Tikrit Journal of Pure Science Vol. 25 (6) 2020

TJPS

IASJ

المجلات الاكاديمية العراقية

Tikrit Journal of Pure Science

ISSN: 1813 – 1662 (Print) --- E-ISSN: 2415 – 1726 (Online)

Journal Homepage: http://tjps.tu.edu.iq/index.php/j

Simulation study of back surface and electron transport layers on Sb_2Se_3 solar Cell

Muaamar A. kamil , Sabri J. Mohammed

Department of physics , Collage of Education for pure science , Tikrit University , Tikrit , Iraq

https://doi.org/10.25130/tjps.v25i6.319

ARTICLE INFO.

Article history:

-Received: 14 / 8 / 2020

-Accepted: 6 / 9 / 2020

-Available online: / / 2020

Keywords: SCAPS -1D ,Sb_2Se_3 absorption layer, solar cell

Corresponding Author:

Name: Muaamar .A.kamil

E-mail:

muaamar.a.kamil@tu.edu.iq

sabri.jasim@tu.edu.iq

Tel:

ABSTRACT

In this paper a simulation study was conducted to improve the properties of the cell with a glass / ITO / CdS / Sb_2Se_3 / Au) using SCAPS-1D program and practically manufactured.To find out the credibility of the program, a simulation of the practical model was performed and we found that there is a very large match between the practical and theoretical results.Initially a back surface layer (BSL) was added to the base cell (CuO, CuI, CuSCN, PEDOT: PSS, $MOSe_2$) and it was found that the best layer that gave good results is (CuO),where Conversion efficiency value (16.02%). Then buffer layers (CdS) was replaced by other Electron transport layer (ZnO, ZnO: Al, TiO2, V2O5, CdO). It was found that the best layer gave good results is (V2O5), where the conversion efficiency was increased from (4.78%) to (15.06%) for the enhanced cell. The other step was the selection of the best back surface layer with the best buffer layer, and thus the conversion efficiency was increased to (19.48%) for the composition cell (glass / ITO / V_2O_5 / Sb_2Se_3 / CuO / Au). Then a second buffer layer was added and the effect of the solar cell output was studied.

1- Introduction

The urgent need for a low-cost, high-performance solar cell has prompted researchers to study new absorption materials for photovoltaic applications. In recent years, they studied absorption material, an antimony selenide (Sb_2Se_3) as an excellent photo absorbent due to its photovoltaic properties such as high absorption coefficient (> 105 cm^{-1}) and its possession Energy gap (1-1.3 eV) In addition to these properties, it consists of abundant and non-toxic materials [1].

In order to increase the performance of the solar cells with absorption layer (Sb2Se3), the work of each layer of the cell must be studied and for this use the (SCAPS-1D) program to model the solar cell layers and study all its parameters that effect on performance of the device such as thickness , density of defects , the movement of carriers and type of front and back contact. All these parameters contributes to indicating the trend to improve the electrical properties of cells[2].

One of the most important losses of solar cells (CdS / Sb_2Se_3) is the amount of blue light absorbed by the layer (CdS), where the charge carriers cannot be collected in this layer due to the high density of defects. One solution is to reduce the thickness or replace this layer with other layers with a wide energy gap such as (ZnO, CdO, V_2O_5, TiO_2, ZnO: Al) as it is characterized by its high ability to absorb a large amount of wavelengths of light [3].

One of the things that is recommended to be added to this type of solar cell is a back reflection layer where it works to reflect the photons in force from the absorption layer, which increases the concentration of charge carriers and reduces the recombination ,increases the current of photons [4].

In this study, the compound (Sb2Se3), the effect of BSL and ETL on short circuit current (Jsc), open circuit voltage (Voc), fill factor (F.F.%) and conversion efficiency (eff%) been studied

2- Modeling

2-1- Numerical simulation in SCAPS -1D:

SCAPS-1D (solar cell capacitance simulator) is a one-dimensional solar cell simulation program, developed in Electronics and Information Systems (ELIS), University of Gent. The SCAPS is freely available for PV research. The user can describe a maximum of seven layers solar cell with different properties, such as thickness, optical absorption, doping, density and distribution of defects. It is then possible to simulate a number of common measurements: I-V, QE, C-V, and C-f [5].This program has been developed and applied to all solar cells, as it is a freely available program. The program is based on solving semiconductor equations. We begin by writing a equation of Poisson [6].

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

Hence the continuity equation that is given by the following relationship .

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

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

Finally, the charge carrier equations for the density of propagation current and drift can be obtained from the following equations [7].

$$J_n = q(\mu_n nE + D_n \nabla n) - - - 4$$

$$J_p = q(\mu_p PE + D_p \nabla p) - - - 5$$

Where (E)electric field (N_D, N_A) the concentration of donors and acceptor, q The charge (G, R) represents the rate of carrier generation and (n, p) represents the density of electrons and holes and (Jn, Jp) the density current for 104lectrons and holes,(D) diffusion coefficient.To calculate the total current of the solar cell, the following equation was used [8].

$$I = I_o\left[exp\left(\frac{qv}{KT}\right) - 1\right] - I_L - - - 6$$

Where K is the Boltzmann constant, T is the temperature measured in Kelvin. To calculate the open circuit voltage (Voc) which is at its highest value when the current is zero and according to the following equation.

$$V_{oc} = \frac{KT}{q} Ln\left(\frac{I_L}{I_o} - 1\right) \approx \frac{KT}{q} Ln\left(\frac{I_L}{I_o}\right) - - - 7$$

Where I_o is the saturation current and is calculated from the following equation.

$$I_o = DT^3 exp\left[\frac{-E_g}{KT}\right] = A\left[\frac{q D_e n_i^2}{L_e N_A} + \frac{q D_h n_i^2}{L_h N_D}\right] - -8$$

Eg, the energy gap, (Le, Lh) represents the length of diffusion of electrons and holes, A cross-sectional area of the diode.The relationship between the short circuit current and the open circuit voltage is given by the following relationship.

$$I_{sc} = I_o\left[e^{qv_{oc}/KT} - 1\right] - 9$$

Where, Voc, Jsc, η, FF are variables and are related to each other according to the following equations [7].

$$FF = \frac{P_{max}}{P_t} = \frac{V_{max}.I_{max}}{Voc.J_{sc}} - -10$$

$$\eta = \frac{P_m}{P_{in}} = \frac{Voc.Jsc.FF}{P_{in}} - - - 11$$

quantum efficiency is inversely proportional with wavelengths, depending on the equation(12).

$$Q_E = 1.24\frac{R_\lambda}{\lambda} \text{-------}12$$

(R_λ) represents the responsive of back surface layer , (λ) the wavelength, FF Fill factor, η cell efficiency, J_{sc} short-circuit current, V_{oc} open circuit voltage , V_{max} maximum voltage, I_{max} maximum current, P_{max} maximum power, Pin input power [9].

