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DESIGN, PERFORMANCE ANALYSIS AND EFFICIENCY OPTIMIZATION OF COPPER INDIUM GALLIUM SELENIDE (CIGS) SOLAR CELL

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Abstract

A comparative investigation of the cell performance of Copper Indium Gallium Selenide (CIGS) thin-film solar cell, fabricated using ZnO:Al/i-ZnO/CdS/CIGS layers, has been reported. ADEPT 2.0, a 1D simulation software, were used throughout the whole research for the simulation of light J-V characteristics for different designs. Energy conversion efficiency for each design was calculated from its corresponding light J-V characteristics curve. The efficiency variation were investigated under 1 sun, AM1.5G illumination and optimized layer parameters (thickness) for each layer of the device. The device has designed with an n-type ZnO window layer, an n-type CdS as buffer layer and a p-type CIGS as absorber layer. Molybdenum (Mo) substrate is used for the structure. A total-area efficiency of 19·75% for ZnO:Al/i-ZnO/CdS/CIGS based thin-film solar cells had been found. Performance is improved due to higher fill factor. The device parameters are optimized separately for each layer. Based on these optimizations, the ultra-thin film solar cell design is proposed after careful consideration of lattice mismatch between two adjacent layers of the device.

Keywords: CIGS, AM1.5G, Window Layer, Buffer Layer, Fill Factor

Introduction:

Solar cells are naturally illuminated with sunlight and are intended to convert the solar energy into electrical energy. Current trends suggest that the solar energy will play an important role in future energy production (Kaelin et al.,2004). Solar energy conversion is part of a long term strategy to ensure a stable and adequate supply of electrical power in the future. Photovoltaic's are the only method of converting sunlight directly into electrical energy. The efficiency of a photovoltaic system is measured as the ratio of electrical power produced to the energy of the incident solar radiation. It strongly depends on the quality of the semiconducting materials used for the fabrication of solar cells. Presently, the photovoltaic market is dominated by silicon technologies, however, the challenge is to manufacture more cost effective solar cell materials and maintain a high efficiency. The thin-film solar cells, such as polycrystalline $Cu(In,Ga)Se_2$ (CIGS) solar cells are promising candidates, since in contrast to conventional wafer-based solar cells these solar cells consume much less semiconductor material and energy during their fabrication. Copper Indium Gallium Selenide (CIGS) solar cells have the highest production among thin film technologies (Robert,2008). It's one of the leading contenders for low-cost production of relatively high-efficiency cells. Thin film cells which are the leading commercial thin film technologies. Material, manufacturing time and weight savings are driving the increase in thin films. CIGS cells are also superior to GaAs cells in radiation hardness (Rudmann et al.,2004). Moreover, the flexibility of these cells allows for novel storage and deployment options (Otte et al.,2006). Solar cell based on CIGS has reached conversion efficiencies 18% and 19.5% (Thin-Film,2011). A CIGS cell with 21.5% efficiency and an area of 0.1 cm^2 has been fabricated on soda-lime glass (SLG) (Ward et al.,2002). Laboratory specimens can provide power conversion efficiency as high as 20% (Repins et al.,2008) despite the poly-crystalline structure of the semiconductor thin film.

In our investigation, device parameters (layer thickness) are optimized for each layer of the device. This was done by varying a particular parameter of a layer, while keeping every other device parameter fixed at some default value, and observing the changes in the output characteristics. Proper analysis of these changes led to the optimization of all the device parameters. The aim of the simulation was to check the effect of different (ZnO/CdS/CIGS layer) layer thickness on the performance of the CIGS solar cell structure. All the simulations conducted for this work were done by ADEPT/F (Gray et al., 2008).

