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Research Article

Effect Of Carrier Concentration And Thickness Of Absorber Layer On Performance CBTS Solar Cell

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Abstract: In this research, using computer simulations, the solar cell (CBTS / CdS / ZnO) was studied by the effect of the thickness and concentration of the absorption layer in it with respect to the properties curve (I - V), the characteristic curve (C - V) and the quantum efficiency curve (QE) of the cell, when thickness of the absorption layer increased It leads to an increase in the short circuit current (Isc), the open circuit voltage (Voc) and the efficiency of the solar cell (Eta) . Also, the quantum efficiency of the solar cell increases with the increase in the thickness of the absorption layer. As for the effect of the carrier concentration of the absorption layer, we found that by increasing the concentration of the absorption layer, (Voc) increases with the increase in the concentration of the doping, while (Jsc) decreases. Therefore, the conversion efficiency depends on the effect of the concentration density. As for the effect of the carrier concentration of the absorption layer on the properties of C-V, it is noticed that increase in capacitance of the solar cell with increasing concentration .

1. Introduction

Semiconductor devices play an important role in commercial applications and can be widely used in power generation in the form of photovoltaic . Photovoltaic absorb sunlight and convert it into electrical energy [1]. Thin film technology is one of the most cost-effective and efficient technologies in manufacturing photovoltaic cells, with the passage of time and the increasing demand for energy the need for energy sources increased more. One of alternative source of energy is solar energy as photovoltaic are widely used [2].

Solar cell: An electronic device that converts the energy of sunlight into electrical energy through a process of the photoelectric effect. Because of the mechanism of action of the solar cell, the two most important points must be achieved in choosing the material as an absorbent layer: firstly: the ability to absorb light as much as possible in order to excite the electrons to higher energy states and secondly the ability to move free electrons from the solar cell to an external circuit. The choice of non-toxic, environmentally friendly and air-stable materials plays a vital role in manufacturing thin-film PV devices [3]. Chalcogenide compounds are well-known semiconductor materials that have attracted great interest among scientists due to their the ability to be used in PV devices and solar cells. Recently, Cu2BaSnS4 (CBTS) has been identified as a potential alternative to PV cells due to the wide energy gap (1.9ev), Non-toxicity, suitable defect properties, environmentally friendly PV material, high absorption coefficient ($>10^4$ cm^{-1}), and p-type conductivity [4]. In this work, Enhancing the efficiency of CBTS/CdS/ZnO

structured experimental reference cell [5].CBTS was simulated using the SCAPS - 1D program, One method enhancing the efficiency and improving the performance of the CBTS-based photovoltaic device is :

- Validation of the CBTS experimental cell.
- Proposing novel structure of CBTS/CdS/ZnO for solar cells.
- Optimization of absorber layer thickness .
- Optimization of doping concentration.
- Comparison of results

2. Device structure

The photoelectric device used in this work is CBTS / CdS / ZnO as in Fig. 1, which contains a CdS buffer layer, ZnO window layer, CBTS absorption layer , front and back contact(ohmic). In this work, the effect of physical factors such as thickness and carrier concentration on the performance of the device is studied.

