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Study the Effect of Temperature, Resistors, and Absorption Layer CNTS on Cell Performance Using SCAPS

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Keywords:

CNTS; Chalcogenide Quaternary; SCAPS; Solar Cell; Simulation.

Highlights:

- The thickness increases the cell efficiency to increase the number of photons absorbed by the absorbing layer.
- Increasing the lifetime of the carriers reduces recombination and thus increases the efficiency of the solar cell.
- Adding a background reflection layer increases the number of absorbed photons and increases the cell efficiency.
- Increasing the parallel resistance increases the cell performance by increasing the number of Traps (electron gap).
- Series resistance and temperatures negatively affect cell performance.

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Abstract: The ZnO/CdS/CNTS solar cell was simulated using the SCAPS program. It was found that increasing the concentration of the acceptor and the thickness of the absorber layer increased (η , Voc) and decreased (FF). The best concentration was $1.0 \times 10^{12} \text{ cm}^{-3}$, and the best thickness was (2.5 μm). Increasing the lift time of minority carriers increased (η , FF, Jsc) and decreased (Voc). Adding a back-reflection layer (BSF) increased the conversion efficiency from 14.07 % to 15.15%. The effect of increasing the acceptor concentration in the reflection layer was similar to the absorption layer; however, increasing the thickness was opposite to the absorption layer, meaning it increases (FF) and decreases (η , Voc). The results showed that increasing the shunt resistance increased (η , FF, Voc), while increasing the series resistance decreased (η , FF, Voc), and increasing the temperature reduced (η , Voc, Jsc) and increased (FF).

دراسة تأثير درجة الحرارة والمقاومة وطبقة الامتصاص CNTS على أداء الخلية باستخدام Scaps

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الخلاصة

تمت محاكاة الخلية الشمسية ZnO/Cds/CNTS باستخدام برنامج SCAPS، وتبين أن زيادة تركيز القابلات والسلك لطبقة الامتصاص يزيد من (η , Voc) ويقلل من (FF) وأن أفضل تركيز كان $1.0 \times 10^{12} \text{ cm}^{-3}$ وأفضل سمك ($2.5 \mu\text{m}$). زيادة ديمومة حاملات الأقلية يزيد من (η , Jsc, Voc) ويقلل من (FF). وأن إضافة طبقة انعكاس خلفي (BSF) يزيد من كفاءة التحويل من 14.07% إلى 15.15% وأن تأثير زيادة تركيز القابلات لطبقة الانعكاس مشابه لطبقة الامتصاص ولكن تأثير زيادة السمك معاكس لطبقة الامتصاص بمعنى بزداد (FF) ويقلل من (η , Voc). وأظهرت النتائج أن زيادة مقاومة التوازي يزيد من (η , FF, Voc)، وأما زيادة مقاومة التوالي فيقلل من (η , FF, Voc) وأن زيادة درجة الحرارة يقلل من (η , Voc, Jsc) ويزيد (FF).

الكلمات الدالة: الكولكوجينيد الرباعي، SCAPS، CNTD، محاكاة، الخلية الشمسية.

1. INTRODUCTION

The wide spread of energy in recent years due to the development of civilization has depleted large amounts of non-renewable energy (oil, natural gas, and coal), which led humans to look for alternatives to non-renewable. It is called non-renewable energy because its composition rate is much lower than the consumption rate. In addition to the limited capacity of this energy, the pollution problems associated with its use are increasing daily. Many attempts have been made to obtain more permanent power than traditional energy sources, and the renewable relationship of solar power, wind power, and hydropower has been discovered. [1] The subject of the study is solar energy, resulting from converting sunlight to electric power using solar cells. The solar cell is a thin film of a semiconductive material doped with impurities n-type and p-type, the thin film not exceeding the thickness of micrometers placed on glass or silicon pillars; it is low cost due to the lowest materials used. It has been used since 1970, and its efficiency has increased to 28.8% [2,3]. For several centuries, researchers have been using the compounds cadmium telluride (CdTe) and copper gallium indium selenide (CIGS) in manufacturing the thin film of solar cells. These materials are characterized by high efficiency and, in return, high cost and occupy a large area. Some are rare, and others toxic, so the researchers sought to replace them with other materials. They found alternative materials with discrete structures, such as CZTS, CNTS, and others called chalcogenide quaternary, are available in the earth's crust, have a low cost of production, are non-toxic, and have bandgap close to the ideal value, and have a high absorption coefficient [4,5]. Therefore, the interest in these materials has increased as they are characterized by good visual and electrical qualities for manufacturing thin films. Solar cells (CZTSSe) were simulated to increase cell functions, and the improvement was achieved by inserting a layer of p-Si on the surface. The apparent results of inserting the layer increased

the cell efficiency, i.e., was (12.6%) and became 16.59%, which is an important development [6]. CNTS was prepared as a powder, and its crystal structure was cubic. It was prepared in thin films by a coating method and had a nanostructure. The energy gap of the CNTS compound is 1.5eV [7]. The thin films of the CNTS compound were fabricated on a glass floor by electric deposition method after being annealed at a temperature of 550 K, and the energy gap was 1.61 eV [8,9]. CNTS thin films were fabricated by the dip-and-spin coating method on soda lime glass SLG, FTO-coated tin-oxide-coated glass, and Mo-coated glass by dissolving CuCl_2 , NiCl_2 , SnCl_2 , thioacetamide, and MEA in ethanol at 50 °C [10,11]. This study presents CNTS and its effectiveness as an absorbent layer for the unique characteristics of this compound as it has a direct bandgap (1.45-1.74 eV), is available in the earth's crust, non-toxic, p-type. Also, it has a high absorption coefficient, so it is an important and candidate compound for manufacturing solar cells [12-14].

