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SIMULATION OF THE PERFORMANCE OF CDTE/CDS/ZNO MULTI- JUNCTION THIN FILM SOLAR CELL

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ABSTRACT

Multi-junction solar cell layers containing CdTe/CdS/ZnO photovoltaic cells were created using SCAP 1D software using parameters based on the previous theoretical characterization to determine the significance effect on the optimization in terms of efficiency on the solar cell. The simulation of the models were carried out by varying the band gap and thickness of the absorber layer and subsequently formulate model equation using regression analysis to determine the efficiency and fill factor at any given value. Result shows that increase in the thickness of absorber layer increases fill factor, current density and open voltage from 83.74- 84.77, 26.26 -28.85mA/cm2, 0.71- 0.73, 15.51 -17.82% that ultimately resulted in a high efficiency of solar cell while increase in band-gap of the absorber layer reduces efficiency of the solar cell. Model equation gives errors ranges between 0.026 – 0.4 for thickness and efficiency, 0.0068 – 0.078 for thickness and fill factor and 0.003 – 0.2 for band gap and efficiency. The study shows that large thickness of absorber layer and low band gap favor the optimization and model equations can be used to estimate/forecast the efficiency and fill factor within the limit of the variable parameters and this offers better direction for laboratory experiment.

Keywords: Simulation, Thin film Solar cell, CdTe/CdS/ZnO, Efficiency, SCAPS-1D.

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Contribution/ Originality

This study contributes in the existing literature that energy is an uncompromised essential ingredient for socio-economic development and economic growth. We have created multi-junction solar cell layers containing CdTe/Cds/ZnO photovoltaic cells using the common SCAP ID software with varying parameters for characterization. Simulations were achieved by varying band gap and thickness of the absorber layer and thereby formulating developing model equations. Model equations were obtained using regression analysis. Yielded model equations gave minimal errors that was adequate for the simulations resulting in higher efficiency.

1. INTRODUCTION

Energy is an essential ingredient for socio-economic development and economic growth. The main goal of all energy transformations is to provide energy services that improve quality of life (e.g. health, life expectancy and comfort) and productivity. Currently, energy for most of the applications is being met mainly through the use of fossil fuel which often produces greenhouse gases thus generating global warming which is harmful to environment. With carbon dioxide levels rising, Wind energy, hydroelectric power, and solar cells have all received significant attention as potential modes of producing sustainable energy. Public fears nuclear power and its dangers, and extraction of natural gas can harm the environment through cracking and additional heating of the atmosphere

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caused by pipe leaks and ventilation of shale gas wells. Even though solar energy as the parent of photovoltaic materials is not available at night but still has the most potential unlike fossil fuel reserves. The present growing interest in photovoltaic conversion is a consequence of the concern to identify future sources of energy that will be inexpensive as well as consistent with the maintenance and safety of the environment. Second generation of photovoltaic devices, like thin film devices using low-cost substrates and semiconductors, are just aimed at reducing the amount of material at the expense of a significant penalization in terms of performance with respect to the first generation of solar cells. This opened the way to third-generation devices which are aimed at saving costs and at improving the conversion efficiency, reaching performance levels comparable or even better than those obtainable by first-generation solar cells. Despite the fact that there exists an extensive literature on CdTs solar cells, which has best performances compared to other thin film photovoltaic sector, scientific knowledge of this family of solar cells are not yet exhaustive. This concerns mainly the loss mechanisms in the cell, the substitution of the toxic CdS layer by other alternative layers, and the reduction of the absorber thickness (M. Gloeckler and Sites [1] and Jehl, et al. [2])

Matin, et al. [3] conducted a study on the efficiency on thin film solar cell using CdS as window layer, CdTe as absorber layer using Microelectronic and Photonic Structure (AMPS 1D) Simulator and concluded that cell normalized efficiency linearly decreased with the increasing operating temperature at the gradient of 0.4% which indicated better stability of the CdS/ CdTe solar cell. Tobbeche and Amar [4] used SCAPS- 1D to investigate efficiency of Copper – Indium – Gallium – Diselenide (CIGS) and CdS structure by simulating how absorber thickness affect the efficiency of short circuit current density J_{sc} , Open circuit voltage (V_{oc}) and came to conclusion that the performance improved when ultra-thin absorber ($w < 500$nm) were used.

Also, Tobbeche and Amar [5] concluded that the rise of the CdS thickness decreases all output parameters and the external quantum efficiency when atlas software was used to evaluate the defect created at the grain boundaries of CdS/ CiGS by simulating J-V characteristics and the external quantum efficiency under Am 1.5 illumination.

