OPTIMIZATION OF THE PERFORMANCE OF GaAs SOLAR CELLS: EFFECT OF THE WINDOW LAYER

H. BOURBABA*, S. KADRI, K. DJERMANE
Physics laboratory in semiconductor devices University of TAHRI Mohamed Bechar, Department of Matter Sciences, Faculty of exact sciences, University of TAHRI Mohamed, Bechar, BP 417, Bechar, ALGERIA

Improving the photovoltaic conversion efficiency requires a good choice for the structure of the cell. The front surfaces of the thin-film cell could improve these performances. In our work we have studied thin-film GaAs cells with thin ternary InGaP and AlGaAs layers used as a window. The one dimensional program SCAPS 1D has been used to study and optimize the performance of the GaAs cells in particular the window layer effect (the thickness and doping) and to compare between the two cells with $In_{0.5}Ga_{0.5}P$ and $Al_{0.2}Ga_{0.8}As$ window layers. The results have shown that the $In_{0.5}Ga_{0.5}P$ layer window epitaxially grown on GaAs solar cell have the best performance compared with the $Al_{0.2}Ga_{0.8}As$ layer window. The optimum thickness of the window is 0.1µm, and the maximum efficiency is about 25.02%.

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1. Introduction

The choice of the semiconductor material is a crucial element in the manufacture of solar cells to have a good performance. A precise knowledge about the band structure of the studied material is necessary for the evaluation of its application fields, the direct and indirect transitions according to the composition are particularly of principal importance for the study and the manufacture of the cells solar.

Different materials as well as several architectures of solar cells appeared to make a photovoltaic module with high efficiency. In fact, III-V semiconductors such as GaAs and InGaP have a band gap close to the optimum absorption value. Components made from these semiconductors, which have remarkable physical properties, play a major role in microwave applications, power electronics, but especially in the field of optoelectronics [1].

The main limitation of GaAs solar cell performance is the reduction in collection efficiency from high surface recombination. Among the approaches available to optimize the characteristics of solar cells on GaAs is the deposition of thin films as a window layer, such as as InGaP-GaAs or $Al_xGa_{1-x}As$-GaAs. The front surfaces of the cell composed of many thin layers could be a part of the optical design that minimizes reflection losses. In fact, the window of the upper layer of the solar cell can be recognized as window layers on the optical characteristics of the cell [2].

In this work, a GaAs-based heterojunction solar cell is described and fully simulated using the "SCAPS" simulation tool that was developed to simulate the electrical characteristics of thin-film heterojunction solar cells [3].

In order to optimize the efficiency of the GaAs solar cell, we study the effect of the thickness (doping) properties on the cell response and make a comparison between the optimized InGaP and AlGaAs window layer.

* Corresponding author: belhouaria@yahoo.fr

2. Studied solar cells and model description

The electrical functioning of a component is described by the three basic equations of semiconductor physics: Poisson's equation, and electron and hole continuity equations. The SCAPS program developed at ELIS (Electronics and Informatics Systems) at the University of Gent, Belgium to simulate the electrical characteristics of mine-layer heterojunction solar cells is able to take into account the presence of several layers in the cell; the phenomenon of recombination at the interface of the layers, It can treat the problem of recombination and the centers of generation-recombination in the deep states in the volume of the layers and calculate the characteristic I (V), but also the spectral response and the capacity measurements C(V) and C(f) [4] [5].

Improving the photovoltaic conversion efficiency requires improving the mechanisms involved in the manufacturing process by making a good choice for the structure of the cell. In this work we try to contribute to the understanding the role played by the window layer and to predict the optimal thickness of this layer. The structures of the GaAs-based cell studied are shown in Figure 1. The structures that are used in this modeling are the n/$Al_{0.2}Ga_{0.8}As$ n/GaAs P GaAs and n/$In_{0.5}Ga_{0.5}P$ n/GaAs p/GaAs [6]. These structures are extensively analyzed with numerical simulations in order to explore the optical performance and the electrical transport that defines the final value of the total current.

Window n/$In_{0.5}Ga_{0.5}P$	0.1μm
Emmiter n/GaAs	0.3μm
Base p/ GaAs	3μm
BSF p/$In_{0.5}Ga_{0.5}P$	0.2μm
Substrate p/GaAs	

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Fig. 1. Structures of the GaAs solar cells studied with numerical simulation.

3. Numerical simulation of GaAs cells

The electrical transport and the optical behaviour of the solar cells discussed in this paper were studied with the simulation code SCAPS (Solar Cell Capacitance Simulator in one Dimension). In SCAPS the technique of finite differences method are used to solve the Poisson and the continuity equations that are subject to appropriate boundary conditions and under various conditions: equilibrium, DC, AC, Illumination Recombinations (Radiative, Auger, and Shockley-Read-Hall).