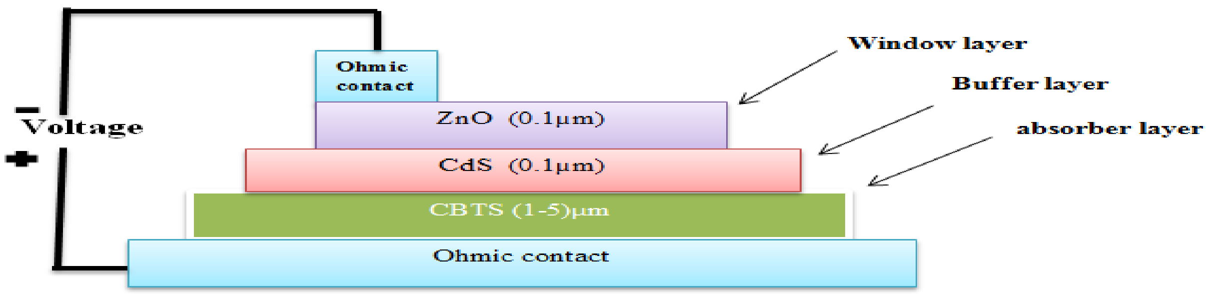


Figure (1) the structure of the device

Simulation of the device was performed in SCAPS software which is a one-dimensional solar cell capacitance simulation program developed in the Department of Electronics and Information Systems (ELIS) at the University of Ghent, Belgium where it is able to calculate the properties of J-V and its photoelectric parameters, the most important of which is the voltage Open circuit (Voc), short circuit current density (Jsc), fill factor (FF), efficiency (η), C-V properties, as well as the QE curve under standard illumination AM 1.5 solar radiation with a power density of 100 mW / cm^2 as the light source. [6] by solving basic semiconductor equations.

In performance of the device, the basic semiconductor equations play a crucial role. To analyze the performance of the device, the simulator must be able to solve these equations.[7]

- **Poisson's equation** is used to describe the form of the relationship between voltage and space charges, as shown in the equation below :

$$\frac{\partial 2}{\partial x2}\emptyset(x) = \frac{q}{\varepsilon}[n(x) - p(x) - ND^{+}(x) + NA^{-}(x) - P_t(x) + n_t(x)] \quad (1)$$

Where **∅** voltage, **q** elementary charge, **ε** permittivity, **n** free electron density, **p** free hole density, $\mathbf{N_D^+}$ ionized donor charge density, $\mathbf{N_A^-}$ Ionized charge density, $\mathbf{p_t}$ bound hole density, $\mathbf{n_t}$ bound electron density.[8]

- **The continuity equation** is defined as the equation that defines the carriers transport process, represented by the equations below :

$$q\frac{\partial n}{\partial t} = \frac{\partial J_n}{\partial x} + qG - qR \quad (2)$$

$$q\frac{\partial p}{\partial t} = -\frac{\partial J_p}{\partial x} + qG - qR \quad (3)$$

Where G is the generation rate , R is the recombination rate .[9]

- **Diffusion-drift equations** of charge carriers used to measure electron current and hole current density of a solar cell are shown in the equations below.

$$J_n = qn\mu_n\frac{\partial \emptyset}{\partial x} + qD_n\frac{\partial n}{\partial x} \quad (4)$$

$$\boldsymbol{J_p = -qp\mu_p\frac{\partial \emptyset}{\partial x} + qD_p\frac{\partial p}{\partial x}} \quad (5)$$

Where **G** is the generation rate, **R** is the recombination rate, $\mathbf{D_n}$ is the electron diffusion coefficient, and $\mathbf{D_P}$ is the hole diffusion coefficient, $\mathbf{\mu_n}$ the electron mobility, $\mathbf{\mu_p}$ the hole mobility .[10] The measure of a photovoltaic cell quality is the Fill Factor (FF). FF is premeditated by equating the maximum power (Pmax) to the theoretical power (Pt) which would be output at both the short circuit current (Jsc) and the open circuit voltage (Voc) as given in Eq.

$$FF = \frac{Pmax}{Pt} = \frac{I_{max}V_{max}}{I_{sc}V_{oc}} \quad (6)$$

The ratio of the energy output from the photovoltaic solar cell to the energy input from the sun is the power conversion efficiency (PCE) mathematically expressed in Eq.

$$PCE = \frac{I_{sc}.FF.V_{oc}}{P_{in}} \quad (7)$$

The parameters listed in Table (1) are used to simulate and analyze the basic properties of solar cells in the SCAPS-1D program.

Table 1: Physical parameters for device modeling in SCAPS-1D

Parameters	symbol (unit)	n-ZnO (Window layer) [1]	n- CdS (Buffer layer) [11]	p- CBTS (Absorber layer) [12][13]
thickness	W (µm)	0.1	0.2	3
Band gap	E_g (eV)	3.3	2.45	1.9
Electron affinity	χ (eV)	4.5	4.4	3.6
Dielectric permittivity	ε_r	9	9	5.4
CB effective density of states	$N_C(cm^{-3})$	2.2×10^{18}	1.8×10^{19}	2.2×10^{18}