2. MODELING

2.1. Numerical Simulations in SCAPS

SCAPS program is a one-dimensional solar cell simulation program and was manufactured to simulate traditional crystalline materials for CIGS, CdTe, or other materials, such as SnS. The user can describe a cell of seven layers maximum for different properties, such as optical absorption, thickness, doping, and bandgap. Spectral responses to J-V, QE, C-F, and C-V were determined and calculated in the dark and the light as a function of temperature. This program has been developed and applied to all solar cells. Also, it is freely available depending on the Poisson equations of the electron and hole continuity. Starting by writing a Poisson equation: [15,16]

$$\nabla(E) = \frac{q}{\epsilon} (p - n + N_D^+ - N_A^-) \quad (1)$$

The continuity equation is expressed as:

$$\frac{dn}{dt} = \frac{1}{q} (\nabla (J_n) + G_n - R_n) \quad (2)$$

$$\frac{dp}{dt} = \frac{1}{q} (\nabla \cdot (J_p)) + G_p - R_p \quad (3)$$

Finally, the equations of the charge carriers for diffusion and drift current of propagation

$$J_n = q(\mu_n n E + D_n \nabla n) \quad (4)$$

$$J_p = q(\mu_p p E + D_p \nabla p) \quad (5)$$

where ϵ is the permittivity of the absorber, E is the electrical field, N_D (N_A) is donor (acceptor) concentration, q is the elementary charge, G (R) is carrier generation (recombination) rate, n (p) is the density of electrons (holes), J_n (J_p) is the current density of electron (holes), and D is the diffusion constant.

2.2.Solar Cell Structure

Figure 1 shows the study’s proposed photocell composition.

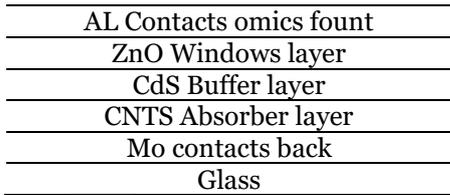


Fig.1 Solar Cell Structure.

The cell consists of a windows layer ZnO of transparent metal oxides that have a relatively large bandgap to allow the passage of the greatest amount of fallen light, followed by the CdS buffer layer, which has a bandgap smaller than the windows layer, and then the absorption layer CNTS. Also, it has a front and back connection of aluminum and gold work function 5.2 eV and 4.1 eV, respectively [17]. The cell is on a glass floor, as well as a full-fledged layer of absorption and gold from CZTS, which is the BSF back surface reference to increase the efficiency of the cell due to reducing the recombination of the back contact and enhance the concentration acceptor of vectors by reversing fallen photons [18]. So, the installation becomes cell ZnO/CdS/CNTS/CZTS. It has been studied the effect of increasing the concentration acceptor and the thickness of the absorption layer on cell performance, and the lift time of minority carriers. The lift time, which plays a major role in cell performance, is the average time needed for recombination. They are associated with the recombination of Ethel [12].

$$\tau = \frac{\nabla n}{R} \quad (6)$$

τ is the lift time of minority carriers, R is the recombination rate, and ∇n is the excess minority carrier. Concentration, the effect of the series resistor, and shunt on the cell’s performance were noted, and the effect of temperature was studied on the cell’s performance. Table 1 illustrates the values of parameters to be entered in the SCAPS program to study cell performance.

Table 1 Parameters Used in the Simulation.

Material Properties	ZnO [19]	CdS [21]	CNTS [21,12,22]	CZTS [23,24]
Thickness (μm)	0.2	0.2	2.5	0.1
Band gap E_g (eV)	3.3	2.4	1.74	1.5
Electron affinity χ (eV)	4.4	4.2	3.87	4.5
Dielectric permittivity ϵ	9	10	9	10
CB density of state N_v (cm^{-3})	2.2E18	2.2E18	2.2E18	2.2E18
VB density of state N_c (cm^{-3})	1.8E19	1.8E19	1.8E19	1.8E19
Electron thermal velocity V_{th} (cm/s)	1.0E7	1.0E7	1.0E7	1.0E7
Hole thermal velocity V_{th} (cm/s)	1.0E7	1.0E7	1.0E7	1.0E7
Electron mobility μ_n ($\text{cm}^2/\text{v.s}$)	100	100	11	100
Hole mobility μ_p ($\text{cm}^2/\text{v.s}$)	25	25	11	25
Donor density N_D (cm^{-3})	1.0E18	1.0E18	0	0
Acceptor density N_A (cm^{-3})	0	0	1.0E12	1.0E18

3.DISCUSSION

The ZnO/CdS/CNTS cell was studied to identify the changes to the I-V curve properties in terms of Voltage opine circuit V_{oc} , Current short circuit J_{sc} , full factor FF, conversion efficiency η , and Quantum efficiency QE and compare the results with practical results to improve cell efficiency.

3.1.The Effect of Absorption

3.1.1.Effect of Concentration Acceptor on the Absorption Layer

The concentration of (1.0e10-1.0e15) eV was changed and observed through Fig. 2. Increases (V_{oc} , η) by increasing the concentration of the Acceptor, and the reason for this increase is the increased disposition of carriers resulting from the increased Saturation current. Also, there was a gradual decrease in the values (J_{sc} , FF) due to the increase in recombination processes. Increasing recombination reduces the probability of photons accumulating, and photons with a longer wavelength have less energy and are more absorbed, and the best concentration of acceptors was $1.0 \times 10^{12} \text{ cm}^{-3}$ [25].

3.1.2.The Effect of the Thickness of the Absorption Layer

The thickness back readings were considered, ranging from (0.1–8) μm we note from Fig. 3. The thick absorption layer increased (J_{sc} , η) to increase generating optical electrons and (V_{oc}). They decreased slightly and then increased. The FF increased up to (2 μm) and then decreased due to the recombination in the cell. The best thickness of the absorption layer was (2.5 μm) [25].

