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Performance of CIGS Thin Film Solar Cell with changes in Absorber Layer Thickness and the Back Contact

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ABSTRACT

The performance of CIGS thin film based solar cell was investigated using a simulation program called Solar Cell Capacitance Simulator (SCAPS 1-D) with variation of thickness of the absorber layer and metal back contacts. The cell structures were based on CIGS semiconductors as the absorber layer, ITO/ZnO as the front contact and CdS as the window layer. The simulation results illustrate that the optimum thickness of the absorber layer with an energy bandgap of 1.1eV should be within 3000nm-3500nm (3-3.5 μm) for a good performance of the solar cell giving efficiency of 16.95% and 17.07% using the common molybdenum back contact. It was also revealed that platinum metal back contacts is preferable due to its non toxic nature when compared with molybdenum and gives a cell with the highest efficiency of 18.44% with just a few thickness of 1000nm compared to palladium and gold metal back contacts with highest efficiency of 11.44% and 14.49% at 2500nm and 3000nm respectively.

Keywords: CdS, CIGS, ITO, Thin film, and ZnO

INTRODUCTION

Increase in energy consumption and the production of environmentally friendly sources of energy have been the major concern of survival and development for humans since the start of the 21st century. International assessments show that in 2040, the global energy consumption may be 48% higher than that of today.[1] Hence, keeping up with the energy demand and protecting the environment have gradually gained the attention of researchers all over the world. In a quest for alternative sources of energy, thin film technology has been singled out to meet these requirements amongst all the other alternatives and a lot of studies have been carried out in this regard. Several thin film devices that have been investigated are amorphous silicon (a-Si), copper indium gallium diselenide (CIGS), cadmium telluride (CdTe), dye sensitized solar cell and other organic solar cell. Of all these, intense researches have been on CIGS and CdTe based solar cells.

Copper-indium-gallium-diselenide (CIGS) thin film is a member of the i–iii–vi$_2$ group semiconductor material that is tetrahedrally bonded with the chalcopyrite structure. It has a chemical formula of $CuIn_xGa_{(1-x)}Se_2$ and a bandgap which varies continuously between 1.0ev and 1.7ev depending on the value of x which can take value between 0 for copper gallium selenide and 1 for copper indium selenide.[2] CIGS has an exceptionally high optical absorption coefficient of more than $10^5 cm^{-1}$ for 1.5eV and high energy photon making it possible to achieve the highest conversion efficiency compared to other cu-chalcopyrite thin film solar cells as well as CdTe and amorphous Si thin film solar cells. [3] A conversion efficiency of about 19.9% has been reported by National Renewable Energy Laboratory (NREL) and 20.3% in the Centre of Solar Energy and Hydrogen Research (ZSW). [4] [5] lots of studies are still going on to improve the conversion efficiency and reduce the overall cost for mass production. Some of the researches were based on enhancing the optical and electrical properties of the cell with the use of various deposition and characterization methods while others resolved to numerical modeling. Numerical modeling has become a necessary tool for scientist and engineers as it enables one to understand certain device properties and different processes which take place in solar cell operation and subsequently to improve their performances. In this work Solar Cell Capacitance Simulator (SCAPS) was used.

MATERIALS AND METHODS

SCAPS 1-D

SCAPS 1-D is a one-dimensional solar cell capacitance simulator developed at the Department of Electronics and Information Systems of Gent University, Belgium. [6] The program was developed to realistically simulate various characteristics of thin-film heterojunction solar cells. It has been tested for thin-film CdTe and CIGS family. The good agreements between the experimental results and the SCAPS simulation results motivated us to use the simulation tool in this work.

Simulation Parameters

The starting point of simulation in this work is a four layer ITO/ZnO/CdS/CIGS. The baseline values of the physical parameters were selected based on experimental data, literature values, theory, or in some cases, reasonable estimates which are summarized in Table 1. The defects level use in the simulation is the same as that used in latest version of SCAPS (3.3.03) CIGS-Baseline. The default operating temperature is set to 300K and the illumination condition is set to the global AM.1.5 standard. For the first part of the simulation, the thickness of CdS layer was set to 100nm, thickness of ZnO to 100nm, thickness of ITO to 500nm, and the thickness of CIGS was varied from 500nm to 6000nm. In the second part of the work, the thickness of ITO, ZnO and CdS were left unchanged while the optimized thickness value of 3000nm for CIGS was used for the variation of different metal back contacts. Table 1 shows the physical parameters used for the work.