2-2- Solar cell structure:

The solar cell structure is composed of (glass / ITO / CdS / Sb_2Se_3 / Au) as shown in fig.1. ITO is the window layer, which is one of the transparent metal oxides and has a relatively large energy gap of about (3.6 eV). Then it is followed by a buffer p-type CdS layer with a suitable energy gap of (2.4eV) and it works on tuning Between the window layer and the absorption layer.

Then comes the p-type Sb_2Se_3 absorption layer, which has a relatively small energy gap that has an energy gap of about (1.2eV). This cell also has an ohmic front contact and back Schottky gold contact with work function of the amount of (5eV)[10]. We also do not forget that the cell is deposited on the ground of glass and Figure (1) It represents the structure of the solar cell. Table (1) shows the values of the parameters that were entered on the program to study the theoretical cell performance and compare it with the experimental side of the parent cell [11].

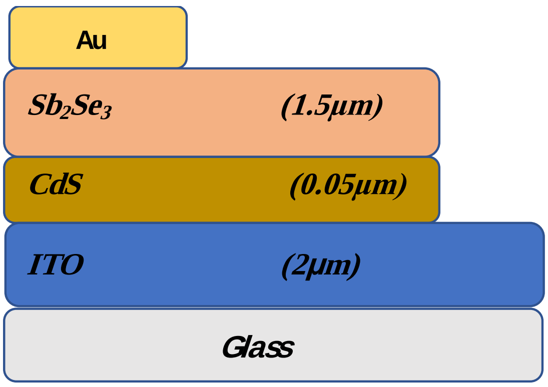

Fig. 1: Device structure

Table 1: The physical parameters of different layer.

Parameters	symbol (unit)	Sb_2Se_3[13]	CdS[14]	ITO[12]
Thickness	W(μm)	1.5	0.5	2
Bandgap	Eg (eV)	1.2	2.4	3.600
Electron affinity	χ (eV)	4.04	4.000	4.100
Dielectric permittivity	$_r\epsilon$	18.000	9.000	10.000
CB effective density of states	$N_C(cm^{-3})$	2.2E+18	2.200E+19	2.000E+19
VB effective density of states	$N_V(cm^{-3})$	1.8E+19	1.800E+18	1.800E+19
Electron thermal velocity	V_n(cm/s)	1.000E+7	1.000E+7	1.000E+7
Hole thermal velocity	V_P(cm/s)	1.000E+7	1.000E+7	1.000E+7
Electron mobility	$\mu_n(cm^2/v.s)$	1.5E+1	1.000E+2	5.000E+1
Hole mobility	$\mu_p(cm^2/v.s)$	5.1E+0	2.500E+1	7.500E+1
Shallow uniform donor density	N_D (1/cm^3)	0	2.000E+17	1.000E+20
Shallow uniform acceptor density	N_A (1/cm^3)	1.13E+17	0	0
Coefficient absorption	α (1/cm)	1E+5	SCAPS	SCAPS

3- results and Discussion

3-1-Comparing experimental cell results with theoretical results:

The experimental results of the cell were matched with the simulation results in the beginning to ensure the reliability of the simulation program, simulation was done for practical research [11] using the SCAPS -1D program. The results showed a very large match between the experimental and theoretical side, as shown show in Table (2).

Table 2: A comparison between the experimental and theoretical.

No	Cell	V_{oc}(v)	J_{sc}(mA/Cm^2)	FF%	η%
1	(experimental)	0.34	25.78	0.520	4.89%
2	(theoretical)	0.36	26.42	0.503	4.78%

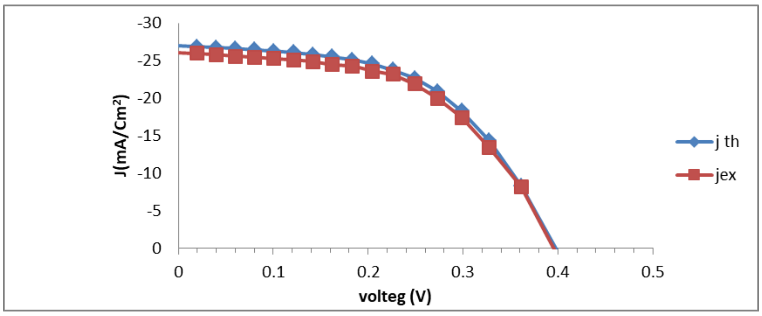

Figure 2: Curved I-V for experimental and theoretical work.

3-2: Adding back surface layer(BSL):

In order to improve the cell ((glass / ITO / CdS / Sb_2Se_3 / Au) we will study the effect of adding different layers of back surface layer (BSL) and it consists of the following compounds (CuO, CuI, CuScN, PEDOT: PSS, $MoSe_2$),with remaining all parameters of the cell for the absorption, buffer and window layer. Table (3) show the parameters of the back surface layer and it is obvious that the inters of these layers on the cell will increase the conversion efficiency and the fill factor, as the back surface layer reflects the photons to the absorption layer, which increases the concentration of charge carriers and reduces the recombination back layer Thus, the connection becomes more ohmic and the photo-current increases [15]. Figure (3) shows increase current and voltage curves after adding the layers of reflection (BSL) compared with the cell before the improvement. From the Figure (4) we note the extent of the change in the voltage open circuit (Voc) and the current short circuit (Jsc). Figure(5)shows the change in fill factor (FF%) and conversion efficiency (η%). where the conversion efficiency increased from (4.78%) of the base cell to (16.26%) For the enhanced cell.

