Structural and Optoelectronic Characterization of CdO/Si Solar Cell Prepared by DC Magnetron Sputtering

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Abstract: ***Cadmium oxide thin films were prepared by DC magnetron sputtering in argon gas mixed with 20% oxygen gas withdifferent sputtering voltages (700-1200) V at 0.3 mbar pressure.The prepared films annealed in oxygen atmosphere at 523 K.The structural and optical properties ofthe produced films were examined by X-ray diffractionand UV-Visible absorbance ,respectively. The results show a polycrystalline structure and the crystallinety of the films were enhanced. Also the results revealed that the crystalline size and the lattice parameter increase with increasing of the sputtering voltage. UV-Visible measurements show that the absorbance thin films increases while the optical energy gap decreases with increasing the sputtering voltage. I-V Characteristics show a low efficiency for all samples, but the efficiency decreases with increasing of the sputtering voltage from 900 to 1200 V.***

Keywords: DC sputtering, CdO thin films ,optical properties., I-V characteristic

1. Introduction

Cadmium oxide (CdO) is n-type semiconductor with direct energy gap (2.2 -2.5) eV[1].CdO thin films deposited by different techniques such asspray pyrolysis[2],DC sputtering [3],Sol-Gel[4] and Chemical bath methods [5] etc.

CdO thin films used in many fields such as used in photodiodes, phototransistors, photovoltaic cells, transparent electrodes, IR detectors, and anti-reflection coating[6].

Sputtering deposition is one of the most important methods that give us a high quality thin films, such as high homogeneity and adhesion, which are useful in many applications[7].

Deposition parameters play major method to tune various properties, such aselectrical, structure and optical properties, of CdO thin films[8]. Study these properties for thin films very important to fabricated solar cells or any photo- electric devices[9].

2. Experimental

2.1 The Films Preparation

DC discharge plasma systemconsists of glass chamber of 18 cm diameter and 35 cm height, vacuumed by double stage rotary pump type Edward and Pirani gauge type Edward, with two disc electrodes of 7 cm radius, the anode made of aluminum while the cathode from cadmium target withring magnet above it to enhance the sputtering, DC-power supply, high voltage voltmeter and ammeter. The gaseswere deliveredinto the chamber usingneedle valve by two flow controller and mixer to control Oxygen: Argon ratio (20%) and gas pressure (0.3 mbar). The electrodeswerepolished before every run. TheCdO thin films were prepared on glass and p-type Si wafer substratesat differentvoltagesfrom700 to1200 Vat constant electrodes separation of 6 cm. The produced thin films annealed in oxygenat atmosphere pressure inside closed vessel at 523 K to enhance films crystallinety.

2.2. Measurements

2.2.1X. Ray Diffraction Spectra

The prepared films on glass substrates were examined by X-ray diffractionusing (BRUKER ,D2 PHSER model)of λ= 1.54 A° from Cu - Kα. The main law in studying the structural properties is the Bragg's law in X-ray diffraction[10]

$$n\lambda = 2 d_{hkl} \sin \Theta \qquad \text{…………………….. (1)}$$

where d_{hkl} is the distance between the adjacent atomic layers, ϴ is the angle of diffraction and λ the XRD wavelength.

While the crystalline size $(G.S)$ calculated by Scherrer equation depending on the full width at half maximum (*FWHM*)[11]

$$G.S = \frac{0.9\,\lambda}{FWHM.\cos(\theta)} \qquad \text{…..……….. ……….(2)}$$

2.2.2 Optical Properties

UV-VIS, Metertech type Sp-8001 device was used to record the optical properties for CdO thin films in the range (300 – 1100)nm.

The intensity reduced with its path in material according to the absorption coefficient α as shown by Beer-Lambert equation [12].

$$I = I_o e^{-\alpha t} \qquad \text{………………………….(3)}$$

Where I_o is the incident light intensity and I is the transmitted one. In Tauc equation r=1/2 for the allowed direct transition [13]:

$$\alpha h\upsilon = B\,(h\upsilon - Eg)^r \qquad \text{………………..(4)}$$

where α is the absorption coefficient (cm)$^{-1}$, $h\upsilon$ is the photon energy (eV), B constant depended on the type of material and preoperational inversely with the amourphosity, Eg is the energy gap and r parameter give the type of the transition..