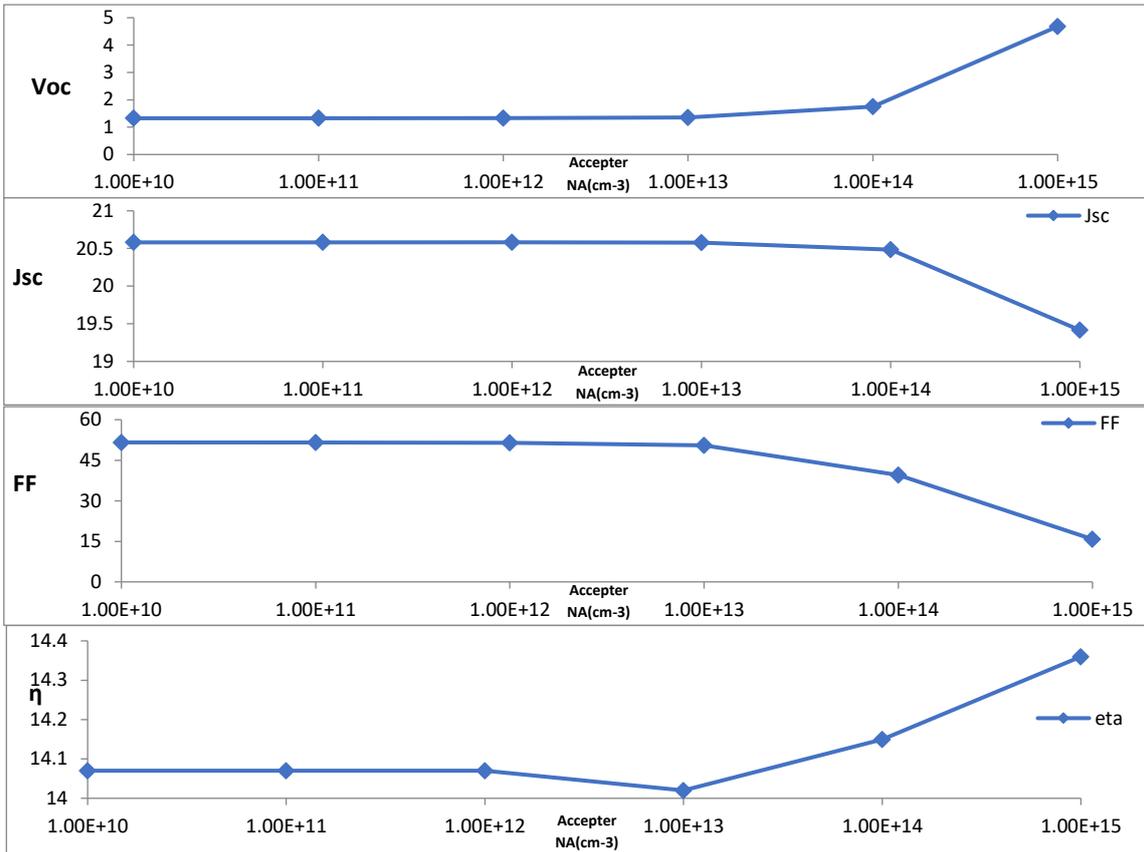


Fig. 2 The Effect of the Concentration Acceptors of the CNTS Absorption Layer.

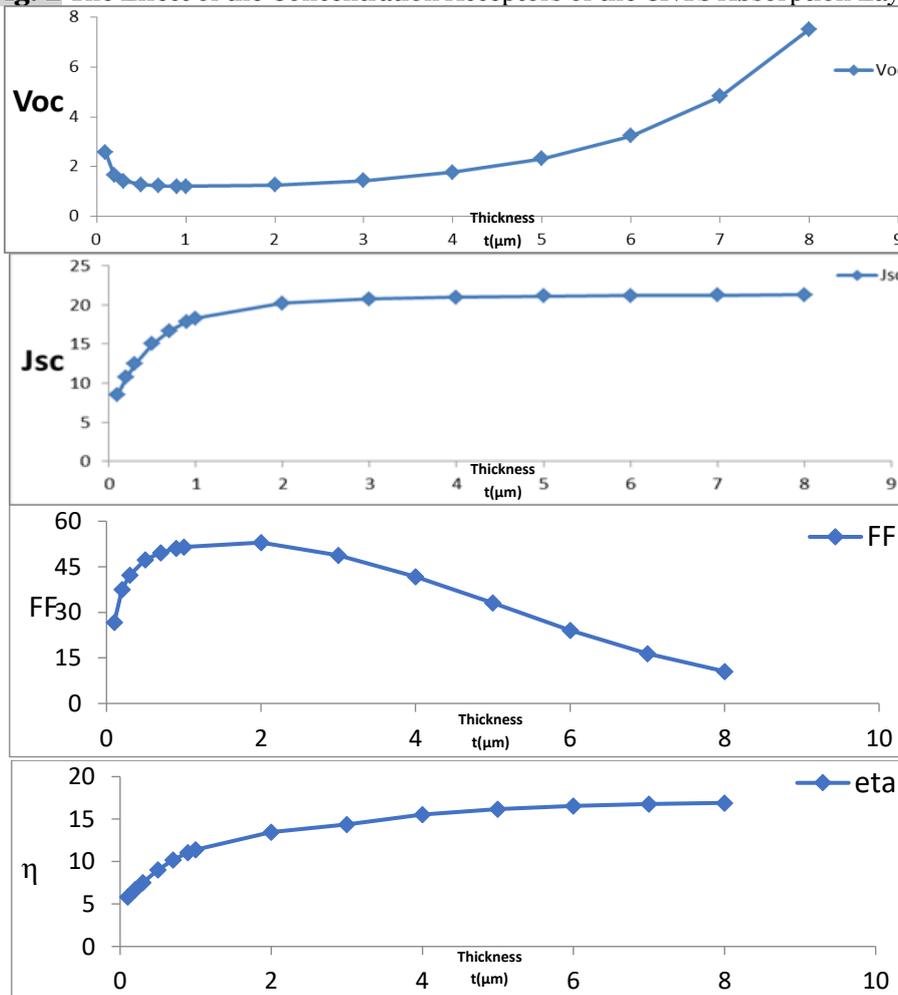


Fig. 3 Effect of Thickness of the CNTS Absorption Layer.

3.1.3. Effect of Minority Carrier Lift Time

Lift time (τ) is the average time needed to recombination minority carriers. The minority carriers play a key role in the performance of the cell; therefore, they are considered one of the most controlled parameters of semiconductor characteristics and are associated with the defects recombination, connectivity, and thermal velocity with the following [26]:

$$\tau = \frac{1}{\sigma V_{th} N_t} \quad (7)$$

Fig. 4 shows the relationship of the lift time of minority carriers with the parameters of the absorption layer, i.e., the lift time changed exponentially with the range that begins from (10000-1) ns.[7] An increase was noted in the short circuit current, the fill factor, and the

conversion efficiency. The more the lift time, the short circuit voltage decreased and improved because increased lift time leads to recombination. Recombination means immersing a free electron in the gap. The time between the presence and disappearance of the free electron is called (lift time). It varies from parts of a nanosecond to a few microseconds depending on the ideality of the crystals and other factors [27]. The lifetime of minority carriers affects quantitative efficiency. Fig. 5 relates the efficiency of wavelength with quantitative efficiency. The quantitative quality became 100% on wavelength less than (400) nm, which has wavelength more than that value, so the quantitative efficiency increased as lift time increased.

