Simulation study of monolithic MoSe\textsubscript{2}/CIGS tandem solar cells

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Received: 22 June 2021 / Accepted: 26 July 2021
Published online: 09 August 2021
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Abstract
This article aims to study MoSe\textsubscript{2}/CIGS tandem solar cells employing SCAPS-1D computational package based on ant colony algorithm. The simulation of Monolithic MoSe\textsubscript{2}/CIGS tandem solar cells has been implemented successfully by employing the Matlab/Simulink. The power output of the Monolithic MoSe\textsubscript{2}/CIGS tandem modules increases by the solar irradiations during the first few days of operation. The J–V characteristic and average daily energy production throughout the year has been calculated. The results show 80.71% FF and 19.29% efficiency of the solar cell. The other parameter for the MoSe\textsubscript{2}/CIGS tandem solar cell are $V_{oc} = 0.62\, \text{V}$; $J_{sc} = 38.69\, \text{mA/cm}^2$.

Keywords Tandem solar cells · SCAPS-1D · Simulation · MoSe\textsubscript{2}

1 Introduction
There are many sources of renewable energy and solar energy is one of the most abundant of the sources [1, 2]. To harness the solar energy, solar radiations are directly converted into electrical energy by using photovoltaic cell which works on the photovoltaic effect [3]. There are many different variations of solar cells and the most common among them are the cells based on silicon for being cost effective [4, 5] and this has resulted in widespread usage of these solar cells in variety of applications [6–9]. The preparation of materials and fabrication of the solar cells with many layers of different materials is costly and time intensive. To investigate the material performance in complex systems, computational techniques, numerical method or simulations can be employed. In the present study also, the simulation technique has been applied to determine the variation of the properties critical for the performance of the solar cells. The present study demonstrates the possibility of the MoSe\textsubscript{2}/CIGS tandem solar cells as the possible material combination for the solar cell applications. There are lots of experimental [10–12], theoretical [13–15] as well as computational studies [16, 17] about the potential materials that can be used in photovoltaic (PV) solar cells. Availability of computers with high computational powers and many computational packages, it has become relatively easy to carry out simulations prior to any experiment. In this study, the computational study has been undertaken to determine the electrical energy generated by a MoSe\textsubscript{2}/CIGS tandem solar cell. The electrical energy has been simulated with the variation of amount of solar energy received and optimum angle for orientation of the solar panels placed in Batna, Algeria located at 35.56° north, 6.19° east [18–20]. This summers in this desert area are longer & with higher temperatures during most of the year. Whereas winters are brief, warm with scarce rainfall. The optimum angle of orientation of the photovoltaic generator is kept between I to 32° with respect to the horizontal. The azimuth of 0° to the south, has been kept throughout the measurement [21, 22].

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2 Material parameters

Figure 1 presents the schematic diagram of the solar cell studied. The schematic diagram shows that the front contacts (exposed to light) on the left side, and the rear contacts on the right as simulated by SCAPS-1D convention. According to Shockley–Read–Hall (SRH) interface approach, the carriers from the conduction bands (CB) as well as valence bands (VB) can contribute in the interface recombination process.

Figure 1 describes different layers of the materials used in a PV device and the conventions. The following parameters are employed in this study: solar spectrum AM1.5, P = 100 mW/cm², and T = 300 K. Details of Materials parameters used in SCAPS-1D simulation are given in Table 1.

3 Ant colony optimization algorithm

There are many probabilistic algorithms used to get the global optimal solution for all nonlinear problems and ant colony optimization (ACO) is one of these. The ACO was implemented in different studies [23, 24], has been formulated to operate continuously, and can be easily adjusted to changing in environmental conditions. The main benefit of ACO’s is its need of only one combination of voltage and current sensors that increases the system’s reliability at considerably lower cost. This also increases the PV system’s efficiency even though it is not applied to the distributed MPPT controllers. It has a set of associated parameters with graph components (either nodes or edges) and values of the components can be modified at runtime by the ants. The block diagram of the proposed system is shown in Fig. 2.

The probability of an ant to move from node i to j is given below:

\[ P_{ij} = \frac{T^{\alpha}_{ij} \eta_{ij}}{\sum T^{\alpha}_{ik} \eta_{ik}} \]

whereas \( T_{ij} \) is the amount of pheromone on edge \( i,j \); \( \alpha \) is a parameter to control the influence of \( T_{ij} \); \( \eta_{ij} \) is the desirability of edge \( ij \) (typically \( 1/d_{ij} \)); \( \beta \) is a parameter to control the influence of \( \eta_{ij} \).

The variation in amount of pheromone is recorded using the following equation:

\[ \Delta T_{ij} = \rho \cdot T_{ij}(t-1) + \Delta T_{ij}/t = 1, 2, 3 \ldots T \]

\( \rho \) Pheromone concentration rate (0–1); \( \Delta T_{ij} \) is the amount of pheromone deposited.
4 Results and discussion

Figure 3 presents the calculated (J–V) characteristic by simulation of MoSe$_2$ based solar cells having illumination below AM1.5 (100 mW/cm$^2$) and $T = 300$ K. At this stage the optimum thickness of MoSe$_2$ layer was set to 0.4 µm. From the model simulations, the (J–V) curve predicts short-circuit current densities (J$_{sc}$) and open-circuit voltages (V$_{oc}$) as 38.69 mA/cm$^2$ and 0.62 V respectively.

The parameters of the cells deduced from the characteristic (J–V) plot are summarized in the Table 2.

Figure 4 exhibits the amount of global radiations received per unit area of the system by the PV modules through a year. The irradiations start increasing from March and the estimated irradiations reach to the maximum (more than 327 kW/m$^2$) during July. The average daily energy production throughout the year is presented in Fig. 5. The energy production mirrors the global irradiations received. The energy production also increases with the increasing of received irradiations. The energy production increases with a peak in the month of July that is about 240 Wh/day and vice versa.

Table 2 Photovoltaic parameters of MoSe$_2$/CIGS tandem solar cells

| Solar cell configuration | Value |
|-------------------------|-------|
| $V_{oc}$ (Volt)         | 0.62  |
| $J_{sc}$ (mA/cm$^2$)    | 38.69 |
| FF (%)                  | 80.71 |
| $\eta$ (%)              | 19.29 |
| $V_{MPP}$ (Volt)        | 0.53  |
| $J_{MPP}$ (mA/cm$^2$)   | 36.61 |
5 Conclusion

In this article, the simulation of Monolithic MoSe$_2$/CIGS tandem solar cells has been implemented successfully by employing the Matlab/Simulink. The power output of the Monolithic MoSe$_2$/CIGS tandem modules increases by getting exposure to light during the first few days of operation. The heat affects the solar panels Therefore; the yields of Monolithic MoSe$_2$/CIGS tandem are high even in desert environments.

Acknowledgements We gratefully acknowledge Dr. Marc Burgelman, University of Ghent, Belgium, for providing the SCAPS-1D simulation software.

Authors’ contributions BZ: conceived the study, coordinated the conduct of the study, interpreted the data, and drafted the manuscript; CS: participated in the design of the study, assisted in interpreting the data, and helped to draft the manuscript; BH: Project administration; SG: Visualization; SZ: Visualization; MAS: Writing—review & editing. All authors read and approved the final manuscript.

Data availability All data and software application support their published claims and comply with field standards.

Declarations

Competing interests The authors declare no competing interests.

Human and animals rights Authors declare no research involving human participants and/or animals was conducted.

Competing interests The authors have no conflicts of interest to declare that are relevant to the content of this article.
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