested composition as a function of Se doping rate at a certain wavelength ( $\lambda = 690$  nm which represents the higher photon energy in the visible region), which emphasis the previous manner of absorption edge shift.



Fig. 7. The absorption coefficient of the tested composition as a function of Se doping rate at  $\lambda = 700$  nm.

Hence  $\alpha$ , increases  $(1.11 \times 10^5 - 1.21 \times 10^5 \text{ cm}^{-1})$  as Se doping increases between 0 and 0.6 being maximum  $(1.3 \times 10^5)$  at 0.3 doping content, then  $\alpha$  decreases from 1.06 x  $10^5$  to 6.1 x  $10^4$  cm<sup>-1</sup> at 0.7-1 Se contents. It should be noted that the following equation, which is based on Tauc's relation for the permitted direct transition [27], gives the absorption coefficient of amorphous semiconductors in the high-absorption region ( $\geq 10^4$ ):

$$\alpha(h\nu) = \frac{A\left(h\nu - E_g^{opt}\right)^{\frac{1}{2}}}{h\nu}$$
(6)

where the optical band gap is  $E_g^{opt}$  and A is a constant that depends on the probability of a transition. A good fitting of  $(ahv)^2$  versus photon energy (hv) is shown in Fig. 8 for thin films with different compositions. The intercept of  $(ahv)^2$  versus (hv) at  $(ahv)^2 = 0$  was used to calculate the optical band gap values for the permitted direct transition. Fig. 9 illustrates the  $E_g^{opt}$  variation with the Se content. It is obviously shown by the figure that  $E_g^{opt}$ , firstly decreases from (1.491-1.463 ev) at doping range (0-0.6), hence the lowest value of  $E_g^{opt}$  is 1.411 ev presented at 0.3 Se content. Secondly,  $E_g^{opt}$  increases from (1.499-1.711 ev) as the Se increases from 0.7 to 1. This manners of the energy gap, refractive index and absorption coefficient variations can be explained in terms of the nanocrystalline size, hence the XRD results illustrate that the composition with 0.3 Se have the largest nanocrystalline size, subsequently this allows to form more overlapping energy states and hence decrease the energy gap.



*Fig.* 8.  $(ahv)^2$  versus photon energy (hv) for the investigated thin films.



Fig. 9. The variation of optical band gap  $\mathbb{E}_{g}^{opt}$  with the Se content of the tested compositions.



Fig. 10. Variation of resistivity ( $\rho$ ) and conductivity ( $\sigma$ ) as a function of Se doping concentration for  $CdSe_xTe_{1-x}$  thin films.



*Fig. 11. The diagram of studied p-n junction n-CdS/p-CdTe and n-CdS/p-CdTe/ CdTe*<sub>0.7</sub>*Se*<sub>0.3</sub> *solar cell.* 

#### 3.4. Electrical characterization of the CdTe<sub>1-x</sub>Se<sub>x</sub> thin films

Hall effect was conducted using the Van der Pauw method in order to estimate the electrical properties of the CdTe<sub>1-x</sub>Se<sub>x</sub> thin films. The estimates of sheet resistance electrical resistivity, electrical conductivity, Hall coefficient, carrier concentration, and Hall mobility, were calculated using four-probe experimental technique and viewed in table 2. Firstly the sheet resistance R<sub>s</sub> was measured using the formula: Rs = 4.43 V/I (ohm/Sq.).Here, V is the applied voltage (Volt), I is the current (Ampere) and 4.53 is a correction constant [31]. In table 2, the R<sub>s</sub> value decreases with the increase in Se percent and reaches its minimum value of 34.12  $\Omega$  at Se equals 0.3% and then again increases for higher Se percents. The electrical resistivity  $\rho$  could be estimated from R<sub>s</sub> as follows:  $\rho = R_{s}$ . d, and d is the thickness (2 µm). While the electrical conductivity  $\sigma$  is the reciprocal of resistivity  $\rho$ ,  $\sigma = 1/\rho$ .

Se (at.%)	$R_s$	$\rho x 10^{-2}$	σ	$R_H$	$n_c x  10^{18}$	μ
	Ω/Sq.	( <i>Ω</i> .cm)	(Ω.cm) <sup>-1</sup>	cm <sup>3</sup> /C	cm <sup>-3</sup>	cm <sup>2</sup> /v.s
0	289.1	5.781	17.3	0.461	13.56	7.98
0.1	132.7	2.654	37.7	0.436	14.34	16.43
0.2	59.63	1.193	83.8	0.425	14.7	35.65
0.3	34.12	0.682	147	0.421	14.83	61.75
0.4	52.81	1.056	94.7	0.424	14.74	40.15
0.5	91.18	1.824	54.8	0.43	14.54	23.56
0.6	161.2	3.224	31	0.44	14.19	13.66
0.7	244	4.88	20.5	0.454	13.78	9.29
0.8	363.7	7.273	13.7	0.474	13.18	6.52
0.9	537.6	10.75	9.3	0.508	12.31	4.72
1	795.2	15.9	6.29	0.567	11.02	3.56

Table 2. Hall effect parameters for  $2 \mu m CdSe_xTe_{1-x}$  thin films.

The carrier concentration  $n_c$  is obtain from the equation:  $n_c = \frac{1}{e \cdot R_H}$ , where  $R_H$  is the Hall coefficient and e is the electron charge. And the carrier mobility  $\mu$  is related to the carrier concentration  $n_c$  and the Hall coefficient  $R_H$  in the relations  $\mu = \frac{1}{n_c \cdot e \cdot \rho}$  or  $\mu = \frac{1}{\rho / R_H}$  [32].