VB effective density of states	$N_V(cm^{-3})$	1.8×10^{19}	2.4×10^{18}	1.8×10^{19}
Electron thermal velocity	V_n(cm/s)	10^7	10^7	10^7
Hole thermal velocity	V_P(cm/s)	10^7	10^7	10^7
Electron mobility	$\mu_e(cm^2/Vs)$	100	100	30
Hole mobility	$\mu_h(cm^2/Vs)$	25	25	10
Shallow uniform donor density	ND (cm^{-3})	1×10^{19}	5×10^{18}	0
Shallow uniform acceptor density	NA (cm^{-3})	0	0	1×10^{14}
Absorption Coefficient	$\alpha(cm^{-1}ev^{1/2})$	Scaps value	Scaps value	2×10^4

3. Results and discussion

3-1 effect of the thickness of the absorption layer on the performance of the device

the thickness of the absorption layer CBTS was changed from 1μm to 5μm . Figure (2) shows the characteristic curve (I-V) of the CBTS / CdS / ZnO cell, as it is found that increasing the thickness of the absorption layer increases the characteristic curve I-V and by studying the effect of thickness on a layer Absorption (CBTS) It was observed that the thickness change has an effect on all the cell parameters, as we obtained an increase in the value of the short circuit current (Isc) and the open circuit voltage (Voc) and fill factor (ff) and thus increase the value of the conversion efficiency (**η**%), in order to increase the rate of energy absorption, as it is proportional to each other directly. With the thickness of the absorption layer, there was an increase in the number of carriers generated [14]. as shown in the figure (3)

