

Study of Efficiencies CdTe/CdS Photovoltaic Solar Cell According to Electrical Properties by Scaps Simulation

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Abstract

The photovoltaic performance (efficiency η) of an ITO/CdS/CdTe structure cell is studied in this article according to its electrical properties. The study is carried out by simulation with SCAPS (Solar Cell Capacitance Simulator) whose mathematical model is based on solving the equations of Poisson and continuity of electrons and holes. An electrical conversion efficiency of 23.58% is obtained by optimizing the mobility of the electrons (100 cm²/Vs), that of the holes (25 cm²/Vs), the density of electrons (10¹⁵ cm⁻³), the density of the effective states in the conduction band (7.9 × 10¹⁷ cm⁻³) and the electronic affinity (3.85 eV) of the CdTe absorbent layer.

Keywords

Solar Cells, Photovoltaic, Thin Films, CdTe, Electron Mobility, Charge Carrier Density, Simulation, SCAPS

1. Introduction

The very high solar potentials in Sahelian countries (5.7 kWh/m²/day on the ground of solar energy) [1], do not relate the equivalent photovoltaic solar performances of the panels installed in these places. They are far lower than the powers obtained by the standard test conditions (irradiation: 1000 W·m⁻², module temperature: 25°C, spectral distribution of the radiation: AM 1: 5). There are many reasons, in particular the fact that very high local temperatures are not taken into account, which are environmental conditions dissimilar to those of

the tests. A photovoltaic panel whose surface temperature exceeds 25 degrees, loses up to half a percent of efficiency per additional degree [2]

The production of photovoltaic electricity is obtained by the conversion of solar energy (solar radiation) with photovoltaic solar panels or modules made up of series/parallel assemblies of photovoltaic solar cells obtained from organic inorganic or hybrid photovoltaic materials [3] [4]. Moreover, thin-film solar cells have many advantages, in particular their ease of synthesis, their low cost in a wide range and their adaptability in industrial production. Indeed, mono-junctions of monocrystalline silicon and of polycrystalline silicon form the first solar technologies offering respectively yields going up to 21% and 14% [5].

With the development of technology and the creation of new basic materials, high yields are obtained [6]. As a result, the performance of photovoltaic modules is strongly linked to the intrinsic parameters of the basic materials constituting each element that a photovoltaic solar cell makes up (chemical nature, gap, doping rate, carrier mobility). Controlling these parameters will therefore effectively improve the performance of solar panels.

This paper presents a study by simulation of heterojunction CdTe solar cells by SCAPS simulation according to the parameters (charge carrier densities, mobilities and electronic affinities) of the components of solar cells. It links the influence of parameters on electrical performance under standard test conditions.

The use of techniques for simulating the performance of a solar cell has several advantages. It minimizes the cost of manufacturing prototypes by offering the possibility of varying all parameters. They make it possible to better understand the impact of different physical parameters on cell performance, and to design and optimize different cells without the need to systematically use experimental procedures which can prove to be expensive. Finally, they make it possible to assess the performance of a structure and its maximum theoretical yield. It also offers the opportunity to study the influence of each layer of the cell in the case of interdependent parameters.

2. Materials and Method

2.1. Presentation of SCAPS (Solar Cell Capacitance Simulator)

SCAPS allows simulation of one-dimensional solar cells [7]. SCAPS software was originally developed to model and simulate the electrical characteristics of heterojunction and thin-film photovoltaic solar cells. It has also been tested on CdTe and CIGS solar cell structures by M. Burgelman *et al.* [8] [9], the developers. The simulated and measured results were in good agreement with the practical cases. Moreover, several versions have improved its capacities allowing their applicability to crystalline solar cells (Si and GaAs) and amorphous cells (a-Si and Si micro-morph) [10]. In addition, SCAPS has a database containing several types of solar cells, data file, with modifiable parameters (thickness, doping).

