Functional Materials and Applied Physics - FMAP-2021 Materials Research Forum LLC
Materials Research Proceedings **22** (2022) 70-79 https://doi.org/10.21741/9781644901878-10

The Performance Study of CIGS Solar Cell by SCAPS-1D Simulator

Virang Shukla[1,a *], Gopal Panda[2,b]

[1]Department of Physics, Sarvepalli Radhakrishnan University, NH-12, Hoshangabad Road, Bhopal, India

[2]Department of Physics, Sarvepalli Radhakrishnan University, NH-12, Hoshangabad Road, Bhopal, India

[a]virangshukla_1983@yahoo.co.in, [b]gopal_panda007@yahoo.com

Keywords: Solar Cell, SCAPS-1D Simulator, CIGS Thickness, Band Gap, EBR

Abstract: The reference structure was simulated by SCAPS-1D simulator. The simulation result showed the effect of CIGS thickness, band gap and effect of EBR on the cell performance. From the simulation it could be seen that all parameters were sharply affected below CIGS thickness of 1000 nm due to increase of recombination velocity at back contact and poor absorption. Open circuit voltage was improved by CIGS thickness and band gap. Reference structure showed 18.78% efficiency after simulation with CIGS thickness of 3000 nm and band gap of 1.15 eV. The back electron reflector (EBR) had been inserted to reduce the effect of back contact recombination. With EBR cell performance was significantly improved. The proposed structure showed 19.30% efficiency with CIGS thickness of 1000 nm.

Introduction

CIGS are enrolled as an effective alternative to silicon technology. One of the important advantages based on CIGS is the reduction of material usage and thereby reducing cost of production. The past performance of CIGS was reported to 20.3% [26]; which is close to silicon whose performance is nearly 25%. For improving performance of CIGS solar cell it is desirable to understand the basic factors limiting the electrical parameters of the cell. The main aim of this work was to study the various parameters of CIGS solar cell. The simulation was done using SCAPS-1D simulator. Various parameters such as absorber layer thickness, band gap and effect of EBR were examined. The parameters were simulated using SCAPS-1D simulator and their influence on electrical parameters of CIGS solar cell was analyzed.

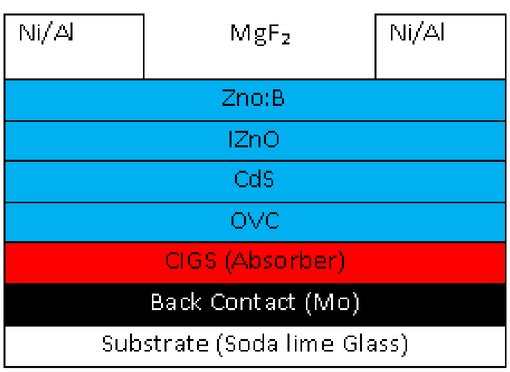

Figure 1(a) Reference Structure

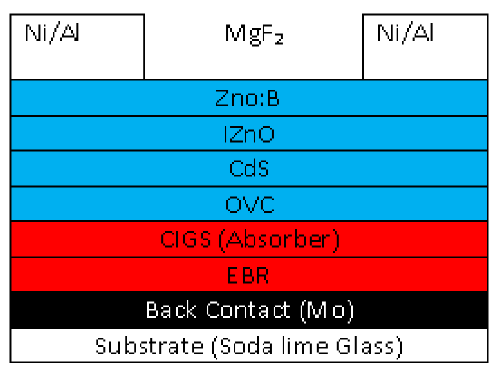

Figure 1(b) Proposed Structure

Cell structure

Materials Research Proceedings **22** (2022) 70-79 https://doi.org/10.21741/9781644901878-10

The structure was simulated using SCAPS-1D simulator. The main part of the cell is CIGS absorber layer and CdS buffer layer. The thin layer OVC is formed between interface states of absorber layer and buffer layer. OVC is normally beneficial for CIGS because of shifting electrical junction from high recombination interface between absorber and buffer layer. As a result recombination rate is reduced [1]. ZnO intrinsic layer and Boron doped ZnO are deposited on the top of the buffer layer. These two layers are commonly considered as a Transparent conducting oxide (TCO). The major drawback of ZnO: Al is absorption loss which leads to decrease in quantum efficiency of CIGS solar cell near infrared region. Therefore Boron doped ZnO would be more beneficial of CIGS solar cell [2]. Transparent conducting oxide is protected with anti-reflected MgF_2 layer to increase the absorption of photons in the absorber layer.