2.2.3 The Electrical Properties

The DC electrical properties of CdO thin films deposited on glass substrate at different sputtering voltage were measured through the change of resistance with temperature. This was done by putting the samples inside the (electrical blast dry box, model WG 20) and using (Keithley 616Multiter) to measure the film temperature, the resistivity (ρ) was determined by equation [13] :

$\rho = R\,A/L$……………………………………(5)

where R is the film resistance , A is the cross section area of the film and L is the distance between the electrode.the conductivity (σ) from the following:

$\sigma = 1/\rho$………………………………………(6)

The films deposited on Si substrates used to fabricated solar cell by doing Ohmic contact on top of CdO as mesh and cover all the back of Si wafer. Then examined the I-V characteristics for solar cell.

3. Results and discussions

Fig. (1) illustrates the XRD patterns for CdO films deposited with different voltages by DC sputtering in Argon: Oxygen gas mixture and annealed at 523 K in oxygen. The XRD patterns shows polycrystalline structure with four peaks, enhanced to five peaks with increasing voltage, located at 2θ = 32.9094^0,38.3425^0,55.2836^0,65.8423^0 and69.2941^{0}matchingwith(111), (200), (202), (311) and (222) directions in standard card No. 96-900-8610. The preferred orientation along (111) direction. The peaks intensities increase with increasing the used voltage which indicate to enhance the crystallinety. The full width at half maximum (FWHM) decrease, i.e. increase the crystalline size,with increase voltage from 700 to 1200 V as shown in Table (1).

