

Optimization of CIGS thin film Solar Cells by using non-cadmium buffer layer and Adjusting absorber Layer Thickness and doping density Using Silvaco-TCAD

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Abstract

Copper indium gallium selenide (CIGS)-based solar cells have exhibited greater performance than the ones utilizing cadmium telluride (CdTe) or hydrogenated amorphous silicon (a-Si: H) as the absorber. CIGS-based devices are more efficient, considering their device performance, environmentally benign nature, and reduced cost. This research designed and simulated the CIGS solar cells using the two-dimensional device simulator Silvaco-Atlas under standard AM1.5G illumination. The purpose of this work is to achieve the best efficiency of CIGS solar cell by replacing the CdS buffer layer with other nontoxic materials, varying the CIGS absorbing layer thickness and doping density. The simulation results revealed that only a doping density of $1 \times 10^{15} \text{ cm}^{-3}$ and 1.5 μm thick-CIGS absorber layer with ZnSe buffer layer in this structure offers an outstanding conversion efficiency of 35.3% with an open-circuit voltage (V_{oc}) of 0.7 V, a short circuit current density (J_{sc}) of 50.4 mA/cm^2 and a fill factor (ff) of 99%.

Keywords: CIGS, solar cell, buffer layer, thickness, ZnSe, Silvaco-Atlas

Introduction

Recently, the growing interest in replacing fossil based fuel with renewable energies pushed up photovoltaic technologies towards novel materials and new designs to improve efficiency and lower costs [1]. In today's solar power industry, about 90% of solar panels are made from silicon materials. However, the high cost of crystalline silicon, pushed the manufacturers to look for other materials less expensive, to produce the solar cell. Among those materials, two options stand out in recent years due to their performance and simplicity for implementing: CdTe and CIGS [2]. The solar cells based on CIGS consisting of a stack of layers contain a thin layer called the buffer layer between the absorber and the window layers. A buffer material should be n-type to make a junction with a p-CIGS absorber [3]. Most recently, thin-film CIGS solar cells have achieved a conversion efficiency of 23.35% which is considered highest efficiency record for a single thin solar cell [4].

In [4], The optimisation of ultra-thin CIGS solar cell has been done by Silvaco-tools. The author achieved a efficiency of 14.30% by investigation parameters such as: Ga/Ga+In ratio, opening width, cell pitch, effect of absorber layer thickness and concentration of carriers. The electrical parameters of the CIGS/Cds solar cell configuration were a short circuit current density (JSC) of 31.42 mA/cm², an open-circuit Voltage (Voc) of 610 mV, a fill factor (FF) of 74.60% and a conversion efficiency (η) of 14.30%.

In [5], increasing the efficiency of CIGS solar cells with silicon carbide (3C-SiC) as an effective buffer layer has been investigated. Cubic silicon carbide can be a potential photovoltaic material for thin-film solar cells due to its wide band gap and non-toxic nature and low-cost. Usually, Cds is used as the window layer or buffer layer of CIGS and CdTe solar cells due to its suitable band gap and interface enhancement properties. But because Cds is a toxic material, researchers are looking for other materials to replace the window and buffer layer. Therefore, by replacing silicon carbide instead of Cds, they have been able to achieve the highest conversion efficiency of 25.51%, an open-circuit Voltage of 0.94V and a short circuit current density of 31.46 mA/cm².

In [6], The writer presents the CIGS-based solar cell with V2O5 as the BSF layer and ZnSe as the buffer layer. The simulation results show that with 1 μ m thick-CIGS absorber in this structure can achieve an open-circuit Voltage of 0.9V and a conversion efficiency of 31.86%.

In [7], CIGS solar cell with ZrS2 layer as buffer layer is investigated by SCAPS. The author has investigated the concentration of carriers and the thickness of the absorber and buffer layer on the performance of the electrical and photovoltaic parameters of the CIGS/ZrS2 solar cells. The result shows that increasing the thickness of the absorber from 0.2 μ m to 2 μ m and the concentration of the absorber carriers from 10¹² to 10¹⁸, increases the conversion efficiency of 26.95%.

In [8], author presents a CIGS solar cell with a non-cadmium buffer layer. By investigation several non-cadmium layers such as ZnO and ZnSe, it was found that the ZnO layer is a good candidate as a buffer layer for CIGS thin film solar cells because its band gap is larger than Cds. By replacing the ZnO buffer layer instead of the Cds buffer, have been obtained the electrical parameters η of 20.63%, Voc of 0.680V, JSC of 37.7 mA/cm² and FF of 80.42%.

