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Optimization of Absorber Layer and Operating Temperature of Copper Indium Gallium Selenide Solar Cells Using Different Metal Contacts

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ABSTRACT: Device simulation was employed to investigate the effect of metal back contact electrodes on the performance of n-type CdS/p-CIGS thin film solar cells using varying thicknesses of absorber layer at operating temperature of 300K. The effect of working temperatures was also studied from 300K to 400K in steps of 10K. The simulations were carried out using standard solar cell capacitance simulator (SCAPS) 3.3.03 version software. The results showed better efficiencies at the optimized thickness of 3µm for all the back contact electrodes under study. The maximum efficiencies of 17.5 %, 15.5 %, 11.5 %, 3.5 % and 3 % were estimated for CIGS thin film solar cell at 300 K for platinum, gold, cobalt, silver and copper back contact electrodes respectively. The efficiency decreases as the operating temperatures increases from 300 K to 400 K. It is recommended that the optimized thickness of 3 µm is appropriate as absorber layer for efficient and cost effective CIGS thin film solar cells for economic reasons.

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Keywords: CIGS, back contact, electrodes, thin film, CdS

INTRODUCTION

The diminishing state of fossil fuels has necessitated the needs for alternative sources of energy and the present state of solar cells demanded for little cost and high energy efficiency for economic reasons. Constantly growing request for low cost photovoltaic (PV) modules have uncovered some characteristic disadvantages of crystalline silicon (c-Si) technology owing to the costly purification of materials needed and vacuum based fabrication processed involved (Ouédraogo *et al.*, 2013). Copper Indium Gallium Selenide (CIGS) is a good absorber material for fabricating solar cells and has received significant attention owing to its direct band of approximately 1.0-1.12 eV, high absorption co-efficient of 10^5 cm^{-1} and a smaller amount of material consumption (Jeyakumar and Udai, 2017). CIGS thin films solar cells are among the alternatives to the silicon technology. The merit of this solar cells based on CIGS is the reduction of manufacturing cost compared to crystalline silicon solar cells. Over the past decade, CIGS thin film solar cell field experienced upward manufacturing development with higher efficiency solar modules (Chihi *et al.*, 2014). A foremost impediment of achieving higher efficiency and low cost solar cell is attributed to lack of using appropriate thicknesses of n-type and p-type materials couplings for building optimized hetero-junctions solar cells. Material couplings can limit open-circuit voltage (V_{OC}), short-circuit current (J_{SC}) and large interface current recombination (Niall *et al.*, 2015). The experimental and simulation studies on CIGS solar cells have contributed to the basic understanding and enhancement of its efficiencies Jeyakumar and Udai, (2017); Ramanathan *et al.*, **(**2005); Koen, (2010); Mostefaoui, (2015); Burgelman, (2000); Burgelman *et al.*, (2013); Chia-Hua, (2018); Samar, (2018) and Koen, (2012); Lawani *et al.*, (2021). Simulation studies on CdS/CdTe solar cells of different back contact electrodes had been studied using solar cells capacitance simulation software Salawu *et al.*, (2016). In this research work, ZnO will be used as window layer, CIGS as absorber layer and CdS as buffer layer.

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The objectives of this paper are to investigate different operating temperatures, thicknesses of absorber layers and metal back contact electrodes on the performance of CIGS thin film solar cell structure for efficient and low cost solar cell fabrication for economic reasons.