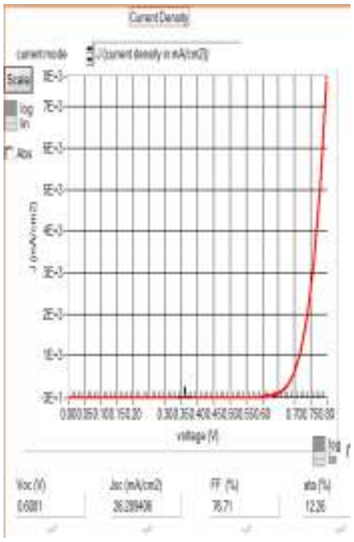
Table 1.0 Physical parameters used in the simulation of ITO/ZnO/CdS/CIGS

Layer properties	ITO	ZnO	CdS	CIGS
Thickness(μm)	0.500	0.100	0.100	
Bandgap(eV)	3.720	3.300	2.400	1.100
electron affinity (eV)	4.500	4.450	4.000	4.500
Dielectric permittivity (relative)	9.400	9.000	10.000	13.600
CB effective density of states (1/cm^3)	4.000E+19	2.200E+18	2.200E+18	2.200E+18
VB effective density of states (1/cm^3)	1.000E+18	1.800E+19	1.800E+19	1.800E+19
electron thermal velocity (cm/s)	1.000E+7	1.000E+7	1.000E+7	1.000E+7
hole thermal velocity (cm/s)	1.000E+7	1.000E+7	1.000E+7	1.000E+7
electron mobility (cm^2/Vs)	3.000E+1	1.000E+2	1.000E+2	1.000E+2
hole mobility (cm^2/Vs)	5.000E+0	2.500E+1	2.500E+1	2.500E+1
shallow uniform donor density ND (1/cm3)	4.000E+20	1.000E+18	1.100E+18	1.000E+1
shallow uniform acceptor density NA (1/cm3)	0.000E+0	1.000E+0	0.000E+0	2.000E+16

RESULTS AND DISCUSSION

Impacts of Absorber Layer Thickness Variation on CIGS Thin Film Solar Cell

The effect of the variation of the absorber thickness on the cell performance was investigated. The simulation results indicate that the overall performance of the cell increases as the thickness of absorber layer is increased. Fig. 1.0-1.12 and Table 1.1 show the effect of this variation on open circuit voltage (Voc), current density (Jsc), fill factor (FF%) and on the efficiency of the cell. The dependency of the cell performance on the thickness of the absorber layer can better be understood by looking at the band diagram of the studied CIGS thin film solar cell of Fig. 1.13. There are four regions in the band diagram as shown. Region 1 represents the recombination at the back contact of the cell and region 2 depicts the Quasi-Neutral recombination (bulk recombination) in the absorber layer. In a cell with thin absorber layer, the back contact is located near the depletion region. This leads to significant increase in back contact recombination. Thus, a large number of photo-generated carriers recombine in the back contact and less photo-generated electrons can contribute to the quantum efficiency. Therefore, with an increase in the absorber thickness, the back contact recombination current decreases and the performance of the cell increases consequently. In addition, the thickness of the absorber layer cannot simply be increased excessively. By looking at Table 1.1, the optimum thickness for CIGS absorber layer would be around 3000nm-3500nm (3-3.5 μm), a value for which the efficiency has no significant increase and Voc, Jsc and FF% can be considered almost persistent or constant. The simulation results have a good agreement with the previous results obtained. [7], [8], [9]