The equations that govern the studied model are the equations of Poisson and

continuity for electrons and holes.

$$\frac{d^2\varphi}{dx^2} = -\frac{q}{\varepsilon_0\varepsilon_r} \left(p - n - N_A^- + N_D^+ + \frac{\rho_t}{q} \right) \quad (1)$$

And:

$$\begin{cases} \frac{1}{q} \frac{dJ_n}{dx} = G - R_n \\ -\frac{1}{q} \frac{dJ_p}{dx} = G - R_p \end{cases} \quad (2)$$

In Equation (1) and Equation (2), φ describes electrical potential, q is the unit charge, ε_0 and ε_r are the dielectric constants of vacuum and semiconductor, respectively; n and p are electron and hole density, respectively; N_A^- and N_D^+ are the density of ionized donors and acceptors, ρ_t the charge density of defects, J_n and J_p the electron and hole current density; G is the generation rate and $R_{n(p)}$ is the recombination loss.

The transportation of carriers is shown by:

$$\begin{cases} J_n = -qD_n \frac{dn}{dx} + q\mu_n \frac{d\varphi}{dx} \\ J_p = -qD_p \frac{dp}{dx} - q\mu_p \frac{d\varphi}{dx} \end{cases} \quad (3)$$

where $\mu_{n(p)}$ is the electron/hole mobility and $D_{n(p)}$ is the diffusion coefficient.

The generation rate is given by:

$$G(\lambda, x) = \varphi_0(\lambda) e^{-\alpha(\lambda)x} \quad (4)$$

where φ_0 is the incident photon flux, x is a depth and α the absorption coefficient of the active material and λ , the absorbed photon wave length. Cell performance was achieved with scaps under standard conditions (a cell temperature of 25°C and radiation of 1000 W/m² with an air mass spectrum of 1.5 (AM1.5)).

2.2. Methodological Approach

We aim to optimize the efficiency of our solar cell by modifying the characteristics (mobility, doping) of CdTe with SCAPS. It makes it possible to study and analyze the evolution of characteristics such as J_{sc} , V_{oc} , FF and therefore the efficiency η as a function of the intrinsic properties of doped CdTe.

The recommended method for introducing a solar cell is to use the graphical interface of SCAPS. In this way, we can interactively introduce all the parameters that will be controlled by SCAPS so as not to have impossible or inconsistent values [7].

2.3. Properties and Structure of Studied CdTe Solar Cell

We used a thin film solar cell in ITO/CdS/CdTe structure, where CdTe the base layer, CdS the emitter and ITO the antireflecting layer. The front contact is made of aluminum. All the thicknesses of ITO, CdS and CdTe layer were respectively 0.30, 0.08 and 4.00 μm . The parameters of the materials used in this modeling

were selected from experimental data in the literature and from the characteristic values (see **Table 1**) [7] [10] [11].

3. Results and Discussions

3.1. J-V Characteristic of the CdTe Solar Cell

With the data, we can save the variations of J_{sc} , V_{oc} , FF and analyze the efficiency η . The J-V characteristic modeled in **Figure 1** uses the values in **Table 1**.

The efficiency of the CdTe/CdS solar cell reached 21.34% similar to that of a practical CdTe based solar cell [11]. This proves that our solar cell model is valid and can be used to perform a simulation analysis of its performance with different parameters of the material. Then, we look for the effect of the evolution of the electrical characteristics (J_{sc} , V_{oc} , FF and η) as a function of the intrinsic properties of the material (doping, mobility) in order to optimize them and predict their behavior of the photocell.

3.2. Effect of the Mobility of CdTe Charge Carriers on Yield

The efficiency (η) is analyzed as a function of the electrons and holes mobility (**Figure 2**). The efficiency of the cell decreases with the increase in mobility of the electrons (**Figure 2(A)**) and increases with the speed of the holes (**Figure 2(B)**). These results are in agreement with those of the literature. Because a couple of mobility of the charge carriers which is not optimized adds constraints on the thickness of the active layer and increases the losses by recombinations [12].

The conversion efficiency is evaluated based on carrier mobility couples. The yield is maximal and equal to 22.10% for a couple of mobility equal to 100 cm^2/Vs for electrons and 25 cm^2/Vs to that of the holes (**Table 2**).