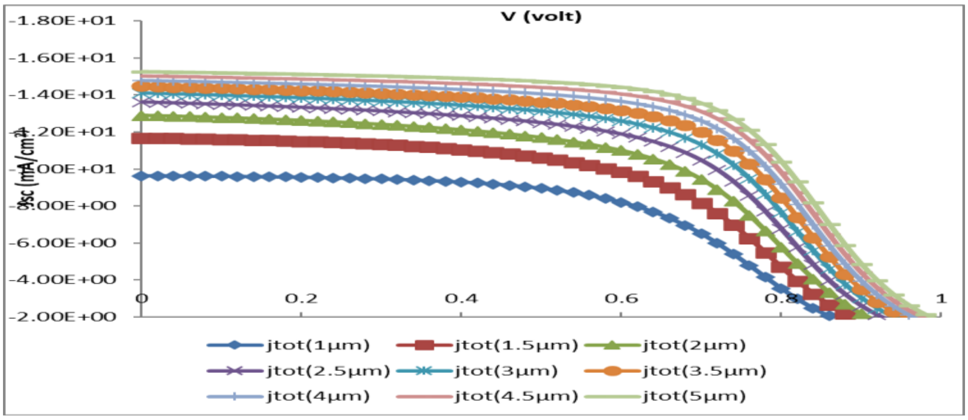


Figure (2) Effect of absorption layer thickness on the I-V curve

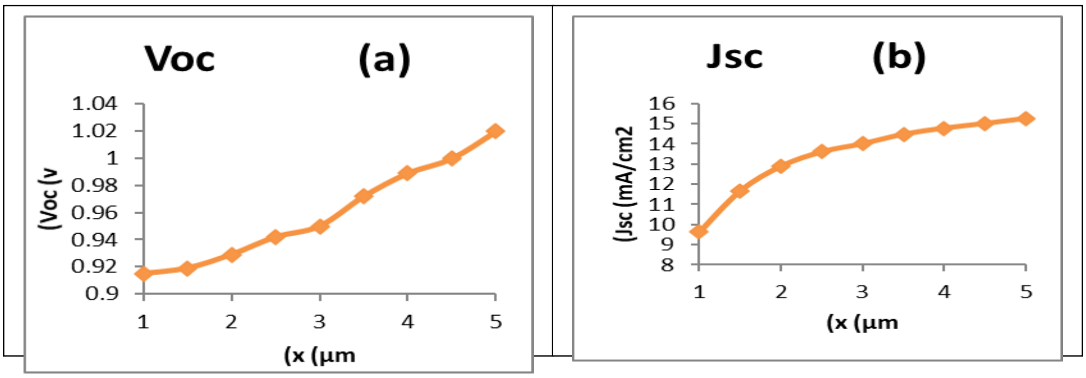
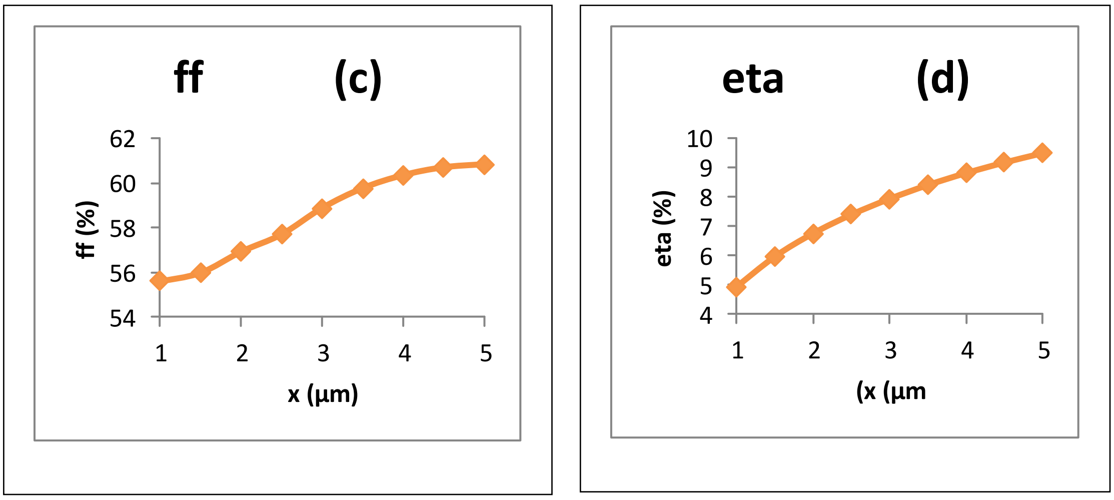


Figure (3) shows the effect of absorption layer thickness on a) open circuit voltage (Voc)



b) short circuit current (Jsc) c) Fill factor(ff) d) Energy conversion efficiency (eta) .

As for the effect of the thickness of the absorption layer on the properties of C-V, as increasing the thickness of the absorption layer increases the number of photoelectrons and thus decreases the recombination interface, the amount of the built-in voltage(Vb) increases, and the width of the depletion area increases, as shown in Figure (5) , We notice the presence of two regions, the first region within the voltage (-0.8 - 0.6V) in which the value of the capacitance is almost constant with the voltage. At this voltage, the capacitance is its lowest value due to the enlargement of the depletion region, which is shown in Figure (5), where it is noticed that the thickness of the depletion region increases and reaches its highest value when the thickness of the (CBTS) layer is about (5µm) . so it have the lowest value of capacitance. The second region, which is between (0.6-0.8v), in which the duo is in forward bias, therefore takes the lowest value for the thickness of the depletion region and thus the highest value for capacitance .

[15] . and thus the capacitance of the solar cell **C** decreases according to Relationship :

$$C = \frac{\varepsilon}{W} \qquad (6)$$

Where **C** is the capacitance per unit area and **W** is the width depletion [16] as shown in Figure (4), which shows the properties of C-V as a function of thickness (CBTS) .