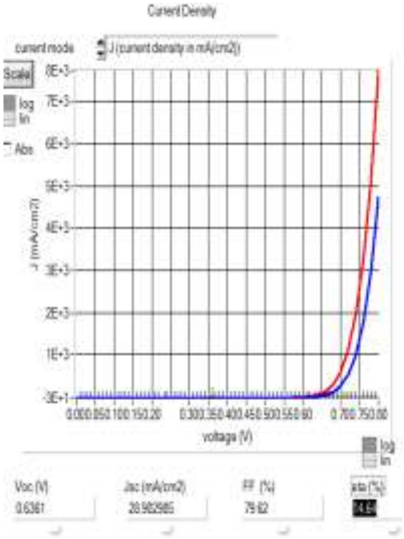
Voc (V) 0.6081

Jsc (mA/cm2) 26.289406

FF (%) 76.71

eta (%) 12.26

Fig. 1.0: Cell performances as a function of the CIGS absorber layer thickness



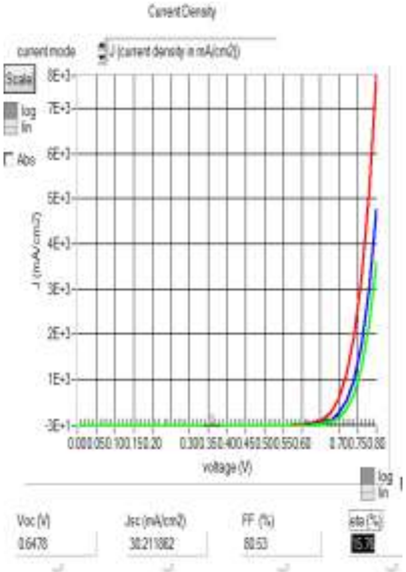
Voc (V) 0.6361

Jsc (mA/cm2) 28.902985

FF (%) 79.62

eta (%) 14.64

Fig. 1.1: Cell performances as a function of the CIGS absorber layer thickness



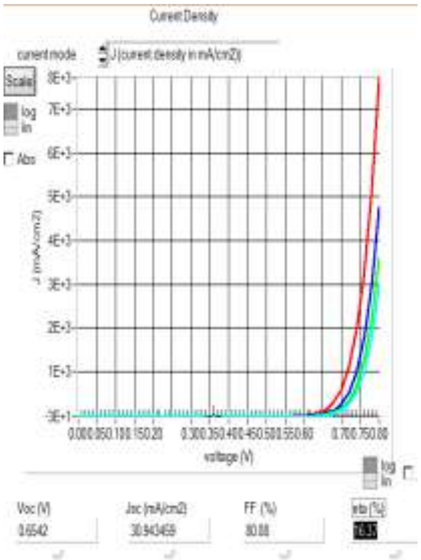
Voc (V) 0.6478

Jsc (mA/cm2) 30.211862

FF (%) 80.53

eta (%) 15.76

Fig. 1.2: Cell performances as a function of the CIGS absorber layer thickness



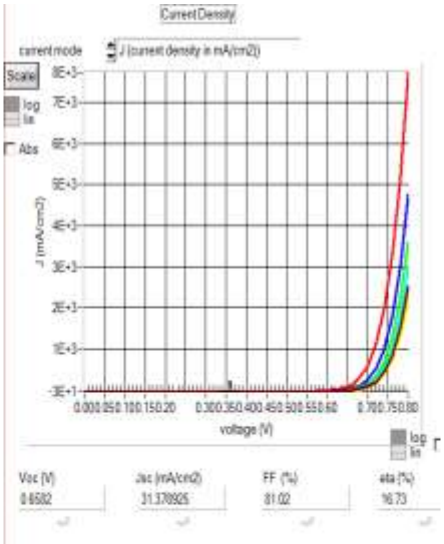
Voc (V) 0.6542

Jsc (mA/cm2) 30.943459

FF (%) 80.88

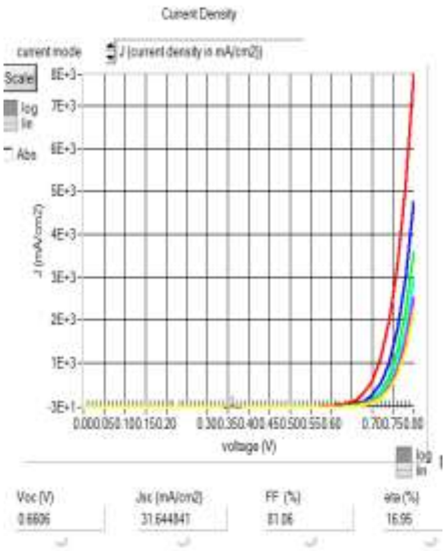
eta (%) 16.35

Fig. 1.3: Cell performances as a function of the CIGS absorber layer thickness



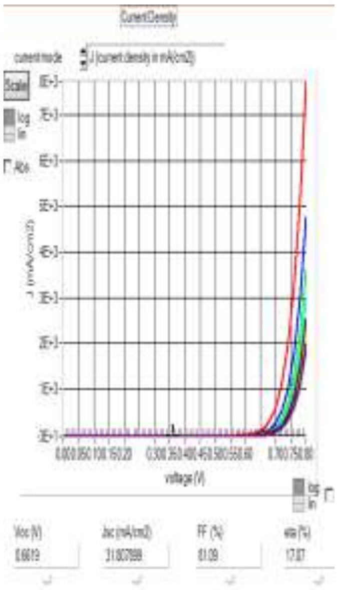
Voc (V) 0.6582
Jsc (mA/cm2) 31.370925
FF (%) 81.02
eta (%) 16.73