In this paper, first we present the Cds/CIGS solar cell then, we investigate the effect of the thickness of absorber layer, doping density of absorber layer and varying the type of buffer layer. Finally, After achieving the optimal values of doping density and thickness of the absorber layer and non-toxic buffer, we present the optimized structure.

2. modeling and simulation

2.1. Physical models

In this work the CIGS solar cells are modeled using Atlas-2D simulator. That is a physically based two- and three-dimensional device simulator. This software predicts the electrical behaviour of the device and enables the design of microelectronics to achieve terminal characteristic (I-V, C-V, ...). The parameters used in this simulation consisting of the bandgap E_g , the relative permittivity ϵ_r , the electron affinity χ_e , the electron band mobility μ_n , the hole band mobility μ_p , the effective density of state in valence band N_v and the effective density of state conduction band N_c are presented in table 1 [9].

Table 1-material parameters used in the simulation

Parameter (unit)	ZnO (n)	CdS (n)	CIGS (p)	Mo(back electrode)
Thickness (μ m)	0.39	0.04	0.36	0.12
Bandgap, E_g (eV)	3.3	2.4	1.3	-
Electron affinity (eV)	4.6	4.2	4.5	-
Dielectric permittivity	9	10	13.6	-
Density of states at conduction band N_C (cm ⁻³)	2.2×10^{18}	2.2×10^{18}	2.2×10^{18}	-
Density of states at valence band N_V (cm ⁻³)	1.8×10^{19}	1.8×10^{19}	1.8×10^{19}	-
Doping density ND/NA (cm ⁻³)	1×10^{19}	1×10^{17}	1×10^{16}	-

2.2 structure of Cds/CIGS solar cell

the Cds/CIGS structure is presented in Fig.1. It consist of the CIGS layer (absorber,p-typ) , cds layer (buffer, n-type) , i-Zno layer, and Al doped ZnO layer as TCO (transparent conductive oxide). Aluminium (Al) is applied as a front grid electrode (cathode Work function $Q=4.7\text{ev}$). Molybdenum (Mo) is used as back electrode [4]. the thickness and doping of each layer are presented in table 1.

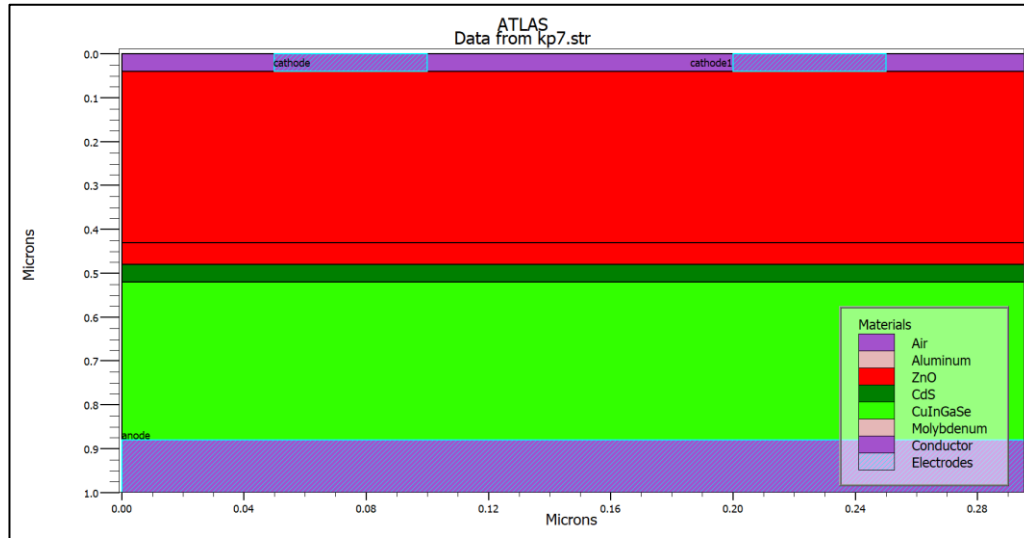


Figure (1) Silvaco-Atlas structure file of the Cds/CIGS solar cell

The J-V curves of the simulated model are presented in Fig.2. The result of J-V characteristic show that the electrical parameters of Cds/CIGS solar cell were short circuit current density (j_{sc}) of 23.34 mA/cm^2 , an open circuit voltage (V_{oc}) of 700 mv , a fill factor (ff) of 67.82% and a conversion efficiency (η) of 16.15% .