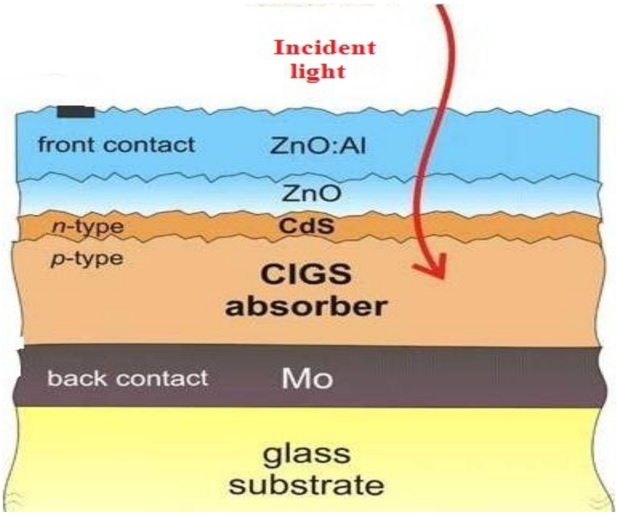

Fig-1 : CIGS solar cell structure

Experimental

CIGS solar cells have a complex multilayer structure. In the modeling of thin-film solar cells one has to take into account to the specific optical and electrical features of the structures. From the optical point of view, thin-film CIGS solar cells are multilayer structures, including thin layers, where the thicknesses are in the range of light wavelengths. The schematic cross section of CIGS solar cell structure is shown in Fig-1. The purpose of the front and back contact is to have as good conducting capabilities as possible without disturbing other processes in the cell. Light enters the cell through the Transparent Conductive Oxide layer (TCO), passes through the CdS buffer layer, and enters the absorber. The p-n junction is formed by p- type CIGS layer and n-type buffer layer. The buffer layer is followed by a thin layer of highly resistive ZnO, which may protect the surface from damage in subsequent process steps. Buffer layer is an intermediate layer film between the absorber and window layers with two main objectives, to provide structural stability to the device and to fix the electrostatic conditions inside the absorber layer (Asenjo et al.,2005). Meanwhile, it will have to make good p-n junction with the p-type absorber layer for the electrical conduction and to allow the transmission of photons into the absorber layer to generate electron-hole pair. The absorber layer is the most important layer in the PV device. It is a direct band-gap semiconductor material and has a large absorption coefficient. Most of the incident sunlight is absorbed close to the p-n junction.

Previous research on CIGS cells indicated that CIGS material is a good candidate for making concentrator solar cells under low to medium concentration (Ward et al.,2002). CIGS solar cells have great potential because of their large optical absorption coefficient. In this paper optical and electrical numerical modeling and simulation of a very thin CIGS solar cell are carried out. Reduction of layer thicknesses in thin-film solar cells is an important issue in order to save expensive active material and to shorten the deposition time. For analysis and optimization of the solar cells, numerical simulation was proven to be an important tool (Tuttle et al.,1995). Different analytical and numerical modeling approaches for CIGS solar cells have been presented (Cernivec et al.,2006). In this part of the work, device parameters (layer thickness) were optimized for each layer of the device. This was done by varying a particular parameter of a layer, while keeping every other device parameter fixed at some default value, and observing the changes in the output characteristics. Proper analysis of these changes led to the optimization of all the device parameters. At the beginning, some default values of layer thickness and doping level were chosen for each layer of the device. The top layer (ZnO) thickness varied from 0.5 to 1.7 μm and doping concentration used 1×10^{18} cm^{-3}. Middle layer (CdS) thickness was varied within the wide range of 0.03 μm to 0.7 μm and doping concentration used 8×10^{18} cm^{-3}. The thickness of the absorption layer (CIGS) was varied from 1 μm to 3.2 μm and doping concentration used 8×10^{16} cm^{-3}. Completion of proper analysis of these changes led to the optimization of all the device parameters. Simulation was conducted with different values and open-circuit voltage (V_{oc}) and short-circuit current density ($J_{sc.}$) were obtained from light I-V characteristics. Then Fill factor (FF) and efficiency (η) were calculated from the V_{oc} and $J_{sc.}$.

Result and Discussion

Simulation is performed to investigate how thickness (ZnO/CdS/CIGS) influences the efficiency of the CIGS solar cell module. At the beginning of the simulation, the window layer thickness has been varied from 0.5 μm to 1.7 μm to carry out the optimum electrical performance of these hetero-junction solar cells. It has been investigated that the efficiency of the solar cell is decreasing with the thickness of ZnO window layer in Figure 2. The highest efficiency measured, when the buffer layer thickness is 0.5 μm. ZnO window layer has the band gap energy of 3.3 eV. It can be attributed to thinner layer thickness where less photon energy will be absorbed. Moreover, the band gap of CIGS layer is 1.200 eV. Therefore, due to low band gap lower photons energy will be captured in the absorber layer, which will influence to produce higher J_{sc} and V_{oc}.

