

Impact of Zinc Sulfide Insulation Layer on The Efficiency of CIGS Solar Cells

Abdelali Laid^{1*}, Bouguenna Abdellah², Meksi Aissa³

¹Applied Material Laboratory, University Djillali Liabes of Sidi Bel Abbes,
Sidi Bel Abbes, Algeria

²Department of Electronics. Faculty of Electrical Engineering, University of Sciences & Technology of Oran,
Algeria

³Electrical Engineering Department, University of Sciences and Technology of Oran, Algeria B.P 1505, El
Mnaouer, Oran, Algeria

*Corresponding author; Email: laid.abdelali@univ-sba.dz

Article Info	ABSTRACT
Article history: Received , 12/04/2025 Revised , 25/05/2025 Accepted , 03/06/2025	In this paper, we present a simulation of a CIGS solar cell with a ZnS buffer layer, performed using the Silvaco-Atlas simulator. However, we obtained an efficiency of 24.13%, short-circuit current of 37.81 mA/cm², an open circuit voltage of 740 mV, and a fill factor of 78.78% at was around 1.41 eV, corresponding to an x ratio of 0.5 for the CIGS solar cell using a ZnS buffer layer. We optimized the performance of the ZnS/CIGS solar cell with the improved effects of layer parameters such as thickness and acceptor densities ZnS buffer layers.
Keywords: Buffer layer (ZnS) ; CIGS ; Solar cell ; Optimization ; Silvaco-Atlas.	

I. Introduction

In the visible solar spectrum, the CIGS compound semiconductor offers captivating features, such as a directly controllable bandgap from (1.0 to 1.7 eV) to maximize irradiance, and an absorption factor of 106 cm⁻¹. CIGS and CdS solar cells are the most popular thin-film photovoltaic technology, with an energy conversion efficiency of 22.6%. When the 2.4 eV bandgap is unsuitable for solar cells, the CdS buffer layer shows optical absorption losses, particularly in the short-wave range [3, 4]. In addition, because of the hazardous cadmium (Cd) waste produced during deposition, the CdS buffer layer can pose a risk to human health and the environment. Given these factors, the CIGS absorption layer is compatible with other wide-bandgap buffer layers. Zinc sulfide (ZnS) prepared using chemical bath deposition (CBD) offers an attractive alternative to CdS in collaboration with CIGS absorbers [8, 9] due to its wide bandgap of around 3.68 eV and its non-toxicity to the environment. Cell efficiency is enhanced by ZnS/CIGS, Zn_{1-x}S_xO_y and CIGS, In_xS_y/CIGS, with rates of 21.0% [5], 18.2% [6] and 18.1% [7] respectively.

The energy of zinc sulfide (ZnS) is much higher than that of CdS in the bandgap. The ZnS buffer layer used in CIGS solar cells improves current generation at shorter wavelengths. CIGS solar cells with a ZnS buffer layer perform almost identically to CdS/CIGS solar cells [10-11]. The use of solar cell simulation has become an essential tool for studying their operation and improving the design of high-performance solar cells. In this research, we perform a simulation of both CIGS and ZnO/ZnS/CIGS solar cells to evaluate their performance [12, 14, 15, 16], where ZnS/CIGS solar cells are more promising than CdS/CIGS solar cells [2, 17].

The main parameters of ZnS/CIGS cells have been identified by several numerical studies, such as thickness, bandgap, gradient of the CIGS absorber layer and thickness of the ZnS buffer layer [17, 18, 19, and 21].

II. Structure Simulated



Figure 1. Structure of CIGS solar cell.

III. Physical Mode

Table 1 [1, 13, 20, 22] shows the parameters for each layer of the solar cell, which serve as input data for the Atlas-Silvaco numerical simulation.

Table 1 Material parameters used in the simulation.