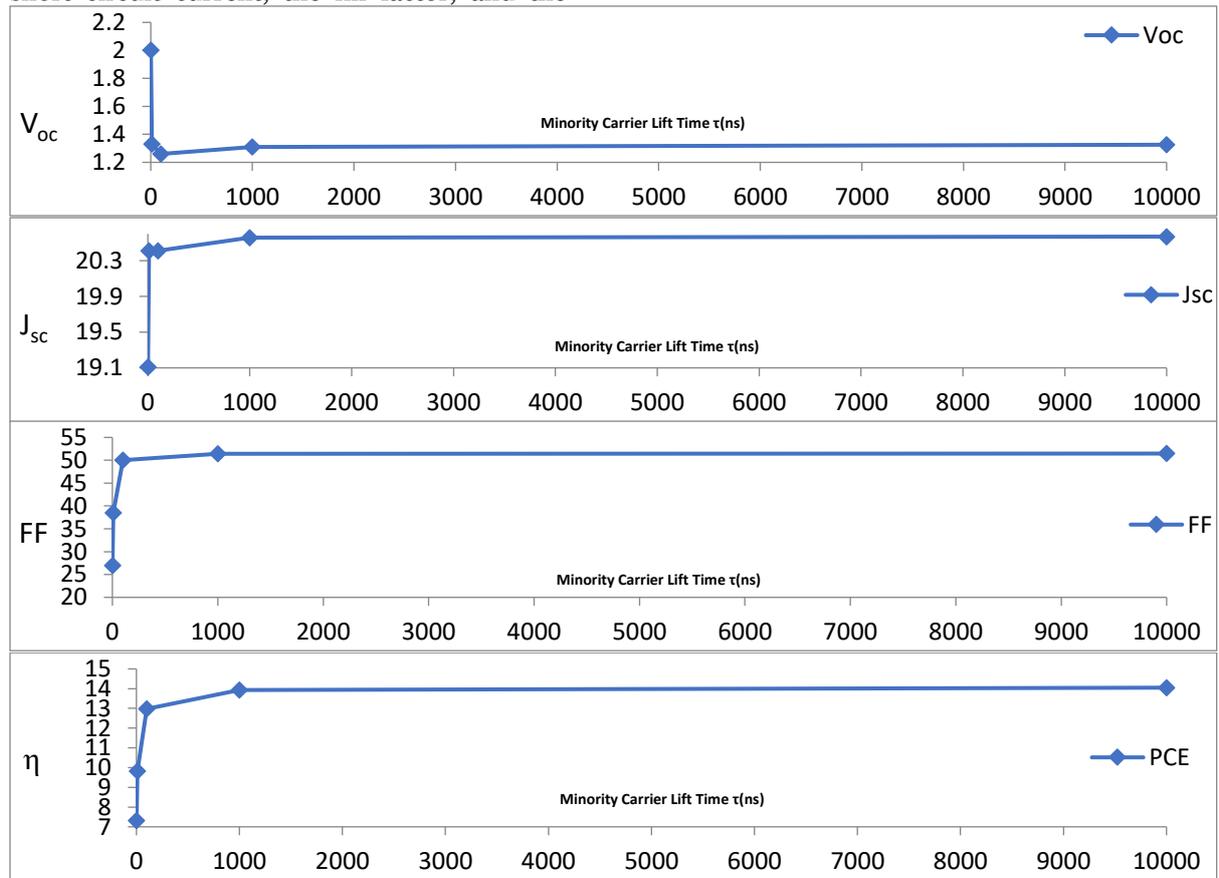


Fig. 4 Relationship of Lift Time with the Cell Parameters of the Absorption Layer.

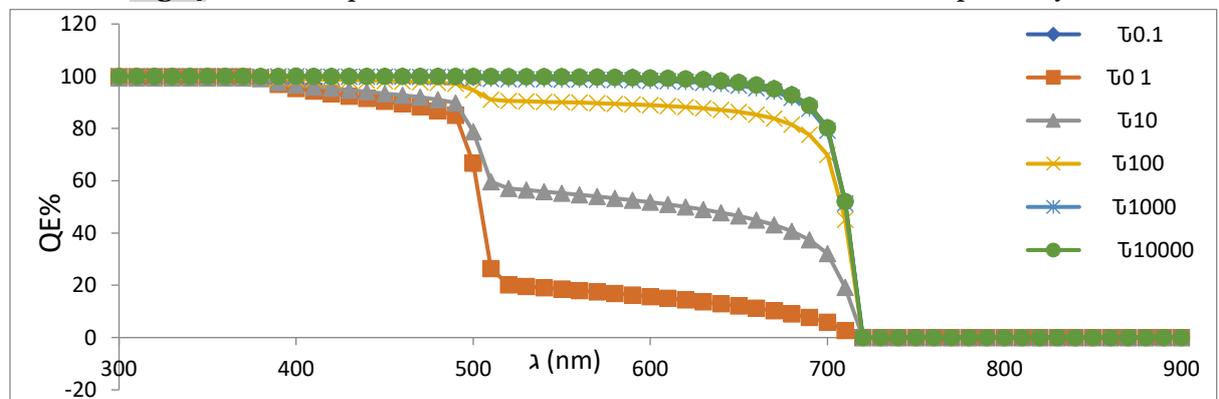


Fig. 5 Relationship of Quantitative Efficiency with Wavelength as a Function of the Lift Time of Minority Carriers of the Absorption Layer.