MATERIALS AND METHOD

The modeling numerical calculations presented in this study was carried out using Solar Cells Capacitance Simulator (SCAPS) 3.3.03 software. SCAPS is specially made for Solar Cell simulation. The software was developed at University of Ghent, Belgium by Professor Marc Burgelman. The CIGS structure was made up of a p-type CIGS absorber layer, n-type zinc oxide (ZnO) and cadmium sulphide (CdS) with respective thickness of 50 nm each used as window and buffer layers respectively. The input parameters employed in this simulation were adopted from diverse literatures and theories as presented in Table I. The default illumination spectrum and operating temperatures were fixed to the global Air Mass (AM) 1.5 standard and 300 K respectively. The performance of CIGS solar cell was investigated using different metals under investigation. Platinum, gold, cobalt, copper and silver with work functions of 5.64 eV, 5.47 eV 5.0 eV, 4.73 eV and 4.70 eV were used for this simulation. The effect of varying thicknesses of CIGS absorber layer was studied from 1µm to 5 µm while keeping ZnO and CdS thickness at 50 nm each at operating temperature of 300 K. The platinum, gold, cobalt, copper and silver electrodes were used differently as back contacts. The effect of operating temperatures on the performance of CIGS solar cells from 300 K to 400 K at interval of 10 K was studied. Figure 1 is the structure of CIGS thin film solar cell under study.

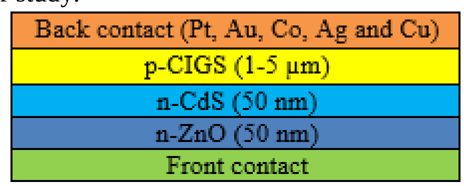

Fig 1: CIGS solar cell architecture.

Table 1: Input parameters of CIGS solar cell used for the simulation

Input parameters	p- CIGS	n- CdS	n- ZnO
Band gap energy (eV)	1.00	2.40	3.3
Electron affinity (eV)	4.50	4.20	4.60
Dielectric permittivity	13.60	10.00	9.0
CB effective density of state (cm^{-3})	2.2E18	2.2E18	2.2
VB effective density of state (cm^{-3})	1.80E19	1.80E19	1.8
Electron thermal velocity (cm/s)	1.0E7	1.0E7	1.0E17
Hole thermal velocity (cm/s)	1.0E7	1.0E7	1.0E7
Electron mobility (cm^2/vs)	1.0E2	1.0E2	1.0E2
Hole mobility (cm^2/vs)	2.5E1	2.5E1	2.5

RESULTS AND DISCUSSION

Figure 2 shows the open circuit voltage of the CIGS solar cell. The performance of the solar cell with gold and platinum back contact electrodes were interwoven from 3 µm to 5 µm thicknesses of absorber layer. Increasing thicknesses of absorber layers above 3 µm does not increase the open circuit voltage appreciably. However, CIGS solar cell with cobalt, copper and silver back contact electrodes showed slight increases in open circuit voltage as the thicknesses of absorber layers increases. These increments are not appreciable above 3 µm thickness of absorber layer. This behaviour is attributed to cell degradation of the p-n junction between the absorber and buffer layer which causes high recombination of electrons at the CIGS/back contact interface. Platinum and gold back contact electrodes had open circuit voltage of about 0.6 V at 3 µm and 0.61 V at 5 µm thicknesses of absorber layers respectively. Cobalt, silver and copper back contact electrodes with work function of 5.0 eV, 4.73 eV and 4.70 eV had open circuit voltages of 0.47 V, 0.2 V and 0.17 V respectively at 3 µm thickness of absorber layer. The values increased to 0.49 V, 0.21 V and 0.18 V for cobalt, silver and copper respectively at 5µm thickness of absorber layer.

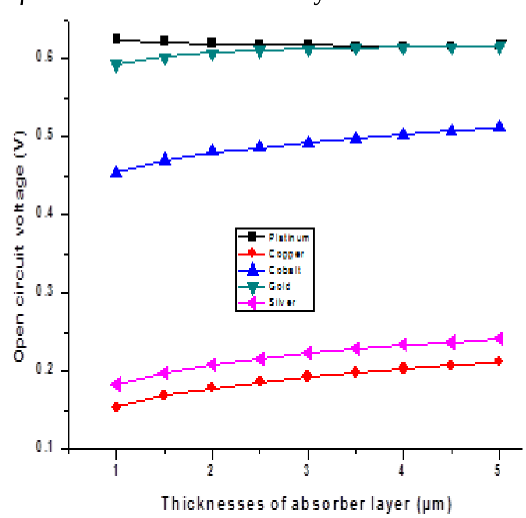

Fig 2: Open circuit voltages (V_{oc}) against thicknesses of absorber layer for different metal back contact.