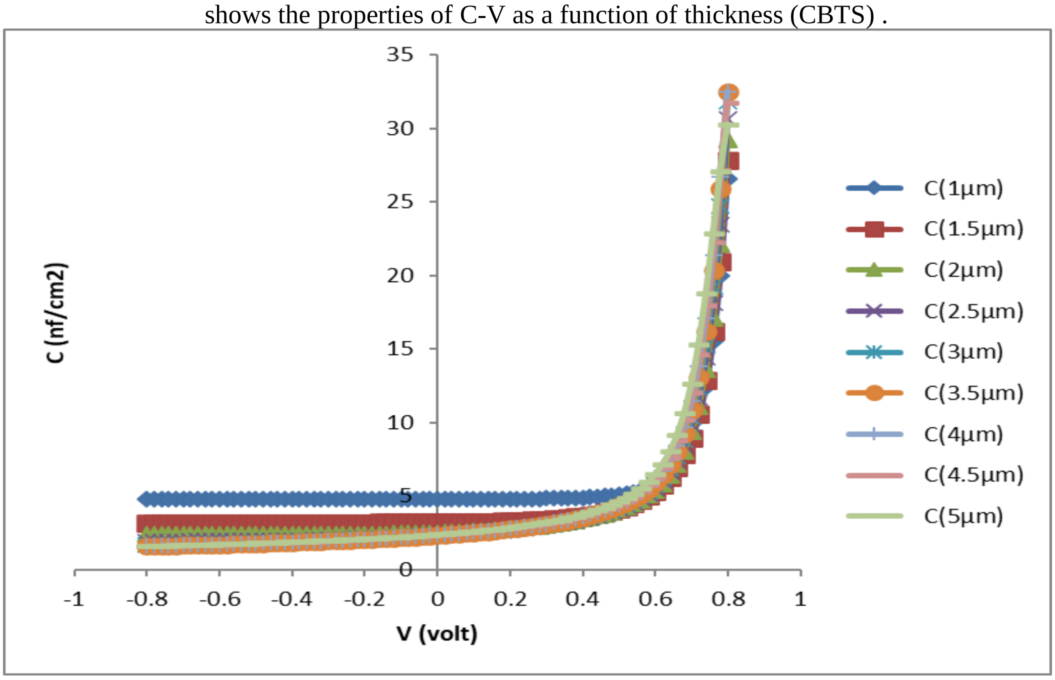


Figure (4) Effect of thickness on the C-V curve

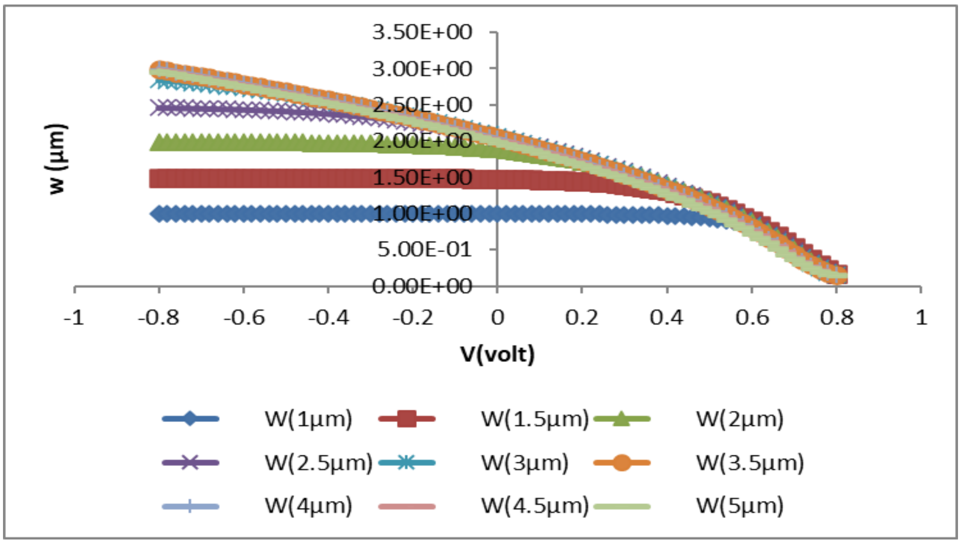


Figure (5) Effect of CBTS thickness on the depletion region

As for the effect of CBTS thickness on the quantum efficiency (QE) curve, it was found that increasing the thickness of the CBTS layer increases the absorbance of the cell and thus increases of generating the electron-hole pair, which is considered a measure of the quantum efficiency. Thus, the greater the thickness of the CBTS layer, the higher the rate of generation of the electron-hole pairs, and thus the quantum efficiency of the cell Solar increases . as shown in the figure. (6) That the quantum efficiency QE is one of the most important optical properties of the solar cell, which is the number of electron-hole pairs generated, which is a function of the width of the depletion region W, the diffusion length of the minority charge carriers, the absorption coefficient α and the wavelength [17]. The higher the thickness of the absorption layer, the higher the quantum efficiency due to the decrease in the level of recombination at the back surface, and thus the increase in its diffusion length and lifetime .