3.2. Effect of the Back-Surface Reflection

To study the effect of the BSF back surface reflection on the performance of the cell, a layer between the back contact and the absorption layer was placed to reverse the photons penetrating from the absorption layer, increasing the concentration of the charge carriers and reducing the recombination, and thus the connection became more omi and increased the current of photons. Fig. 6 shows the voltage relationship with current. Fig. 7 shows the relationship of quantitative efficiency to wavelength with the presence of the reflection layer, so the quantitative efficiency was 100% in all visible wavelengths. Fig. 8 shows the relationship of cell parameters with the concentration of acceptor to the back-

surface reflection; an increase in (η , V_{oc}) was noted by increasing the concentration of acceptor with (J_{sc}) remaining constant values. (FF) decreased by increasing the concentration of acceptors. Back contact generated an electric field that reduced the speed of surface recombination and recombination processes. This field is increased by increasing the doping of the back-reflection layer and improving the solar cell's conversion efficiency [28,29]. Fig. 9 shows the effect of the thickness of the back-surface reflection on the cell's performance. The increase in the back-surface reflection thickness reduced (η and V_{oc}) and conversely increased (FF) by increasing the reflection layer. While (J_{sc}) remained almost constant.

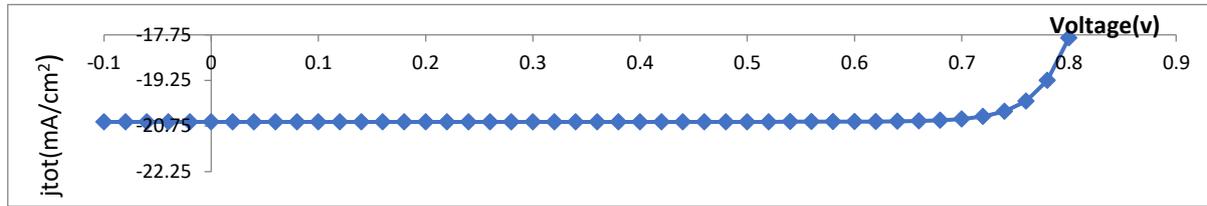


Fig. 6 V - I with the Presence of the Reflection Layer.

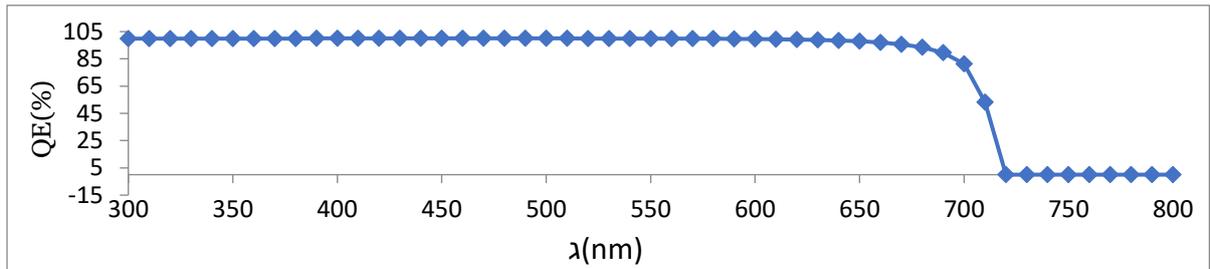


Fig. 7 Quantitative Efficiency Relationship with Wavelength.

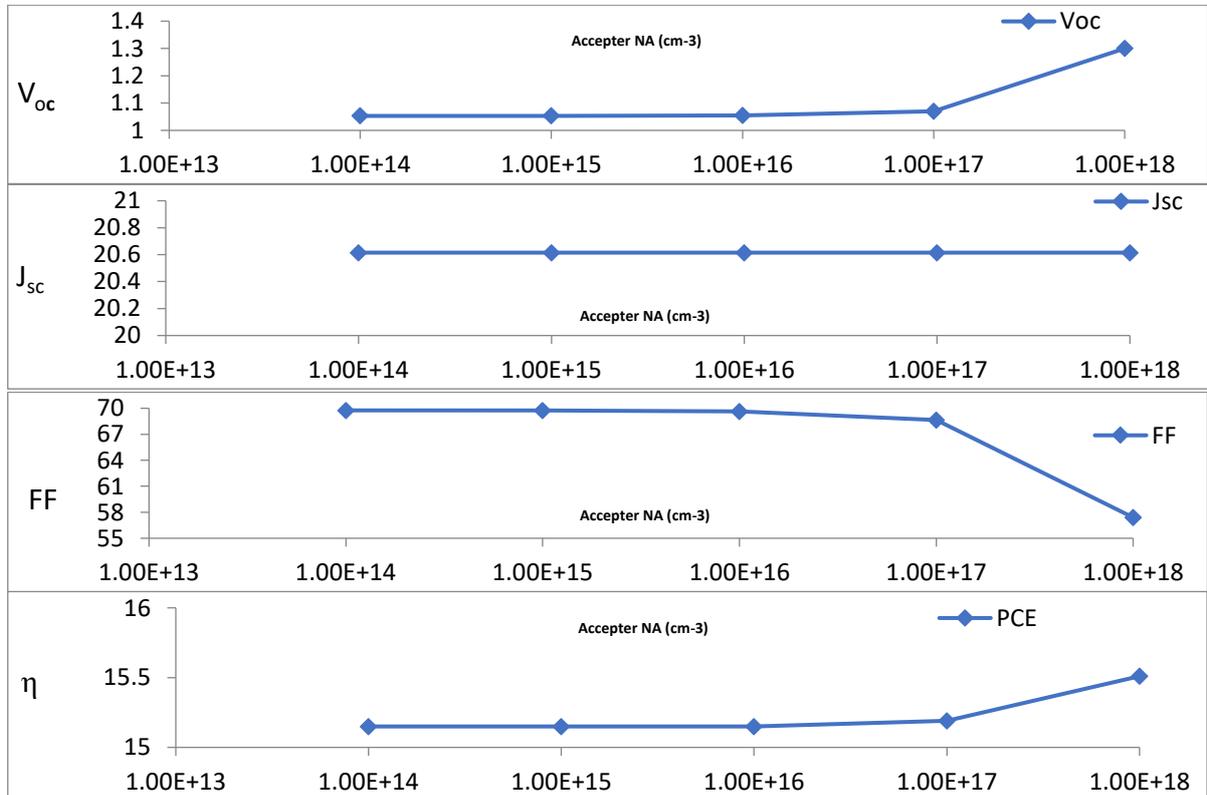


Fig. 8 The Effect of the Concentration of Acceptors on Cell Parameters.