Hamid and Fatima [6] Simulated the limiting factors such as back contact schottky barrier and its relationship to the doping density. The result showed that higher performance may be achieved by adding and optimizing and extended CdTe electron reflector layer at the back schottky contact. The purpose of this work is to study to determine the influence of the absorber layer thickness, electron affinity and donor carrier as it on the performance of thin film solar cell a using Solar cell Capacitance Simulator (SCAPS) - 1D simulation software. SCAPS is one-dimensional simulation program Solar Cell Capacitance Simulator in 1 Dimension (SCAPS-1D)

2. BASIC PRINCIPLE OF SOLAR CELL CAPACITANCE SIMULATOR (SCAPS) - 1D SCAP

1-D SCAP discretized device with length L into N intervals and N + 1 major grid points which may not be uniform as shown in Fig. 2.7 and solve numerically using Poisson's equation and continuity equations at each grid point with the appropriate boundary conditions. Three variables Ψ, E_{Fn}, and E_{Fp} are then solve at each particular grid point 1 to N+ 1, represented by solid lines under the light, voltage, and temperature conditions, and other variables such as electric field, carrier concentration, or trapped charges are defined, the recombination profiles, electron and hole current densities, and other transport information may be obtained. Then the total JV characteristic can be obtained from $J(x) = Jn(x) + Jp(x)$ This is not only the I-V characteristics but also the spectral response Q(h)and the capacitance measurements C-V and C-f

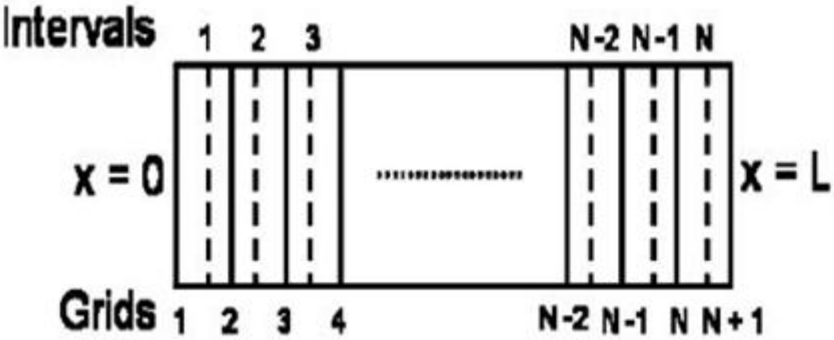


Fig-1. Intervals and grids used in numerical method. There are N intervals (dashed lines) and N + 1 major grid points (solid lines) [7]

3. METHODOLOGY

To demonstrate the influence of alloy composition on the characteristics of a CdTe/CdS/ ZnO solar cell, the study started from a set of baseline parameters of CdTe/ZnO cells. This three-layer device model of a CdTe/CdS/ZnO solar cell is the starting point for the calculations in this project work. CdTe was used as Absorber layer with thickness of 3.0.µm, band gap of 1.45eV, CdS act as the buffer layer and ZnO as the TCO. These are used as the starting point for the simulations. The material parameters of guideline cases are listed in the tables below.

Absorber layer thickness was subsequently varied from 3.0 – 7.0 µm at a step of 0.5 µm interval while other parameters were kept constant. Later, band gap was varied from 1.45 – 1.94 at an interval of 0.05eV while other parameters were kept constant. Those parameters used fall within the range stated and affirmed in Matin, et al. [3] and Hamid and Fatima [6].

For each simulation Voc. Jsc, FF and µ(%) were observed and recorded which were later plotted on the graph of efficiency against thickness and band gap so as to know the influence of those parameters on the efficiency of the solar cell. However, regression analysis was used to formulate model equation from the simulated results to determine the relationship between the thickness and FF, Efficiency and Band gap, efficiency and thickness using equation (3.1 – 3.3) below so as to be able to determine/predict the desired efficiency and fill factor using the same parameters. Thickness and band-gap were used as independent variable while Fill factor and efficiency were used as dependent variable.