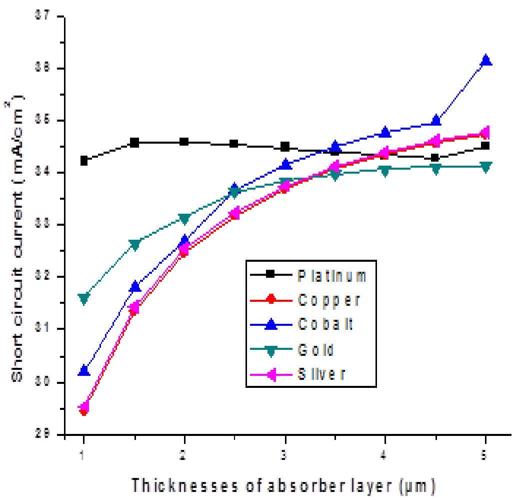

Fig 3: Short circuit current density (J_{sc}) against the thicknesses of absorber layer for different back contact electrodes

Figure 3 is the plot of short circuit current density (J_{sc}) against the thicknesses of absorber layer for different back contact electrodes. The short circuit current density relatively increases as the thicknesses of absorber layer increases to 3 µm. At 3µm thickness of absorber layer, short circuit current of about 34.5 mA/cm^2, 34 mA/cm^2, 33.7 mA/cm^2, 33.25 mA/cm^2 and 33 mA/cm^2 were estimated for the platinum, cobalt, gold, silver and copper back contacts electrodes respectively. The result is in good agreement with the reported work of (Ouédraogo *et al.*, 2013). The difference in the results are due to recombination loses of photo-generated electrons at the back contact. The higher work function electrodes performed relatively better than the lower function metals.

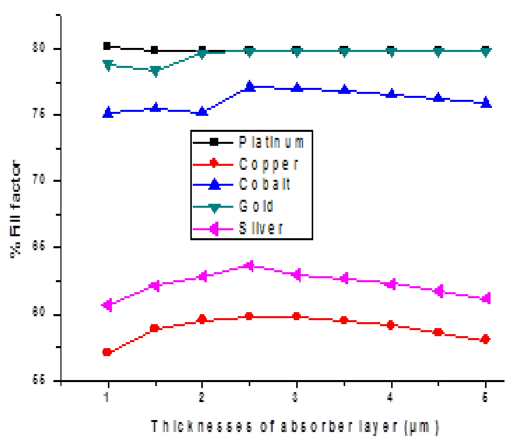

Fig 4: % Fill factors (FF) against the thicknesses of absorber layer for different electrodes

Figure 4 shows the plot of % FF against CIGS absorber layer thicknesses for different back contact metals under study. The results show that platinum and gold with higher work functions had the same % FF at the thickness range of 3 µm to 5 µm while cobalt, silver and copper exhibited optimum % FF at 3 µm thickness of absorber layer. At the optimized thickness of 3 µm, the values of FF were estimated to be 80 % for platinum and gold, 77 %, 62.5 % and 60 % for cobalt, silver and copper respectively.

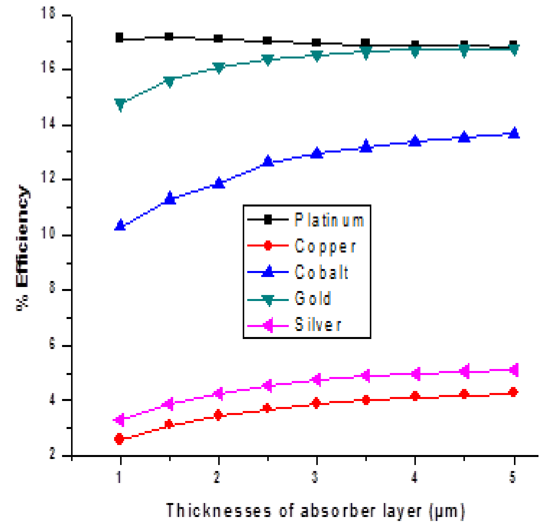

Fig 5: Efficiencies of CIGS against the thicknesses of absorber layers for different metals