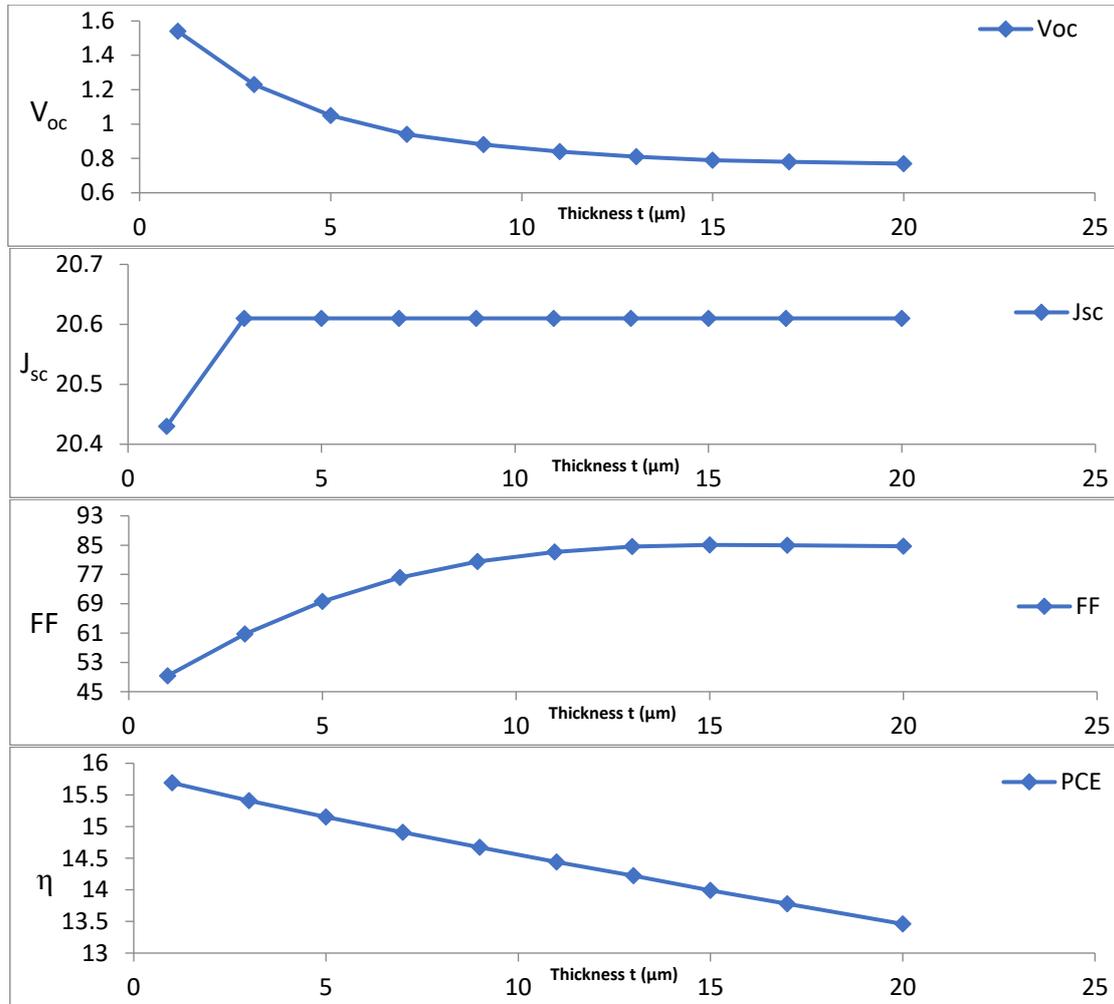


Fig. 9 The Relationship of the Thickness of the Reflection Layer with the Cell Parameters.

3.3. Series Resistor Effect

The resistor is the self-resistor of the semiconductor. The resistance of metal connections and the resistor of the connection between metal - semiconductor mainly affected the fill factor and the short circuit current. Fig. 10 shows a decrease in the fill factor, conversion efficiency, and the short circuit current as the series resistor increased due to saturation current increase; thereby an external capacity decreased [30,31]. The short circuit voltage remained constant because the current was zero. Fig. 11 shows the current and voltage relationship to different resistor values. A match in the values can be observed.

3.4. Shunt Resistor Effect

The current leakage caused the shunt resistor during the diode junction around the edge of the cell and other internal areas due to crystalline defects or internal impurities. Fig. 12 illustrates the relationship between voltage and current in the presence of a shunt resistor. Increasing the shunt resistor increased the curve because a low resistor consumed a large

amount of solar cell capacity [31,32]. Fig. 13 shows the effect of the shunt resistor on cell parameters. An increase in (V_{oc} , J_{sc} , and η) was observed whenever the value of the parallel resistor was higher due to providing an alternate current path for the light-generated current. The short-circuit current is not official in the form because it is not affected by a parallel resistor.

3.5. Temperature Effect

The temperature directly affects the solar cell performance because the increase in temperature reduces the bandgap, increasing light absorption as more photons have more energy or equal the gap. Fig. 14 shows lower values (V_{oc} , FF, and η) as temperature increased because the short circuit's voltage is inversely proportional to the temperature. The short circuit current decreased by increasing the saturation current and thus will decrease the conversion efficiency. The fill factor increased by increasing the temperature to increase the recombination in the area of attrition.