Numerical modeling and parameters for simulation

Simulations can be used to provide the information to interpret measurements and to analyze the potential merits of cell structure. Different software such as SCAPS-1D[22], ASA[3], PC-1D[4], AMPS-1D[18] have been developed for describing the performances of thin film solar cells. SCAPS-1D is widely used simulation program for CdTe and CIGS based solar cells. Single level defect is introduced in each layer. To pin Fermi level at CIGS/OVC and OVC/CDS layer interface neutral defects were introduced at 0.6 eV below the conduction band. The effect of series and shunt resistance was not taken in to the consideration. Band discontinuity at the interfaces between different layers was considered small and avoided. The solar spectrum AM 1.5 was used for the numerical simulation. The temperature was set at 300K.The following parameters were used for numerical simulation.

Table 1. Layer Properties [28]

Parameters	EBR	CIGS	OVC	CdS	iZnO	ZnO:B
W (nm)	10	100-3000	30	50	200	400
E_g (e V)	1.4	Graded	1.3	2.4	3.3	3.3
X (e V)	4.5	4.5	4.5	4.45	4.55	4.55
$\varepsilon/\varepsilon_0$	13.6	13.6	13.6	10	9	9
N_c (cm^{-3})	2.2×10^{18}	2.2×10^{18}	2.2×10^{18}	1.3×10^{18}	3.1×10^{18}	3.0×10^{18}
N_v (cm^{-3})	1.8×10^{19}	1.5×10^{19}	1.5×10^{18}	9.1×10^{18}	1.8×10^{19}	1.8×10^{19}
ν_e (cm/s)	10^7	3.9×10^7	3.9×10^7	3.1×10^7	2.4×10^7	2.4×10^7
ν_h (cm/s)	10^7	1.4×10^7	1.4×10^7	1.6×10^7	1.3×10^7	1.3×10^7
μ_e	100	100	10	72	100	100
μ_h	25	12.5	1.50	20	31	31
Doping (cm^{-3})	2×10^{19}	5×10^{16}(A)	10^{13} (A)	5×10^{17}(D)	10^{17}(D)	10^{20} (D)

Table 2. Bulk defect Properties [28]

Parameters	EBR	CIGS	OVC	CdS	i ZnO	ZnO:B
N(cm^{-3})	10^{14}(D)	10^{14}(D)	10^{14}(D)	5×10^{16}(A)	10^{16}(A)	10^{16}(A)
σ_e (cm^2)	10^{-15}	10^{-15}	10^{-15}	10^{-15}	10^{-15}	10^{-15}
σ_h (cm^2)	10^{-11}	10^{-11}	10^{-11}	5×10^{-13}	5×10^{-13}	5×10^{-13}

Table 3. Properties of Interface [28]

Interface	CIGS/OVS	OVC/CDS
ΔE_C (e V)	0.6	0.6
N (cm^{-3})	10^{11} (N)	3×10^{13} (N)
σ_e (cm^2)	10^{-15}	10^{-15}
σ_h (cm^2)	10^{-15}	10^{-15}

Simulation analysis and result:

Effect of CIGS thickness on the performance of Solar cell

The thickness of CIGS was set at 3000nm. Other parameters were remained constant with variation of CIGS thickness. The CIGS band gap was kept constant at 1.15 e V. The figure (2) shows the influence of CIGS thickness on different electrical parameters of the cell. It could be observed from the result that there is a sudden reduction of all electrical parameters for reducing CIGS thickness below 1000 nm. The short circuit current density (Jsc) decreased abruptly by reducing CIGS thickness below 1000 nm. Recombination of photoelectrons at back contact was the reason of this. Photons having short wavelength deeply penetrate in to absorber layer and can create electron-hole pairs at back contact. In this zone recombination rate is very high. This may leads to lower the short circuit current density from 34.092197 mA /cm^2 to 25.463094 mA /cm^2 when CIGS thickness was reduced from 1000 nm to 100 nm.

For ultrathin thickness V_{OC} lesson due to reduction of the junction. The debase of Voc and Jsc drive to reduce efficiency of CIGS cell. The cell efficiency reduces from 16.93 % for 1000nm thickness of absorber layer to 8.93% for the thickness of 100 nm. The main reason behind this is only few photons are absorbed by absorber layer as the CIGS thickness reduces. As a result efficiency of solar cell reduced. All parameters of solar cell remained constant for CIGS thickness greater than 1000nm. The Jsc increased from the value 34.092197 mA/cm^2 to 36.734819 mA/cm^2 when CIGS thickness was increased from 1000 nm to 3000 nm. This leads to the cell efficiency from 16.93 % to 18.78 %. The quantum efficiency reaches 90% at CIGS thickness of 1000 nm. As the thickness was increased from 1000 nm more photons can be absorbed by absorber layer which can improve the cell performance.