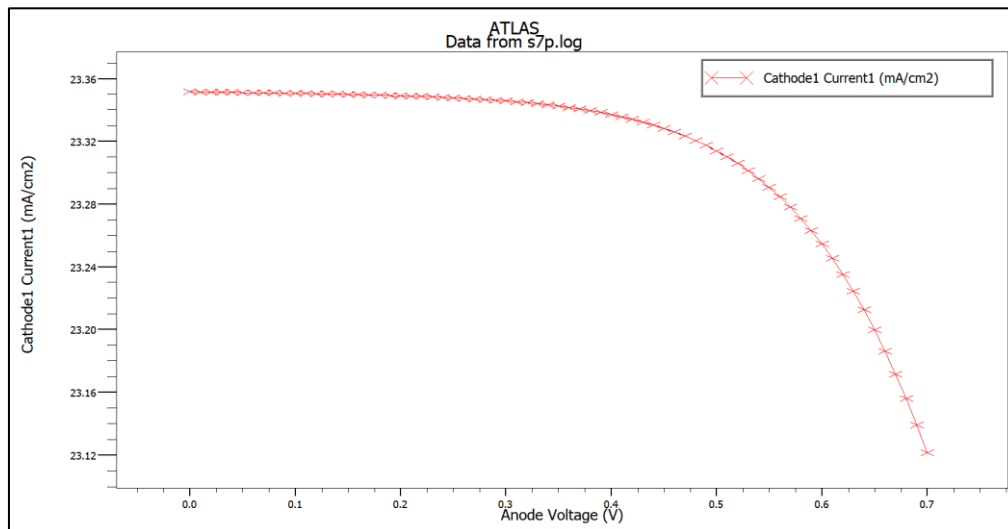


Figure (2) J-V characteristic of Cds/CIGS solar cell

3.Optimized structure

First, investigate the effect of doping density and thickness variation of the absorber layer and Second, the effect of type of buffer layer(non-toxic materials) then with optimal values,we present the final structure.

3.1.Optimisation of the CIGS absorber layer thickness and doping density

Absorber layer plays a key role which absorber the excess generated carriers when photons incident on the solar cells. with increase in absorber layer width more number of photon are captured which increases the quantum efficiency and hence the efficiency of the device[10]. The thickness of CIGS layer was varied from $0.5\mu\text{m}$ to $2\mu\text{m}$ and the doping density of CIGS layer was varied from 10^{15} to 10^{17} cm^{-3} while all other parameters was staid constant. Figure.3 and .4 show the performance electrical parameters such as the conversion efficiency (η), the fill factor (ff), the short circuit current density (J_{sc}) and the open circuit voltage (V_{oc}) as a function of thickness and doping density.