Fig. 1.4: Cell performances as a function of the CIGS absorber layer thickness



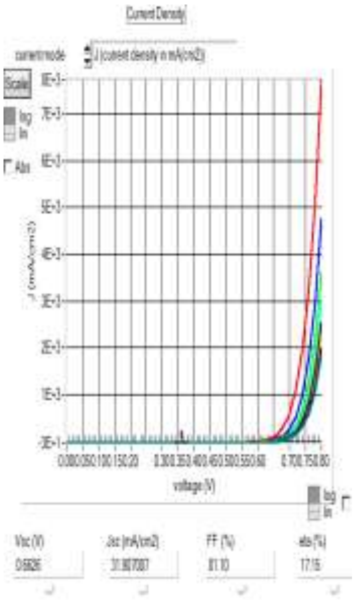
Voc (V) 0.6606
Jsc (mA/cm2) 31.644841
FF (%) 81.06
eta (%) 16.95

Fig. 1.5: Cell performances as a function of the CIGS absorber layer thickness



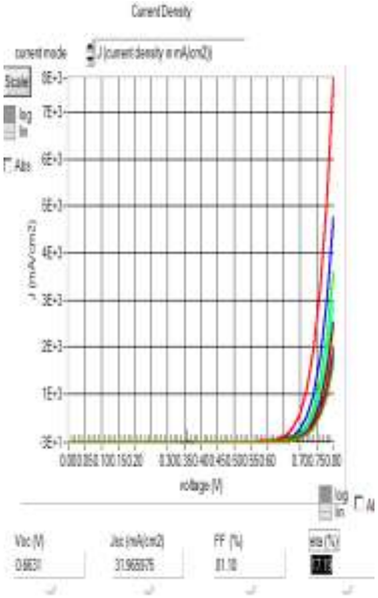
Voc (V) 0.6619
Jsc (mA/cm2) 31.807899
FF (%) 81.09
eta (%) 17.07

Fig. 1.6: Cell performances as a function of the CIGS absorber layer thickness



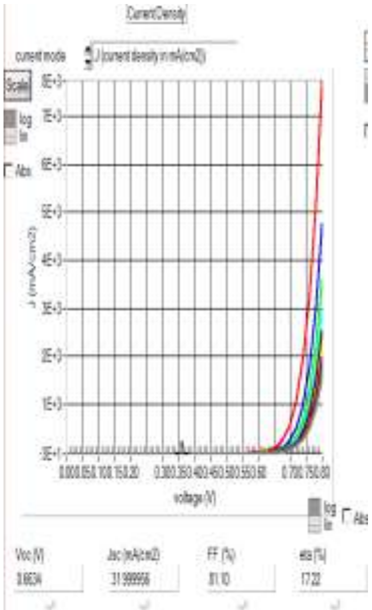
Voc (V) 0.6626
Jsc (mA/cm2) 31.907087
FF (%) 81.10
eta (%) 17.15

Fig. 1.7: Cell performances as a function of the CIGS absorber layer thickness



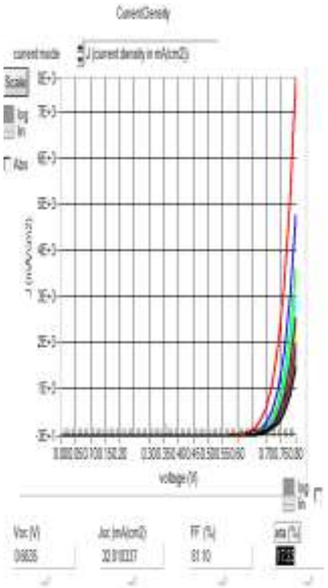
Voc (V) 0.6631
Jsc (mA/cm2) 31.965976
FF (%) 81.10
eta (%) [illegible]

Fig. 1.8: Cell performances as a function of the CIGS absorber layer thickness



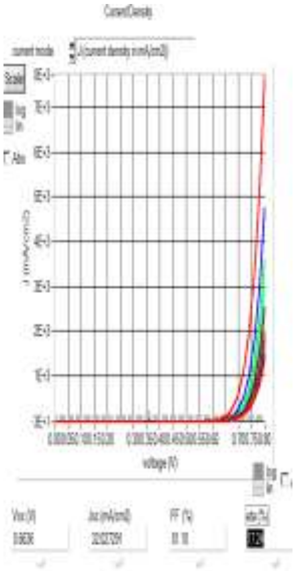
Voc (V) 0.6634
Jsc (mA/cm2) 31.999956
FF (%) 81.10
eta (%) 17.22