$$b_1 = \frac{n(\sum xy)-(\sum x)(\sum y)}{n(\sum x^2)-(\sum x)^2} \qquad 3.1$$

$$b_0 = \bar{y} - b_1\bar{x} \qquad 3.2$$

$$y = b_0 + b_1 x + \epsilon \qquad 3.3$$

Table-3.1. Summary of Parameters used for the Simulations using SCAP ID software

Layer	CdTe	CdS	ZnO
Thickness(µm)	3.0 – .0	0.5	0.2
Band Gap (eV)	1.45 – 1.94	2.4	3.3
Electron Affinity	4.28	4.2	4.4
DieletricPermitivity	9.4	10.0	9.0
Conduction Band	7.5 x 10^{17}	2.2 x10^{18}	2.2 x 10^{18}
Valence Band	1.8 x 10^{19}	1.8 x 10^{19}	1.8 x 10^{19}
Electron Thermal Velocity	1 x 10^{7}	1 x 10^{7}	1 x 10^{7}
Hole Thermal velocity	1 x 10^{7}	1 x 10^{7}	1 x 10^{7}
Electron Mobility	500	100	100
Hole Mobility	60	25	25
Donor Density N_D	1 x10^{16}	1 x10^{17} – 3 x10^{17}	1 x10^{18} – 3 x10^{17}
Acceptor Density	0	0	0

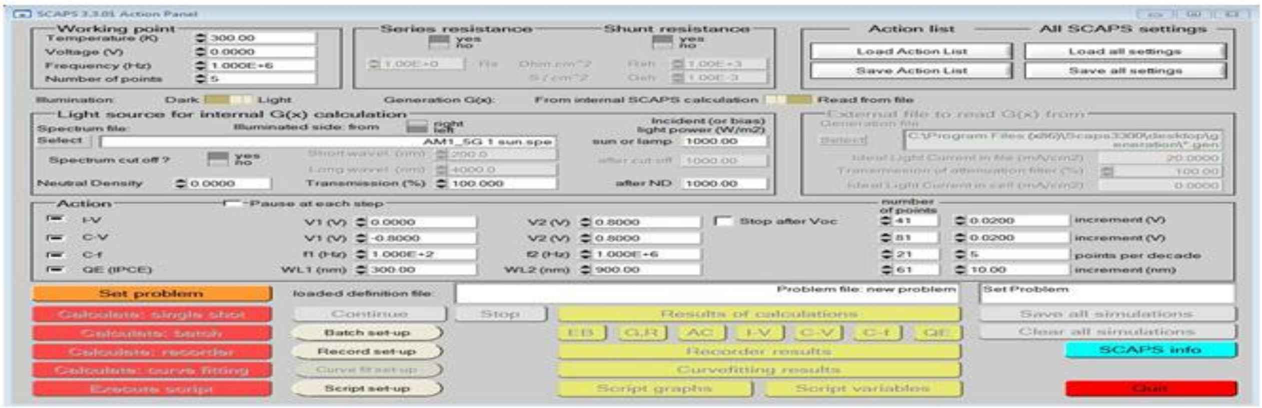


Figure-2. The Scap user interface of the SCAP ID package [8]

4. RESULT AND DISCUSSION

Optimizations of CdTe/CdS/ZnO solar cell multi-junction layers were simulated based on the previous characterization of the material properties of absorber, buffer layers and TCO. It is observed that the fill factor, current density and open voltage increases from 83.74- 84.77, 26.26 -28.85mA/cm2, 0.71- 0.73, 15.51 -17.82% as summarized in the Table 2

Table-2. Summary of the Simulated Result at Varying Thickness of Absorber Layer

Thickness(µm)	Voc	Jsc(mA/cm²)	FF	Eff (%)
2	0.7052	26.26355	83.74	15.51
2.5	0.7096	26.93463	84	16.05
3	0.7132	27.40664	84.17	16.45
3.5	0.7163	27.75703	84.28	16.76
4	0.719	28.02759	84.36	17
4.5	0.7212	28.24355	84.45	17.2
5	0.7229	28.41923	84.54	17.37
5.5	0.7245	28.55065	84.61	17.5
6	0.726	28.66765	84.67	17.62
6.5	0.7273	28.76576	84.73	17.73
7	0.7286	28.84756	84.77	17.82

Increase in Voc signifies higher theoretical maximum power which is desirable for effectiveness of solar panel. With an increase in short circuit current, the overall efficiency increases due to increasing in FF and Voc as shown in the Graph (1 - 4). The rise in the FF might have resulted from decrease in series resistance showing high degree of compatibility of material interface resistance between external contacts and active organic material responsible for absorption of light resulting to increase in the level of efficiency as shown in the Graph (1- 4). This shows that higher efficiency can be achieve by further increase the thickness of the absorber layer using the equation below generated from the set of synthetic data shown in the table 3 with the errors ranges from 0.09 to 0.4

