Numerical analysis of ultrathin CIGS with Si as absorber layer with SCAPS-1D simulator

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Abstract: The paper reports on the performance of ultrathin CIGS solar cells. ZnO/CdS/CIGS/Si structure had been proposed with the help of SCAPS-1D simulator. The main objective of this analysis is to improve device efficiency and reduce material cost as compared to conventional CIGS solar cells. For this purpose p Si of 1um had been inserted. CIGS thickness was ranging from 0.1 um to 1um. The simulation result showed that with improvement of absorber layer thickness performance of cell also improved. The best conversion efficiency 19.56% obtained with ZnO of thickness 0.02um, CdS thickness of 0.05 um CIGS layer thickness of 1um and Si layer of thickness of 1um respectively.

Key words: CIGS, SCAPS-1D, ultrathin layer, Solar cell, simulation.

1. Introduction: Solar cells based on chalcopyrite materials are different from others by their thick absorber layer not exceeding 2um, but it has an ability to cover wide range of solar spectrum. This reduces the material costs and shows excellent performance as compared to silicon based solar cells. CIGS is the most promising material for thin film solar cell and has number of advantages as compared to bulk silicon solar cells [1]. Because of its high absorption coefficient and appropriate band gap CIGS has achieved highest conversion efficiency of 20.4% [3]. The demerits of using CIGS material is high cost of indium and gallium. In order to overcome this shortcoming it is necessary to reduce thickness of CIGS layer leading to reduce the use of indium and gallium. Based on modelling and 1um thickness of CIGS layer Amin et al. [6] has achieved the efficiency of 17.26%. On the experiment side Vermang et al. [7] has employed Si solar cell technology at Angstrom solar centre in Sweden and enhanced the efficiency of ultrathin CIGS solar cell up to 13.5% using CIGS absorber layer with a thickness of 0.385um. In present work alternative CIGS structure was suggested. SCAPS-1D was used to analyse numerically performance of new proposed thin film CIGS solar cell. The performance of cell was observed by adding new absorber layer p Si.

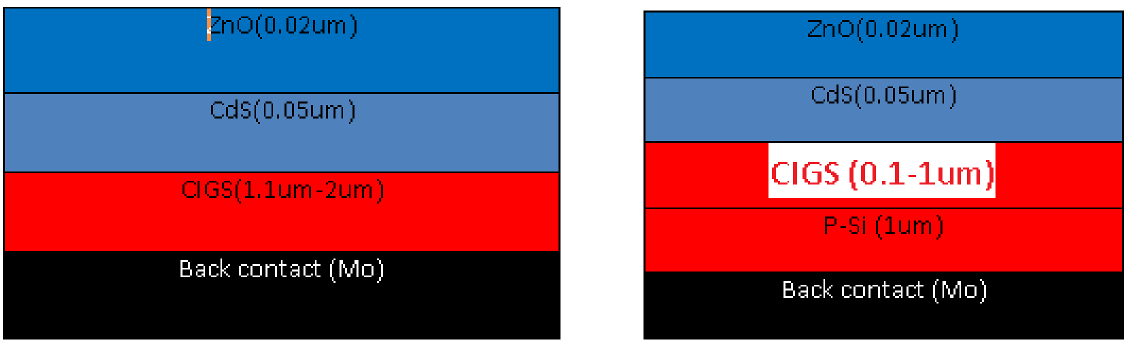

Fig. 1 (a) Schematic view of CIGS solar cells (b) Schematic view of new ultra-thin CIGS structure.

2. Device structure and simulation

SCAPS-1D is one dimensional solar cell simulation program developed at Department of Electronics and Information system (ELIS) of University of Gent, Belgium. The program was originally developed for CdTe and CuInSe2 family. In this model absorber is p type with band gap ranging from 1eV to 1.7 eV. Junction is formed between CIGS and CdS which has a band gap of 2.42 e V and window layer is formed by ZnO with band gap equal to 3.30 eV [18]. In proposed structure new layer p-Si was added which has a band gap 1.12 e V. The effect of new absorber layer was observed using SCAPS-1D simulator. CIGS thickness was ranging from 1.10 to 2 um to investigate performance of ultrathin CIGS solar cell. The cell contains p-Si and CIGS absorber layer thickness of 1um deposited on molybdenum coated glass substrate with n type buffer CdS layer with thickness of 0.05um and window layer thickness of 0.02 um. The proposed structure is shown in the figure.