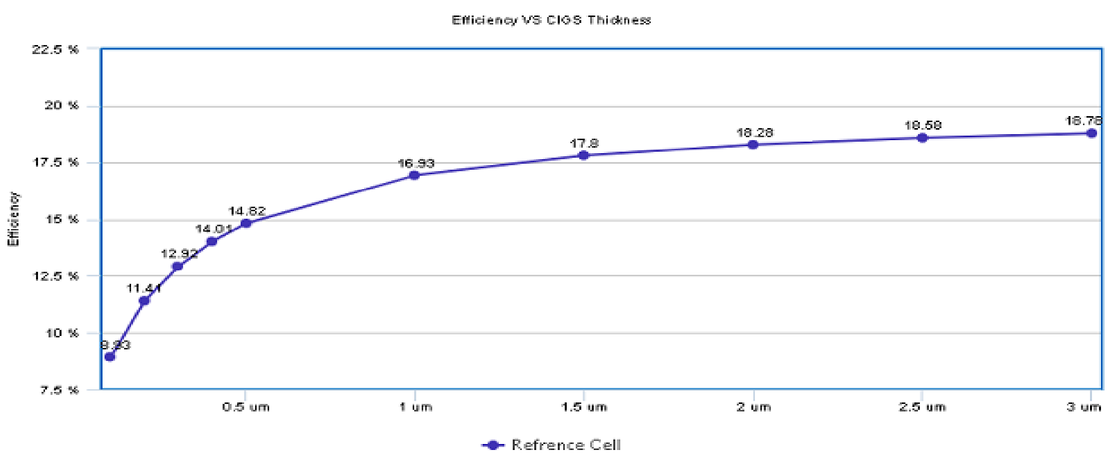

Figure 2 (a) Jsc VS CIGS thickness

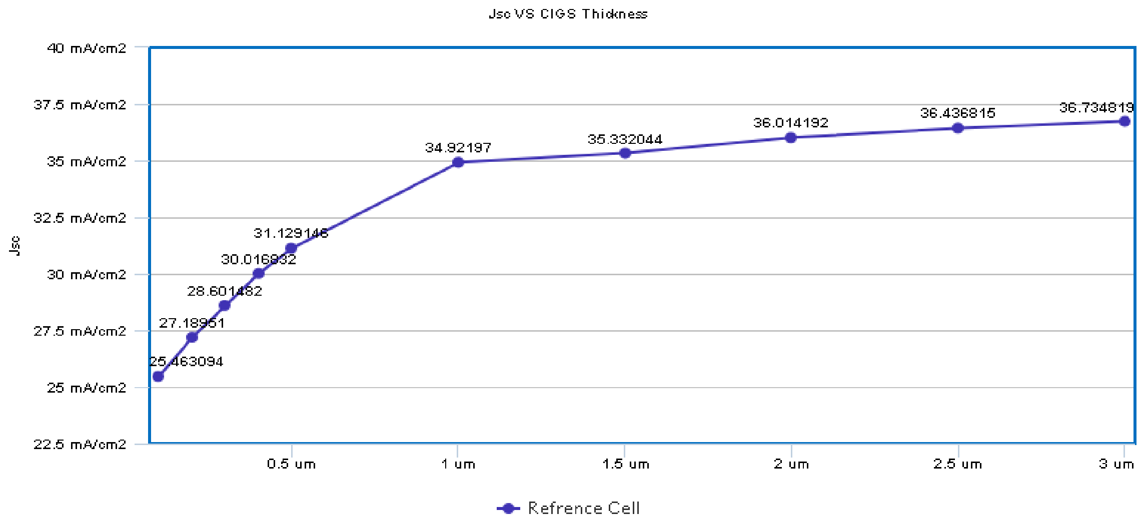

Figure 2 (b) Efficiency VS CIGS thickness

Grading effect on Performance of CIGS solar cell

CIGS band gap could be changed from 1 eV to 1.65 eV based on gallium proportion. The gallium dependency of band gap can be described by following equation.

E_g [eV] = 1.02 +0.67x + bx (x – 1) [8].

Where x denotes the gallium content in CIGS layer, x is the ratio of Ga / (Ga + In). The co efficient b is known as optical bowing coefficient. The band gap was assumed to be varied in accordance with gallium content in absorber layer. All parameters of CIGS layer and parameters of other layers were kept constant. From the simulation it could be seen that Voc increased with increase of band gap for Eg <1.25 eV. However the increment of Voc was not in proportional form with band gap. The relation of Voc was linear for band gap <1.25 eV(X<0.3).The relation became nonlinear for band gap having value >1.25 eV(X > 0.3). However open circuit voltage remains constant with high Ga concentration. This was mainly because of increment of recombination rate in space charge region (SCR). From simulation result it could be seen that short circuit current density decreased sharply with increase of gallium content but strongly dependent on absorber layer thickness. For W < 1000 nm due to combined effect of increase in band gap and decrease in absorption coefficient decrement of Jsc was severe. The efficiency and fill factor increased with increase of band gap for Eg <1.25 eV. Above this value if band gap is increased by adding gallium concentration will decrease cell performance. These results seem to be good in comparison with experimental result obtained from different literature. The cell shows excellent efficiency with Eg = 1.15 eV (X = 0.3) [13]. From the study of Rau et al. [14] and Hanna et al. [9] it could be concluded that increment of band gap by adding Ga concentration can induce deformity in CIGS. These deformity gain degrade cell performance when band gap exceeds beyond 1.15 eV (X = 0.3). Figure (3) and Figure (4) shows variations of electrical parameters due to change in band gap.