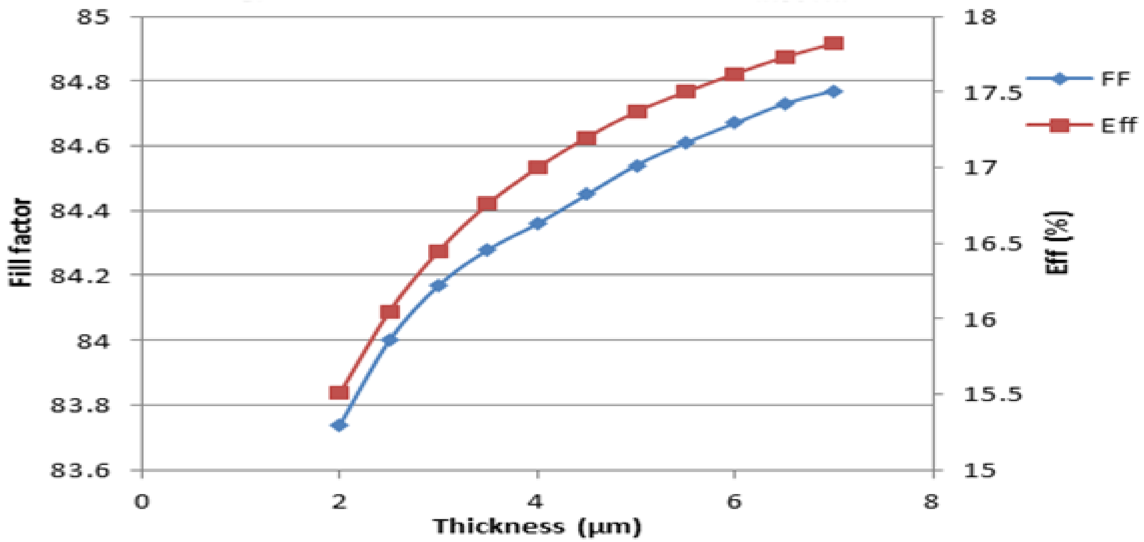
$$\mu = 15.066 \ + 0.43\,T + \epsilon$$

Where T is the thickness of the absorber layer and ϵ is the error while the desired level of fill factor can also be estimated using

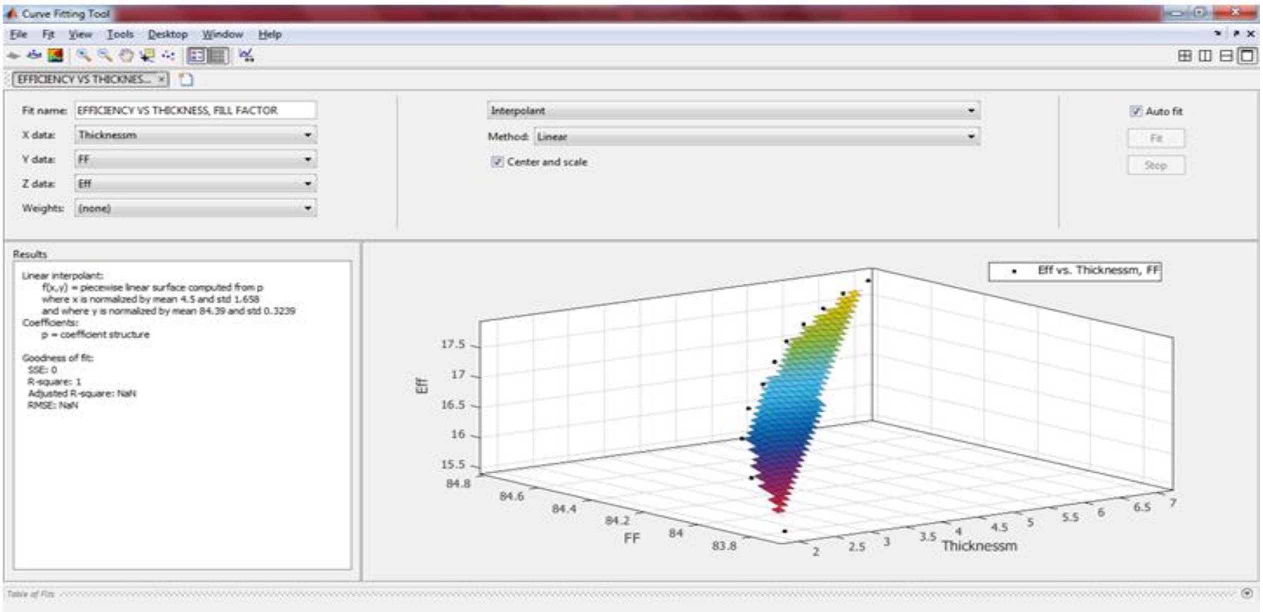
$$FF = 83.541 + 0.1893T + \epsilon$$

Where T is the thickness of the absorber layer, FF is the fill factor and ϵ is the error.