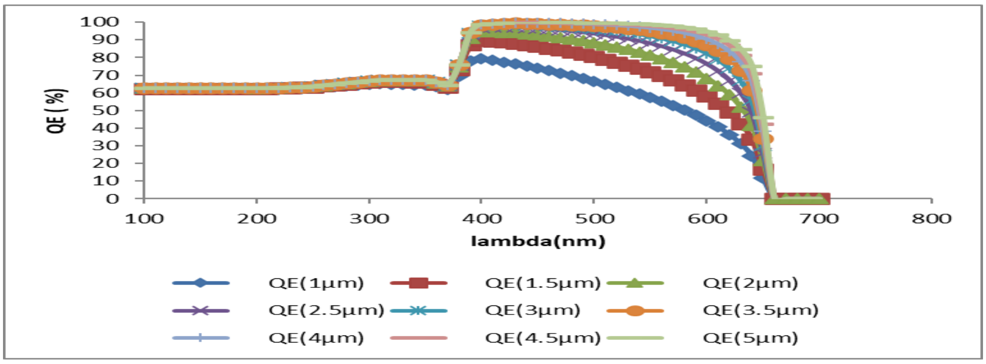


Figure (6) Effect of CBTS thickness on the QE curve

3-2 Acceptor concentration effect on the performance of the device

The concentration of acceptor in the absorption layer was changed from (1E + 13 -1E + 15) cm^{-3}, as Figure (7) shows the effect of acceptor concentration on the (I-V) curve, where it was found that Voc increases with the increase in the doping concentration . The main reason is that the saturation current of the device increases with the increase in the concentration of the acceptor and as a result increases the Voc, however the short circuit current will decrease with the increase in the density of the acceptor. This decrease in Jsc is because the higher carrier density will increase the recombination process and reduce the probability of collecting electrons generated from photons . [1]

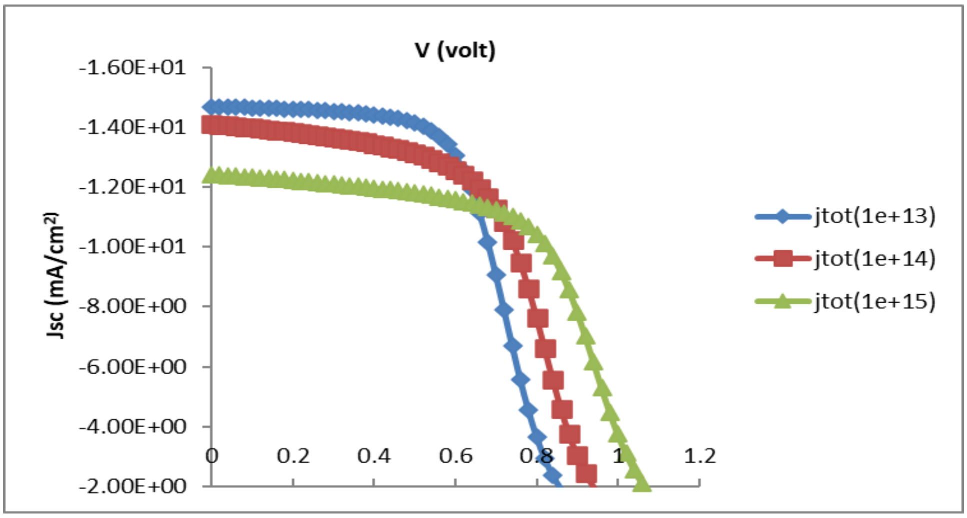
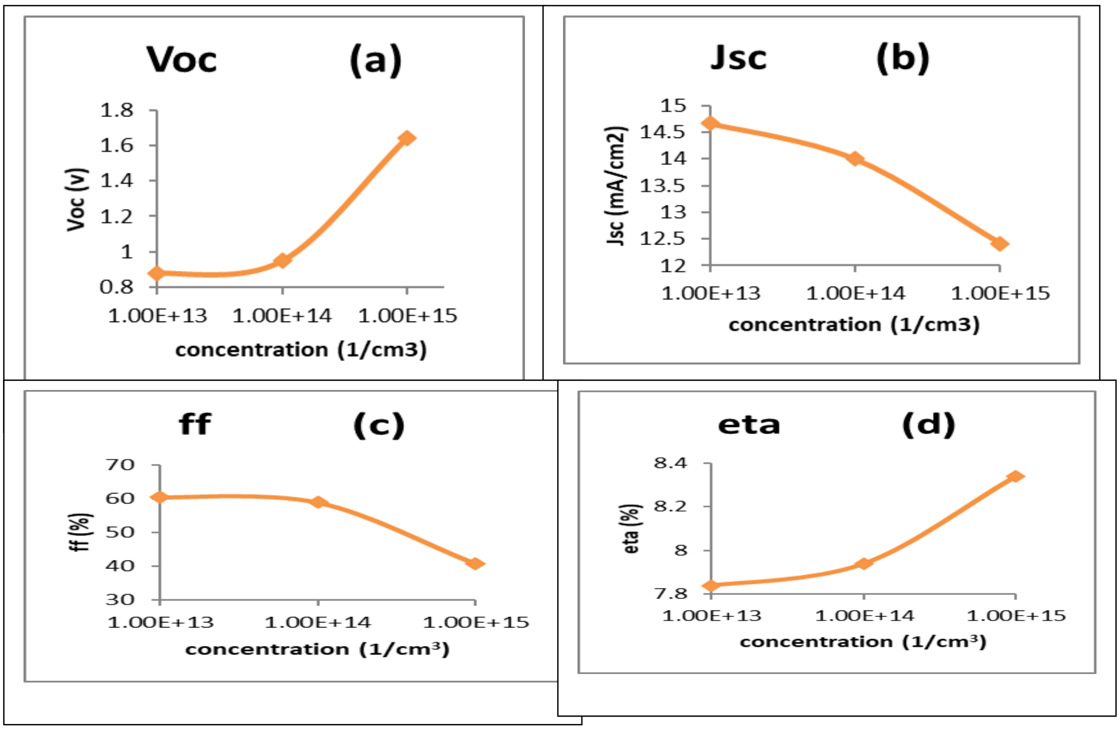