Performance improvement with EBR:

The most affected parameter is short circuit current density by changing of CIGS thickness especially for ultrathin absorber (< 1000nm) as the electron is captured by back contact. Due to capture of electron at back contact Jsc reduces below 1000 nm thickness of absorber layer. With the help of ultrathin layer (EBR) between CIGS and Mo it would be possible to keep photo electrons away from interface. The back electron reflector can keep away electrons from CIGS/Mo interface. As a result short circuit current density increases with increment of absorber layer thickness. Back electron reflector is able to increase all parameters of cell. The efficiency gain is about 2 % with EBR having thickness of 10 nm when absorber layer thickness is 1000 nm. The figure (5) shows gain in Jsc and efficiency due to different EBR thickness by varying the thickness of CIGS.

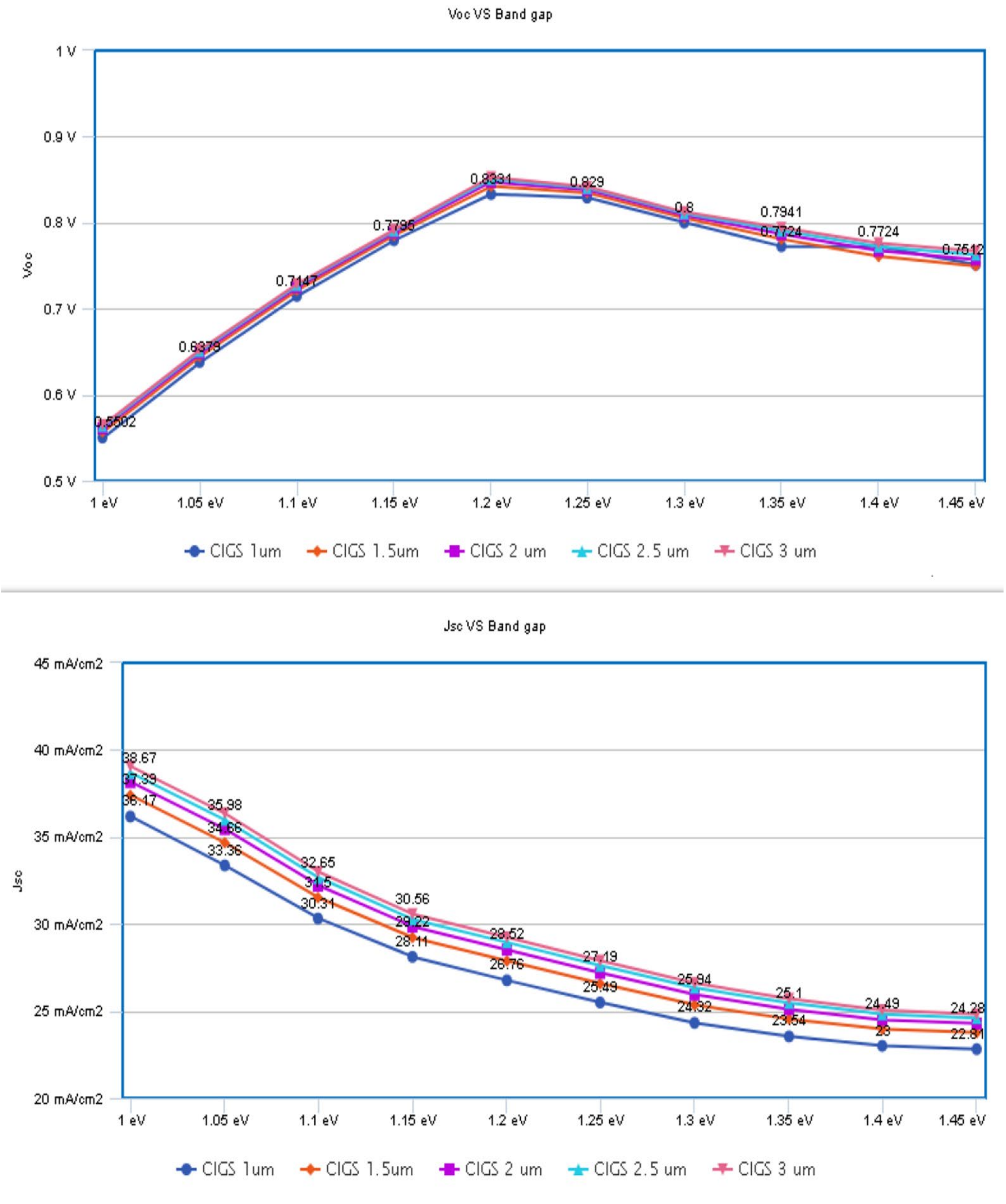

Figure 3. Effect of CIGS band gap on V_{oc} and J_{sc} by varying CIGS thickness

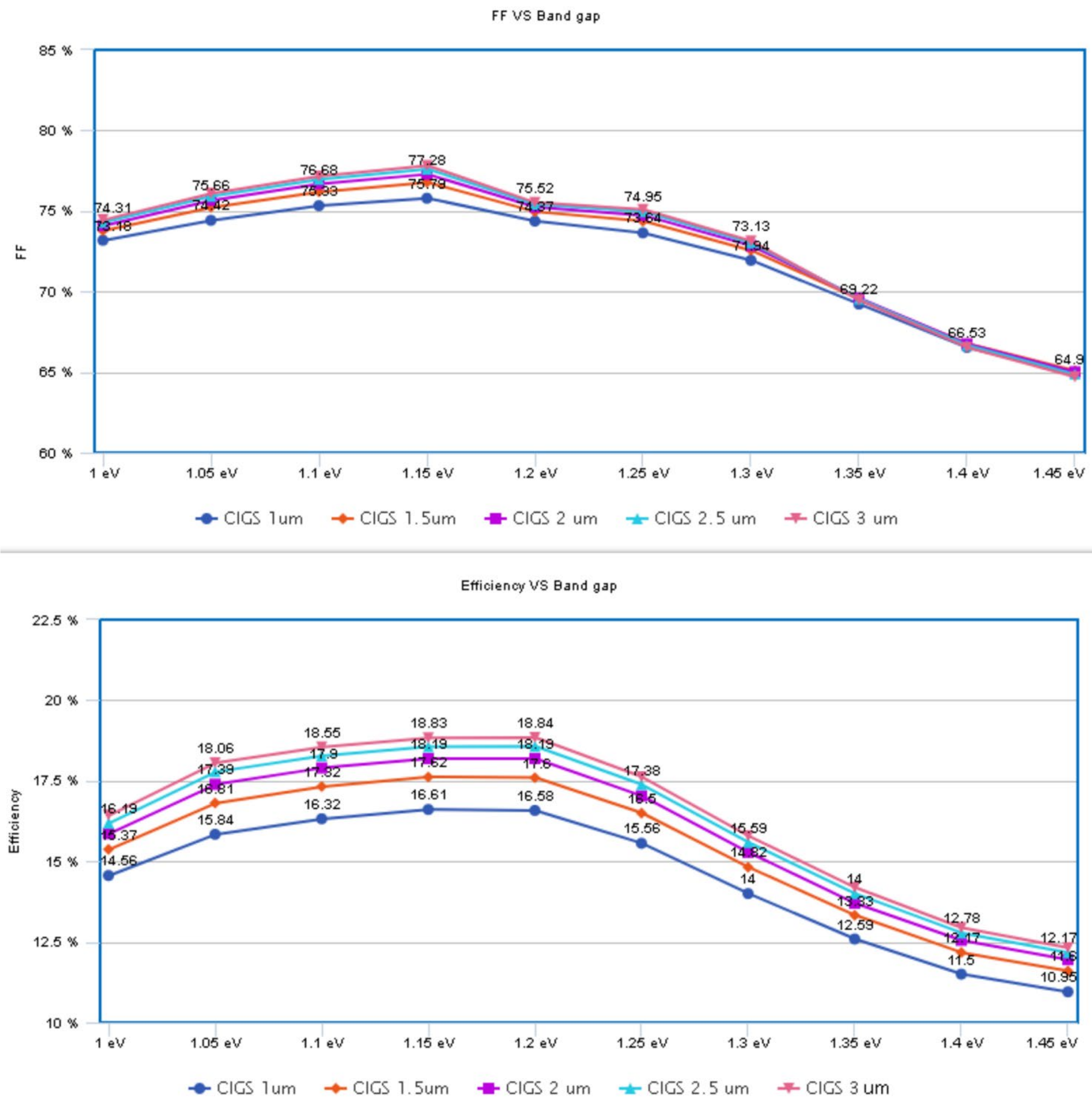

Figure 4. Effect of CIGS band gap on Fill factor and Efficiency by varying CIGS thickness