Table 1. Simulation parameters

Parameters	nZnO	nCdS	pCIGS	p-Si
Band gap(eV)	3.30	2.45	1.10	1.12
Electron affinity(eV)	4.60	4.40	4.50	4.05
Dielectric constant	9	10	13.60	11.90
Nc(cm^{-3})	2.2 x 10^{18}	2.2 x 10^{18}	2.2 x 10^{18}	2.8 x 10^{19}
Nv(cm^{-3})	1.8x 10^{19}	1.8x 10^{19}	1.8x 10^{19}	2.65 x 10^{19}
Electron mobility(cm^2/Vs)	100	100	100	1450
Hole mobility(cm^2/Vs)	25	25	25	500
Electron and hole concentration(cm^{-3})	1.0x 10^{20}	1.0x 10^{20}	2.0x 10^{6}	1.0x 10^{20}
Defect density(cm^{-3})	1.0x 10^{14}	1.0x 10^{14}	1.0x 10^{14}	1.0x 10^{14}

3. Result and discussion:

3.1 Thickness optimization of absorber layer:

The conventional CIGS with CdS buffer had been simulated. The thickness of CIGS was varying from 1.1um to 2um using SCAPS-1D simulator. When thickness increases large numbers of photons are absorbed. This leads to increase the efficiency from 13.74% to 15.12% for thickness of 2um with fill factor 78.58%, open circuit voltage 0.4797V and short circuit current density 40.10mA/cm^2. Both Voc and Jsc were reduced when thickness of absorber layer was reduced. This may be caused by the process of recombination at back contact. By adding p- Si efficiency had been increased from 14.99% to 19.56%. Thickness of CIGS for new structure was varying from 0.1 um to 1 um, while other parameters remained unchanged. The finding showed that efficiency of 19.56% had been achieved. When absorber layer is thicker more photons can be absorbed hence more hole- electron pairs are generated. These increases Jsc from 32.43 mA/cm^2 to 41.14 mA/cm^2 and slightly increase Voc from 0.5721 V to 0.5796 V leading to improve cell efficiency.