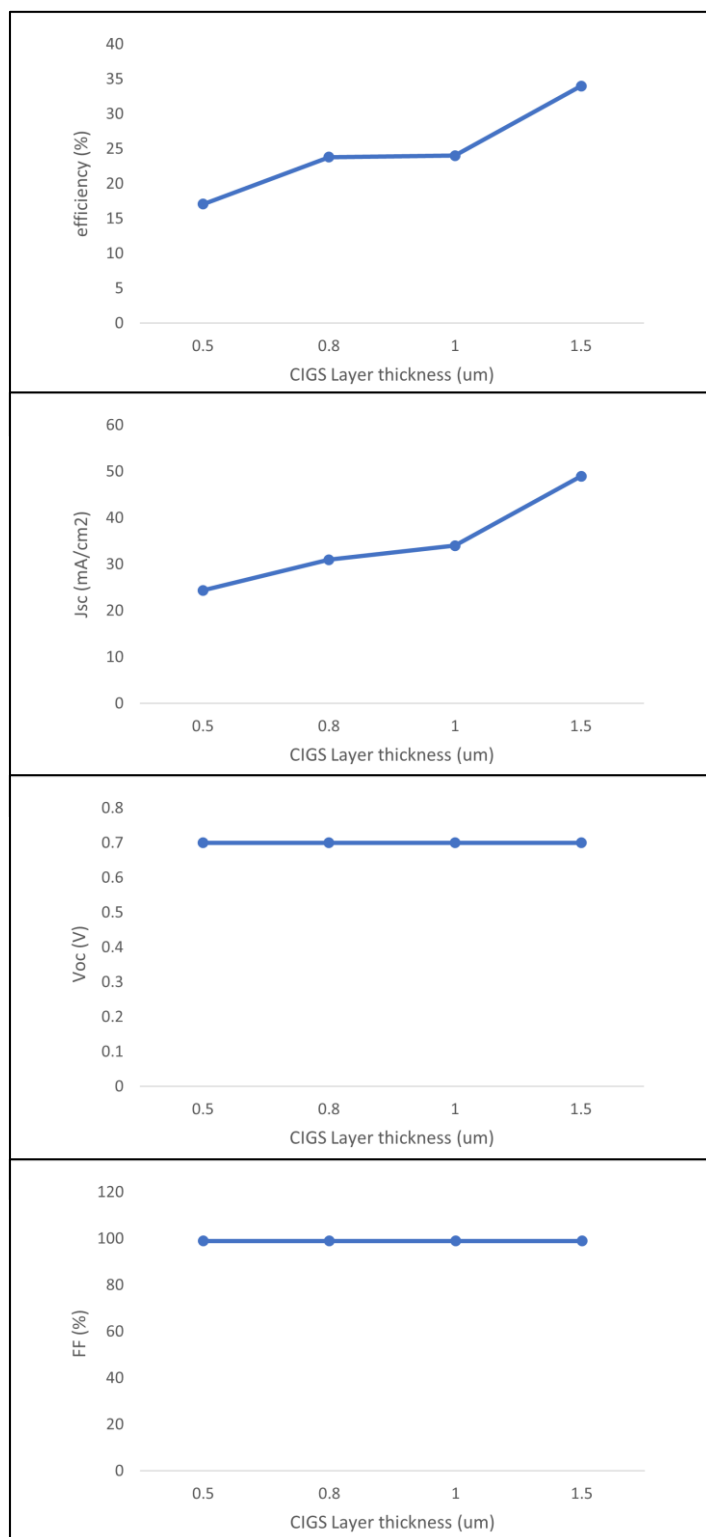


Figure (3) Absorber thickness effect on cell characteristics

Figure.3. shows that as the CIGS layer thickness increases from 0.5μm to 1.5μm , the efficiency, Voc and Jsc increases, but when the thickness of absorber layer is 2μm or more than 2μm the efficiency starts to decrease. Thus, the thickness of 1.5μm is the optimal absorber layer thickness.

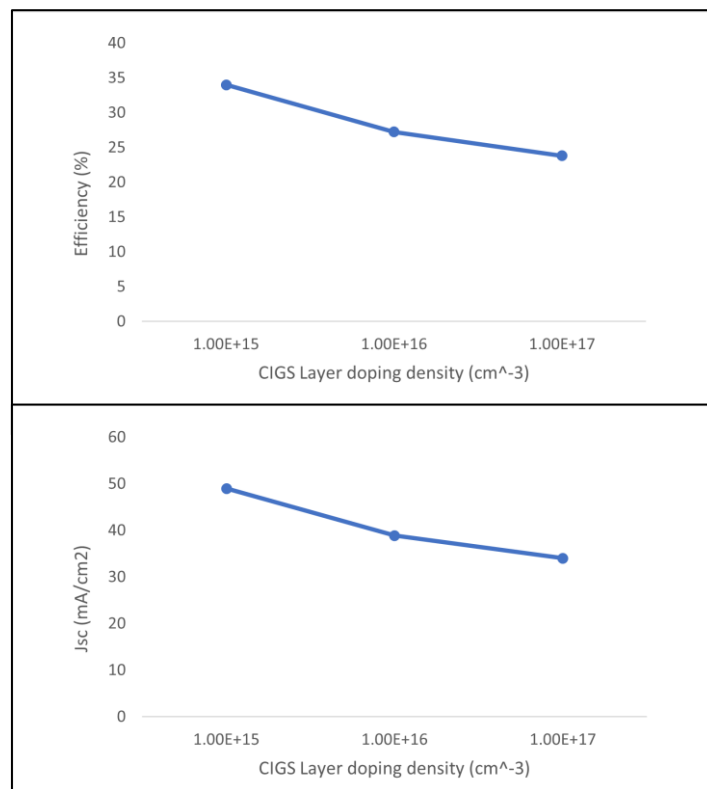


Figure (4) Doping density effect on cell characteristics

Figure.4 shows that as the doping density of CIGS layer thickness from 10^{15} to 10^{17} cm^{-3} , the efficiency (η) and the short circuit current density (j_{sc}) decreases rapidly. Thus the doping density of 10^{15} cm^{-3} is the optimal absorber layer doping.

then it decreases because the increase in acceptor doping leads to decreases in the width of depletion region from which the major contribution to the photocurrent comes [11].

