Numerical modelling of ultrathin CdTe solar cell with back surface field layer

Virang Shukla and Gopal Panda
Department of Physics, Sarvepalli Radhakrishnan University, Bhopal, India
E-mail: virangshukla_1983@yahoo.co.in

Abstract: In CdTe solar cell, CdTe absorber layer needs ohmic contact having work function greater than 5.7 eV. No metals can have such large work function to match properly with CdTe absorber layer. Low resistance is required between CdTe layer and back contact for good performance and long stability of CdTe based solar cell. So there is a need of inserting back surface field layer to reduce the resistance between CdTe layer and back contact. This study highlights the effect of ZnTe BSF layer on the performance of solar cell. In this study two cell were simulated by SCAPS-1D simulator. From analysis it can be seen that with the help of BSF layer high efficiency as well as high stability can be achieved.

1. INTRODUCTION

CdTe based thin film solar cell is one of the leading and popular photovoltaic material. It is very popular because of its low cost, high chemical stability, easy deposition and high optical absorption coefficient. The n type CdS layer is the best suited window layer with type CdTe absorber layer. The most critical issue which is related to the CdTe based solar cell is to create low resistive back contact with CdTe absorber layer. Absorber layer CdTe needs ohmic contact having work function greater than 5.7 eV. No metals can have such large value of work function to match with CdTe properly [1, 3, and 4]. To overcome this problem metals such as Zn, Cu etc. are used as back contact to generate quasi ohmic and non-rectifying contact [2]. The cell with this contact can perform well in beginning. The performance of cell degrades with time because of diffusion of such metals with front contact, which can cause shunting effect [3, 4]. The strategy which can be adopted to overcome the effect of schottky barrier is to develop p type CdTe layer and back surface field is inserting BSF layer in between p type CdTe layer and back contact for higher carrier concentration and low resistivity. The back surface field (BSF) layer is very important to achieve high efficiency in solar cell. The main aim of this paper is to find out high efficiency of CdTe solar cell by introducing BSF layer by SCAPS-1D simulator.

2. OBJECTIVE

The purpose of this study is to achieve following objectives.
1. To study the performance characteristics of reference cell by changing the thickness of various layer.
2. To study the performance of proposed cell after inserting BSF layer.
3. RESEARCH METHODOLOGY

Department of Electronics and Information System (ELIS) of University of Gantt, Belgium developed SCAPS-1D simulation software. It’s one dimension solar cell simulation program. This software was designed the structure of CdTe and CuInSe2 family. All parameters such as band gap, mobility are independent of temperature in this type of simulation software. Three deep levels can be defined for each layer and three interface states can be placed in between those layers in this simulation software. In SCAPS-1D seven layers can be added and all the parameters can be sat such as \( E_g \), \( \varepsilon \), \( \mu \), \( N_{C} \), \( N_{V} \), \( N_{A} \) and \( N_{D} \).

In this simulation software back and front contact can be defined. Tunnelling is also allowed in this type of software. The working point calculation such as frequency, voltage and temperature can be simulated too. All measurements can be calculated for light and dark conditions and as a function of temperature. When simulation is completed results can be seen and can be compared with other results. The operating user can directly see previously calculated result such as I–V, C–V, C–F and Q.E (Figures 2a, 2b and Figures 3a and 3b). The following parameters are used for the simulation in SCAPS-1D (Table 1 and 2).

