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# High Efficient CIGS based Thin Film Solar Cell Performance Optimization using PC1D

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**Abstract -** *Numerical modeling tools have become increasingly useful with the amount of processing power that is available today. We performed modeling and simulation of Cu(In, Ga)$Se_2$ (CIGS) thin film solar cell, using PC1D device simulator, and we especially investigated the influence of absorber layer doping concentration and thickness.* These parameters *were varied to achieve the optimal performances. Based on these results, an optimal structure for Cu(In, Ga)$Se_2$ solar cell with power conversion efficiency more than 21% is proposed.*

***Key Words***: Thin film Solar cell; CIGS; Modeling; PC1D; Optimization

## 1. INTRODUCTION

Finding alternative sources of energy is a vital issue in the modern world for many reasons. One reason is that traditional energy sources like coal, gas, and oil may be depleted relatively soon. Many analysts proposed serious depletion will happen within several decades from now. Another reason is that from the environmental point of view, burning of fossil fuels causes air and water contamination. More importantly, $CO_2$ from fossil fuels will almost certainly increase the average temperature on the planet the phenomenon known as the global warming which is projected to raise the average temperature of the earth's atmosphere by the end of this century.

Solar energy, wind energy, hydrogen fuel energy and other alternatives are not only renewable, but also overall more environmentally friendly.

The highest efficiency of conversion of solar light into electricity has been demonstrated in solar cells made from single-crystal semiconductor wafers. While several techniques are employed today to achieve higher efficiency, the most likely to succeed are thin- film solar cells. Thin-film solar cells, have several advantages compared to their crystalline counterparts. One advantage is cheaper manufacturing compared to the single–crystal growth that demands high energy consumption. Another advantage is the ability to deposit thin films onto large areas at the same time.

CIGS based solar cells has shown good performance in photo conversion and long-term stability against exterior aggression[1]. The low consumption of materials, the energy used in the manufacturing process and the low cost of substrates or superstrates make CIGS based solar cells attractive in industrial and research fields. On the other hand CdS has a bandgap energy of 2.42 eV, and transmits most of the visible spectrum[2-4]. Thin film solar cells based on the CdS/CIGS system with an efficiency of 20.3% has been reported as highest efficiency[5].
The heterojunction CdS/CIGS structure has been shown in Fig.1 at which grid is connected above transparent conductive oxide (TCO) layer and front contact is connected from TCO layer.

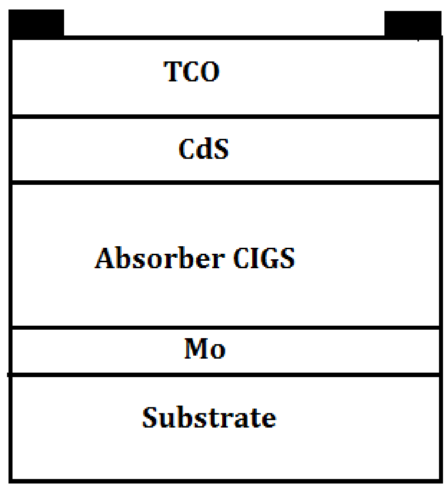


**Fig -1**: Structure of solar cell

Back contact is connected from Molybdenum. Substrate is normally taken as soda lime glass. Here CdS layer is also called window layer whereas CIGS layer acts as the absorber layer.

## 2. MATERIAL AND DESIGN

### 2.1 CIGS based solar cell Perspective and Numerical Simulation

A Copper Indium Gallium Selenide solar cell (or CIGS cell, sometimes CI(G)S or CIS cell) is a thin-film solar cell used to convert sunlight into electric power. It is manufactured by depositing a thin layer of copper, indium, gallium and selenide on glass or plastic backing, along with electrodes on the front and back to collect current. Because the material has a high absorption coefficient and strongly absorbs sunlight, a much thinner film is required than of other semiconductor materials. $CuInSe_2$ based solar cells has shown good performance in photo conversion and long-term stability against exterior aggression.

The fact that CIGS does not contain toxic cadmium it is really good for household appliances and marketing point of view . This material has a direct band-gap and high absorption co-efficient requiring only a few micrometers to absorb the maximum of incident photons. One of the most interesting qualities of this material is its band-gap, depending on its composition.