Layer properties	ZnO	ZnS	CIGS
$E_g (ev)$	3.3	3.68	Varied
ϵ_r	4.1	4.5	4.8
$\chi_e (ev)$	9	8.32	13.9
$\mu_n (cm^2 / Vs)$	100	250	100
$\mu_p (cm^2 / Vs)$	25	40	25
$N_c (cm^{-3})$	2.2×10^{18}	1.5×10^{18}	2.2×10^{18}
$N_v (cm^{-3})$	1.8×10^{19}	1.8×10^{19}	1.8×10^{19}
Gaussian defect states			
$N_{DG}, N_{VG} (1 / cm^3)$	$D : 10^{17}$	$A : 10^{15}$	$D : 10^{15}$
$E_A, E_D (eV)$	Mid gap	Mid gap	Mid gap
$W_G (eV)$	0.1	0.1	0.1
$\sigma_e (cm^2)$	10^{-12}	10^{-17}	10^{-13}
$\sigma_h (cm^2)$	10^{-15}	10^{-13}	10^{-15}

In this simulation, we use the illumination conditions of the AM1.5 G solar spectrum at one sun, with an incident power density of 100 mW/cm² and an ambient temperature of 300°K.

IV. Simulation Results and Discussion

IV.1 Optimal CIGS absorbing layer bandgap

We set the thickness of the CIGS absorber layer at $3\ \mu\text{m}$ and varied the bandgap by changing the x ratio from 0 to 1. The characteristics of the CIGS cell for different band gaps as a function of efficiency are shown in Figure 2. It can be seen that an increase in the bandgap of the CIGS absorber layer, and therefore an increase in the x-ratio, leads to a proportional increase in efficiency. In Figure 4(d), we can see that an increase in efficiency from 16.75% to 24.13%, and then a decrease to ratio $x=1$. The excellent efficiency obtained for the CIGS solar cell was 24.13%. The optimum efficiency of the CIGS cell was achieved when the optical bandgap was around 1.27 eV, corresponding to an x ratio of 0.3.

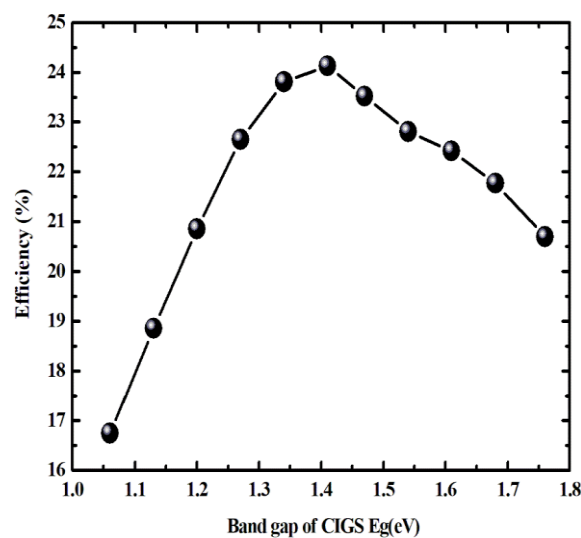


Figure 2. The variation band gap energy of CIGS as function of efficiency.

IV.2 Influence of absorber layer thickness

The CIGS solar cell structure, obtained using Silvaco-Atlas, is shown in Figure 3.

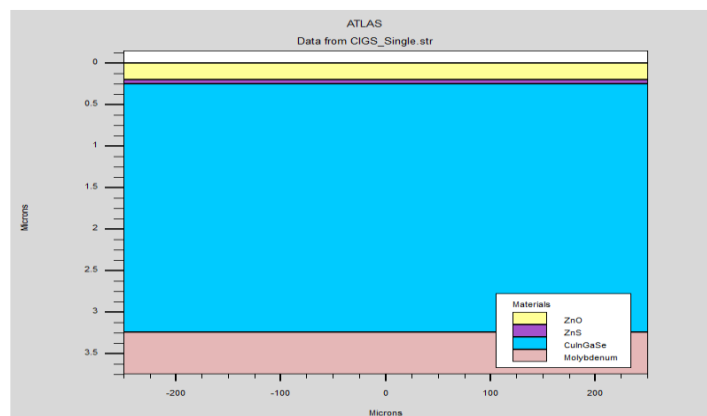


Figure 3. Silvaco-Atlas structure file of the CIGS solar cell.