Back surface layer that gives best results is (CuO) for two reasons. The first is that the sum of the energy gap and the electro affinity is equal to or slightly greater than the work function. The greater agreement values it gave us less heat energy wast and the second reason is that the decrease in value of the electronic affinity of back surface layer leads to an increase in the potential barrier, which leads to an increase in the number of photons reflected from the back surface[13]. Table (4) shows the results obtained when adding BSL to the cell basis with all parameters remaining constant .

Table 3: The physical parameters of (BSL).

Parameters	symbol (unit)	CuO [4]	Cui[14]	CuScN[4]	PEDOT:PSS[12]	MoSe2[10]
Thickness	W(µm)	0.03	0.03	0.03	0.03	0.03
Bandgap	Eg (ev)	2.1	2.98	3.4	2.2	1.4
Electron affinity	χ (ev)	3.2	2.1	1.9	2.9	4.32
Dielectric permittivity	ϵr	7.11	6.5	10	3	7.29
CB effective density of states	$N_C(cm^{-3})$	2.2E20	2.8E18	1.7E19	2.2E15	9E17
VB effective density of states	$N_V(cm^{-3})$	5.5E19	1E19	2.5E18	1.8E19	9E20
Electron thermal velocity	V_n(cm/s)	1.000E+7	1.000E+7	1.000E+7	1.000E+7	1.000E+7
Hole thermal velocity	V_P(cm/s)	1.000E+7	1.000E+7	1.000E+7	1.000E+7	1.000E+7
Electron mobility	$\mu_n(cm^2/v.s)$	3.4	1.7E-4	1E-4	2E-2	25
Hole mobility	$\mu_p(cm^2/v.s)$	3.4	1.7E-4	1E-1	2E-4	100
Shallow uniform donor density	ND (1/cm3)	0	0	0	0	0
Shallow uniform acceptor density	NA (1/cm3)	1E18	1E18	1E18	1E18	5E19
Coefficient absorption	α (1/cm)	1 E+5	1 E+5	1 E+5	1 E+5	1 E+5

Table 4: Shows the results obtained when adding a back surface layer.

Material	$Jsc(mA/Cm^2)$	Voc(v)	F.F.(%)	Eff(%)
CuO	30.46	0.78	68.35	16.26
CuI	30.43	0.71	73.99	15.95
CuScN	30.46	0.71	74.28	16.04
PEDOT:PSS	30.44	0.71	74.05	15.97
MoSe2	30.45	0.70	64.74	13.74
Without BSL	26.42	0.36	50.29	4.78

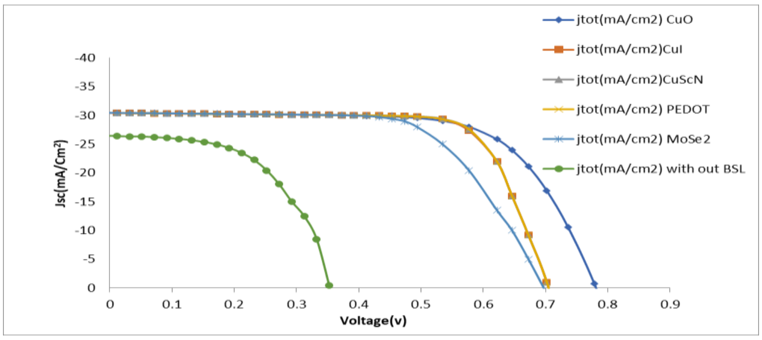

Fig. 3: Curve I-V after adding BSL and without BSL.

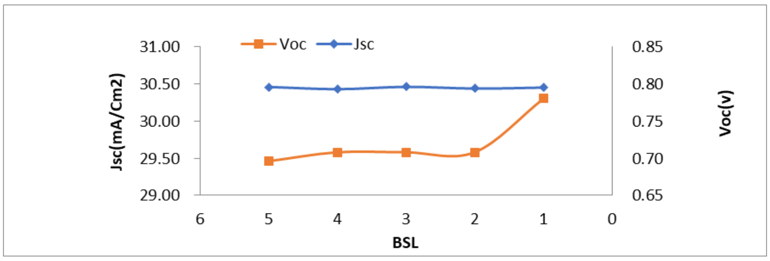

Fig. 4: change in the (Voc) and (Jsc) with BSL.

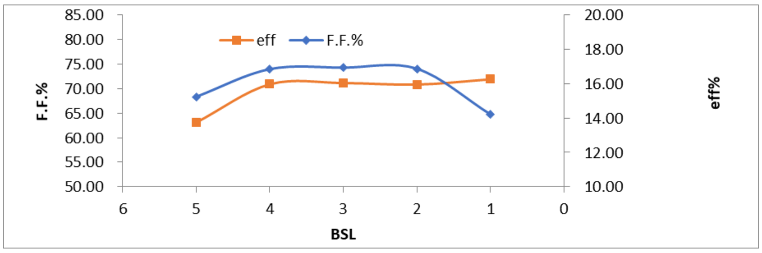

Fig. 5: change in the (F.F) and (η%) with BSL.

by study the effect of energy levels of cells after adding the reflection layers (BSL), we notice from the Figure. (6) that represents the energy levels of the cell before the improvement (glass / ITO / Cds /

Sb2Se3 / Au) that there is no potential barrier or that the potential barrier has a negative value relative to the electrons i.e. It works to attract electrons, which is why we note the accumulation of electrons at the back surface and increases the possibility of recombination[16].

As for the Figure. (7), which represents the energy levels of the cell that gave the best results (glass / ITO / Cds / Sb2Se3 / CuO / Au) that generate a high potential barrier for the electrons and a little voltage barrier for the holes, which led to reversing the direction of the largest number of charge carriers to the absorption layer which It greatly improved cell parameters[17].