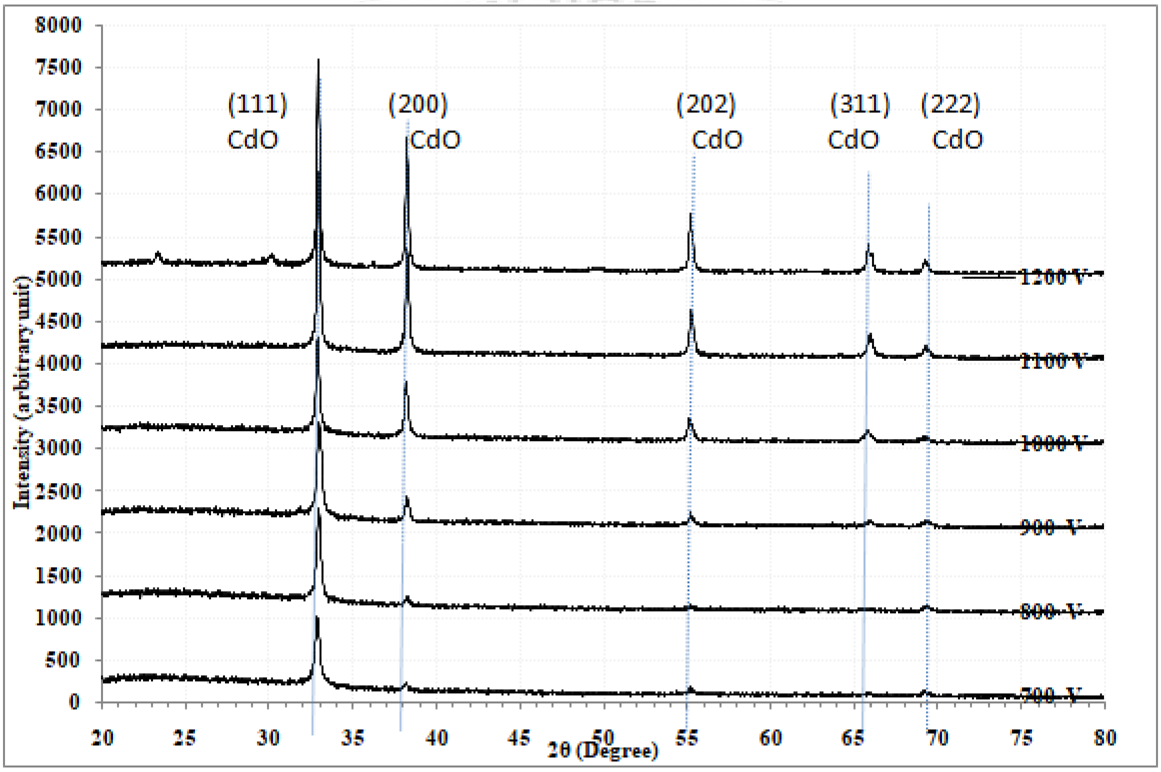


Figure 1: X-ray diffraction curves CdO films deposited by different voltages

Table 1: XRD peaks, standard and experimental d_{hkl},for CdO films deposited by different voltages

V (volt)	2θ (Deg.)	FWHM (Deg.)	d_{hkl} Exp.(Å)	G.S (nm)	hkl	d_{hkl} Std.(Å)	card No.
700	32.9094	0.3888	2.7194	21.3	(111)	2.7108	96-900-8610
	38.3425	0.3239	2.3457	26.0	(200)	2.3477	96-900-8610
	55.2836	0.3564	1.6603	25.2	(202)	1.6600	96-900-8610
	69.2941	0.6479	1.3549	14.9	(222)	1.3554	96-900-8610
800	32.8990	0.2916	2.7203	28.4	(111)	2.7108	96-900-8610
	38.3397	0.4211	2.3458	20.0	(200)	2.3477	96-900-8610
	55.2484	0.4860	1.6613	18.4	(202)	1.6600	96-900-8610
	69.2765	0.4535	1.3552	21.3	(222)	1.3554	96-900-8610
900	32.8914	0.3887	2.7209	21.3	(111)	2.7108	96-900-8610
	38.2873	0.3563	2.3489	23.6	(200)	2.3477	96-900-8610
	55.2160	0.3888	1.6622	23.1	(202)	1.6600	96-900-8610
	65.8423	0.4536	1.4173	20.9	(311)	1.4157	96-900-8610
	69.2613	0.7127	1.3555	13.5	(222)	1.3554	96-900-8610

1000	32.8818	0.2916	2.7217	28.4	(111)	2.7108	96-900-8610
	38.2549	0.3239	2.3508	26.0	(200)	2.3477	96-900-8610
	55.2012	0.4212	1.6626	21.3	(202)	1.6600	96-900-8610
	65.7775	0.5183	1.4186	18.3	(311)	1.4157	96-900-8610
	69.2593	0.5183	1.3555	18.6	(222)	1.3554	96-900-8610
1100	32.8766	0.2592	2.7221	32.0	(111)	2.7108	96-900-8610
	38.2073	0.2267	2.3537	37.1	(200)	2.3477	96-900-8610
	55.2010	0.3564	1.6626	25.2	(202)	1.6600	96-900-8610
	65.9071	0.4212	1.4161	22.5	(311)	1.4157	96-900-8610
	69.2441	0.4535	1.3558	21.3	(222)	1.3554	96-900-8610
1200	32.8742	0.1620	2.7223	51.1	(111)	2.7108	96-900-8610
	38.1749	0.1943	2.3556	43.3	(200)	2.3477	96-900-8610
	55.1836	0.2916	1.6631	30.7	(202)	1.6600	96-900-8610
	65.8423	0.2916	1.4173	32.5	(311)	1.4157	96-900-8610
	69.1793	0.324	1.3569	29.8	(222)	1.3554	96-900-8610

Fig. (2) shows the variation of average crystalline size with used voltage. The crystalline size increase with increasing voltage from 700 to 1200 V as a result ofincreasing the rate of deposition.Fig. (3) shows the variation of lattice constant (a) with used voltage, which calculated using the preferred peak. This figure shows that the lattice constant increase with increasing used voltage as a result of increase the average crystalline size, where decreasing the particle size to nano range cause a strain in lattice.