Almost 99% of the light shining on a CIGS solar cell will be absorbed in the first micrometer of the material. Cells made from CIGS are usually heterojunction structures, structures in which the junction is formed between semiconductors having differtent bandgaps. The most common material for the top or window layer in CIS devices is cadmium sulphide(CdS), although zinc is sometimes added to improve transparency. Adding small amounts of gallium to the lower absorbing CIS layer boosts its bandgap from its normal 1.0 eV, which improves the voltage and therefore the efficiency of the device. This particular variation is commonly called a copper indium gallium diselenide or "CIGS" cell. CdS is a II–VI compound semiconductor and has an energy band gap of 2.42 eV at room temperature. CdS is important material as window layer because of its high band gap energy.

In this study, numerical modelling of CIGS thin film solar cell has been carried out by PC1D numerical simulator.

### 2.2 PC1D Simulator

PC1D is a computer program written for IBM-compatible personal computers which solves the fully coupled nonlinear equations for the quasi-one-dimensional transport of electrons and holes in crystalline semiconductor devices, with emphasis on photovoltaic devices. This version of the program is supported and distributed by the Photovoltaics Special Research Centre at the University of New South Wales in Sydney, Australia.

It allows to simulate the behaviour of photovoltaic structures based on semi-conductor by respecting to one-dimensional (axial symmetry). The program was initially written at Sandia National Labs by Dr. Paul Basore and co-workers and was further developed by Dr. Don Clugston at the University of New South Wales, Australia.

## 3. MODELING RESULT AND DISCUSSION

Input parameters of CdS and CIGS were selected based on experimental data, literature values, theory, or in some cases, reasonable estimates. The drift-diffusion equation in conjunction with poisson and continuity equations are solved by the device solver to give the outputs. In this study the effect of absorber layer thickness and doping concentration have been carried out.

**Table -1:** CIGS Baseline modeling parameters

| Parameters | CdS | CIGS |
|---|---|---|
| Thickness (nm) | 60 | 2000 |
| Dielectric constant | 10 | 13.6 |
| Bandgap (eV) | 2.4 | 1.5 |
| Electron affinity (eV) | 4.2 | 4.5 |
| Electron thermal velocity (cm/s) | 1.00E+7 | 1.00E+7 |
| Hole thermal velocity (cm/s) | 1.00E+7 | 1.00E+7 |
| Doping concentration of acceptors ($cm^{-3}$) | 0 | 2.00E+16 |
| Doping concentration of donors ($cm^{-3}$) | 1.00E+17 | 0 |

### 3.1 Optimization of CIGS absorber layer thickness

Initially by the simulation, the conventional CIGS structure with CdS buffer layer has been verified in terms of CIGS absorber and CdS buffer layer. Then, the CIGS absorber layer thickness has been varied to find out the optimum thickness for the conventional CIGS structure with CdS as the window layer. It has been found that the efficiency of the solar cell is increasing with the thickness of the CIGS absorber layer, but with a much slower rate over 3000 nm. The optimum thickness for CIGS absorber layer would be around 3000-4000 nm as given in Table-2.

**Table -2:** Performance for different absorber CIGS layer thickness

| CIGS thickness | Isc | Voc | η(%) | FF(%) |
|---|---|---|---|---|
| 5 μm | 32.7 | 0.7687 | 21.1 | 85.53 |
| **4 μm** | **31.7** | **0.7534** | **20.8** | **87.09** |
| 3 μm | 30.2 | 0.7547 | 20 | 87.75 |
| 2 μm | 28 | 0.7353 | 18.9 | 91.48 |

Variation of CIGS absorber layer thickness reflects the resultant I-V curve variations as depicted in Fig 2.