Figure.(8) represents the cell that gave the least results after adding the reflection layer (glass / ITO / Cds / Sb2Se3 / MoSe2 / Au) The presence of a potential barrier reflects most of the electrons toward the absorption layer, which improved the conversion efficiency and voltage open circuit but because of the additional potential barrier for the holes with Schottky potential barrier where at the point (0.03), a cliff like between the absorption layer and the back surface layer is generated which gives the least improvement from the rest of the added reflection layers[18].

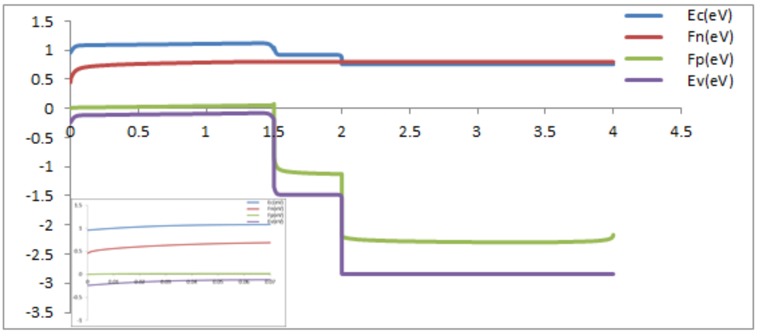

Fig. 6: Energy band for cell((glass / ITO / Cds / Sb_2Se_3 / Au)) before adding BSL.

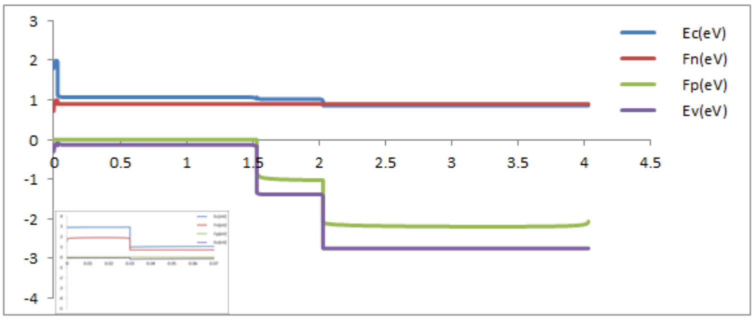

Fig. 7: Energy band for cell (glass / ITO / Cds / Sb2Se3 / CuO / Au) after adding(CuO) BSL.

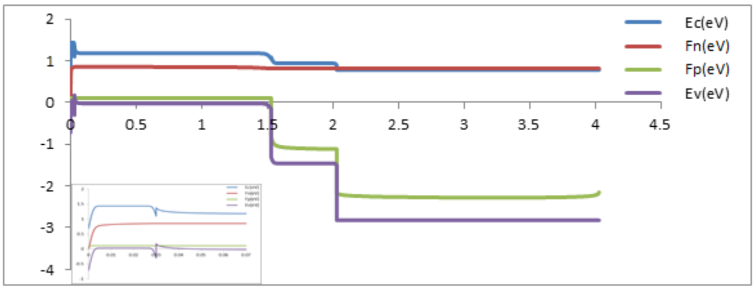

Fig. 8: Energy band for cell (glass / ITO / Cds / Sb_2Se_3 / $MoSe_2$ / Au) after adding ($MoSe_2$)BSL.

To study the effect of the influence on the quantum efficiency (QE), which is defined as the number of pairs of an electron hole generated due to the incident light on the solar cell. Fig. (9) shows the value of the quantum efficiency before and after adding back surface layers to the cell.

Where its value is (2%) at the wavelength (100nm) and then increases until it reaches (81%) at the wavelength (350nm). The reason is due to the high absorption of photons returning from the reflection layer, which has long wavelengths and for this we note the form of quantum efficiency has become closer To the square[19] . which is the ideal case for the work of the solar cells. Then they start with a gradual decrease until they become zero at the wavelength (1050nm). The main reason because low diffusion length and absorption is zero at long wavelengths.As for the cell before adding back surface layers, we notice that the curve of the quantum efficiency begins degrease at the wavelength

(380nm) and continues until it reaches zero at the wavelength (1050nm).

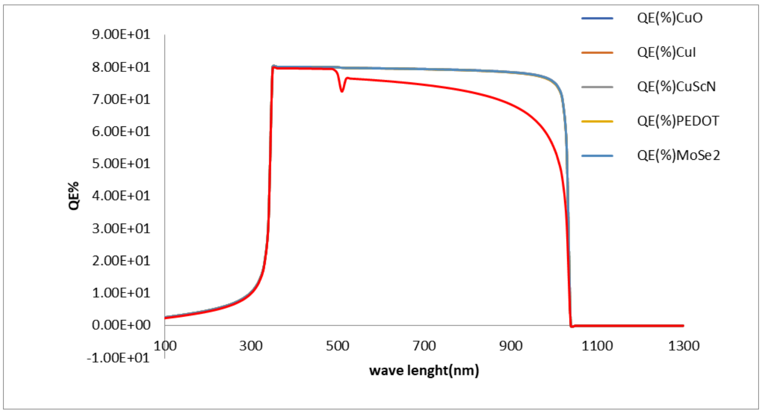

Fig. 9: Wavelength relation with quantum efficiency for BSL and without BSL.

3-2: adding buffer layer (ETL):

The main role of buffer layer in the solar cells with absorption layer (Sb2Se3) is to form an interface with the absorption layer. Its allow passage maximum amount of light to absorption layer [20,21]. This layer should have the least amount loss of absorption and be able to take out photo generated carriers that were created using the least amount of recombination losses, and transfer them to the outer circuit with minimum of electrical resistance. For high performance photovoltaic with minimal resistance loss. It is preferable that the energy gap of the buffer layer be high in order for the series resistance to remain low. buffer layer should be improved because it aligns energy gap between Sb_2Se_3 and ITO [22]. compounds (ZnO, ZnO: Al, TiO_2, V_2O_5, CdO) can be used as a buffer layer with an energy gap between (2.28-3.33eV). Table(5) shows the values of the parameters of the buffer layer used in a simulation.

Table 5: The physical parameters of (ETL).