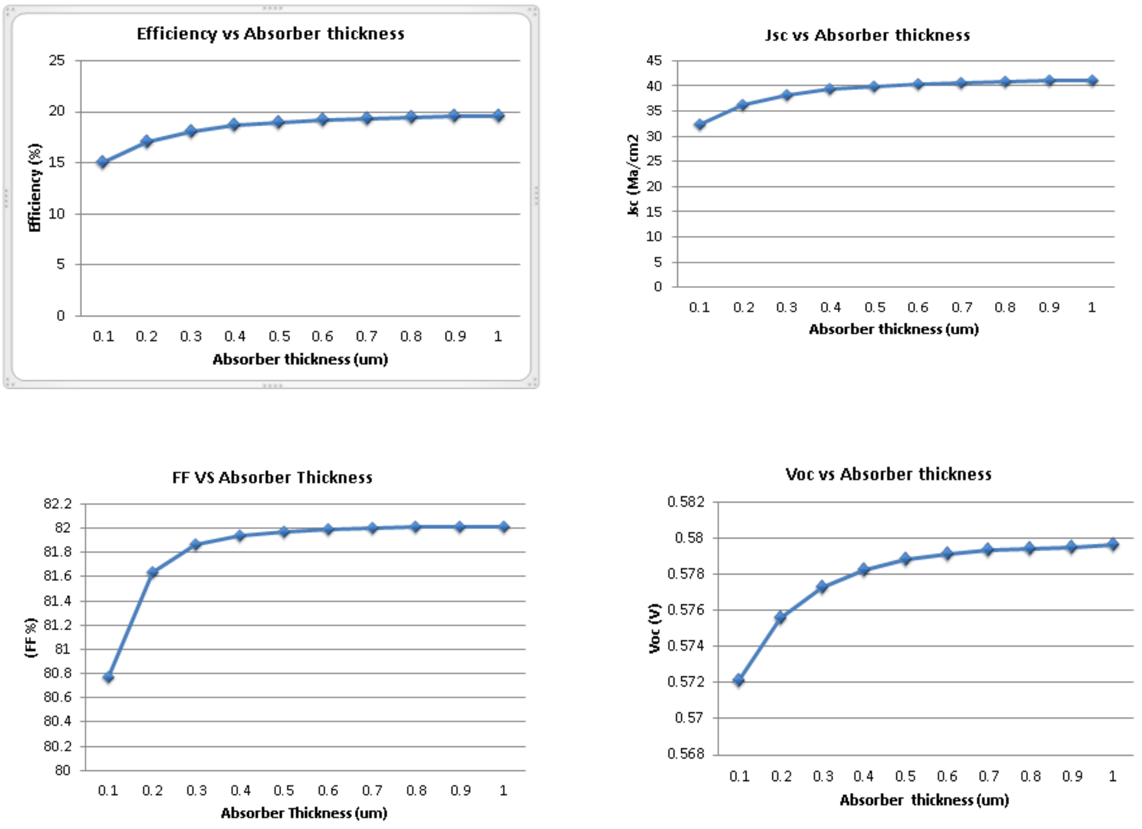

Figure 2. Absorber thickness vs. PCE, Jsc, FF, and Voc of proposed Cell

3.2 Effect of operating temperature

The performance of solar cell is highly influenced by temperature because all electrical parameters are temperature dependent. Jsc increases due to increase in temperature due to the reduction of band gap energy. As a result more photons have enough energy to generate electron-hole pairs. On the other hand Voc decreases with increase in temperature. The decrement of Voc with increase in temperature lies in the fact that Voc directly depends on saturation current which in turn decrease rapidly with excess of temperature. At higher temperature all parameters such as electron and hole mobility, carrier concentration and band gap would be much more affected would result in degrade the cell performance.

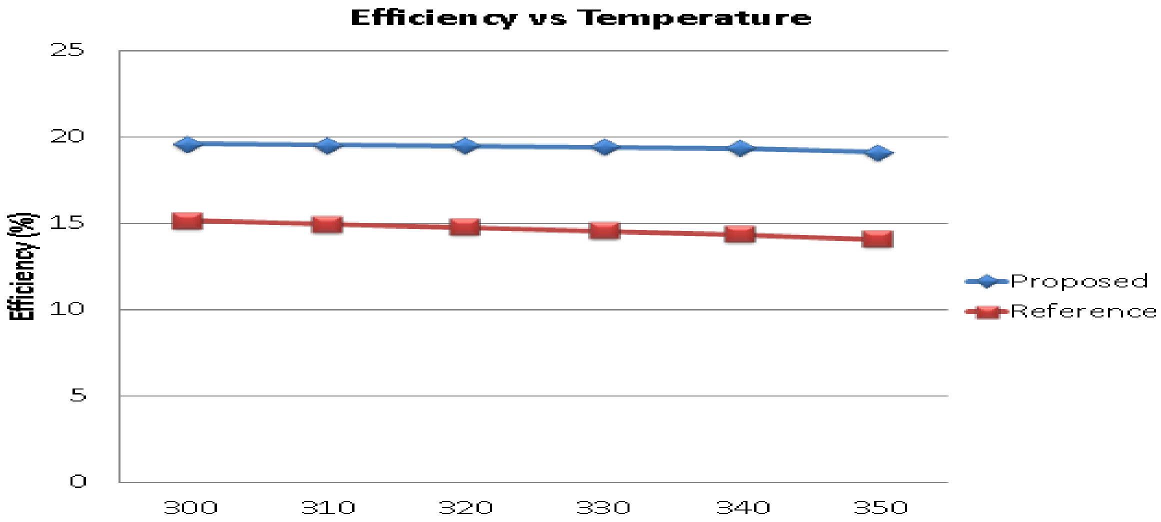

Figure 3 efficiency vs. Temperature graph for reference and proposed structure

3.3 Effect of series resistance on cell

R_s had been varied between 0 and 5 Ωcm^2. The performances of both cells were much more affected by increasing the value of series resistance. This indicates that increase in series resistance affect significantly to efficiency and FF of both solar cells.

Table 2. Comparison between efficiencies of solar cells with and without Si.

Series resistance(Ωcm^2)	Solar cell efficiency without Si layer (1um)	Solar cell efficiency with Si layer(1um)
0	15.12%	19.56%
1	13.74%	18.04%
2	12.43%	16.54%
3	11.14%	15.13%
4	9.89%	13.73%
5	8.90%	12.37%

4. Conclusion:

The reference structure was simulated and accordingly proposed structure was given with Si as absorber layer. ZnO/CdS/CIGS/Si structure shows efficiency of 19.56% with open circuit voltage 0.5796 V, Short circuit current density 41.146218 mA/cm^2 and FF 82.01%. The proposed structure showed excellent performance with reduced cost as compared to conventional CIGS solar cells.

5. References:

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