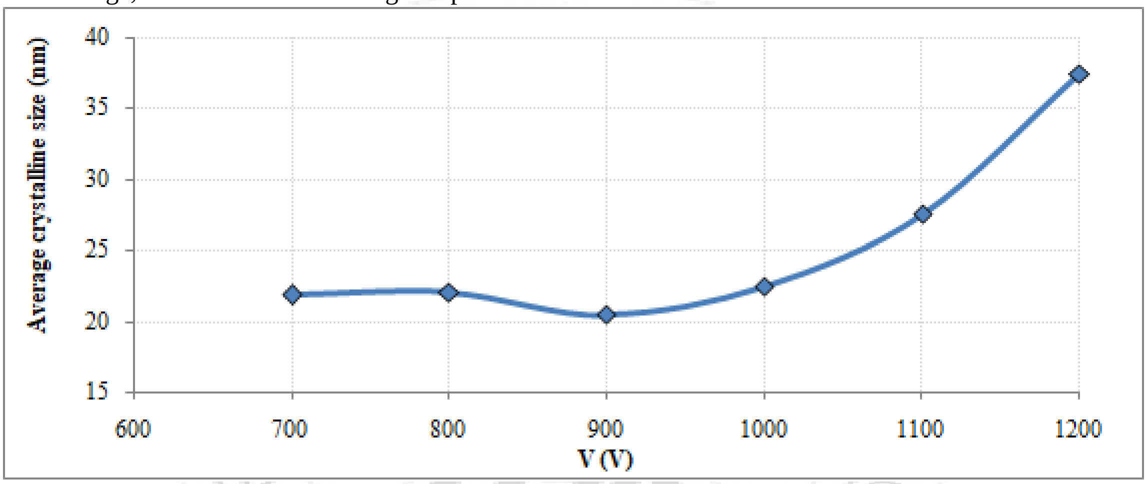


Figure 2: The variation of crystalline size for CdO with used voltages

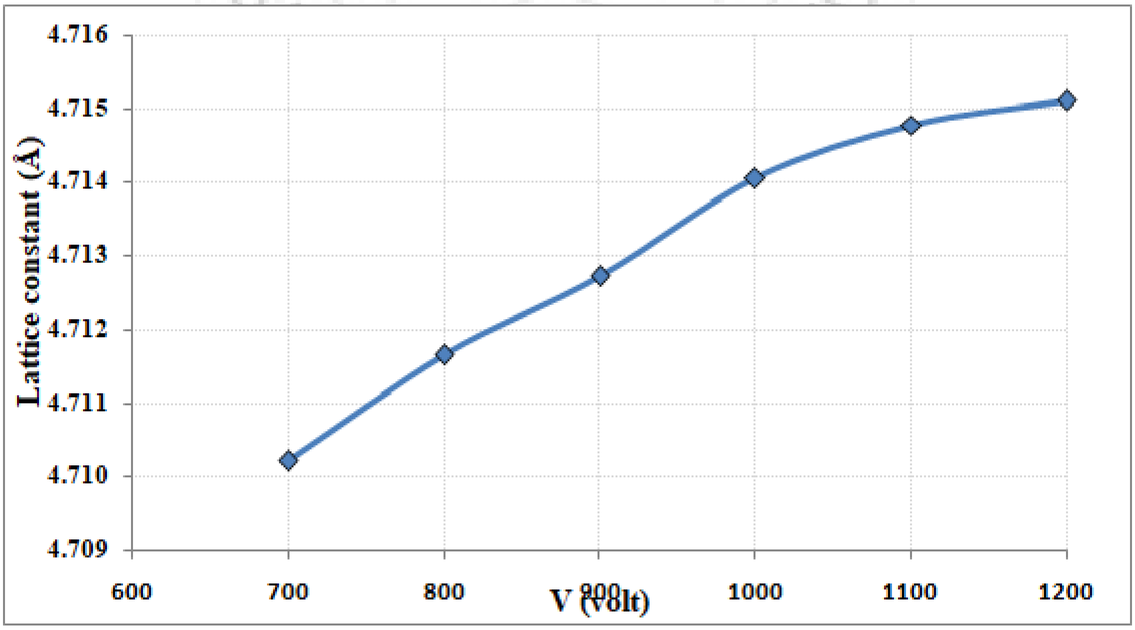


Figure 3: The variation of lattice constant for cubic CdO with used voltages

Fig. (4) shows the variation of absorbance for cadmium oxide as a function of wave length, within the range (300 – 1100) nm deposited at different sputtering voltage (700 to 1200) V. It can be noticed that all films have high absorbance at small wavelength and low values in the visible and near infrared region due to that the incident photons with small energydo not interact with atoms, the photon will transmitted, while high energy photon , greater than the energy gap, interact with valance electrons create hole-electron pairs and then the absorbance will increase[14].