Parameters	symbol (unit)	Zno[23,24]	ZnO:Al[23]	TiO_2[25]	V_2O_5[26]	CdO[27]
Thickness	W(μm)	0.5	0.5	0.5	0.5	0.5
Bandgap	Eg (ev)	3.3	3.3	3.2	2.3	2.28
Electron affinity	χ (ev)	4.2	4.2	4	3.99	4.5
Dielectric permittivity	ϵr	9	9	100	4.28	5.3
CB effective density of states	$N_C(cm^{-3})$	2.2E18	3E18	1E21	2.2E18	2.2E18
VB effective density of states	$N_V(cm^{-3})$	1.8E19	1.8E19	2E20	1.8E19	1.8E19
Electron thermal velocity	V_n(cm/s)	1E7	1E7	1E7	1E7	1E7
Hole thermal velocity	V_P(cm/s)	1E7	1E7	1E7	1E7	1E7
Electron mobility	$\mu_n(cm^2/v.s)$	100	100	0.06	1.26	146
Hole mobility	$\mu_p(cm^2/v.s)$	25	30	0.06	34.5	39.5
Shallow uniform donor density	ND (1/cm3)	1E18	5E19	1E16	1E19	1E22
Shallow uniform acceptor density	NA (1/cm3)	0	0	0	0	0
Coefficient absorption	α (1/cm)	1E5	1E5	1E5	1E5	1E5

The composition of solar cells (Sb_2Se_3) was studied with different buffer layers to obtain the best performance of the solar cells, where an improvement in the output values (Voc, Jsc, FF, eff) was observed. we note a difference in values where the best cell gave good results with Composition (glass / ITO / V_2O_5 / Sb_2Se_3 / Au). That mean (V_2O_5) improved the interface with the absorption layer, and it has higher current carriers in a short wavelength region where it has an energy gap (2.3eV),so it absorbs photons with a wavelength Less than (450nm) which covers approximately 21% of the solar spectrum. Therefore it represents a transparent layer for wavelengths greater than (450nm), which forms the main part of the solar spectrum[26]. Table (6) shows the values of the solar cell's outputs to which buffer layers are added. Figure (10) shows how the voltage and current curves are affected after replacement (CdS) layer in the original cell. Figure (11) represents the energy band of the cell that gave the best results (glass / ITO / V_2O_5 / Sb_2Se_3 / Au). Figure (12) shows the energy band of the cell that gave the lowest level of conversion efficiency (glass / ITO / ZnO / Sb_2Se_3 / Au).

Table 6: shows the results obtained when adding a back surface layer.

Material	**Jsc(mA/Cm^2)**	**Voc(v)**	**F.F.(%)**	**Eff(%)**
ZnO	26.32	0.46	64.17	8.32
ZnO:Al	28.45	0.67	72.1	13.7
TiO_2	25.67	0.6	70.11	10.84

V_2O_5	26.818	0.76	73.92	15.06
CdO	26.25	0.52	67.35	9.17

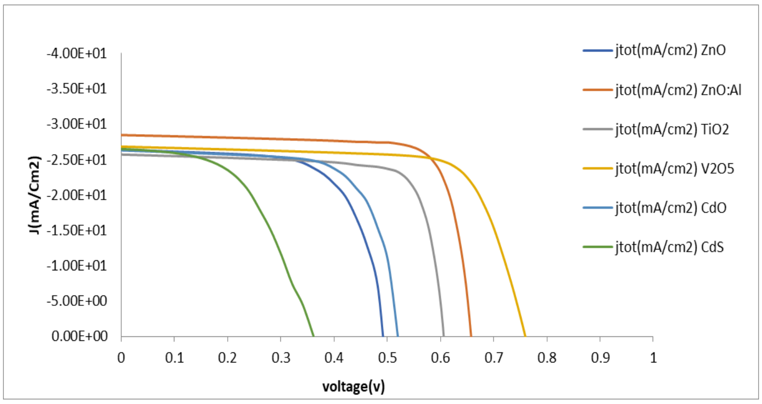

Fig. 10: Curve I-V after changing ETL and with(CdS).

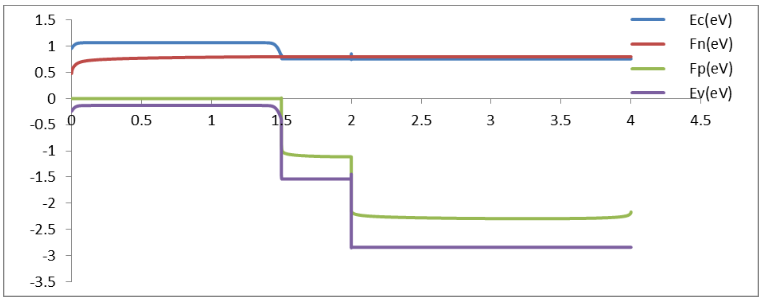

Fig.11: energy band of the cell(glass / ITO / V_2O_5 / Sb_2Se_3 / Au).

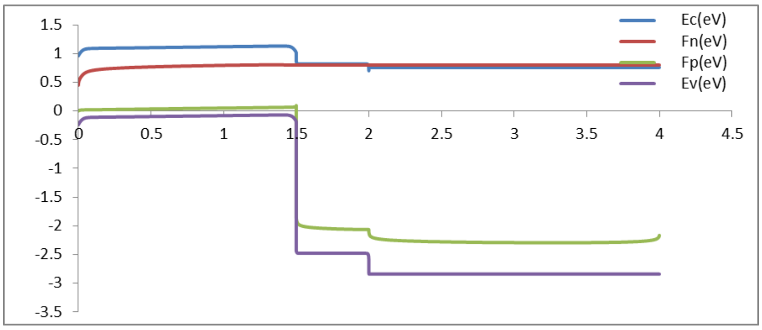

Fig. 12: energy band of the cell(glass / ITO/ ZnO / Sb_2Se_3 / Au).

Figure (13) represents the quantum efficiency (QE%) of the cells after optimization in comparison with the original cell, where we notice that the change occurred between the confined area (375nm-539nm). This change is due to the energy gap of the buffer layers confined between (2.2eV-3.3eV). equation(12) .That is, buffer layers are transparent with respect to the wavelength which is greater than (539nm), and this allows the absorption of largest number of photons reach to the absorption layer[10] .