Table 1. Used characteristic values on SCAPS.

Parameters	Layers		
	ITO	CdS	CdTe
Permittivity	9.0	10.0	10.2
Effective state density in the BC (cm^{-3})	$2.20 \times 10^{+18}$	$2.20 \times 10^{+18}$	$8.0 \times 10^{+17}$
Effective density of states in BV (cm^{-3})	$1.80 \times 10^{+19}$	$1.80 \times 10^{+19}$	$1.80 \times 10^{+19}$
Electrons mobility (cm^2/Vs)	$1.0 \times 10^{+2}$	$1.0 \times 10^{+2}$	$3.2 \times 10^{+2}$
Holes mobility (cm^2/Vs)	$2.5 \times 10^{+1}$	$2.5 \times 10^{+1}$	$4.0 \times 10^{+1}$
Donor density N_d (cm^{-3})	$1.0 \times 10^{+17}$	$1.0 \times 10^{+17}$	0.0
Acceptor density N_a (cm^{-3})	0.0	0.0	$1.0 \times 10^{+14}$
Absorption coefficient (cm^{-1})	$1.0 \times 10^{+6}$	SCAPS	$1.0 \times 10^{+5}$

Table 2. Performance with different mobilities of charge carriers.

Electron Mobility (cm^2/Vs)	100	100	320	700
Holes Mobility (cm^2/Vs)	20	25	40	65
η (%)	22.03	22.10	21.34	20.82

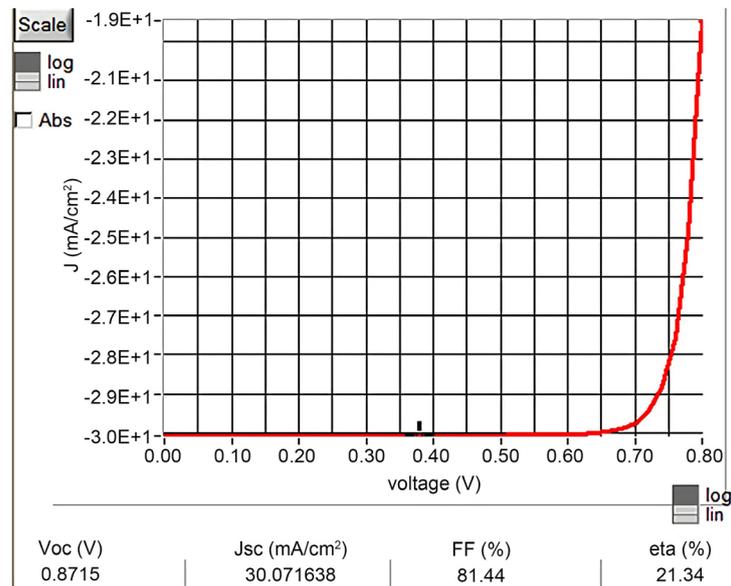


Figure 1. J-V characteristic of the modeled CdTe solar cell.