### Table 1. Parameters used for the simulation of proposed cell [2, 4]

| Parameter                  | n ZnO: Al | n CdS | p CdTe | ZnTe |
|----------------------------|-----------|-------|--------|------|
| Thickness (\( \mu m \))    | 0.1       | 0.05  | 1.5    | 0.1  |
| Band gap (e\ V)            | 3.3       | 2.42  | 1.5    | 2.26 |
| Electron Affinity (e\ V)   | 4.35      | 4.3   | 4.28   | 3.5  |
| Dielectric constant \( \varepsilon /\varepsilon_0 \) | 9         | 10    | 9.4    | 9.67 |
| Electron mobility( \( \mu_e \) cm\(^2\)/Vs) | 100       | 100   | 320    | 330  |
| Hole mobility( \( \mu_p \) cm\(^2\)/Vs)   | 25        | 25    | 60     | 80   |
| Density of Sates at conduction band (\( N_c \)) cm\(^{-3}\) | 1.8\times10\(^{19}\) | 1.8\times10\(^{19}\) | 1.8\times10\(^{19}\) | 2\times10\(^{19}\) |
| Density of Sates at valance band (\( N_v \)) cm\(^{-3}\) | 2.2\times10\(^{18}\) | 2.2\times10\(^{18}\) | 8\times10\(^{17}\) | 7\times10\(^{16}\) |
| Carrier concentration(cm\(^{-3}\)) | 2\times10\(^{17}\) | 5\times10\(^{17}\) | 2\times10\(^{16}\) | 1\times10\(^{18}\) |

### Table 2. Simulation data used in front and back contact [2, 4]

| Parameter                                               | Front contact | Back contact |
|---------------------------------------------------------|---------------|--------------|
| Thermionic emission/ surface recombination velocity (cm/s) |               |              |
| Electrons                                              | 1\times10\(^{7}\) cm/s | 1\times10\(^{7}\) cm/s |
| Holes                                                  | 1\times10\(^{7}\) cm/s | 1\times10\(^{7}\) cm/s |
| Metal work function                                     | 4.1           | 5            |
| Majority carrier barrier height                         |               |              |
| Relative to \( E_f \)                                  | -0.2500       | 0.7600       |
| Relative to \( E_v \) or \( E_c \)                     | -0.3845       | 0.7658       |

4. LITERATURE REVIEW

Lee did the first simulation work of solar cell using one dimensional solar cell simulation program. Fahren Bruch gave starting simulation parameters and set the structure of CdTe baseline. This simulation study also describes effect of thin CdS window layer between CdTe and TCO layer. J – V curve can be obtained after the simulation. AMPS were also used by S. Fonah and co-workers of Pennsylvania State University. There are other simulation programs also available for getting the performance of solar cell. Other solar cell simulation software are thin film semiconductor simulation
program (TFSSP), solar cell analysis program in one dimension (SCAPS-1D), solar cell analysis program in two dimensions (SCAPS-2D), PUPHS and PUPHS-2D. One dimensional simulation is used in this paper and SCAPS-1D (Figure 1b) is taken as a tool for the simulation of CdTe based solar cell.

5. ANALYSIS, FINDING AND DISCUSSION

In this work CdTe baseline structure (ZnO/CdS/CdTe) had been investigated and got the conversion efficiency 18.61% (Voc = 0.7939, Jsc = 27.331135, FF = 85.75) with 4 µm CdTe absorber layer, 100 nm of n-CdS window layer and 100 nm of ZnO layer as TCO. It can be seen from the result that solar cell parameters are almost constant above the thickness of 1500 nm of CdTe absorber layer. By reducing the thickness of CdTe absorber layer up to 1500 nm, current density slowly decreased (Jsc) but Voc and FF remains almost unaffected. Further reducing the thickness of CdTe absorber layer below 1500 nm all the cell parameters are reduced drastically. The efficiency decreased very slowly with reduction of CdTe thickness up to 1500 nm. But below 1500 nm it can be seen that efficiency reduces rapidly (Figures 4a and 4b). It shows that with CdTe absorber layer having thickness 1500 nm there is a possibility of reducing very less efficiency. The CdTe absorber layer having thickness 1500 nm shows efficiency = 16.27% (Voc = 0.7661, Jsc = 24.946584, FF = 85.15). It shows that only 25% of CdTe absorber material of baseline structure cell (Figure 1a) loss is 18.61% to 16.27%.

