Simulation Analysis on CIGS Solar Cell On Different Absorber Layer Thickness Subject To Temperature Change Using SCAPS 1-D Software

M. Najib Harif
Faculty of Applied Sciences
Universiti Teknologi MARA
Shah Alam, Malaysia
najib@ns.uitm.edu.my

Siti Fazlili Abdullah
Dept of Electronics and Communication Engineering
Universiti Tenaga Nasional
Kajang, Malaysia
siti@uniten.edu.my

Ahmad Wafi Mahmood Zuhdi
Dept of Electronics and Communication Engineering
Universiti Tenaga Nasional
Kajang, Malaysia
wafi@uniten.edu.my

Fazliyana Za'abar
URND Sdn. Bhd
Universiti Tenaga Nasional
Kajang, Malaysia
fazliyana@uniten.edu.my

Mohd Shaparuddin Bahrudin
URND Sdn. Bhd
Universiti Tenaga Nasional
Kajang, Malaysia
shaparuddin@yahoo.com

Azri Husni Hasani
URND Sdn. Bhd
Universiti Tenaga Nasional
Kajang, Malaysia
azri.husni@uniten.edu.my

***Abstract*— The Copper Indium Gallium Selenide (CIGS) solar cell due to temperature change has been studied and the analysis was simulated using SCAPS 1-D software with the operating temperature varied from 25°C to 50°C. There are 3 parameters of thickness of CIGS absorber layer had been taken into account. The output characteristics were analyzed through a graphical method. The results showed a decreasing performance on the temperature change with respect to the efficiency, fill factor (FF) and open circuit voltage (V_{oc}) except for short circuit current density (J_{sc}). The average degradation of efficieny, fill factor and open circuit voltage with respect to temperature are 7.87%, 1.61% and 6.81% respectively while short current density increase 0.50%. It can also be suggested that there are significant direct correlations between band gap energy and temperature change.**

Keywords—CIGS solar cell, SCAPS 1-D, Efficiency, Fill Factor, Open Circuit Voltage, Short Circuit Current, Band Gap Energy, Temperature Coefficient

I. INTRODUCTION

Thin film solar cell, also referred as the second generation photovoltaic technology, is made from compound material that is much thinner compared to first generation silicon solar cell technology due to its direct band-gap properties. It could be adapted with various engineering design to improve the efficiency performance. Moreover, the simple fabrication and deposition process for develop these solar cell surely would spark the idea of cost effectiveness durability [1]. Among the thin film is Copper Indium Galium diSelenide (CIGS) solar cell also known as chalcopyrite material solar cell. CIGS solar cell currently shows the highest efficiency among all thin film technologies. According to previous research that had been conducted, the highest efficiency of CIGS solar cell has achieved was 22.6% on lab scale. This progress performance has been improvised in terms of deposition method and designs [2].

Nowadays CIGS solar cell still ongoing research and development for pushing the current achievement for further increase in efficiency and reduce in cost. The CIGS layer acts as p-type absorber material with a direct band gap for potentially high coefficient absorption and simpler fabrication process from silicon solar cells are reasons why CIGS become perfect choice [3]. Despite higher band gap energy, another aspect that needs attention is the CIGS absorber layer thickness. It is important mainly because these materials would be the key ingredients in terms of performance and cost effective [4]. In other research also been done to find related behavior between band gap energy and temperature coefficient by NREL team reported an interesting finding of the correlation between thermal behaviour and temperature coefficient of the fill factor in CIGS solar cell modules. Accordingly, the temperature coefficient of the fill factor of CIGS modules is found to be increased after light soaking. It is suggested that this is due to light induced reduction in the conduction band offset between the buffer and the absorber [5]. Further investigation regarding temperature effect and behaviour are vital in order to develop more robust CIGS solar cells. In this paper, simulation study on the temperature change on CIGS absorber layer is demonstrated.