The absorbance for all type of films increase with increasing sputtering voltage as a result of increasing film thickness and decreasing the energy gap.

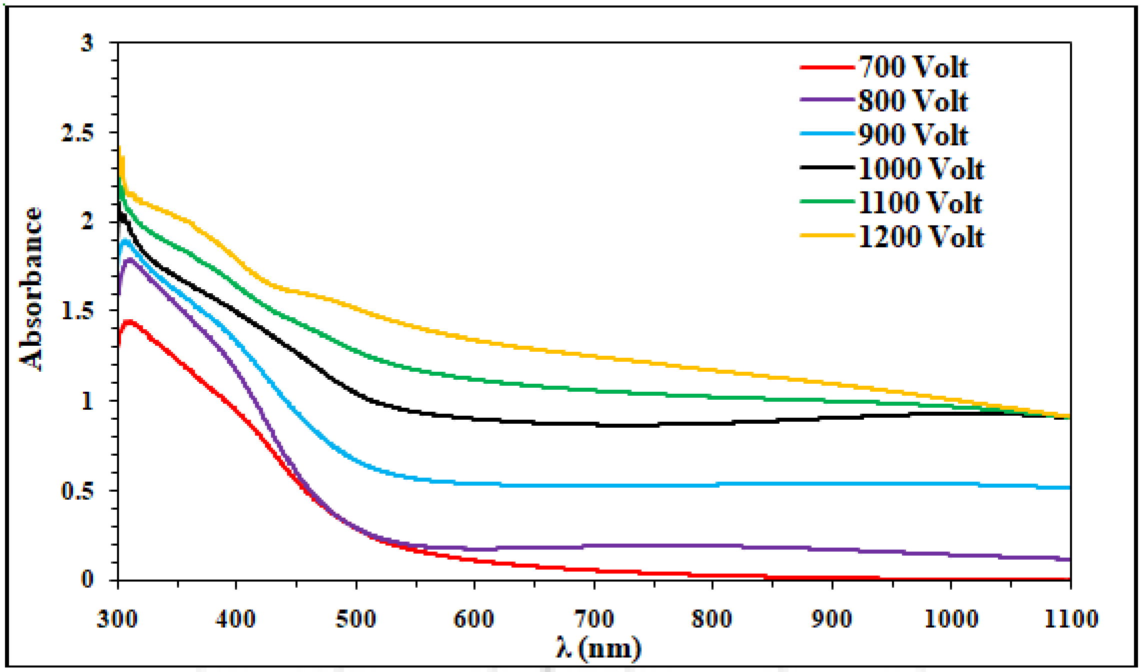


Figure 4: The absorbance curves for CdO thin films deposited by different voltages

The optical energy gap values have been determined by using Tauc equation by plotting the relation $(\alpha h\upsilon)^2$ versus photon energy (hυ). The energy gap (E_g^{opt}) was determined from the intersection of tangential line with hυ axis as shown in Fig. (5) for samples with different sputtering voltage.The energy gap decrease from 2.9 eV to 2.4 eV with increasing the sputtering voltage as a result of increasing the particle size due to increasing the ion collided energy with target [15]