![Figure 1](image1.png)
(a) Reference cell structure
(b) solar cell definition panel

![Figure 2](image2.png)
(a) Energy band diagram for reference cell
(b) Current density diagram for reference cell
Figure 3. (a) Carrier density curve for reference cell (b) (J-V curve for reference cell)

Figure 4. (a) J-V curve for CdTe thickness 1µm to 4µm (b) QE graph for CdTe thickness of 1 to 4µm

Figure 5(a) shows that Jsc increased with reduction of CdS layer. Thus efficiency is increased with reduction of CdS layer. The thickness of CdS is varied from 20nm to 100 nm. It is clear from the QE graph (Figure 5b) that below 500nm QE is affected much more with increment of CdS layer thickness. CdS thickness below 50nm efficiency becomes constant. So for getting higher performance CdS layer has been reduced up to 50nm. This reduce layer will allow forward leakage current to front contact. In order to prevent unwanted forward leakage current high resistive buffer materials must be inserted in between front contact and CdS window layer to avoid this unwanted leakage current. By doing further analysis efficiency of CdTe solar cell has been improved by inserting buffer layer. Different materials are used as buffer layer in between front contact and CdS window layer.

Figure 5(a) J-V Curve for CdS thickness from 0.05 to 0.02µm (b) QE curve for CdS Thickness from 0.05 to 0.02µm
ZnO as buffer layer has been inserted between front contact and CdS layer with CdTe thickness of 1500 nm and CdS layer of 50 nm. It can be seen from simulation that output characteristics are independent with ZnO thickness ranging from 20 nm to 100 nm. However it was found that spectral response has no effect for ZnO thickness from 20 nm to 100 nm (Figure 6a and 6b). Therefore ZnO thickness of 100nm was selected for achieving high efficiency.

5.1. Effect and Need of BSF Layer
The main goal of BSF layer between back contact and absorber layer is to form a bridge. BSF layer reduces junction mismatch and reduces back contact schottkey barrier [2]. It also reduces the carrier loss at back contact by reducing carrier recombinations, which increases efficiency of solar cell. The BSF layer is an important structural element to acquire high efficiency in solar cell. The main role of this layer is to provide confinement for photo generated minority carries and keep them within the reach of p-n junction for collecting efficiently [2]. The layer has been inserted without increasing series resistance of device.

The structure which has been simulated in this paper consists of BSF layer of 100nm, absorber layer CdTe of 1500nm, CdS window layer of 50nm and ZnO as TCO of 100nm (Figure 7a). 

It can be seen from simulation that $V_{OC}$ and $J_{SC}$ of proposed cell decreased significantly below the CdTe thickness Od 1500 nm (Figure 8a and 8b). This could be happened because of minority carrier recombination at back contact in ultrathin CdTe solar cell. The result shows that output parameters were improved by inserting BSF layer ZnTe having thickness of 100nm. The highest conversion efficiency of 21.57% (Figure 7b) can be achieved by inserting BSF layer for CdTe thickness of just 1500 nm.
After inserting BSF layer and if thickness of CdTe is varied from 1µm to 4µm, efficiency of proposed cell shows the stability unlike reference structure. If you reduced the thickness of CdS layer below 50nm of propose cell it can be seen that all the parameter such as Voc, Jsc, FF and η are almost seen constant. The proposed cell shows more stability with reduction of CdS layer with BSF layer. Similarly with change the thickness of ZnO: Al proposed cell parameters show the constant values.

6. CONCLUSION

From analysis it is evident that proposed structure with 100nm of ZnTe thickness, 1500nm of CdTe thickness, 50nm of CdS thickness and 100nm of ZnO thickness outstanding efficiency 21.57% (Table 3) can be achieved. BSF layer significantly improved cell parameters and efficiency of cell. Therefore it is evident that the ultra-thin solar cell structure (ZnO: Al/CdS/CdTe/ZnTe) is economical and shows better result as compare to reference cell. However this proposed structure need to be investigated using standard fabrication techniques for practical implementation.

| Performance parameter | Reference structure (ZnO: Al/CdS/CdTe) | Proposed structure (ZnO: Al/CdS/CdTe/ZnTe) |
|------------------------|---------------------------------------|------------------------------------------|
| CdTe Thickness(µm)     | 4                                     | 1.5                                      |
| Voc (V)                | 0.7939                                | 1.5285                                   |
| Jsc (mA/cm²)           | 27.331135                             | 28.355106                                |
| FF (%)                 | 85.75                                 | 49.70                                    |
| Efficiency (%)         | 18.61                                 | 21.57                                    |

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