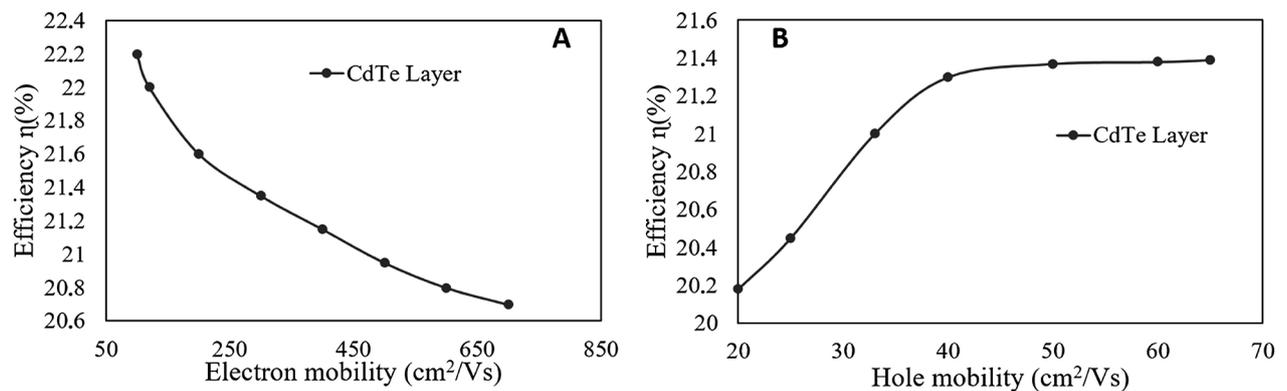


Figure 2. Variation in yield as a function of mobility (A): electrons and (B): holes in the CdTe layer.

We found that the optimum torque value of carrier mobility is required to obtain maximum efficiency of the cell.

3.3. Effect of Carrier Density (for Acceptor) of CdTe

The acceptor density was varied from 10^{12} cm^{-3} to 10^{19} cm^{-3} in steps of 10 cm^{-3} . The decrease in the acceptor density of CdTe greatly reduces the yield (**Figure 3**). Recombination becomes important with an increase in the density of carriers. Therefore, an increase in density can drop the collection of free electrons generated by the incident radiation on front contact and contribute to lowering the value of J_{sc} [13]. In our conditions, a density of 10^{16} cm^{-3} is the optimum value which would increase the yield.

3.4. Effect of the Density of Effective States in the BC of the CdTe Layer on the Yield

The density of the effective states was varied from $7.9 \times 10^{17} \text{ cm}^{-3}$ to $22 \times 10^{17} \text{ cm}^{-3}$.

An effective state density in the smaller conduction band (CB) gives the best performance [14]. The more the density of the effective states in the CB increases the more the efficiency of the cell decreases (Figure 4). A density of $7.9 \times 10^{17} \text{ cm}^{-3}$ is the best value.

3.5. Effect of the Electronic Affinity of the CdTe Layer on the PV Conversion Efficiency

A low electronic affinity of the CdTe absorber indicates a low efficiency from 3.8 eV. For an electronic affinity between 3.8 eV and 3.85 eV, the efficiency equal to 21.37% is maximum and almost constant throughout the range before decreasing after 3.85 eV (Figure 5).

The results obtained are consistent because the differences in electronic affinities and band gap energies cause a discontinuity at the level of the connection of the conduction and valence bands. Therefore, the influence of the electronic affinity of the CdTe layer ($\text{CdTe}_{\text{gap}} = 1.45 \text{ eV}$ vs $\text{CdS}_{\text{gap}} = 2.5 \text{ eV}$) in the solar cell, acts on the energy difference in the conduction band.

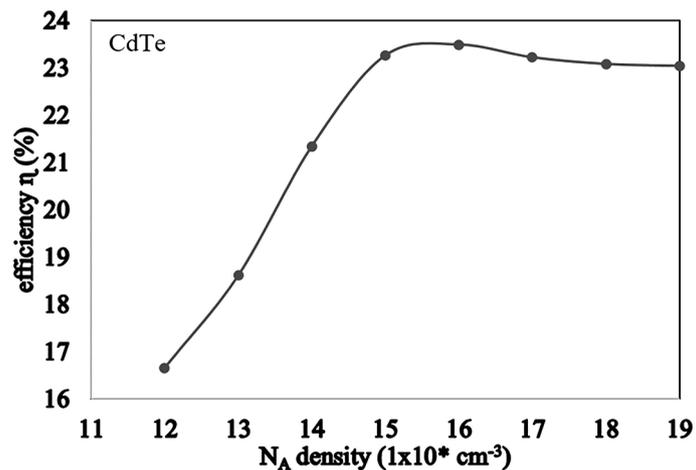


Figure 3. Yield as a function of the density of carriers (acceptor) of CdTe.