Fig. 1.9: Cell performances as a function of the CIGS absorber layer thickness



Voc (V) 0.6626
Jsc (mA/cm2) 32.010037
FF (%) 81.10
eta (%) [illegible]

Fig. 1.10: Cell performances as a function of the CIGS absorber layer thickness



Voc (V) 0.6636
Jsc (mA/cm2) [illegible]
FF (%) 81.10
eta (%) [illegible]

Fig. 1.11: Cell performances as a function of the CIGS absorber layer thickness

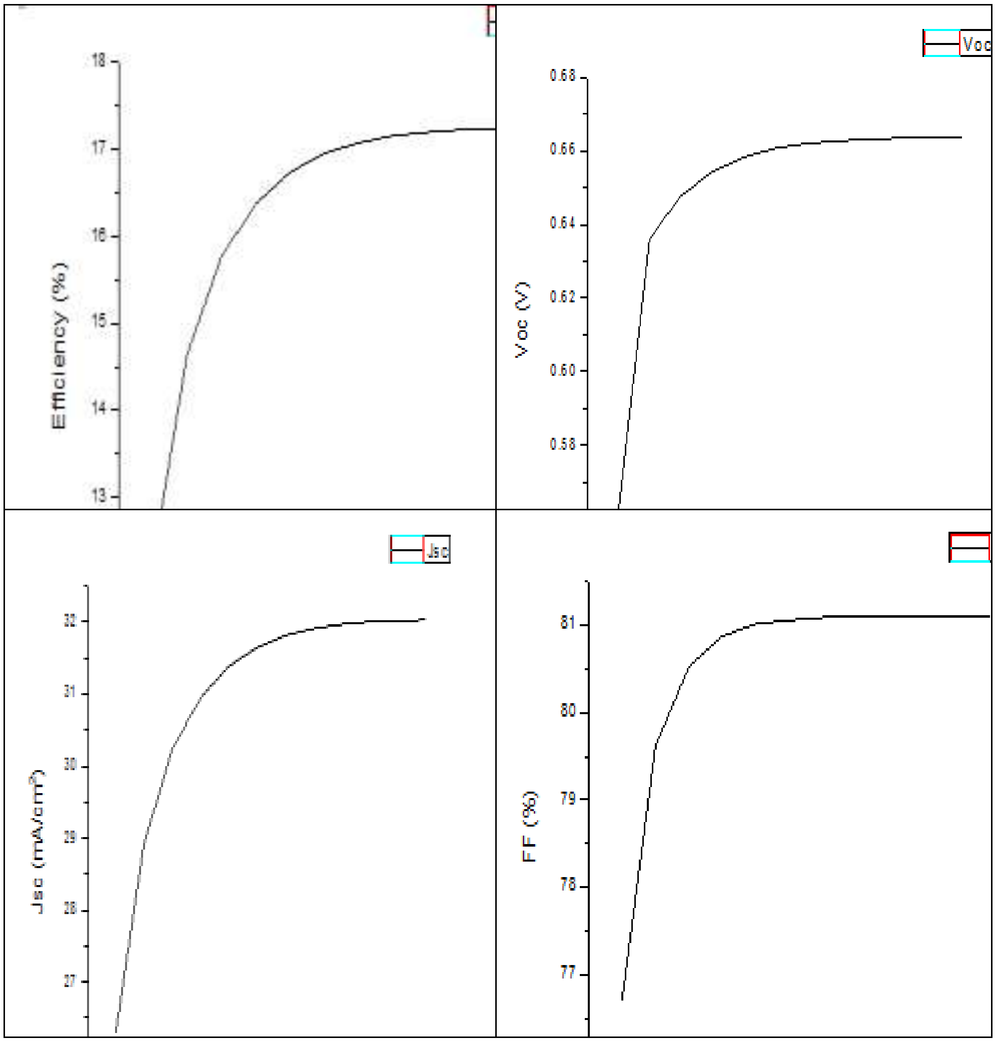


Fig. 1.12: Cell's performance enhancement induced by increase of CIGS absorber layer thickness