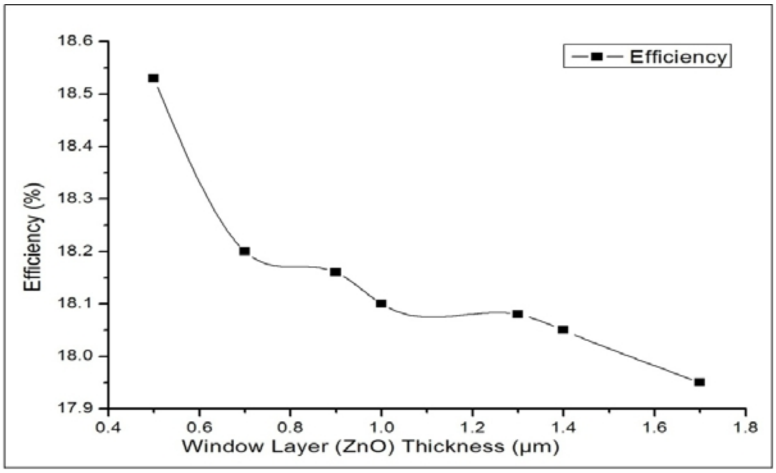

Fig- 2: Efficiency response for different window layer (ZnO) thicknesses

In this simulation, the thickness of the buffer layer (CdS) has been varied between 0.03 nm and 0.7 µm. Buffer layer has the band gap energy of 2.4 eV. The efficiency decrease with increasing CdS buffer layer thickness as shown in Figure 3. More photon will be absorbed in this region because of thicker buffer layer. Fill factor increases slightly as the buffer layer thickness approaches 0.7 µm. It can be due to less discontinuity at the absorber and buffer layer interface. For 0.03 µm of CdS buffer layer recorded the highest efficiency for the whole CdS/CIGS cases.

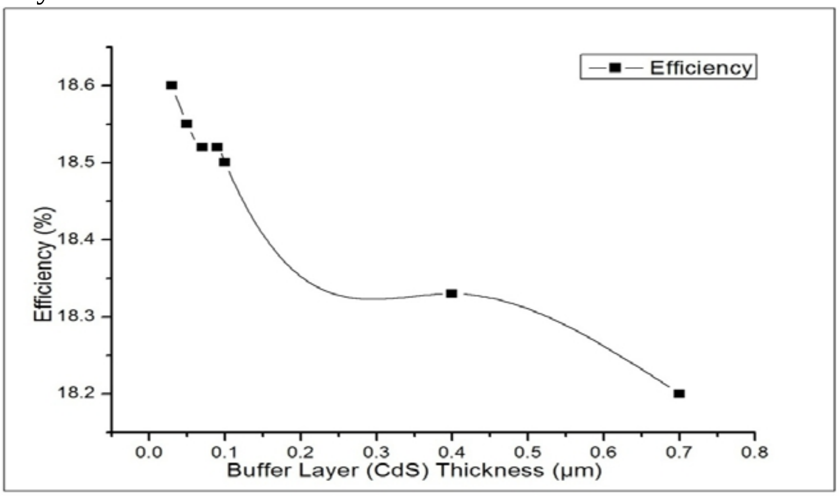

Fig-3: Efficiency response for different Buffer layer (CdS) thicknesses(µm)

Thinner buffer layer means majority of photons can pass through the buffer layer without being absorbed. The efficiency of the solar cell drops rapidly as the buffer layer is increased to .7 µm. This is due to the photon loss that occurs inside the buffer layer. When less photon makes it through the buffer layer, less electron-hole pair is produced hence less electricity is produced. Figure 4 shows the efficiency response for the different thickness of absorber layer of CIGS solar cell structure. It has been seen that the efficiency of the solar cell is increasing with the thickness of CIGS absorber layer in Figure 4. As the thickness of the absorber layer increases, the recombination probability of the photon-generated carriers with back-contact is decreases. Recombination is mainly depend on the junction depth. As the thickness of the layer increases, the junction depth decrease relative to the thickness of the layer. Therefore, the photo generated carriers are collected efficiently at higher thickness of the absorber layer.