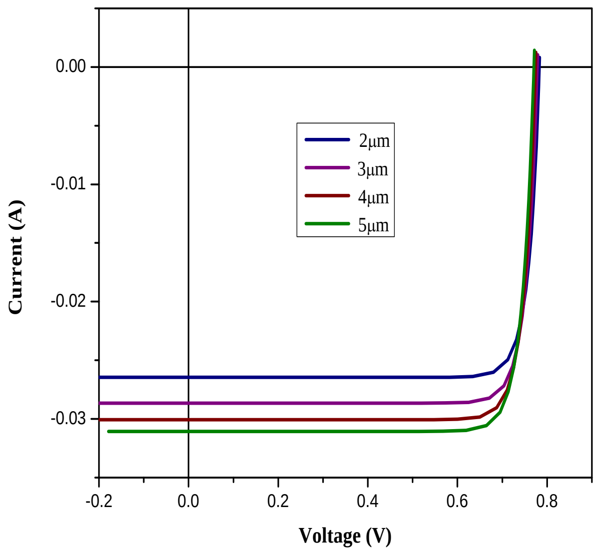


Fig-2: I-V Plot of CdS/CIGS solar cell with CIGS thickness of 2-5 μm

Open circuit voltage ($V_{OC}$) and short circuit current ($I_{SC}$) of the CIGS solar cells are also shown in Fig. 2. Both values are increasing with the thickness of the absorber layer. This may mainly due to the increase of the absorber layer, which is the p-type region in solar cell. This allows the longer wavelengths of the illumination to be collected which in turn contribute to more electron–hole pair (EHP) generation. Therefore, the value for $V_{OC}$ and $I_{SC}$ are increased. It is also to be noted that both the $V_{OC}$ and $I_{SC}$ value will be reduced if the thickness of the absorber layer is reduced.

### 3.2 Optimization of CIGS absorber layer doping concentration

Our solar cell of concern is crystalline in nature. In the material say absorber layer material doping concentration might be different for different cells. So the doping concentration might affect the performance of the cell as well. We have studied the performance and results truly support that.

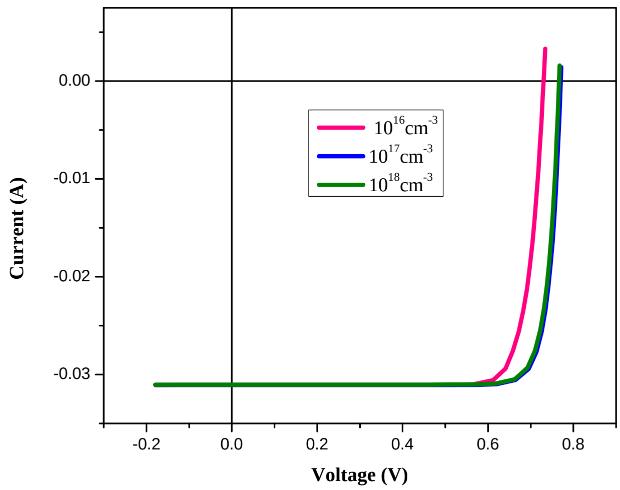


Fig-3: I-V Plot of CdS/CIGS solar cell with CIGS doping concentration $10^{16}$ - $10^{18}$ cm$^{-3}$

The baseline model was run with a range of CIGS layer doping concentration ranging from $10^{16}$ cm$^{-3}$ to $10^{18}$ cm$^{-3}$. It is evident that optimum efficiency of 21.4% and fill factor around 87%. Efficiency decreases drastically after the doping density of $10^{18}$ cm$^{-3}$, suggesting it to be in optimum range. This may be caused by the recombination process at the back contact of the solar cell. Since higher doping density in the absorber layer reduces the depletion width thus effective length is increasing and causing the problem of carrier collection. Performance parameters are shown in Table-3.

**Table -3:** Performance for different absorber CIGS layer thickness

| CIGS doping density (cm$^{-3}$) | $I_{SC}$ (*mA*) | $V_{OC}$ (V) | Efficiency (%) | Fill Factor (%) |
|---|---|---|---|---|
| 1E+16 | 32.8 | 0.7278 | 19.5 | 81.68 |
| **1E+17** | **32.7** | **0.7518** | **21.4** | **87.04** |
| 1E+18 | 32.7 | 0.769 | 20.8 | 85.89 |

## 4. CONCLUSIONS

In this study we have investigated the influence of absorber layer thickness and doping density to get optimum performance using PC1D device simulator. The selection of different input parameters for a realistic baseline model has been presented. The simulation and modeling process indicate that it is possible to optimize the solar cell performance and improve the efficiency of the cell by appropriate selection of the thickness and doping concentration of the layers. In optimum condition we achieved power conversion efficiency of 21.4% and fill factor of around 87%. Parasitic absorption and recombination plays important role to limit the device performance. Back surface field reduces the recombination mechanism to some extent. Optimizations of other parameters are also recommended for enhancing device performance.

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