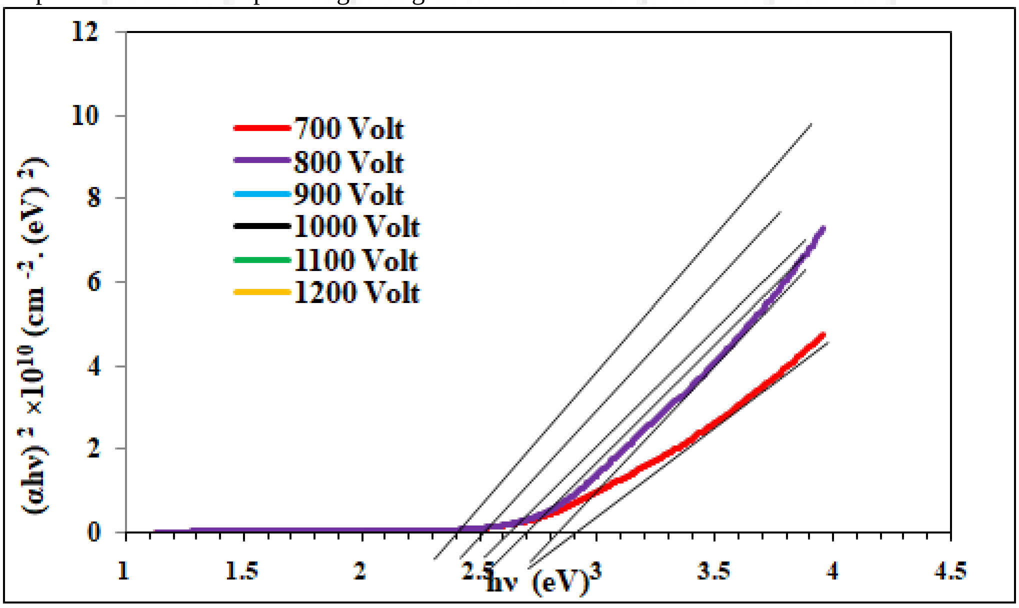


Figure 5: variation of $(\alpha hv)^2$ with *hv* for CdO thin films prepared with different applied voltages

The incremental in CdO energy gap sample compare with bulk CdO due to the quantum size effect [16].

Fig. (6) shows the variation of natural logarithm of conductivity with the inverse of temperature for all film deposited with different applied voltage. This figure shows linearly relation with two activation energies ranges from 303-393K and 393-473 K. The conductivity enhanced with increasing the sputtering voltage from 700 to 1200 V, While the activation energies decrease with it. All activation energy values have been listed in Table (2).