Figure (7) effect of the acceptor on the I-V curve

Figure (8) shows the effect of the acceptor concentration on
a) open circuit voltage (Voc)
b) short circuit current (Jsc)
c) Fill factor (FF)
d) Energy conversion efficiency (Eta) .

As for the effect of the acceptor concentration of the absorption layer on the properties of the C-V, it can be seen from Figure (9), as increasing the concentration of the absorption layer reduces the built-in voltage V_b and thus reduces the width of the depletion region as shown in figure (10), which leads to the carriers crossing through it easily, thus increasing the capacitance of the solar cell With increasing concentration according to relationship (6), the relationship is inverse between the capacitance and the depletion region of the device . [18],[19]



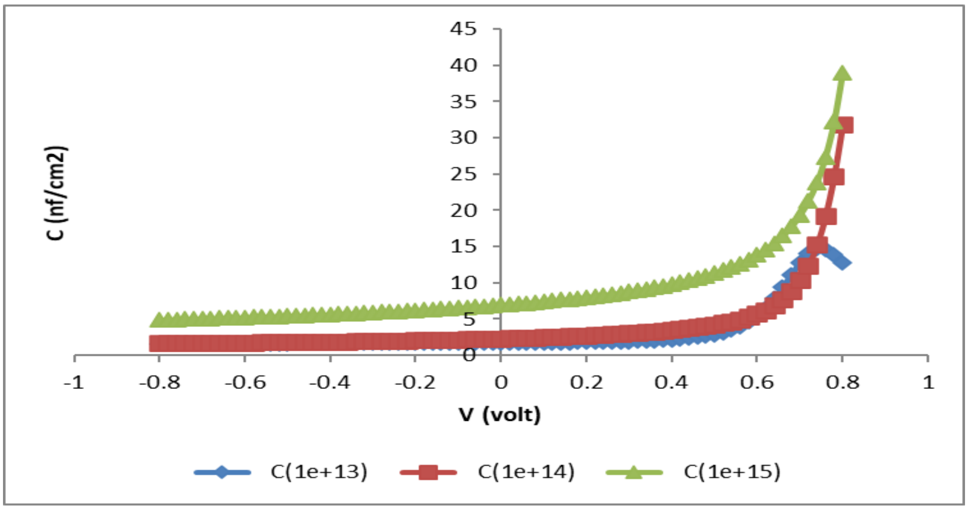


Figure (9) effect of the acceptor concentration on the C-V curve

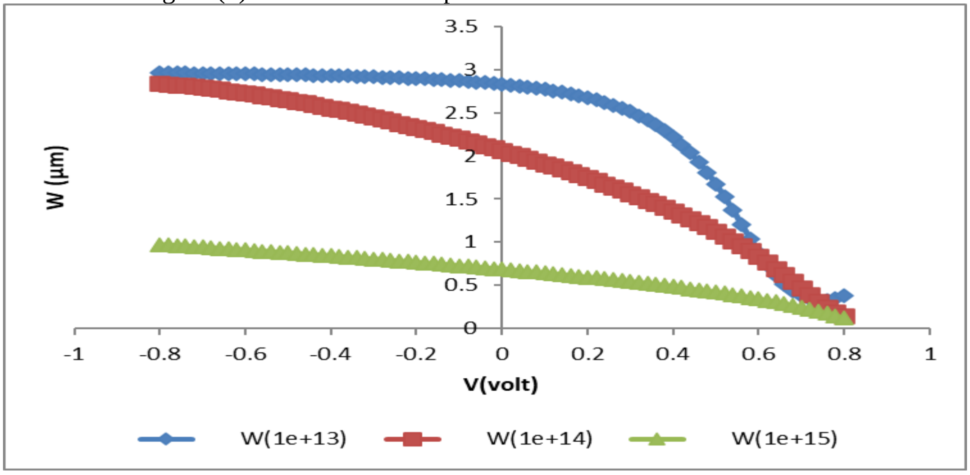


Figure (10) effect of the acceptor concentration on the depletion region

As for the effect of the acceptor concentration on the quantum efficiency QE curve, we found that the quantum efficiency curve is accompanied by a decrease with increasing doping , and the reason is that the increased concentration of carriers