In this section of the simulation, we first opted for a CIGS layer thickness of $2\ \mu\text{m}$, then adjusted the thickness of the zinc sulfide (ZnS) buffer layer from $0.1\ \mu\text{m}$ to $0.03\ \mu\text{m}$. We observed that the efficiency increases and then decreases with increasing ZnS buffer layer thickness. We also found that the high efficiency

of CIGS thin-film solar cells decreases as the thickness of the zinc sulfide buffer layer increases (from 22.45% for 0.035 μm to 20.91% for 0.1 μm). As is obvious, the performance of all solar cells decreases as the buffer layer thickness increases, with the exception of open-circuit voltage, which remains constant. Even if some absorption losses in solar cells are caused by the ZnS buffer layer or emitter thickness, this may explain the profile of this result. The ZnS layer has a thickness ranging from 10 nm to 30 nm, while the CIGS layer varies from 1 μm to 4 μm . Figures 4 (a, b, c and d) shows the impact of ZnS layer thickness on the performance of CIGS-based solar cells. The short-circuit current density increases from 30.69 to 35.70 mA/cm^2 as the thickness of the ZnS buffer layer increases from 10 to 35 nm.

The increase leads to a rise in the solar cell's conversion rate. In physical terms, a very thin absorber layer indicates that the back contact and the depletion zone are very close, which favors electron capture by this contact. Cell performance is affected by this form of recombination process, as it has an impact on conversion efficiency.