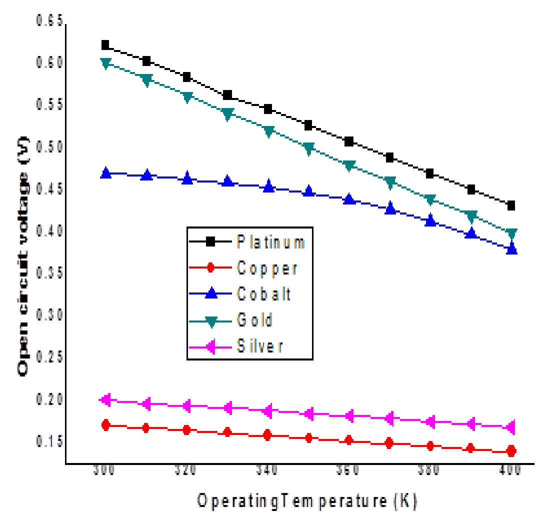

Fig 6: Open circuit voltages (V_{oc}) against the operating temperatures of CIGS solar cell

Figure 5 shows the efficiency of CIGS solar cell against the CIGS absorber thicknesses. The simulation results show relative increases in the efficiencies as the thicknesses of the absorber layers' increases. The increase in the efficiencies is not appreciable above 3 µm thickness of absorber layer. Efficiencies of 16 %, 12.5 %, 4.5 % and 3.5 % were estimated for gold, cobalt, silver and copper back contacts respectively at the optimized thickness of 3 µm. Platinum and gold back contacts had efficiencies of about 17 % at 3 µm and reduces slightly as the thicknesses of absorber layer increases. The difference efficiencies obtained depends on the work functions of the metals employed as back contacts. The minimum thermodynamic work required to remove electrons from the absorber layer depends on the work function of metal back contacts used. At above the optimized thickness of 3 µm, efficiencies of CIGS solar cell are either reducing or not appreciable. Summarily, the efficiencies of the thin film solar cell depend on whether the contact is ohmic or non ohmic. Figure 6 shows the open circuit voltage (V_{oc}) against the operating temperatures of CIGS solar cell for different metal back contacts. Increasing operating temperatures from 300 K reduces the open circuit voltage of the cell for all the back contact electrodes under study. The temperature of the system above 300 K does not contribute to photon current of the cell but significantly increases the heat of the system and gradually degrades the cell and resulted to efficiencies losses.

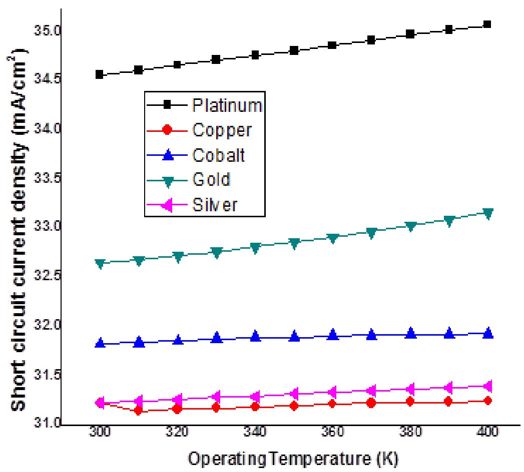

Fig 7: Short circuit current density (J_{sc}) against the operating temperature of CIGS solar cell for different back contact electrodes