Table 1.1 Comparative table of the cell performance as Function of the CIGS absorber layer thickness with usual Molybdenum metal back contact

Absorber thickness (nm)	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eta (%)
500	0.5621	26.289406	76.71	12.26
1000	0.6361	28.902985	79.62	14.64
1500	0.6478	30.211862	80.53	15.76
2000	0.6542	30.943459	80.88	16.37
2500	0.6582	31.378925	81.02	16.73
3000	0.6606	31.644841	81.06	16.95
3500	0.6619	31.807899	81.09	17.07
4000	0.6626	31.907087	81.10	17.15
4500	0.6631	31.965975	81.10	17.19
5000	0.6634	31.999956	81.10	17.22
5500	0.6635	32.018337	81.10	17.23
6000	0.6636	32.027291	81.10	17.24

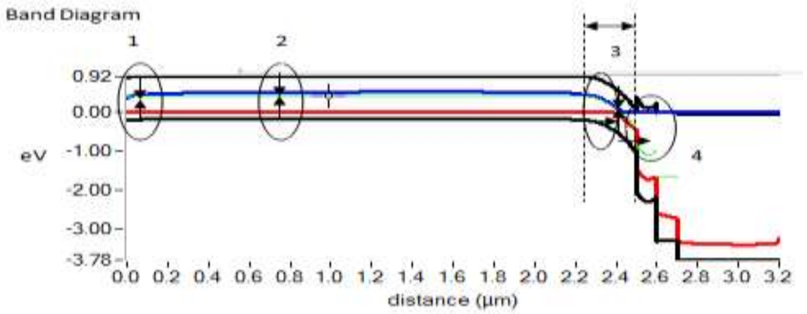


Fig 1.13: Band Diagram of CIGS Thin film Solar cell

Impacts of Different Back Contacts on CIGS Thin Film Solar Cell

The effect of different back contact on the cell performance was investigated alongside absorber thickness. The back contacts that were tested are gold, platinum and palladium. Tables 1.2-1.4 show the comparative study of these back contacts on the cell. It can be deduced that in using gold as back contact for the cell, there is an increase in Voc, Jsc and efficiency of the cell but there is an increase in the fill factor of the cell initially as the absorber thickness increases gradually to 2.5μm before it starts decreasing. As for palladium back contact, Voc, Jsc, FF%

and efficiency of the cell increases alongside absorber thickness. Lastly, there is a general increase in Voc, Jsc, FF% and efficiency of the cell in using platinum as the back contact. It can be concluded that platinum back contact is preferable as it gives the highest cell efficiency owing to its high work function which makes it reflects unabsorbed light back into CIGS absorber.

Table 1.2 Comparative table of the cell performance as Function of Gold Back Contact

Absorber thickness (nm)	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eta (%)
500	0.5182	24.788953	74.57	9.58
1000	0.5527	28.329961	77.73	12.17
1500	0.5686	29.885615	78.30	13.31
2000	0.5796	30.721173	78.16	13.92
2500	0.5884	31.210929	77.73	14.28
3000	0.5960	31.508427	77.17	14.49

Table 1.3 Comparative table of the cell performance as Function of Platinum Back Contact

Absorber thickness (nm)	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eta (%)
500	0.7939	30.571422	73.80	17.91
1000	0.7088	32.646039	79.70	18.44
1500	0.6866	33.047988	80.68	18.31
2000	0.6765	32.997300	80.94	18.07
2500	0.6711	32.817905	81.02	17.84
3000	0.6680	32.629235	81.06	17.67

Table 1.4 Comparative table of the cell performance as Function of Paladium Back Contact

Absorber thickness (nm)	Voc (V)	Jsc (mA/cm^2)	FF (%)	Eta (%)
500	0.4193	24.475633	72.41	7.43
1000	0.4538	28.148860	75.41	9.63
1500	0.4697	29.745907	75.87	10.60
2000	0.4810	30.600021	75.61	11.13
2500	0.4900	31.099285	75.05	11.44

CONCLUSION

The cell performance of CIGS was simulated and analyzed using SCAPS 1-D. The simuations show that the optimized thickness for the absorber CIGS with energy bandgap of 1.1eV is within 3000-3500nm, values for which there is no appreciable increase in the efficiency which is around 17.07% with usual molybdenum back contacts. It was also discovered that platinum metal back contact gives the highest efficiency of the metal back contacts that were investigated with an absorber thickness of 0.1µm (1000nm) as compared to 0.3µm and 0.25µm with the other metal back contacts

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