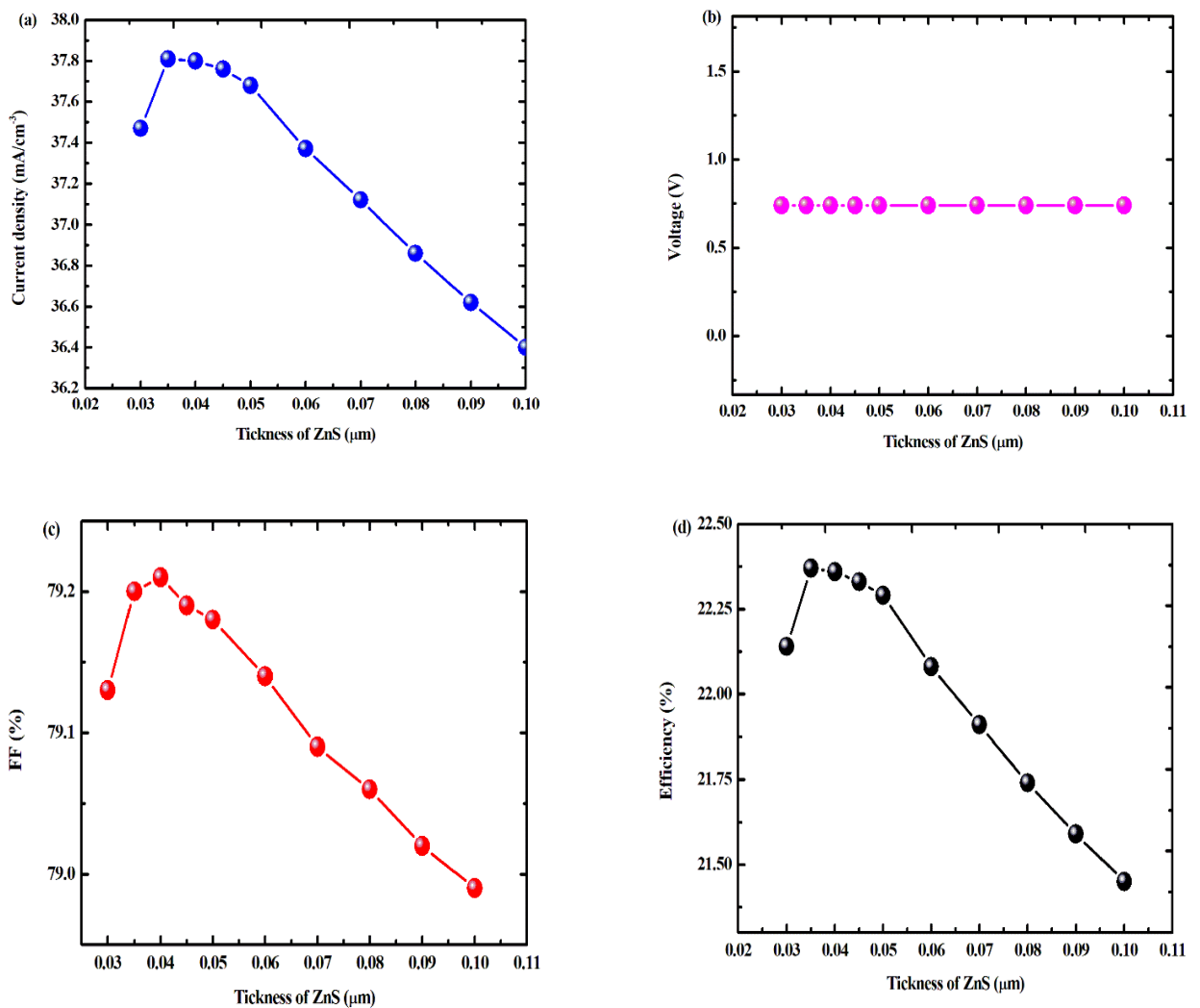


Figure 4. Impact of ZnS thickness CIGS solar cells on a) current density, b) the voltage, c) the factor form, d) the efficiency η (%).

V. Conclusion

In this work, we have presented and discussed the results of a numerical simulation study of the electrical characteristics of a CIGS-based thin-film hetero-junction solar cell. We studied the electrical stimulation of the CIGS cell with the ZnS cell, proving that the ZnS cell is better than the other cells. Then we studied the impact of ZnS buffer layer with the aim of designing an optimal ZnO/ZnS/CIGS hetero-junction structure that gives the best electrical performance.

Acknowledgements

This study is supported by the applied materiel laboratory, university of Sidi Bel Abbes, Algeria.