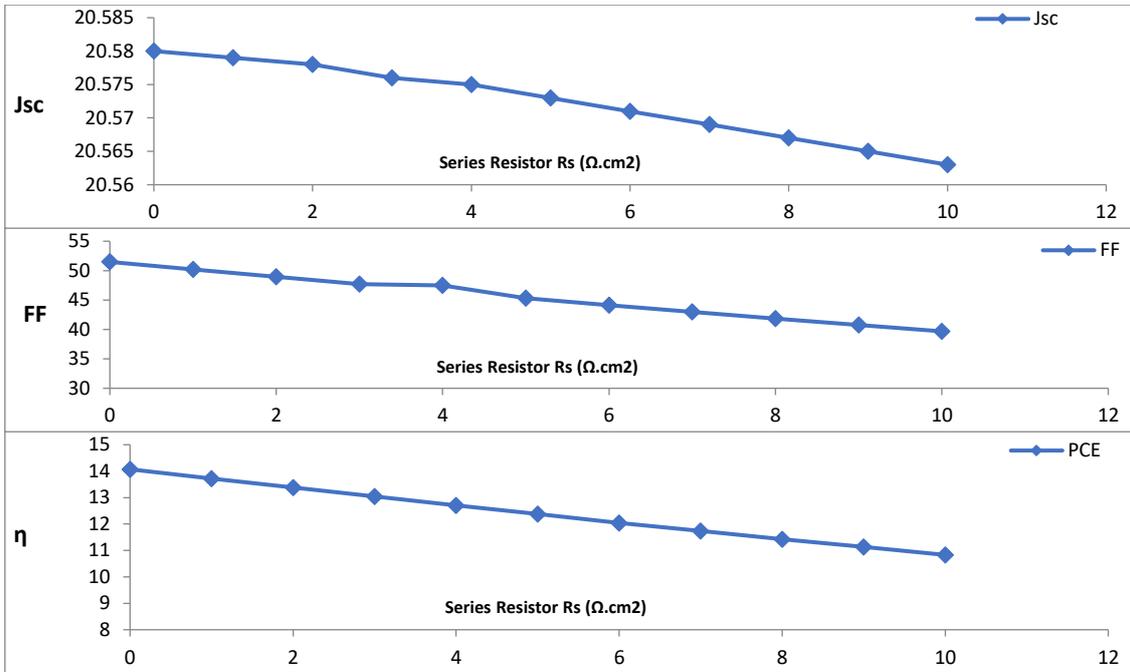


Fig. 10 The Effect of Running Resistor on Cell Parameters.

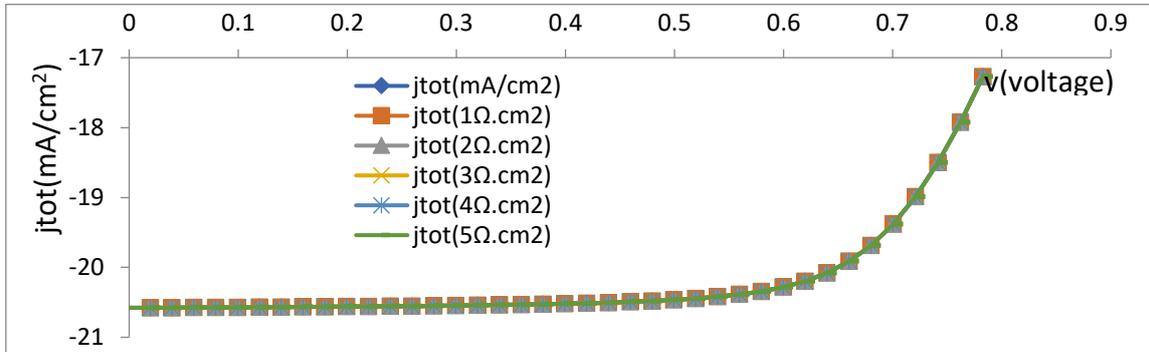


Fig.11 Voltage and Current Relationship to a Series Resistor.

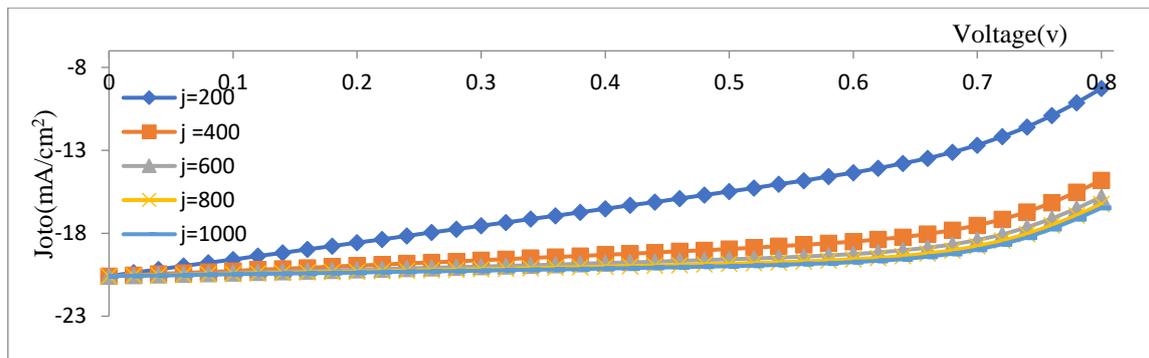
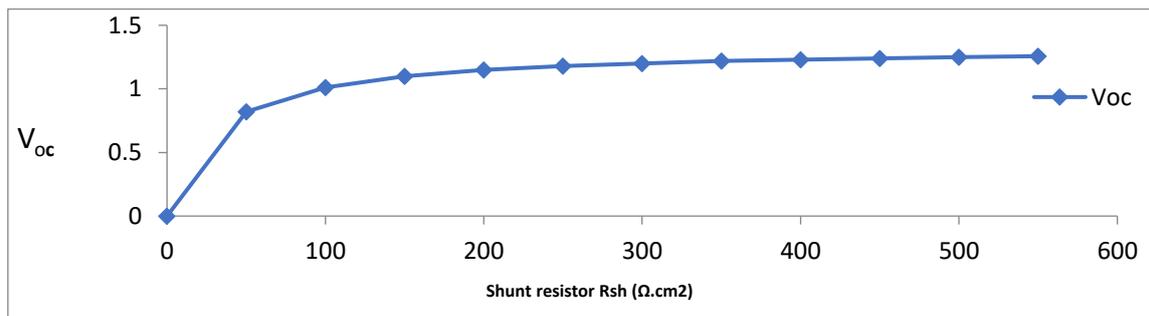


Fig. 12 Voltages, Current, and Effect of Shunt Resistor Curves Shunt.