II. SIMULATION APPROACH USING SCAPS 1-D SOFTWARE

The output characteristics of CIGS thin film solar cell were simulated using Solar Cell Capacitance Simulator (SCAPS) software version 3.3.0.7 which allows users enter the parameters to define the materials and interfaces of the solar cell [6]. The CIGS/CdS/ZnO cell structure that was designed in SCAPS is shown in Fig 1. The structure consist of window layer ZnO, buffer layer CdS, p-type absorber layer CIGS back contact layer (Molybdenum) and glass substrate layer. The thickness for both window layer and buffer layer are set to 0.05 µm. For this study, all materials properties for the buffer layer and window layer are kept constant in order to optimize the output characteristic of the absorber layer CIGS with regards to the temperature change as previously studied [7]. The thickness and material properties for the back contact and glass substrate are pre-defined in SCAPS software.

The absorber layer CIGS thickness on the other hand, was varied at 1 µm, 2 µm and 3 µm respectively. However the band gap energy, E_g was kept constant at 1.20 eV as well as the electron affinity, χ_e at 4.25 eV. These value were selected based on the optimum Ga/(Ga + In) composition as $Cu(In_{0.7},Ga_{0.3})Se_2$ which has been reported in [8]. Table 1 summarized the parameters used in the simulation design.

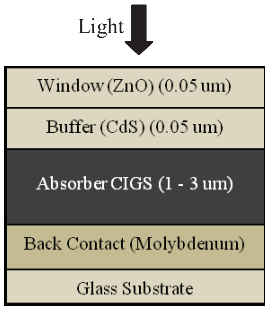

Fig 1. Schematic design for CIGS solar cell

TABLE 1. BASELINE PARAMETER FOR CIGS SOLAR CELL USING SCAPS SIMULATION

Parameters	**p-CIGS**	**n-CdS**	**n-ZnO**
Band gap, E_g (eV)	1.20	2.40	3.30
Electron affinity, χ_e (eV)	4.25	4.20	4.45
Thickness (µm)	1.0, 2.0, 3.0	0.05	0.05

In order to understand the trend of the CIGS cell output characteristics, each absorber layer CIGS thickness as 1µm, 2 µm and 3 µm were used to simulate at variant temperature. In this study, the operating temperature was setup from 25 °C to 50 °C. While both CdS and ZnO layer thicknesses were kept constant. The simulation focused on how temperature affects the efficiency and fill factor. These two parameters play an important part in solar cell which indicates the performance of a solar cell.

III. RESULTS AND DISCUSSION

Firstly, the efficiency for CIGS solar cell versus temperature is analyzed as shown in Fig 2. It can be seen from the graph that, when the temperature increases from 25 °C to 50 °C, the efficiency of the cell has seen approximately linear decrement for all absorber layer a significantly and linearly decrease. CIGS absorber layer with thickness of 3 µm shows 8.14% degradation on efficiency from the temperature 25 °C to 50 °C while thickness of 2 µm and 1 µm shows degradation of 7.96% and 7.44% respectively from the gradient over the same range of temperature. Therefore, the average degradation for these layers can be calculated to be about 7.87% gradient. Temperature coefficient is a vital component role in order to determine the solar cell efficiency as well as to quantify the sensitivities of the performance of any solar cell. It is mainly determined by the absorber layer composition and doping concentration. Typically if the temperature of solar cell increases, the efficiency decreases almost linearly for all silicon and thin film solar cells [9]. In this study, the thickness of the absorber layer shows little effect to the change in the temperature coefficient. This suggests that the thickness of the absorber layer has small contribution to the change of efficiency due to the change of operating temperature. However, higher temperature coefficient will lead to loss mechanism of the CIGS solar cell. Furthermore, higher temperature would also cause higher recombination carriers effect in CIGS solar cell layers area that will drop the performance as well.