References

- [1] H. Heriche, Z. Rouabah and N. Bouarissa New ultra-thin CIGS structure solar cells using SCAPS simulation program *International Journal of Hydrogen Energy* **42**(15), 9524-9532, (2017)
- [2] P. Jackson, R. Wuerz, D. Hariskos, E. Lotter, W. Witte and M. Powalla, Effect of heavy alkali elements in Cu (In, Ga) Se₂ solar cells with efficiencies up to 22.6% *Rapid Research Letters* **10**(8), 583-86, (2016)
- [3] D. Hariskos, S. Spiering and M. Powalla, Buffer layers in Cu (In, Ga) Se₂ solar cells and modules *Thin Solid Films* **480**, 99-109, (2005)
- [4] Martin A. Green, Yoshihiro Hishikawa, Ewan D. Dunlop, Dean H. Levi, Jochen Hohl- Ebinger, Masahiro Yoshita, W.Y.Ho-Baillie Anita, Solar cell efficiency tables (Version 53), *Prog Photovolt Res Appl* **27**, 3-12, (2019)
- [5] T. M. Friedlmeier, P. Jackson, A. Bauer, D. Hariskos, O. Kiowski, R. Wuerz and M. Powalla, Improved photocurrent in Cu (In, Ga) Se₂ solar cells: from 20.8% to 21.7% efficiency with CdS buffer and 21.0% Cd-free *IEEE Journal of Photovoltaics* **5**(5) 1487-1491, (2015)
- [6] S. Spiering, A. Nowitzki, F. Kessler, M. Igalsen and H. A. Maksoud, Optimization of bufferwindow layer system for CIGS thin film devices with indium sulphide buffer by in-line evaporation *Solar Energy Materials and Solar Cells* **144**, 544-550, (2016)
- [7] T. Törndahl, A. Hultqvist, C. Platzer-Björkman and M. Edoff, Growth and characterization of ZnO-based buffer layers for CIGS solar cells. *Oxide-Based Materials and Devices International Society for Optics and Photonics*, 76030D-1-76030D-9, (2010)
- [8] M. A. Olopade, O. O. Oyebola and B. S. Adeleke, Investigation of some materials as buffer layer in copper zinc tin sulphide (Cu₂ZnSnS₄) solar cells by SCAPS-1D Adv. Appl. Sci. Res. **3**, 3396-400, (2012)
- [9] T. Kobayashi, T. Kumazawa, Z. J. L. Kao and T. Nakada, Cu (In, Ga) Se₂ thin film solar cells with a combined ALD-Zn(O, S) buffer and MOCVD-ZnO:B window layers *Sol. Energy Mater. Sol. Cells*, **119**, 129-33, (2013)
- [10] M. Fedawy, S. M. Ali and T. Abdolkader, Efficiency enhancement of GaAs solar cell using Si₃N₄ antireflection coating *Journal of Advanced Research in Materials Science* **42**(1), 1-7, (2018)
- [11] M. A. Green, K. Emery, Y. Hishikawa, W. Warta, E. D. Dunlop, D. H. Levi and H. Baillie, Solar cell efficiency tables (version 49) *Prog. Photovolt: Res. Appl.* **25**(1), 3-13, (2017)
- [12] N. Khoshsirat, N. A. Yunus, M. N. Hamidon, S. Shafie and N. Amin, Analysis of absorber layer properties effect on CIGS solar cell performance using SCAPS *Optik* **126**(7-8) 681-686, (2015)
- [13] M. Mostefaoui, H. Mazari, S. Khelifi, A. Bouraiou and R. Dabou, Simulation of high efficiency CIGS solar cells with SCAPS-1D software *Energy Procedia* **74**, 736-744, (2015)
- [14] F. Za'abar, A. W. Zuhdi, M. S. Bahrudin, S. F. Abdullah, M. N. Harif and A. H. Hasani, Optimization of baseline parameters and numerical simulation for Cu (In, Ga) Se₂ solar cell. In *2018 IEEE International Conference on Semiconductor Electronics (ICSE)* 209-213. (2018)
- [15] J. Park and M. Shin, Numerical optimization of gradient bandgap structure for CIGS solar cell with ZnS buffer layer using technology computer-aided design simulation *Energies* **11**(7), 1785, (2018)
- [16] M. B. Hosen, A.N. Bahar, M. K. Ali and M. Asaduzzaman, Modeling and performance analysis dataset of a CIGS solar cell with ZnS buffer layer. *Data Brief* **14**, 246-250, (2017)

- [17] T. Shawky, M. H. Aly and M. Fedawy, Performance analysis and simulation of c-Si/SiGe based solar cell *IEEE Access* 9, 75283-75292, (2021)
- [18] A. Sylla, S. Touré and J. P. Vilcot, Theoretical analysis of the effects of band gaps and the conduction band offset of ZnS-CIGS layers, as well as defect layer thickness *Int. J. Sci. Res.* 6(11), 855-861, (2017)
- [19] K. Luo, Y. Sun, L. Zhou, F. Wang and F. Wu, Theoretical simulation of performances in CIGS thin-film solar cells with cadmium-free buffer layer *Journal of Semiconductors* 38(8) 084006, (2018)
- [20] S. Tobbeche, S. Kalache, M. Elbar, M. N. Kateb and M.R. Serdouk, Improvement of the CIGS solar cell performance: structure based on a ZnS buffer layer *Optical and Quantum Electronics* 51(8) 1-3, (2019)
- [21] J. Park and M. Shin, Numerical optimization of gradient bandgap structure for CIGS solar cell with ZnS buffer layer using technology computer-aided design simulation *Energies* 11(7), 1785-1785, (2018)
- [22] N. Khoshsirat and N. A. Yunus, Numerical simulation of CIGS thin film solar cells using SCAPS-1D *In 2013 IEEE Conference on Sustainable Utilization and Development in Engineering and Technology (CSUDET)*, 63-67, (2013)