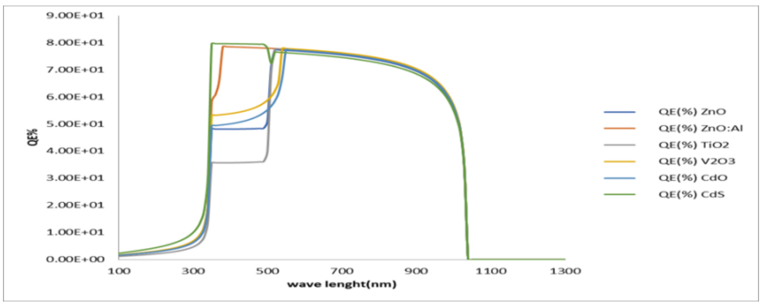

Fig: 13: Wavelength relation with quantum efficiency for different buffer layer.

3-3: Choose the best cell after adding the Reflection and buffer layers:

After studying adding layers of the BSL, we notice that the cell with the structure (glass / ITO / Cds / Sb_2Se_3 / CuO / Au) gave the best results to the cell outputs shown in the figure (14). Then after making a change of the buffer layers to the original cell and replacing the layer (CdS) with layers (ZnO, ZnO: Al, TiO_2, V_2O_5, CdO) cell (glass / ITO / V_2O_5 / Sb_2Se_3 / Au) was selected, which gave the best results for the buffer layers[9]. Figure (15) shows the behavior of the current and voltage curves, where the short circuit current (30.52 mA / Cm^2), the open circuit voltage (0.83 V). As for the fill factor (F.F.) it has a value of (76.22%) and conversion efficiency (η%) whose value has become (19.48). Figure (16) represents the quantum efficiency (QE), and Figure (17) represents the enhanced cell energy band[16].

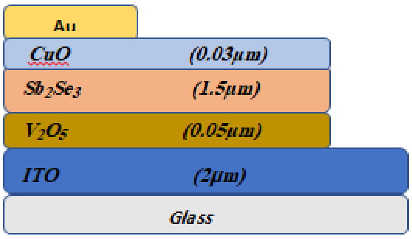

Fig. 14: Device structure with best BSL and ETL.

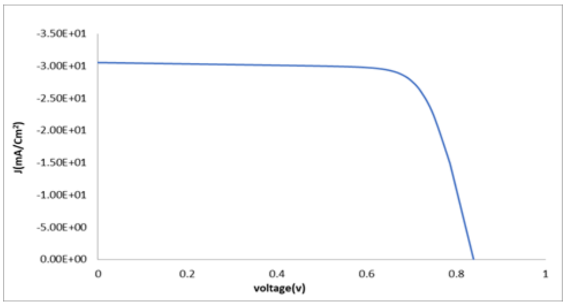

Fig. 15: I-V curve for the best cell.

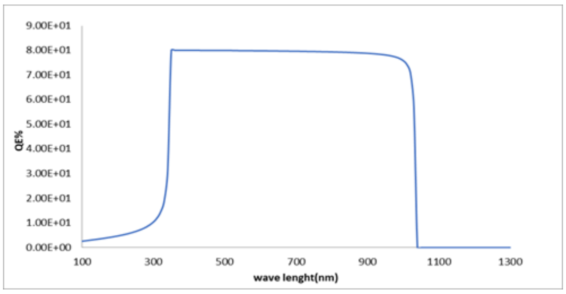

Fig. 16: Wavelength relation with quantum efficiency for the best cell.

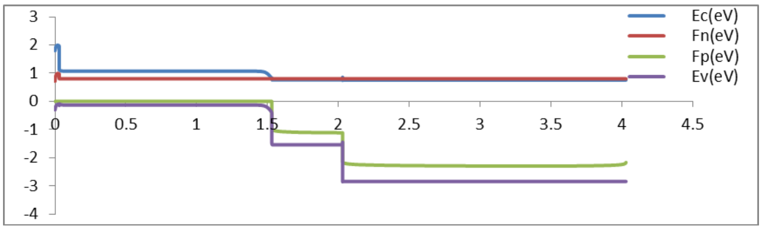

Fig. 17: Energy band diagram for the best cell.

3-4:Double buffer layers:

Buffer layer (V2O5) was added which gave the best results by having the best back surface layer (CuO) for the tested cells to see the extent to which the outputs of the cell were effected. The same compounds were used while maintaining the thickness of the buffer layer (0.5µm) in other words, each of buffer layers with Thickness (0.25µm), with remaining cell parameters constant .Tabel (7) shows the output of the solar cells before adding two buffer layers and after addition. Figure (18) represents the current and voltage curves, Figure (19) the amount of quantum efficiency. From observing results we found that the effect of adding two matching layers with the same thickness of the original layer reduced the conversion efficiency and the scientific explanation is for the difference in the value of the electronic affinity for buffer layers and the appear a cliff area between the buffer and absorption layer[27]. This led to obstruction the movement of electrons towards absorption layer . Figure (20) Shows energy bands for the valence and conduction band.

Table 7: shows the results obtained when adding double ETL .

NO.	cells	V(v)	J(mA/Cm^2)	FF%	η%
1	glass / ITO/V_2O_5 / Sb_2Se_3 / CuO/Au(before)	0.83	30.52	76.22	19.48
2	glass / ITO/TiO_2 / V_2O_5 / Sb_2Se_3 / CuO/Au	0.81	30.16	75.62	18.4
3	glass / ITO/CdO / V2O5 / Sb_2Se_3 / CuO/Au	0.81	30.15	75.31	18.4
4	glass / ITO/ZnO:Al / V_2O_5 / Sb_2Se_3 / CuO/Au	0.81	30.25	75.67	18.47
5	glass / ITO/ZnO / V_2O_5 / Sb_2Se_3 / CuO/Au	0.81	30.16	75.63	18.41
6	glass / ITO/V_2O_5 / V_2O_5 / Sb_2Se_3 / CuO/Au	0.8	30.16	75.63	18.41

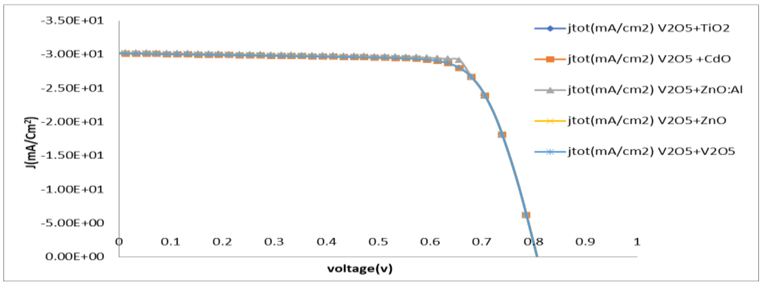

Fig. 18: I-V for the cell having dubel ETL.