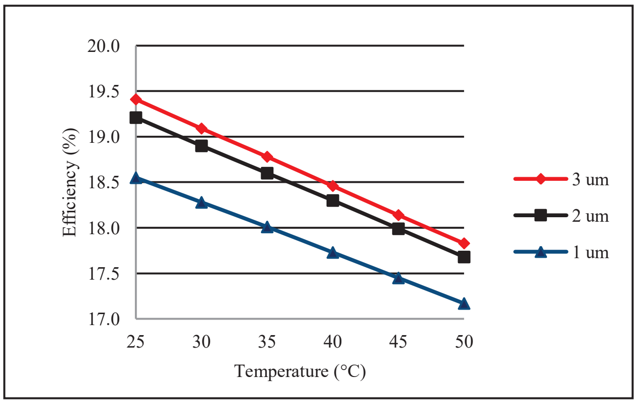

Fig 2. CIGS solar cell efficiency versus temperature

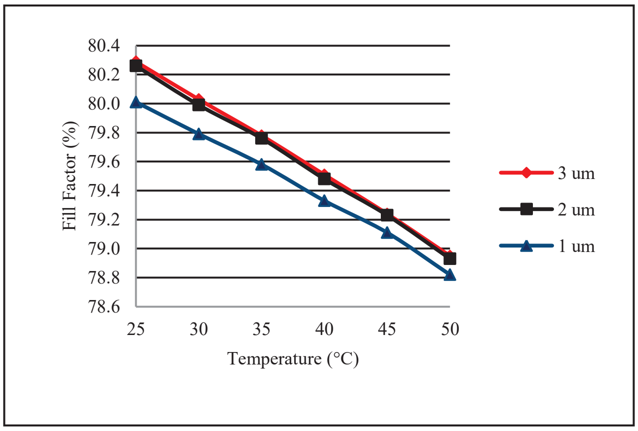

Fig 3. CIGS solar cell fill factor versus temperature

Fig 3 shows the effect of temperature on CIGS solar cell fill factor. From the graph it shows that the fill factor also decreases when the operating temperature rises. From the graph as well, the 3 µm thickness and 2 µm CIGS absorber layer solar cell show similar behavior of around 1.67% to 1.66% gradient degradations of fill factor. For thickness of 1 µm, slightly lower degradation of around 1.49% gradient was recorded. The degradations are similar for all thickness, where for efficiency 3 µm seems higher degradation than other thickness. Thus the average degradation of the fill factor from Fig 3 can be calculated to be 1.61% gradient. Again, these suggest that the thickness of the absorber layer has small contribution to the changes in fill factor due to the change of temperature. From the simulation results, it can be said that the performance of this CIGS solar cell has a direct correlation between efficiency and fill factor. When the efficiency decreases, the fill factor will decrease as well. This is because the efficiency in solar cell has a directly proportional to the fill factor [10]. As explained earlier, temperature coefficient exists instead of operating temperature of the solar cell. Besides, when the temperature coefficient increases, the fill factor will drop. This correlation can be determined in equation below that has been published in [11] as:

$$\beta_{FF_0} = \frac{1}{FF_0}\frac{dFF_0}{dT_c} \approx (1 - 1.02\ FF_o)\left(\frac{1}{V_{OC}}\frac{dV_{OC}}{dT_c} - \frac{1}{T_c}\right) \qquad (1)$$

Where β_{FF_0}, FF_0, T_c, and V_{oc} are temperature coefficient, fill factor, solar cell temperature and open circuit voltage respectively. From this equation, note that any temperature changes in solar cell, it is clearly will affect open circuit voltage as well apart from of fill factor. Furthermore major contribution that leads to detrimental of these solar cell performances is band gap energy in CIGS solar cell materials. This study only covers CIGS absorber layer material band gap which is already fixed to 1.20 eV into the simulation. CIGS material has direct band gap energy. Usually the band gap energy for CIGS absorber layer can be tuned from 1.0 eV to 1.7eV depending on compositions of the Indium and Gallium [12]. The band gap energy also has similar correlation between temperature effects. Taken together, these results suggest that higher temperature will decrease the band gap energy. When the band gap energy decreases in CIGS absorber layer, more photons will have energy higher than band gap energy to break free from the bond and create electron-hole pair which leads to an increase in photo-generated current. For this reason, the efficiency, fill factor and open circuit voltage tend to has detrimental issue [13], [14].