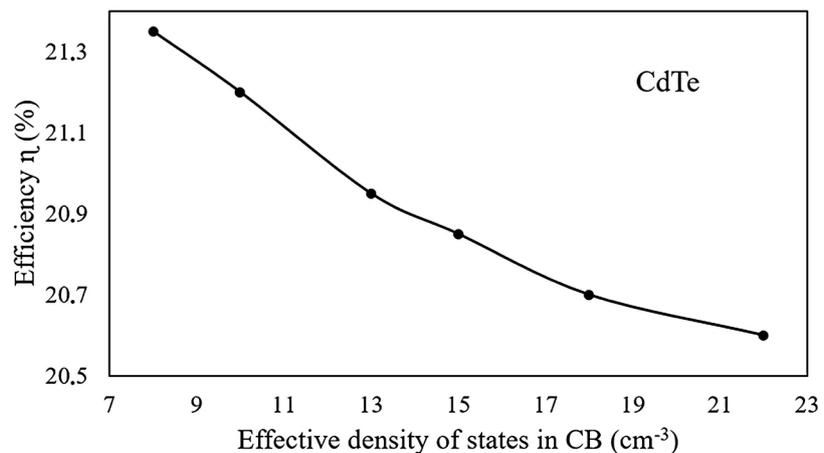


Figure 4. Efficiency as a function of the effective state density in the CB of CdTe.

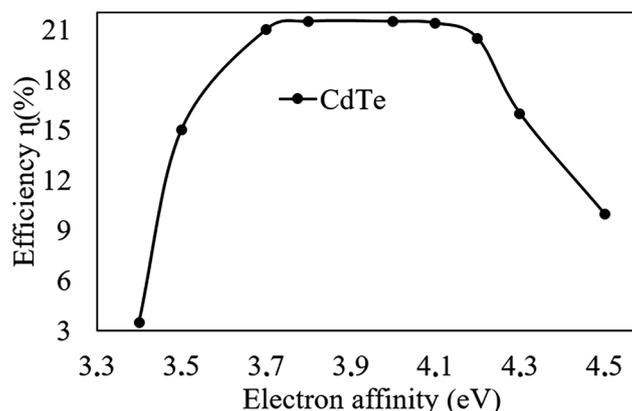


Figure 5. Yield based on the CdTe layer of electron affinity.

However, for CdS/CdTe cell, the values of ΔE_c ($\chi_{\text{CdS}} - \chi_{\text{CdTe}}$) lie between 0.20 and 0.25 eV and are found to be independent of the process of cell fabrication [15].

4. Conclusions

This work established an analysis of the relationship between the properties of the layers of the ITO/CdS/CdTe structure cell and their performance with an optimal electrical conversion efficiency of 23.58%.

In fact, the optimized values are:

- A couple of mobility of charge carriers of the CdTe layer (mobility of the electrons of $100 \text{ cm}^2/\text{Vs}$ and that of the holes of $25 \text{ cm}^2/\text{Vs}$).
- A density of the electrons in the CdTe absorber layer which allows us to obtain coherent results and a good yield of 10^{15} cm^{-3} .
- A density of the effective states in the conduction band in the absorber layer CdTe of $7.9 \cdot 10^{17} \text{ cm}^{-3}$.
- A reasonable and acceptable dielectric permittivity of the absorber layer CdTe of 8.
- An electronic affinity of the absorber layer CdTe = 3.85 eV.

However, the increase in the optical gap of the CdTe absorber layer reduces the intensity of the photocurrent while the open circuit voltage increases. The compromise between these two phenomena gives an optimum value of the optical gap $E_{g\text{CdTeopt}} = 1.47 \text{ eV}$ which corresponds to the maximum efficiency of the cell.

Thus, we were able to show the impact of the studied characteristics (charge carriers mobility, the density of carriers, the density of effective states, the dielectric permittivity and the electronic affinity) on the efficiency of the solar cell with SCAPS. The results of simulation of the thin film solar cell based on CdTe, are in good agreement with those of the literature, which show that the parameters of the photovoltaic cell have significant effects on the photovoltaic performances (V_{oc} , J_{sc} , FF and η).

Therefore, we can say that the main factors limiting photovoltaic performance

in African ecosystems, linked to the physical properties of materials, can be circumvented by also taking temperatures into account.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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