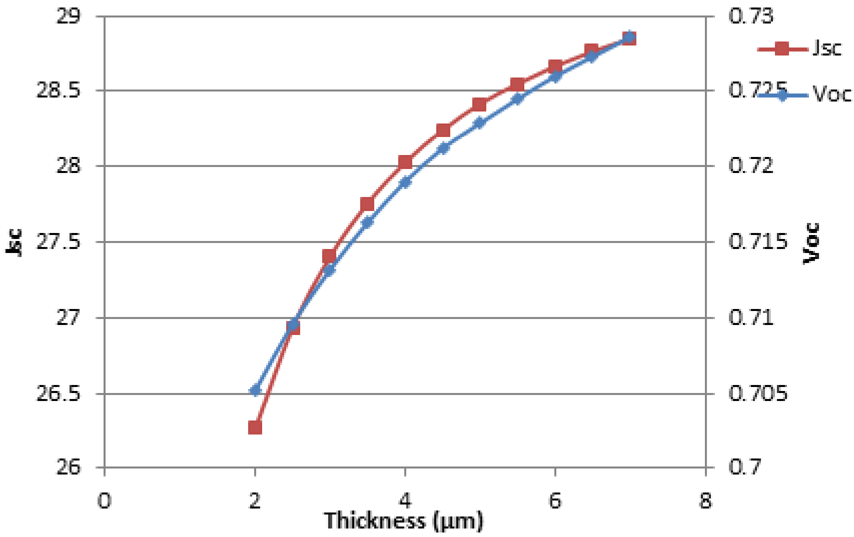
Efficiency of 17.82% at 7µm is achieved which is relatively higher than the efficiency stated by Matin, et al. [3]



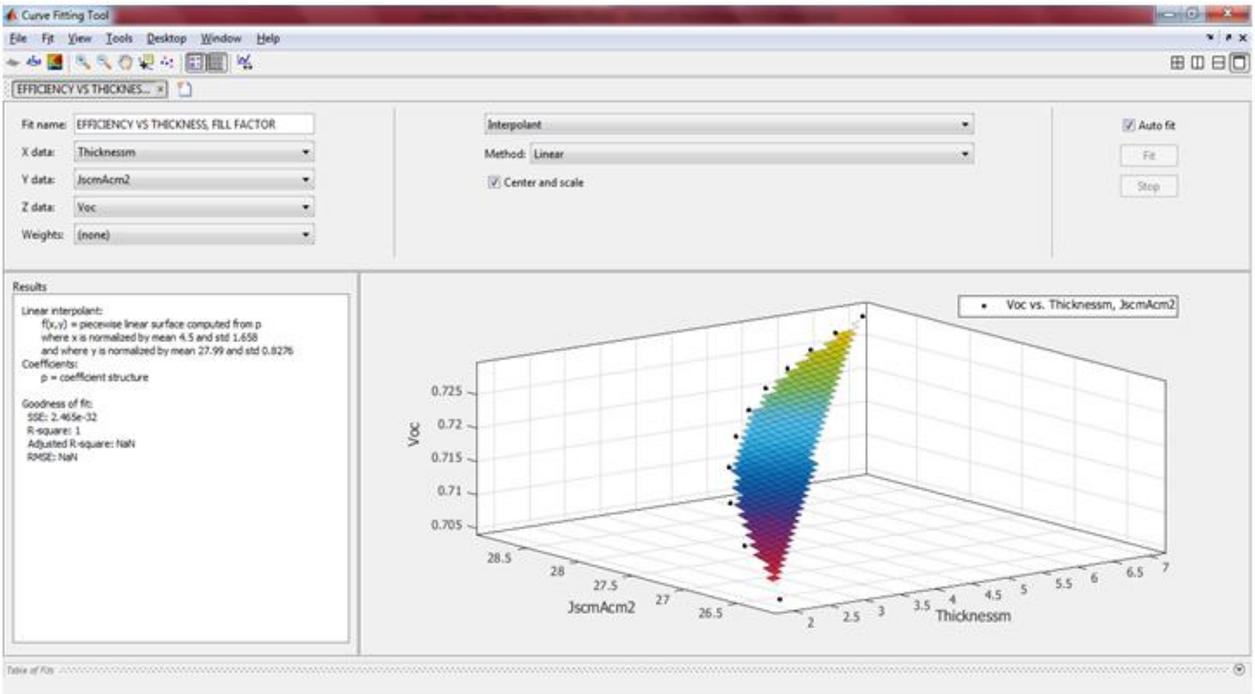
Graph-1. Graph Fill factor and Eff(%) against Thickness(µm)