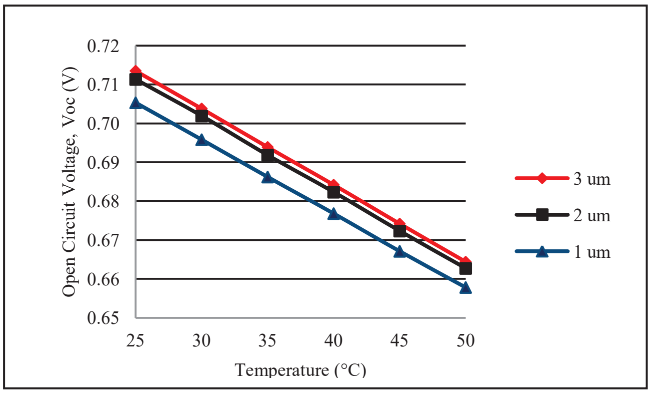

Fig 4. CIGS solar cell open circuit voltage versus temperature

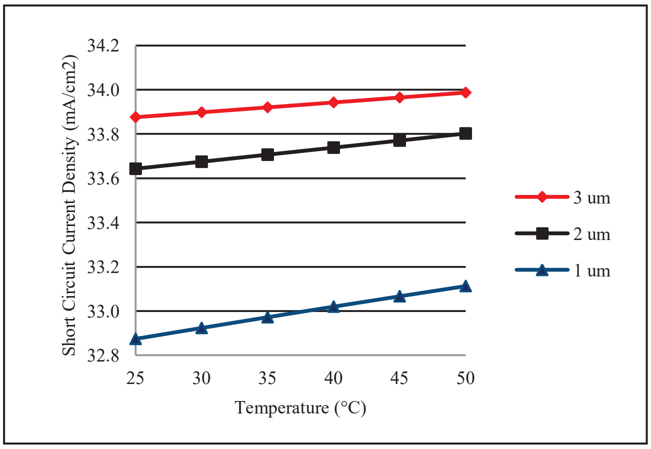

Fig 5. CIGS solar cell short circuit current vesus temperature

Another key point in this study is the open circuit voltage (V_{oc}) and the short circuit current density (J_{sc}). These two output characteristics would determine the efficiency of the solar cell as well. Fig 4 and Fig 5 have shown the opposite characteristics between them. When the temperature rise linearly, the V_{oc} of CIGS solar cell decrease for all thicknesses of the absorber layer. Surprisingly the J_{sc} of the CIGS solar cell slightly increase when simulating to higher temperature. From Fig 4, the 3 µm thickness CIGS absorber layer solar cell shows 7.00% gradient degradations of open circuit voltage due to temperature effect. Moreover, the 2 µm and 1 µm also show similar behavior as 6.75% and 6.67% gradient degradations respectively. That means total average degradation of open circuit voltage for three thicknesses of CIGS solar cells are 6.81% gradient. However in Fig 5, the J_{sc} shows slightly increase about 0.32%, 0.47% and 0.72% for absorber layer thickness 3 µm, 2 µm and 1 µm respectively as the average slope increment is 0.50%. This slope increment essentially is expected because most semiconductor band gaps decrease due to high temperature as the J_{sc} depends on the number of photons that able to to create an electron-hole pair. Hence it would create a loss mechanism factor such as parasitic absorption or surface recombination [15]. This finding confirms the association of efficiency, fill factor, V_{oc} and J_{sc} as output value of this solar cell. By all means the I-V characteristics of CIGS solar cell rely on temperature dependence. Besides, it is also has significant correlation between band gap energy reductions as defined earlier.

To understand the effect of temperature for CIGS solar cell, a few points need to be considered. Previous study, reported that by theoretically, most of parameter for common solar cell performance was temperature dependence [16]. From the study, it was found that the thickness of the CIGS absorber layer does not have significant contribution to the degradation of solar cell performance since all thickness resulted in similar performance trend. However, it is found that the 3 µm absorber layer produces better efficiency, fill factor, Voc and Jsc in comparison to thinner absorber layer as shown in Fig 2-5. This is because the absorber layer is a p type region area where the wavelengths of the illumination are absorbed. If the absorber layer is thick, more photons of the longer wavelength will be absorbed which in turn contributes to generation of electron–hole pair (EHP). The efficiency of the develop model was found to be 19.41% with the thickness of the absorber layer or 3um.