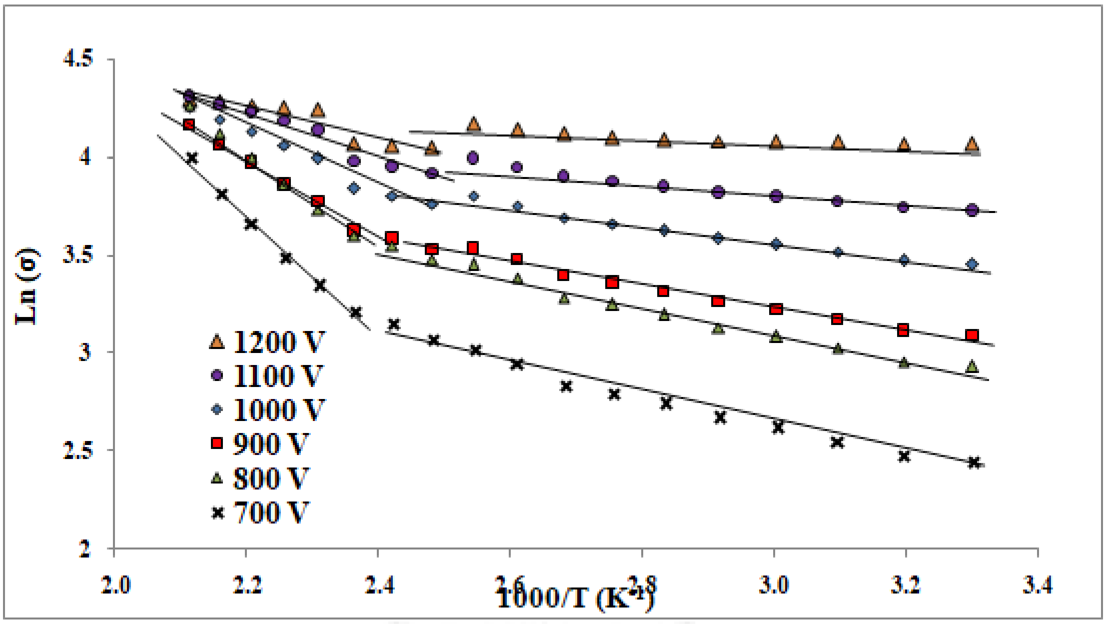
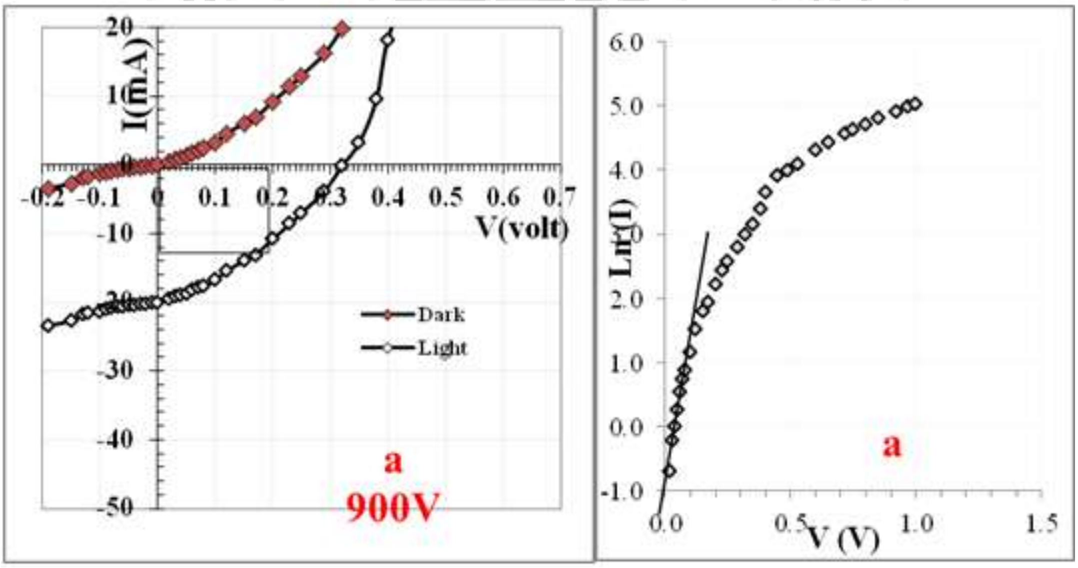


Figure 6: variation of *Ln (σ)* with *1000/T* for CdO thin films prepared with different applied voltages

Table 2: Activation energies and their ranges and electrical conductivity at RT

V (V)	E_{a1} (eV)	Range (K)	E_{a2} (eV)	Range (K)	σ_{RT} ($\Omega^{-1}.cm^{-1}$)
700	0.065	303-393	0.197	393-473	11.58
800	0.059	303-393	0.169	393-473	18.73
900	0.050	303-393	0.136	393-473	22.02
1000	0.040	303-393	0.105	393-473	31.63
1100	0.029	303-393	0.082	393-473	41.65
1200	0.010	303-393	0.048	393-473	58.63

Fig. (7-a,b,c,d) shows the I-V characteristics for n-CdO/p-Si hetrojunction for films deposited with different sputtering voltage. This figure shows that the efficiency (η)decrease with increasing the voltage as a result ofincreasing the film absorption as shown in Table (3).