3.2.Impact of non-cadmium buffer layer

cds is a promising option for use as a buffer layer in CdTe thin film solar cells due to its properties of low surface recombination and little absorption loss. On the other hand, cds can be hazardous to the environment and human health due to its high toxicity[12],[13]. green and less dangerous chemicals (such as ZnSe, ZnS, ZnO and In₂S₃) should be studied and assessed as a substitute for the traditional hazardous semiconductors that are often used in heterojunction thin film solar cells [14]. ZnSe thin film are considered to be one of the most important semiconductor materials and photovoltaic samples because they have wide bandgap of 2.4 to 2.7eV. For this reason, the ZnSe thin film replaces the cds thin film in the solar cell [15].

A promising candidate is ZnSe especially since it can be deposited in a dry process, in contrast to the chemical bath deposition of the usual cds buffer [16].

In this work, different buffer layers replace CdS, including ZnS, ZnSe, and ZnO have been simulated and their effect on cell performance is examined in Figure.5.

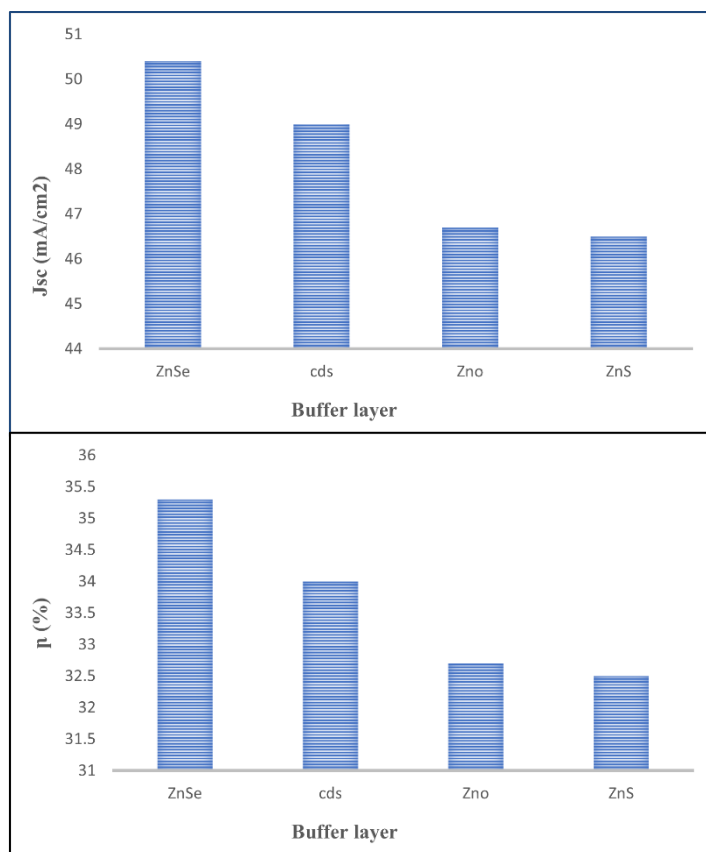


Figure (5) different buffer layers effect on cell characteristics

According to the simulation results, ZnSe is a good alternative to the CdS buffer layer. ZnSe has very good optical properties, including the ability to absorb light at different wavelengths and high light transmission capability, which can help improve the efficiency of solar cells.

The results show that ZnSe has achieved a higher efficiency and short-circuit current density compared to other materials, which are 35.3% and 50.4 mA/cm², respectively.

The optimized ZnSe/CIGS solar cell structure, obtained using Silvaco-Atlas is shown in Figure.6.