IV. CONCLUSION

In this paper, the analysis of CIGS solar cell on temperature effect has been simulated successfully using SCAPS software. The parameters were defined based on the previous study. From the simulations, it is clearly justify that the temperature significantly has effect on the CIGS solar cell performances. The efficiency, fill factor and open circuit voltage show a little percentage degradation when temperature increase. The thickness of CIGS absorber layer shows that the 3 µm CIGS absorber layer has better efficiency compare the two others which is 19.41%.

ACKNOWLEDGEMENT

The authors would like to thank Universiti Tenaga Nasional (UNITEN) and UNITEN R&D Sdn Bhd for the grant through this project.

REFERENCES

[1] P. Chopra, P. Paulson, V. Dutta, "Thin-film solar cells: An overview," Progress in Photovoltaics: Research and Applications, vol. 12, no. 2-3, pp. 69-92, 2004.

[2] T. Feurer, P. Reinhard, E. Avancini, B. Bissig, J. Löckinger, P. Fuchs, R. Carron,T. Weiss, J. Perrenoud, S. Stutterheim, S. Buecheler, and A.N. Tiwari, "Progress in thin film CIGS photovoltaics – Research and development, manufacturing, and applications.," Prog. Photovolt: Res. Appl., p. 645–667., 2016.

[3] Kato, Takuya, "Cu(In,Ga)(Se,S)2 solar cell research in Solar Frontier: Progress and current status," Japanese Journal of Applied Physics, vol. 56, no. 8S2, 2017.

[4] P. Jackson, D. Hariskos, E. Lotter, S. Paetel, R. Wuerz, R. Menner, W. Wischmann and M. Powalla, "New world record efficiency for Cu(In,Ga)Se2 thin-film solar cells beyond 20%.," Prog. Photovolt: Res. Appl., vol. 19, pp. 894-897, 2011.

[5] M. G. Deceglie, T. J. Silverman, B. Marion and S. R. Kurtz,, "Metastable changes to the temperature coefficients of thin-film photovoltaic modules," in IEEE 40th Photovoltaic Specialist Conference (PVSC), Denver, CO, 2014.

[6] M. Burgelman, P. Nollet and S. Degrave, "Modelling polycrystalline semiconductor solar cells," Thin Solid Films, Vols. 527-53, pp. 361-362, 2000.

[7] Nima Khoshsirat, Nurul Amziah Md Yunus, Mohd Nizar Hamidon, Suhaidi Shafie, Nowshad Amin,, "Analysis of absorber layer properties effect on CIGS solar cell performance using SCAPS,," Optik - International Journal for Light and Electron Optics,, vol. 126, no. 7-8, pp. 681-686, 2015.

[8] F.B. Dejene, "The structural and material properties of CuInSe2 and Cu(In,Ga)Se2 prepared by selenization of stacks of metal and compound precursors by Se vapor for solar cell applications," Solar Energy Materials and Solar Cells, vol. 93, no. 5, pp. 577-582, 2009.

[9] Olivier Dupré, Rodolphe Vaillon,Martin A. Green, Thermal Behaviour of Photovoltaic Devices, vol. 42, Cham, Switzerland: Springer Nature, 2017, pp. 9524-9532.

[10] Arno Smets, Klaus Jäger, Olindo Isabella, Rene Van Swaaij, Miro Zeman, Solar Energy: The physics and engineering of photovoltaic conversion, technologies and systems, Delft: UIT Cambridge Ltd, 2015.

[11] Jef Poortmans and Vladimir Arkhipov, Thin Film Solar Cells, Leuven, Belgium: John Wiley & Sons Ltd, 2007.

[12] Priyanka Singh, N.M. Ravindra, "Temperature dependence of solar cell performance - an analysis," Solar Energy Materials and Solar Cells, vol. 101, pp. 36-45, 2012.

[13] H. Heriche, Z. Rouabah, N. Bouarissa,, "New ultra thin CIGS structure solar cells using SCAPS simulation program,," International Journal of Hydrogen Energy,, vol. 42, no. 15, pp. 9524-9532, 2017.

[14] M. Theelen, A. Liakopoulou, V. Hans, F. Daume, H. Steijvers, N. Barreau, Z. Vroon, and M. Zeman, "Determination of the temperature dependency of the electrical parameters of CIGS solar cells," Journal of Renewable and Sustainable Energy, vol. 9, no. 2, 2017.