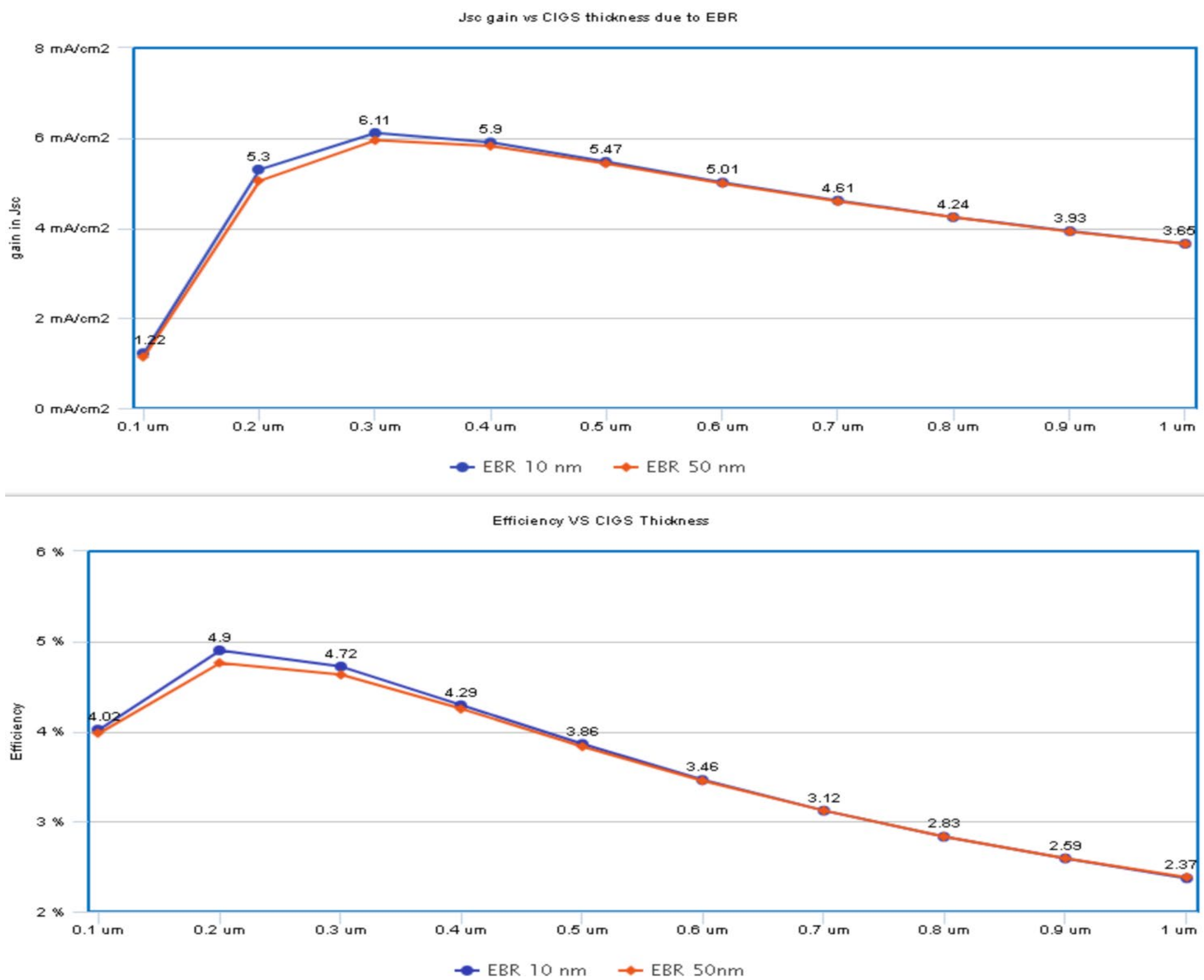

Figure 5. Gain in Jsc and Efficiency with back electron reflector by changing CIGS thickness

Conclusion

The thickness of CIGS layer, band gap and effect of EBR were analyzed using SCAPS-1D simulator. Following results could be obtained after simulation.

1. All parameters of cell are affected by varying CIGS thickness; short circuit current density degrades when thickness reduces from 1000 nm to 100 nm because of increment of recombination at CIGS/Mo interface.
2. The Ga grading can enhance solar cell performance. Jsc reduces drastically with increment of Ga in absorber. The relation between Voc and band gap is linear for E_g<1.25 eV. With increase in gallium concentration in absorber can enhance efficiency for E_g < 1.2 eV. Above this value increase in gallium concentration in absorber layer can reduce the cell efficiency. At E_g =1.15 cell shows the highest efficiency.
3. Back electron reflector can improve the cell performance. The efficiency is gained by 2 % with the presence of EBR with thickness of 10 nm when absorber layer thickness is 1000 nm.