Graph-2. 3D equivalent Graph Fill factor and Eff(%) against Thickness(µm)



Graph-3. Graph of Jsc and Voc against Thickness(µm)



Graph-4. 3D Equivalent Graph of Jsc and Voc against Thickness (μm)

Table-3. Estimated Results for Efficiency from derived equation with errors

Thickness(μm)(X)	Eff (%) (Y)	Reg. Result $\mu = 15.066 + 0.43T$	Error (ϵ) (Eff – Reg result)
2	15.51	15.926	-0.416
2.5	16.05	16.141	-0.091
3	16.45	16.356	0.094
3.5	16.76	16.571	0.189
4	17	16.786	0.214
4.5	17.2	17.001	0.199
5	17.37	17.216	0.154
5.5	17.5	17.431	0.069
6	17.62	17.646	-0.026
6.5	17.73	17.861	-0.131
7	17.82	18.076	-0.256

Table-4. Estimated results from derived equation with errors at varying thickness

Thickness [X]	FF [Y]	Reg. Result	ERROR
2	83.74	83.9196	-0.1796
2.5	84	84.01425	-0.01425
3	84.17	84.1089	0.0611
3.5	84.28	84.20355	0.07645
4	84.36	84.2982	0.0618
4.5	84.45	84.39285	0.05715
5	84.54	84.4875	0.0525
5.5	84.61	84.58215	0.02785
6	84.67	84.6768	-0.0068
6.5	84.73	84.77145	-0.04145
7	84.77	84.8661	-0.0961

However, increase in band gap increases Jsc, Voc, fill factor but decreases the efficiency as shown in Table 5

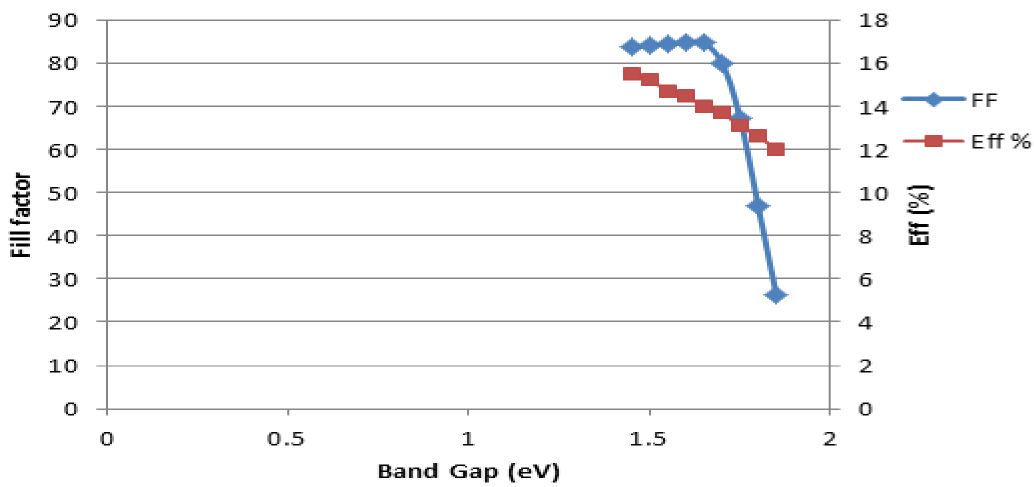
Table-5. Estimated results from derived equation with errors at varying thickness

Band gap(eV)	Voc	Jsc(mA/cm²)	FF	Eff(%)
1.45	0.7052	26.26355	83.74	15.51
1.5	0.73	24.81415	84.14	15.24
1.55	0.7556	23.08442	84.49	14.74
1.6	0.7808	21.89065	84.8	14.49
1.65	0.8098	20.4442	84.74	14.03
1.7	0.8854	19.35764	80.2	13.75
1.75	1.089	17.81435	67.46	13.09
1.8	1.6119	16.65773	46.99	12.62
1.85	2.9481	15.41958	26.43	12.02