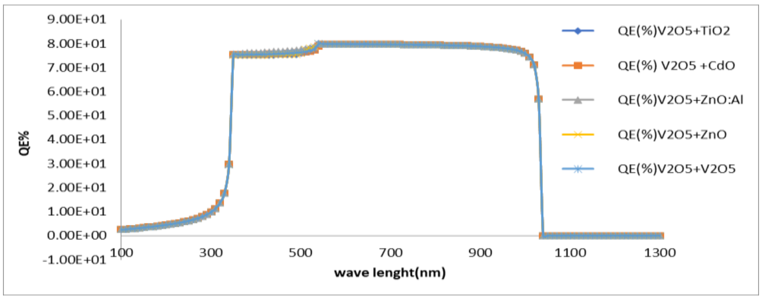

Fig. 19: Wavelength relation with quantum efficiency for the cell having dubel ETL.

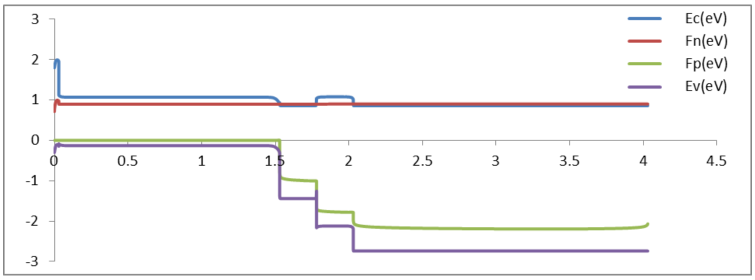

Fig. 20: Energy bande digrame for the cell having dubel ETL .

4- Conclusions

The (ITO /CdS/Sb_2Se_3/Au) cell was simulated by the SCAPS-1D program and compared with an experimental results. Found a very large convergence between the experimental and theoretical results. Then was improved the theoretical cell by added BSL to the cell .saw efficiency increase because back reflection layer increase the voltage barrier and increase the number of photon reflected toward absorber layer. Then was added buffer layer to increase the efficiency because it allowed photons to pass through to the absorption layer. Then we inserted the best buffer layer with the best reflection layer in the optimized cell so the efficiency increase from (4.78%)to(19.48%) .then was added double buffer to the cell, we saw decrease efficiency from (19.48%)to (18.4%)because a cliff will be happened between buffer and absorber layer.

References

[1] Ling-yan, L.;Lin-qin, J. b.; Yu Qiua,b.; Bao-dian, F.b. (2018) . Analysis of Sb2Se3/CdS based photovoltaic cell: A numerical simulation approach. *Journal of Physics and Chemistry of Solids* **122(11)**. 19–24.

[2] Gang, L.; Zhiqiang, L.; Xiaoyang, L.; Chunsheng, G. (2019).Improvement in Sb2Se3 Solar Cell Efficiency through Band Alignment Engineering at the Buffer/Absorber Interface. *ACS Appl. Mater. Interfaces* . **11(1).**828–834.

[3] Yu Caoa,b, Xinyun Zhua,b, Hanbo Chenc, Xintong Zhangc, Jing Zhoucc, Ziyang Hud, ,Jinbo. Pange.(2019). Towards high efficiency inverted Sb2Se3 thin film solar cells. *Solar Energy Materials and Solar Cells* .**200(9)**. 109945.

[4] Alaa, H. N. ;Ayed, N. S.(2019).Study effect of window and BSF layers on the properties of the CZTS / CZTSe solar cell by SCAPS–1D. *Tikrit Journal of Pure Science **Vol. 24**.*

[5] Ganvir, R.(2016). Modelling of the nanowire CdS-CdTe device design for enhanced quantum efficiency in Window-absorber type solar cells. M.Sc. Department Electrical Engineering. College of Engineering .University of Kentucky. USA.

[6] Falah, H ; Oraibi and Faeq, A.AL-Tememe .(2012). Theoretical Study of the effect of impurity concentrations on the efficiency of the single crystal silicon solar cell. *JOURNAL OF KUFA-PHYSICS*,**4(1).** :93-98.

[7] Guo, H., Li, Y., Guo, X., Yuan, N., & Ding, J. (2018**).** Effect of silicon doping on electrical and optical properties of stoichiometric Cu2ZnSnS4 solar cells. *Physica B: Condensed Matter*, **531(16)**: 9-15.