Table 4. Performance parameters of Reference and Proposed cell

Parameters of cell	Reference cell	Cell with EBR (Proposed)
Thickness of CIGS (μm)	1.0	1.0
Open circuit voltage(V)	0.6567	0.6727
Jsc (mA /cm^2)	34.092197	37.746186
FF (%)	75.62	76.03
Efficiency (%)	16.93	19.30

Acknowledgements
Authors would like to acknowledge SCAPS-1D program developed by Marc Burgelman and colleagues at University of Gent, Belgium.

References

[1] J. Song, S. S. Li, C. H. Huang, O. D. Crisalle, and T. J. Anderson, "Device modeling and simulation of the performance of Cu (In1−xGax)Se2 solar cells," *Solid-State Electronics*, vol. 48, no. 1, 2004, pp. 73–79. https://doi.org/10.1016/S0038-1101(03)00289-2

[2] Y. Hagiwara, T. Nakada, and A. Kunioka, "Improved J_{sc} in CIGS thin film solar cells using a transparent conducting ZnO:B window layer," *Solar Energy Materials and Solar Cells*, vol. 67, no. 1–4, 2001, pp. 267–271. https://doi.org/10.1016/S0927-0248(00)00291-9

[3] A. M. K. Dagamseh, B. Vet, P. Šutta, and M. Zeman, "Modelling and optimization of a-Si:H solar cells with ZnO:Al back reflector," *Solar Energy Materials and Solar Cells*, vol. 94, no. 12, 2010, pp. 2119–2123. https://doi.org/10.1016/j.solmat.2010.06.039

[4] P. A. Basore and D. A. Clugston, "PC1D version 4 for windows: from analysis to design," in *Proceedings of the 25th IEEE Photovoltaic Specialists Conference*, May 1996, pp. 377–381. https://doi.org/10.1109/PVSC.1996.564023

[5] M. Gloeckler, A. L. Fahrenbruch, and J. R. Sites, "Numerical modeling of CIGS and CdTe solar cells: setting the baseline," in *Proceddings of the 3rd World Conference on Photovoltaic Energy Conversion*, May 2003, pp. 491–494.

[6] O. Lundberg, M. Bodegård, J. Malmström, and L. Stolt, "Influence of the Cu(In, Ga)Se_2 thickness and Ga grading on solar cell performance," *Progress in Photovoltaics*, vol. 11, no. 2, 2003,pp. 77–88. https://doi.org/10.1002/pip.462

[7] P. Chelvanathan, M. I. Hossain, and N. Amin, "Performance analysis of copper-indium-gallium-diselenide (CIGS) solar cells with various buffer layers by SCAPS," *Current Applied Physics*, vol. 10, no. 3, 2010, pp. S387–S391. https://doi.org/10.1016/j.cap.2010.02.018

[8] O. Lundberg, M. Edoff, and L. Stolt, "The effect of Ga-grading in CIGS thin film solar cells," *Thin Solid Films*, vol. 480-481,2005, pp. 520–525. https://doi.org/10.1016/j.tsf.2004.11.080

[9] G. Hanna, A. Jasenek, U. Rau, and H. W. Schock, "Influence of the Ga-content on the bulk defect densities of Cu(In,Ga)Se_2," *Thin Solid Films*, vol. 387, no. 1-2, 2001, pp. 71–73. https://doi.org/10.1016/S0040-6090(00)01710-7

[10]T. Minemoto, T. Matsui, H. Takakura et al., "Theoretical analysis of the effect of conduction band offset of window/CIS layers on performance of CIS solar cells using device simulation," *Solar Energy Materials and Solar Cells*, vol. 67, no. 1–4, 2001, pp. 83–88. https://doi.org/10.1016/S0927-0248(00)00266-X

[11] C.-H. Huang, "Effects of Ga content on Cu(In,Ga)Se_2 solar cells studied by numerical modeling," *Journal of Physics and Chemistry of Solids*, vol. 69, no. 2-3, 2008, pp. 330–334. https://doi.org/10.1016/j.jpcs.2007.07.093

[12] R. Kniese, D. Hariskos, G. Voorwinden, U. Rau, and M. Powalla, "High band gap Cu(In,Ga)Se_2 solar cells and modules prepared with in-line co-evaporation," *Thin Solid Films*, vol. 431-432, 2003, pp. 543–547. https://doi.org/10.1016/S0040-6090(03)00260-8