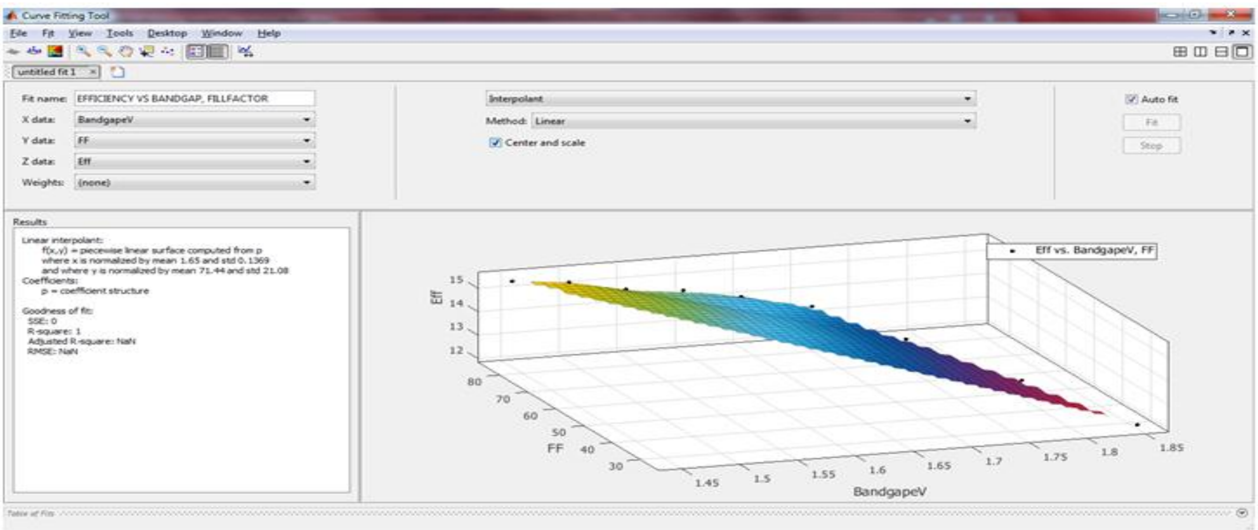
Increase in bandgap increases Voc and FF but decreases Eff and Jsc. This signifies that larger band gap reduces the optimitization of solar due to reduction in its efficiency as shown in the Graph(5- 8). However, efficiency at any particular bandgap can be extrapolated using the model equation below derived from data in the table 5 with the range of errors shown in the table 6

$$\mu = 28.16633 \ - 8.62\, B + \epsilon$$

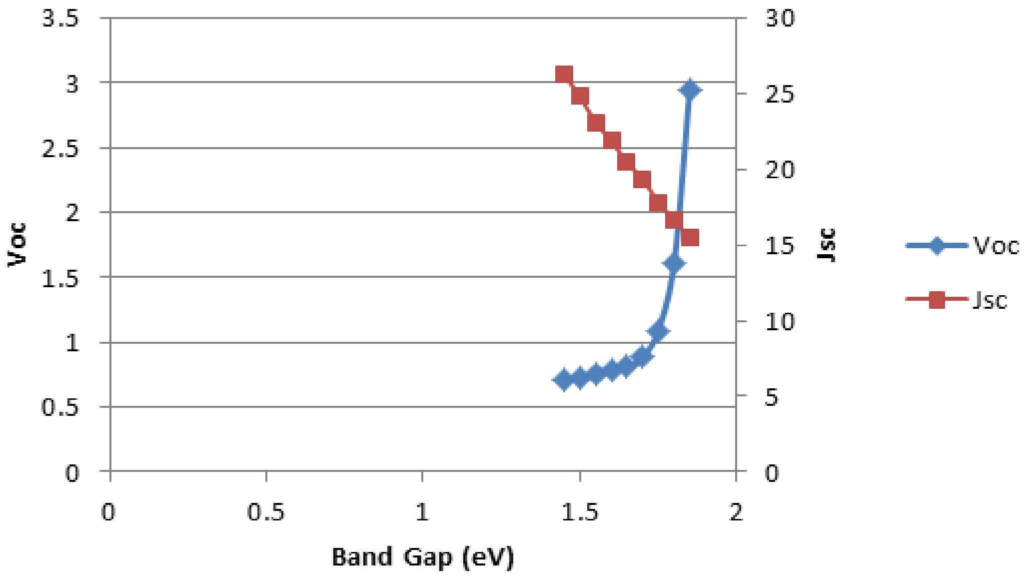
Where B is the band gap (eV)