[8] Kajal, M. P.; Fermi, H. I. & Joseph, J.P. (2018). Thickness optimization of CdS/ZnO hybrid buffer layer in CZTSe thin film solar cells using SCAPS simulation program. *Materials Research Innovations*.**12(7)**.231-235.
[9] Iman, G. a.; Ali A. O.; Samaneh, S. A.(2020) . Towards high efficiency Cd-Free Sb2Se3 solar cells by the band alignment optimization. *Solar Energy Materials & Solar Cells* . **21(2)** .110581.
[10] Guo, H.; Li, Y.;Guo, X.; Yuan, N. & Ding, J. (2018) .Effect of silicon doping on electrical and optical properties of stoichiometric Cu2ZnSnS4 solar cells .*Physics B: Condensed Matter*. **531(4)**. 9-15.
[11] Xiaobo, H.;Jiahua, T.; Shiming, C.; Juanjuan, X.; Guoen, W.; Kaijiang, Z.o H. (2018). Improving the efficiency of Sb2Se3 thin-film solar cells by post annealing treatment in vacuum condition. Solar energy materials and solar cells .18(9).170-175.
[12] Zhen-Qi, L.; Ming, N. and Xiao-Dong, F. (2020) . Simulation of the Sb2Se3 solar cell with a hole transport layer. Mater. Res. Express. 7(2) .016416.
[13] Puvaneswaran, C. A.; Mohammad ,I. H.; Nowshad, A. (2010). Performance analysis of copper–indium–gallium–diselenide (CIGS) solar cells with various buffer layers by SCAPS. *Current Applied Physics* .**10(13)** .S387–S391.
[14] Seck, S. M.; Ndiaye, E. N.; Fall, M. & Charvet, S. (2020). Study of Efficiencies CdTe/CdS Photovoltaic Solar Cell According to Electrical Properties by Scaps Simulation. *Natural Resources*. **11(4).** 147-155.
[15] Büecheler S. F.. (2010). Investigation of compound semiconductors as buffer-layer in thin film solar cells. PhD,University Zürich.
[16] Khattak, Y.H.;Baig, F.; Ullah, S.; Marí, B.; Beg, S. and Khan, K. (2018). Effect of Cu2O hole transport layer and improved minority carrier life time on the efficiency enhancement of Cu2NiSnS4 based experimental solar cell**.** *Journal of Renewable and Sustainable Energy*. **10(4)**, p.043502 .doi: 10.1063/1.5037471.
[17] Baig, F. (2019**).** Numerical analysis for efficiency enhancement of thin film solar cells . PhD,University Holand.
[18] Sawicka-Chudy, P.; Sibiński, M.; Wisz, G.; Rybak-Wilusz, E.; & Cholewa, M. (2018). Numerical analysis and optimization of Cu2O/TiO2, CuO/TiO2, heterojunction solar cells using SCAPS. *In Journal of Physics: Conference Series* . **1033(1)** .12-20.
[19] Rau, U.; Schmidt, M.; Jasenek, A.; Hanna, G.; andSchock, H. W. (2011). Electrical Characterization ofCu(In,Ga)Se2 Thin-Film Solar Cells and the Role of Defects for the Device Performance. *Solar EnergyMaterials and Solar Cells*. **67(4).** 37-43.
[20] McCandless, B.; Hegedus, S. (1991). Photovoltaic Specialists Conference. *Solar EnergyMaterials and Solar Cells* .**78(3)**. 967–972.
[21] Eisele, W.; Ennaoui, A.; Schubert-Bischoff, P.; Giersig, M.; Pettenkofer,C.;Krauser, (2003) . investigations of Zn(Se, OH)/Zn(OH)2 films on Cu(In, Ga)(S, Se)2 substrates for highly efficient solar cells .*Solar Energy Materal*. **7(1–2)**. 17–26.
[22] Aleksandra, B;. Djuris,I. and Yu Hang, L. (2006). Optical Properties of ZnO Nanostructures. *small* . **2 (8-9),** 944 – 961.
[23] Maykel, C.; Thalia, J. A.; Arce-Plazac, D.; Seuret-Jimenezb, J.P. ;Moran-Lazaroa,F.J. (2019) . A theoretical study on Sb2S3 solar cells: The path to overcome the efficiency barrier of 8%. *Solar Energy Materials and Solar Cells* **.201(11)**. 12-19.
[24] Quanrong, D.Y.; Yiqi, Li.; Lian. C.; Shenggao, W.;Geming, W.; Yonglong, S. and Guosheng, . (2016) . The effects of electron and hole transport layer with the electrode work function on perovskite solar cells**.***Modern Physics*.**165(34).**10-18.
[25] Irani, A. R.; Rozati, S.M. ; Beke, S.b**.** (2013) . Structural and optical properties of nanostructural V2O5 thin films deposited by spray pyrolysis technique: Effect of the substrate temperature. *Materials Chemistry and Physics* .**139(48)** .45-49.
[26] Najim, A. H.; & Saleh, A. N.(2019). Study effect of window and BSF layers on the properties of the CZTS/CZTSe solar cell by SCAPS–1D. *Tikrit Journal of Pure Science*.***24*(3)**. 77-83.
[27] Hardan, T.G.; Ayed, N. S . (2020). Enhance the efficiency of the CZTS/CdS/ZnO/ITO solar cell by a BSL and Buffer layers using SCAPS -1D**.** *Tikrit Journal of Pure Science.*

دراسة محاكاة السطح الخلفي وطبقات نقل الالكترونات على الخلية الشمسية Sb_2Se_3

معمر عبد العزيز كامل , صبري جاسم محمد

قسم الفيزياء , كلية التربية للعلوم الصرفة , جامعة تكريت , تكريت , العراق

الملخص

تم في هذا البحث اجراء دراسة محاكاة لتحسين خواص الخلية ذات التركيب ($glass/ITO/CdS/Sb_2Se_3/Au$) باستخدام برنامج SCAPS-1D والمصنعة عمليا . لمعرفة مدى مصداقية البرنامج تم اجراء محاكاة للنموذج العملي ووجدنا هناك تطابق كبير جدا بين النتائج العملية والنظرية. في بادئ الامر تم إضافة طبقة انعكاس خلفي(BSL) للخلية الأساس ($CuO,CuI,CuScN,PEDOT:PSS,MoSe_2$) ووجد انه افضل طبقة أعطت نتائج جيده هي (CuO) بلغت قيمة كفاءة التحويل (16.02%). تم بعدها استبدال طبقة الموائمة (ETL) بطبقات أخرى (ZnO,ZnO:Al,TiO2,V2O5,CdO) وجد انه افضل طبقة أعطت نتائج جيدة هي (V_2O_5) حيث ازدادت كفاءة التحويل من (4.78%) الى (15.06%) للخلية المحسنة. الخطوة الأخرى تم اختيار افضل طبقه للانعكاس مع افضل طبقة موائمة وبهذا ارتفعت قيمت كفاءة التحويل الى(19.48%) للخلية ذات التركيب ($glass/ITO/V_2O_5/Sb_2Se_3/CuO/Au$).تم بعدها إضافة طبقة موائمة ثانية وتم دراسة مدى تاثرمخرجات الخلية الشمسية .