Figure 7 shows the short circuit current density (J_{sc}) against the operating temperatures of CIGS solar cell for different metal back contacts. The short circuit current of a cell is the current of the cell when it is not delivering any voltage. There is an increase in short circuit current density as the operating temperature of the cell increases for all the metal back contact under study. This may be as a result of decreasing band gap energy of the absorber material as the temperature increases. Platinum back contact electrode exhibited maximum short circuit current density of 34.5 mA/cm^2 and 35 mA/cm^2 at temperature of 300 K and 400 K respectively. Figure 8 shows the % fill factor against the operating temperatures of CIGS solar cell. The ratio of maximum power to the product of short circuit current and open circuit voltage is called the fill factor. The increasing in temperature causes reduction of % FF as the working temperature of the cell increases for all the electrodes under study. The % FF of platinum and gold are interwoven at various temperatures under study. This may be due to the closeness of their work function. Platinum and gold had FF of about 80 % at 300 K and 75 % at 400 K.

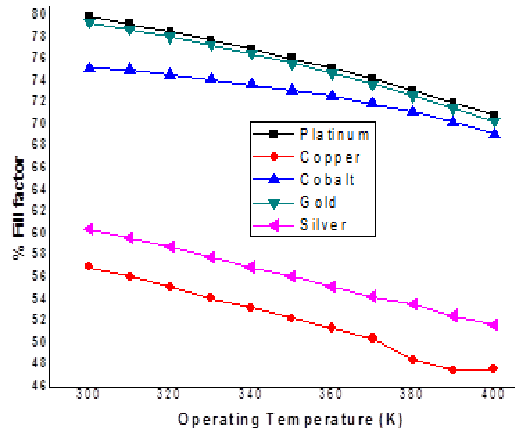

Fig 8: % Fill Factor (FF) against the operating temperatures of CIGS thin film solar cell.

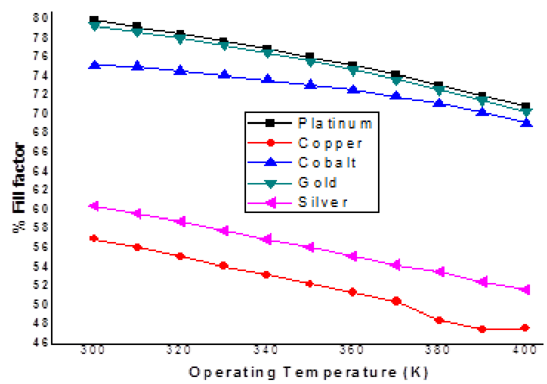

Fig 9: Efficiency against the operating temperatures of CIGS solar cell

Figure 9 shows the efficiency against the operating temperature of CIGS thin film solar cell for different back contact electrode. Efficiency relates the ratio of maximum power to the input power of solar energy. Efficiencies of the CIGS thin film solar cell drops abruptly as the working temperatures of the cell increases from 300 K to 400 K. The decrease of efficiencies as temperature increases may be due to film degradation of the component layers and thermal agitation of the cell at higher temperature. This occurred for all the back contact electrodes under investigation. The maximum efficiency of 17.5 %, 15.5 %, 11.5 %, 3.5 % and 3 % were estimated for CIGS thin film solar cell at 300 K for platinum, gold, cobalt, silver and copper back contact electrodes respectively. These efficiencies reduce gradually as the working temperature increases from the room temperature. The least efficiencies at 400 K were estimated to be 12 %, 10.5 %, 8.5 %, 3 % and 1 % for platinum, gold, cobalt, silver and copper back contact electrodes respectively.

Conclusion: The performance of CIGS thin film solar cell exhibited higher efficiencies at 300 K operating temperature for all the back contact electrodes under investigation. The optimized thickness of 3 µm is most appropriate for the absorber layer and platinum back contact electrode exhibited highest efficiency among gold, cobalt, copper and silver. The maximum efficiencies of 17.5 %, 15.5 %, 11.5 %, 3.5 % and 3 % were estimated for CIGS thin film solar cell at 300 K for platinum, gold, cobalt, silver and copper metal back contacts respectively.

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