enhances the recombination process and thus reduces the probability of collecting of the generated carriers and thus reduces the quantum efficiency with long wavelengths because photons of long wavelengths will It is absorbed far into the absorption layer, so the efficiency will depend on diffusion length of the carriers. as in Figure (11).[20]

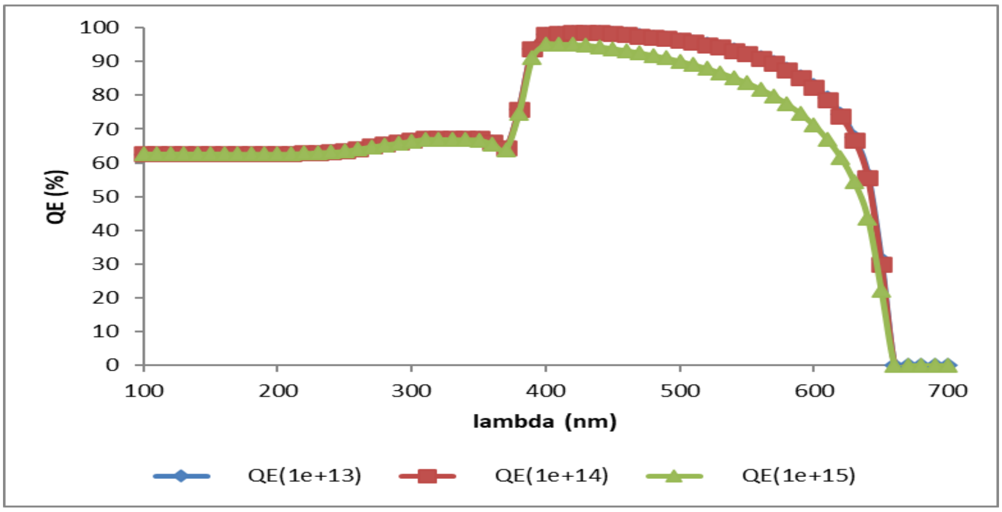


Figure (11) effect of the acceptor concentration on the QE

Table 2 Functional parameters comparison of different structure

Device structure	PCE (%)	FF (%)	Jsc (mA/cm2)	Voc(v)
Experimental cell [5]	1.55	46.71	5.25	0.63
Optimized cell	9.50	60.82	15.25	1.02

4. Conclusion

The CBTS / CdS / ZnO solar cell proposed in this work was simulated by the effect of the thickness and concentration of the carriers of the absorption layer on the performance of the cell. Where the characteristic curve I-V, the characteristic curve C-V, as well as the quantum efficiency curve QE were studied, they were analyzed using SCAPS software to improve device performance. Promising results with PCE (9.50%) , FF (60.82%) , Jsc (15.25 Ma/cm^2) This work will play a key role in improving the performance of CBTS based devices with best performance.

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