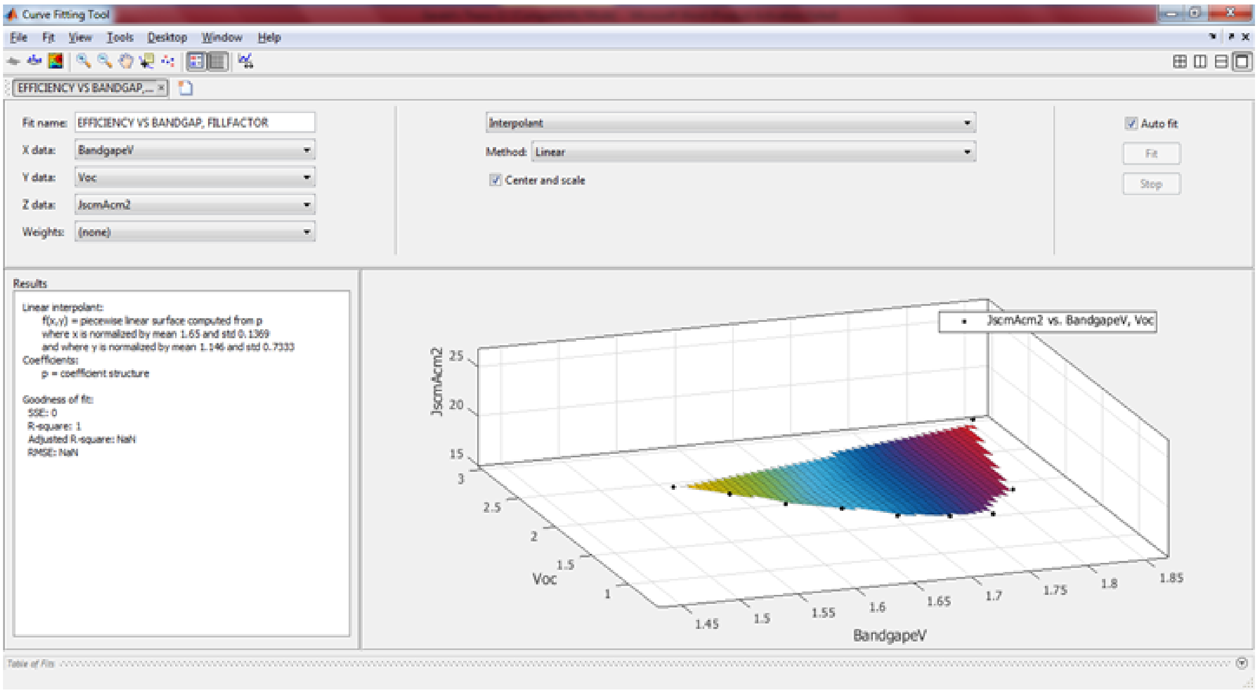
Graph-5. Graph of Fill factor and Eff (%) against Band Gap (eV)



Graph-6. 3D Equivalent Graph of Fill factor and Eff (%) against BandGap(eV)



Graph-7. Graph of Voc and Jsc against Band Gap (eV)



Graph-8. 3D Equivalent Graph of Voc and Jsc against Band Gap (eV)

Table-6. Estimated results from derived equation with errors at varying Band Gap

Band gap(eV)(X)	Eff(%)(Y)	Reg. Result	Errors
1.45	15.51	15.668	-0.158
1.5	15.24	15.237	0.003
1.55	14.74	14.806	-0.066
1.6	14.49	14.375	0.115
1.65	14.03	13.944	0.086
1.7	13.75	13.513	0.237
1.75	13.09	13.082	0.008
1.8	12.62	12.651	-0.031
1.85	12.02	12.22	-0.2

This shows that their exist the relationship among the variable with minimum errors ranges between 0.026 – 0.4 for thickness and efficiency, 0.0068 – 0.078 for thickness and fill factor and 0.003 – 0.2 for band gap and efficiency and this can be used to extrapolate(forecast) efficiency of the solar cell within and outside the limits of observation.

5. CONCLUSION

The effect of absorber layer thickness and band gap on the effectiveness of CdTe/CdS/ZnO solar cell was simulated using SCAP -1D software at varying thickness and band gap of the absorber layer were varied order to achieve an optimum efficiency.

The analysis of the result shows that increase in the thickness absorber layer of this structure yielded better Jsc and Voc that ultimately resulted in a high efficiency of solar cell while increase in band-gap of the absorber layer reduces efficiency of the solar cell.

It can be concluded that large thickness of absorber layer and low band gap favour the optimization and those equation can be used to estimate efficiency at any given value of the parameters and this offers better direction for laboratory experiment

However, the model equations show minimum degree of errors signifying that these may be used effectively to extrapolate (forecast) efficiency of the solar cell within and outside the limits of observation.

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Contributors/Acknowledgement: All authors contributed equally to the conception and design of the study.

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