The variation of electrical resistivity  $\rho$  and electrical conductivity  $\sigma$  of CdTe<sub>1-x</sub>Se<sub>x</sub> thin films are displayed in Fig.12; as the Se concentration increases, the resistivity  $\rho$  decreases until it reached a minimum value of 0.682  $\Omega$ .cm and the conductivity  $\sigma$  increases until it reached a maximum value of 147 ( $\Omega$ .cm)<sup>-1</sup>, at Se concentration of 0.3% and then  $\rho$  return to its increasing behavior and  $\sigma$  return to its decreasing behavior. In table 2 the carrier concentration n<sub>c</sub> and the mobility  $\mu$  of the CdTe<sub>1-x</sub>Se<sub>x</sub> thin films are shown as a function of the Se content. The mobility increases with Se content increase, up to 61.75 cm<sup>2</sup>/v.s at Se 0.3%, also the carrier concentration increases with Se content increase, up to 14.83 x 10<sup>18</sup> cm<sup>-3</sup> at Se 0.3% and then both  $\mu$  and n<sub>c</sub> decrease. The raising in mobility values is due to the decrease in resistivity. The reduction in resistivity and the rising in conductivity and mobility are attributed to the increase of the crystallize size, that would lead to decrease in grain boundary concentration and minimization in the grain boundary scattering, which in turn increases the films crystallinity [33-35]. Since the optimal doping level of Se in CdTe<sub>1-x</sub>Se<sub>x</sub> thin films is 0.3%, with low grain boundary concentration, high crystallite size, high crystallinity, low resistivity, high conductivity, high carrier concentration and carrier mobility, then CdTe<sub>0.7</sub>Se<sub>0.3</sub> thin film is an adequate candidate for solar cell applications.



*Fig. 12. Illuminated J-V curves obtained under AM1.5 conditions forCdS/CdTe and CdS/CdTe/CdTe*<sub>0.7</sub>Se<sub>0.3</sub> (red points) solar cells.

#### 3.5. Device characterization of CdTe<sub>1-x</sub>Se<sub>x</sub>/CdTe solar cells

Two solar cells were fabricated n-CdS/p-CdTe and n-CdS/p-CdTe/CdTe<sub>0.7</sub>Se<sub>0.3</sub>, with thicknesses of the CdS inter-layer (~ 80nm), CdTe (~2  $\mu$ m) and CdTe<sub>0.7</sub>Se<sub>0.3</sub> (~0.5  $\mu$ m) as seen in Fig.11.

The CdS/CdTe and CdS/CdTe/CdTe<sub>0.7</sub>Se<sub>0.3</sub> solar cells current density J was plotted against the voltage V in Fig.12. From this figure solar cells parameters, short-circuit current density (J<sub>sc</sub>), open-circuit voltage (V<sub>oc</sub>) were derived, and were found to be equal 0.028 A/cm<sup>2</sup> and 0.816 V for CdS/CdTe and 0.029 A/cm<sup>2</sup> and 0.797 V for CdS/CdTe/CdTe<sub>0.7</sub>Se<sub>0.3</sub>, respectively. Afterwards the fill factor (FF) was measured form the equation  $FF = \frac{V_M J_M}{VocIsc}$ , where J<sub>M</sub> is the current density and V<sub>M</sub> is the voltage at maximum power point. FF values were found to equal 65.4% for CdS/CdTe

 $V_{\rm M}$  is the voltage at maximum power point. FF values were found to equal 65.4% for CdS/CdTe and 69.6% for CdS/CdTe/CdTe<sub>0.7</sub>Se<sub>0.3</sub>, respectively. Lastly the power conversion efficiency  $\eta$  were

deduced from the relation  $\eta\% = \frac{FFVocJsc}{P_{in}} \times 100$ , here is the incident light intensity (100mW/cm<sup>2</sup>) were evaluated to be equal 17.71 for CdS/CdTe and 18.92 for CdS/CdTe/CdTe0.7Se0.3, respectively [38]. The power P was calculated from the equation  $P = V_{ocJsc}$ , the maximum power point is higher in CdS/CdTe than in CdS/CdTe/CdTe<sub>0.7</sub>Se<sub>0.3</sub> solar cell.

### 4. Conclusion

The structural, electrical and optical properties of 2 microns  $CdTe_{(1-x)}Se_x$  thin films at doping concentrations of ( $0 \le x \le 1$  wt. %) were studied in order to optimize the most effective absorptive layer in solar cell applications. XRD revealed the nanostructures nature of these films.  $CdTe_{0.7}Se_{0.3}$  had the largest crystalize size and the lowest lattice strain, which contributed to the reduction in imperfection in this sample. Also,  $CdTe_{0.7}Se_{0.3}$  had the lowest energy gap (1.41 eV) and the highest refractive index (n = 3.267 at  $\lambda = 950$  nm), which was responsible for this composition's largest crystallize size (D = 65 nm).  $CdTe_{0.7}Se_{0.3}$  had low resistivity (0.796 x  $10^{-2}$   $\Omega$ .cm), high conductivity, high carrier concentration ( $n_c = 14.83 \times 10^{18} \text{ cm}^{-3}$ ), and high carrier mobility ( $\mu = 61.75 \text{ cm}^2/\text{v.s}$ ), according to the Hall effect measurements of these films. Two different types of solar cells were created: n-CdS/p-CdTe and n-CdS/p-CdTe/CdTe\_{0.7}Se\_{0.3}. The power conversion efficiency of these two solar cells was determined to be 17.71for CdS/CdTe and 18.92 for CdS/CdTe/CdTe\_{0.7}Se\_{0.3} thin film a suitable candidate for solar cell applications.

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