[13] N. Amin, P. Chelvanathan, M. I. Hossain, and K. Sopian, "Numerical modelling of ultra thin Cu(In,Ga)Se_2 solar cells," in *Proceedings of the 6th International Conference on Materials for Advanced Technologies (ICMAT '11)*, July 2011, pp. 291–298. https://doi.org/10.1016/j.egypro.2012.02.034

[14] U. Rau, M. Schmidt, A. Jasenek, G. Hanna, and H. W. Schock, "Electrical characterization of Cu(In,Ga)Se_2 thin-film solar cells and the role of defects for the device performance," *Solar Energy Materials and Solar Cells*, vol. 67, no. 1–4, 2001, pp. 137–143. https://doi.org/10.1016/S0927-0248(00)00273-7

[15] Z. J. L. Kao, N. Naghavi, F. Erfurth et al., "Towards ultrathin copper indium gallium diselenide solar cells: Proof of concept study by chemical etching and gold back contact engineering," *Progress in Photovoltaics*, vol. 20, 2012, pp. 582–587. https://doi.org/10.1002/pip.2162

[16] A. Kanevce, Anticipated performance of Cu(In, Ga)Se_2 solar cells in the thin-film limit [Doctoral thesis], Colorado State University, (2007).

[17] S. Singh, S. Kumar, and N. Dwivedi, "Band gap optimization of p-i-n layers of a-Si:H by computer aided simulation for development of efficient solar cell," *Solar Energy*, vol. 86, no. 5, 2012, pp. 1470–1476. https://doi.org/10.1016/j.solener.2012.02.007

[18] N. Hernández-Como and A. Morales-Acevedo, "Simulation of hetero-junction silicon solar cells with AMPS-1D," *Solar Energy Materials and Solar Cells*, vol. 94, no. 1, 2010, pp. 62–67. https://doi.org/10.1016/j.solmat.2009.05.021

[19] A. Niemegeers, S. Gillis, and M. Burgelman, "A user program for realistic simulation of polycristalline heterojunction solar cells: SCAPS-1D," in *Proceedings of the 2nd World Conference on Photovoltaic Energy Conversion*, Wien, July 1998.

[20] R. Scheer, "Towards an electronic model for Culn1−xGaxSe2 solar cells," *Thin Solid Films*, vol. 519, no. 21, 2011, pp. 7472–7475. https://doi.org/10.1016/j.tsf.2011.01.092

[21] A. Bouloufa, K. Djessas, and A. Zegadi, “Numerical simulation of CulnxGa1−xSe2 solar cells by AMPS-1D,” *Thin Solid Films*, vol. 515, no. 15, 2007, pp. 6285–6287. https://doi.org/10.1016/j.tsf.2006.12.110

[22] S. Degrave, M. Burgelman, and P. Nollet, “Modelling of polycrystalline thin film solar cells: new features in scaps version 2.3,” in *Proceddings of the 3rd World Conference on Photovoltaic Energy Conversion*, May 2003, pp. 487–490.

[23] J. Pettersson, C. Platzer-Björkman, U. Zimmermann, and M. Edoff, “Baseline model of graded-absorber Cu(In,Ga)Se_2 solar cells applied to cells with Zn1−xMgxO buffer layers,” *Thin Solid Films*, vol. 519, no.21, 2011, pp. 7476–7480. https://doi.org/10.1016/j.tsf.2010.12.141

[24] Z. Jehl, F. Erfurth, N. Naghavi et al., “Thinning of CIGS solar cells: part II: cell characterizations,” *Thin Solid Films*, vol. 519, no. 21, 2011, pp. 7212–7215. https://doi.org/10.1016/j.tsf.2010.12.224

[25] M. Gloeckler and J. R. Sites, “Potential of sub micrometer thickness Cu (In,Ga) Se_2 solar cells,” *Journal of Applied Physics*, vol. 98, no. 10, Article ID 103703, 2005, pp. 1–7. https://doi.org/10.1063/1.2128054

[26] P. Jackson, D. Hariskos, E. Lotter et al., “New world record efficiency for Cu(In,Ga)Se_2 thin-film solar cells beyond 20%,” *Progress in Photovoltaics*, vol. 19, no. 7, 2011, pp. 894–897. https://doi.org/10.1002/pip.1078

[27] T. M. Razykov, C. S. Ferekides, D. Morel, E. Stefanakos, H. S. Ullal, and H. M. Upadhyaya, “Solar photovoltaic electricity: current status and future prospects,” *Solar Energy*, vol. 85, no. 8, 2011, pp. 1580–1608. https://doi.org/10.1016/j.solener.2010.12.002

[28] S.ouedraogo,F.Zougmore,J.M.Ndjaka, “Numerical analysis of Copper-Indium-Gallium-Diselenide based solar cell by SCAPS-1D”,International Journal of Photoenergy,vol.2013. https://doi.org/10.1155/2013/421076