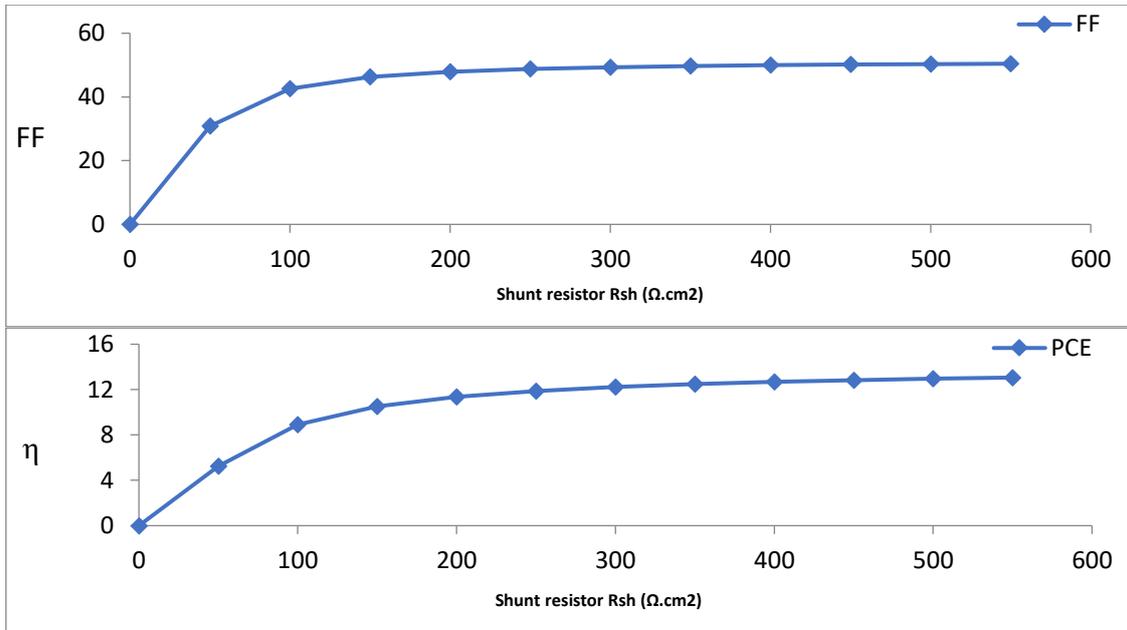


Fig. 13 The Effect of Shunt Resistor on Cell Parameters.

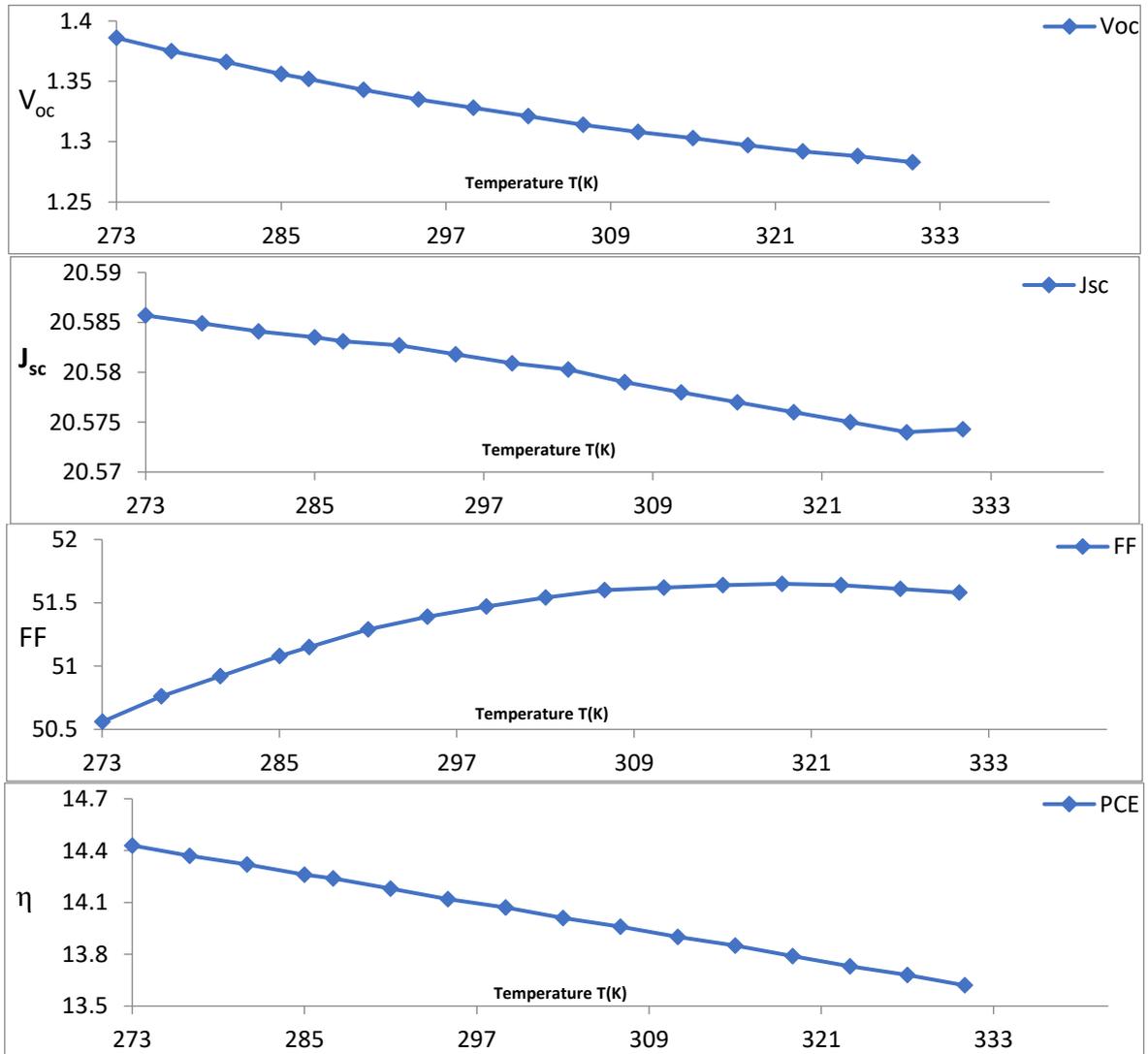


Fig. 14 The Effect of Temperature Difference on Cell Parameters.

4. CONCLUSIONS

The ZnO/CdS/CNTS cell was studied using SCAPS. It was found that the absorption thickness directly affected the cell performance. So, increasing the thickness increased the conversion efficiency and quantitative efficiency. However, increasing the thickness decreased the fill factor and increased the concentration of acceptors. The absorption layer increased the cell efficiency. Adding the back surface reflection of the cell increased the cell quality by changing the thickness and concentration of the reflection layer. The effect of the series resistor and shunt on the cell performance was noted. Increased series resistor reduced cell efficiency. When the shunt resistor increased, it increased efficiency. The effect of temperature was studied, and it was noticed that the increase in disputing temperature reduced the cell efficiency.

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