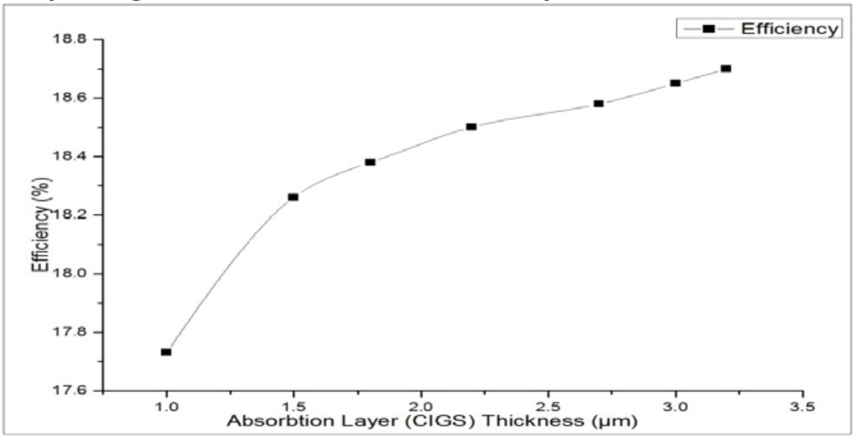

Fig-4: Efficiency response for different absorber layer (CIGS) thicknesses(µm)

After analyzing all the types of efficiency variation curves obtained from different layer thickness (ZnO/CdS/CIGS) , an optimum design has been proposed. For optimum design the window layer (ZnO) has a thickness of 0.5 µm and buffer layer (CdS) thickness 0.03 µm. The absorber layer (CIGS) is made very thick 3.2 µm for maximum optical absorption.

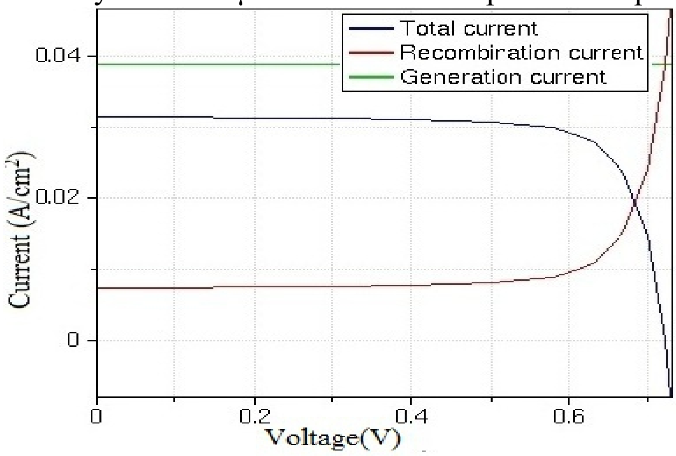

Fig-5: Light J-V characteristics of the CIGS thin-film solar cells fabricated using optimum thickness of each layer

From Figure 5, it is found that the resulting open-circuit voltage (Voc) is 0.73 V, and the short circuit current density (J_{sc}) is 31.8 mA/cm^2. The fill factor (FF) is calculated to be 0.8506, and the calculated efficiency (η) is 19.75%.

Conclusion:

Simulations were performed to optimize the performance of the CIGS solar cell module with respect to efficiency. This results shows, how solar cell performances are affected by in terms of thickness. In our investigation, it has been demonstrated the effect of thickness on the solar cell parameters like open-circuit voltage (V_{oc}), short circuit current density (J_{sc}) and conversion efficiency (ɳ). The effect of thickness play significant role on the performances of the CIGS solar cell (ZnO/CdS/CIGS) structures. The optimum conversion efficiency is 19.75% observed. These observation leads to the conclusion that for the optimum performance of the solar cell device thickness is an effective technique for improving the conversion efficiency of CIGS thin-film solar cells. Our future work will focus on doping concentration and temperature effect on CIGS solar cell.

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