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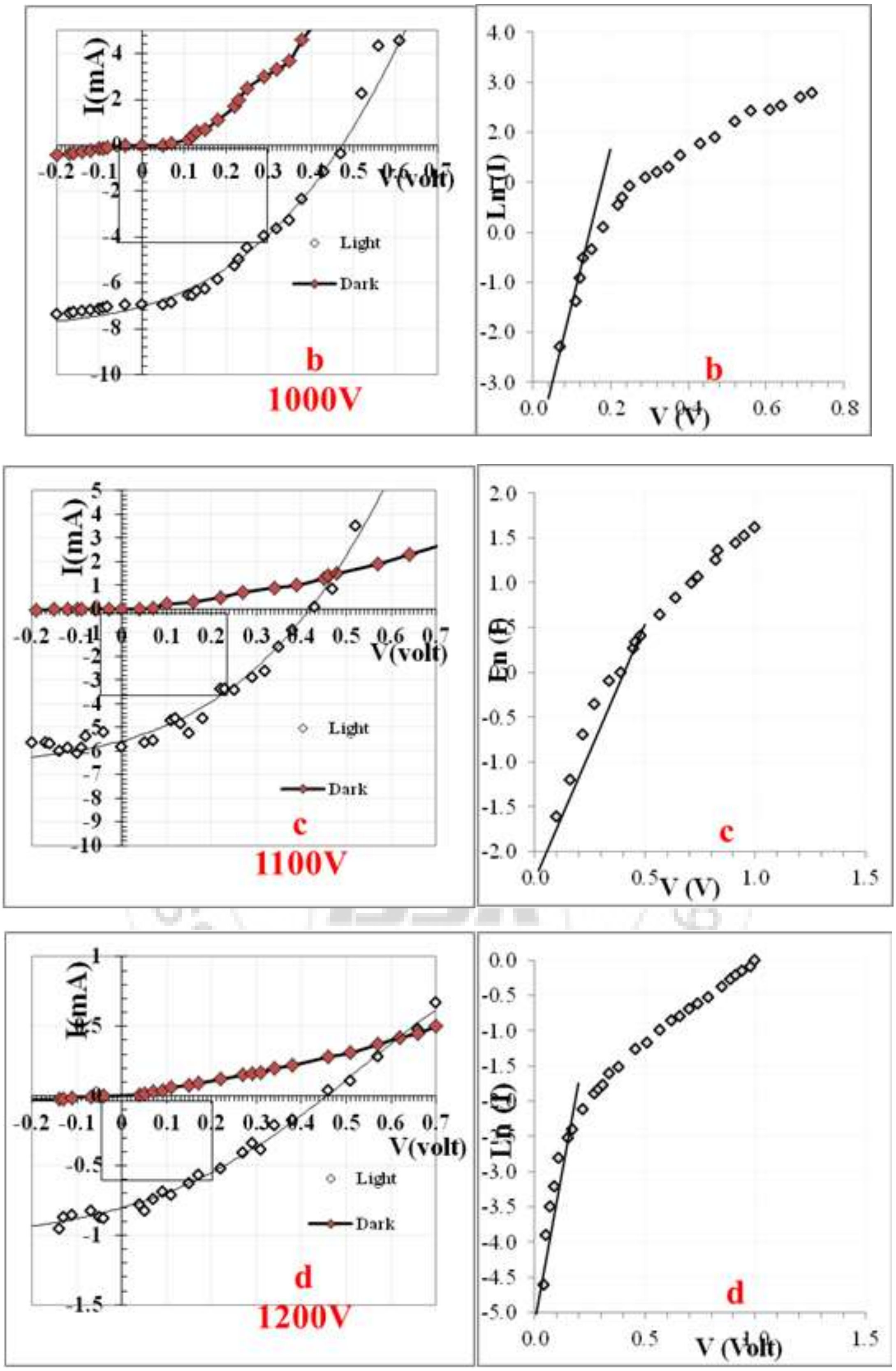

Figure 7: a,b,c,d: I-V Characteristics and the Ideality Factor calculation for n-CdO/p-Si hetro junction prepared with different voltage

Table 3: Solar cells parameters for CdO/Si deposited with different voltage

V(v)	I_{sc}(mA)	V_{oc}(V)	I_m(mA)	V_m(V)	F.F	η%	β
900	20.0	0.320	13.00	0.170	0.345	2.210	1.4
1000	7.0	0.480	4.000	0.300	0.357	1.200	1.7
1100	6.0	0.430	3.400	0.250	0.329	0.850	2.9
1200	0.8	0.440	0.600	0.220	0.375	0.132	1.7

4. Conclusions

CdO thin films synthesized by DC magnetron sputtering show a variety in its properties with deposition voltage. XRD results show that the crystallinety enhanced and the crystalline size increase with increasing used voltage. From Optical properties, it is found that the optical energy gap decreased with increasing sputtering voltage as a result of increasing particle size. Also, increasing the used voltage enhance the electrical conductivity and reduce the activation energies.

Solar cell measurements show a low efficiency for all samples, but the efficiency increased with increasing the sputtering voltage to from 900 to 1200 V.

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