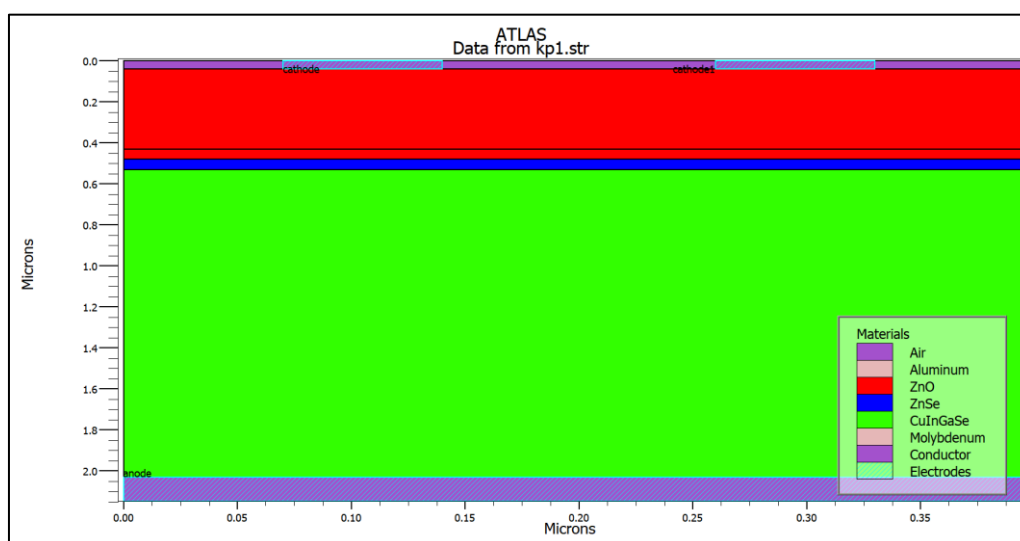


Figure (6) Silvaco-Atlas structure file of the ZnSe/CIGS solar cell

The result of the proposed model such as J-V curve is shown in Figure.7.

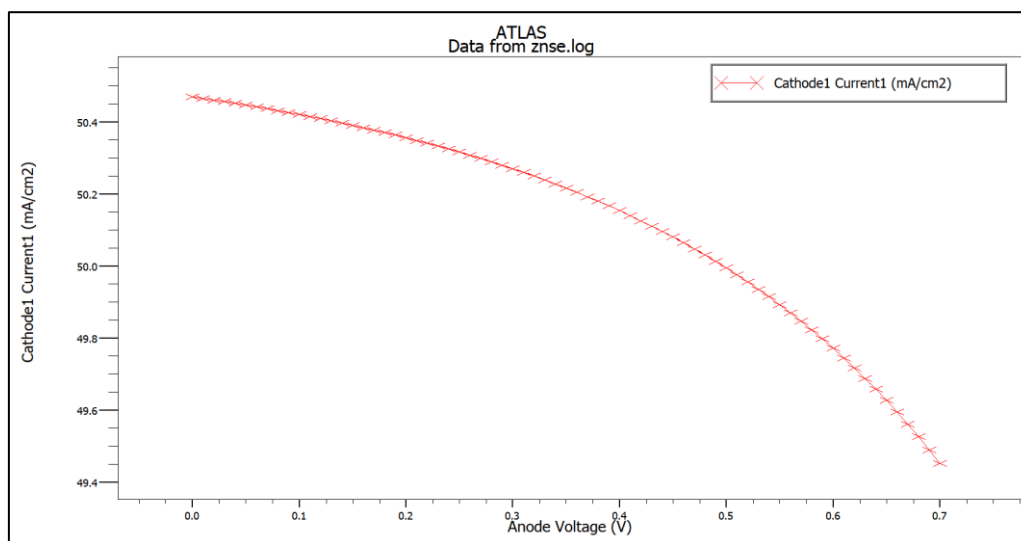


Figure (7) J-V characteristic of ZnSe/CIGS solar cell

Conclusions

In this paper, the simulation of a single-junction CdS/CIGS solar cell was conducted using Silvaco Atlas, along with variations in doping density and the thickness of the absorber layer, to achieve an optimal structure with high efficiency. Ultimately, with a doping density and absorber layer thickness of 10^{15} and 1.5 μm , respectively, and ZnSe as buffer layer, we achieved an optimal structure with a conversion efficiency of 35.3 %, a short-circuit current density of 50.4 mA/cm², an open-circuit voltage of 0.7 V, and a fill factor of 99%.

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