InGaP is a ternary material and forms a good interface with the GaAs material for a molar fraction x=0.5, it has a direct gap for a molar fraction less than 0.74 [7,8], but the best compromise between the two materials GaAs and AlGaAs is obtained for a molar fraction x ~0.8 [9]

In this study different layers are used for modeling solar cells with window layers. The main parameters used in our simulations are listed in Table 1 [10-12].

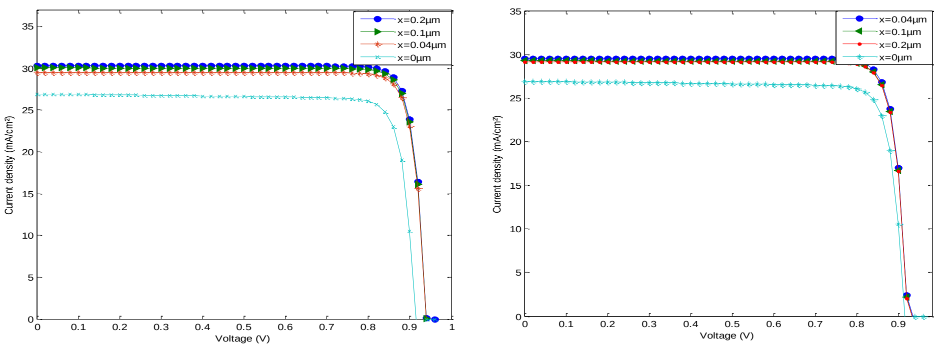
Table 1. Typical parameters used in our numerical simulations.

Layer parameters	n/$Al_{0.2}Ga_{0.8}As$	n/$In_{0.5}Ga_{0.5}P$	n/GaAs	p/GaAs
Bandgap E_g (eV)	1.67	1.85	1.42	1.42
dielectric constant ,ε	13.11	13.21	13.18	13.18
Carrier density (cm^{-3})	2×10^{18}	2×10^{18}	1.1×10^{18}	1×10^{17}
Electron mobility μ_n (cm^2/vs)	3200	671	2830	6650
Hole mobility μ_p (cm^2/vs)	146.4	40	154	345
The effective density,N_c (cm^{-3})	5.6×10^{17}	6.5×10^{17}	4.7×10^{17}	4.7×10^{17}
The effective density,N_v (cm^{-3})	7.8×10^{18}	1.45×10^{19}	9.8×10^{18}	9.8×10^{18}
Electronic affinity χ(eV)	3.85	4.08	4.07	4.07

4. Results of simulation

4.1. The InGaP and AlGaAs window thickness effect

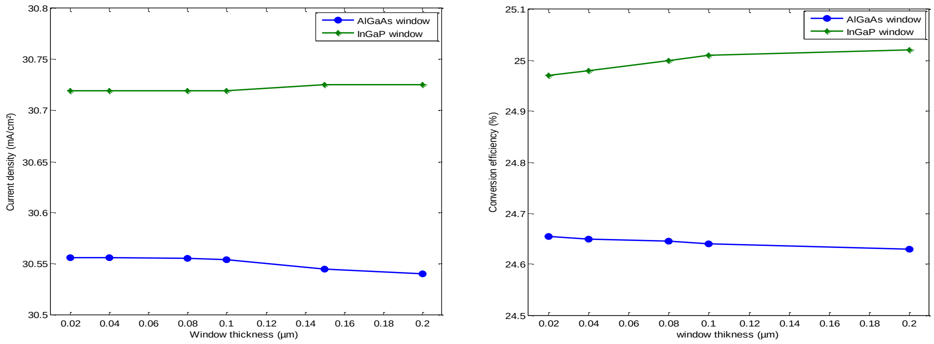
We studied the structure under a solar spectrum AM1.5 and at room temperature T = 300K. The electrical characteristics of the two GaAs-based cells with an InGap and AlGaAs window layer are shown in Fig. 2, we have tested the effect of the thickness of the window layer (from 0.04 μm to 0.2 μm) on the cell's performance and the GaAs cell without a window layer. The variation of the short-circuit current and efficiency as a function of the thickness of the window layer for the two cells is represented in Fig. 3.



(a) *(b)*

Fig. 2. Current voltage characteristic of GaAs solar cells at different values of thickness (a) for $In_{0.5}Ga_{0.5}P$ window layer, (b) for $Al_{0.2}Ga_{0.8}As$ window layer

For the cell with an $In_{0.5}Ga_{0.5}p$ window layer, we notice that the short circuit current J_{sc} and the efficiency η increases with the increased thickness value. An optimized thickness InGaP window layer of 0.1μm allowed us to obtain a maximum efficiency of 25 %. On the other hand, the efficiency and the short circuit current decreases by increasing the thickness of the $Al_{0.2}Ga_{0.8}As$ window layer, the maximum value of efficiency is 24.86% obtained for a thickness of 0.04 μm.



(a) *(b)*

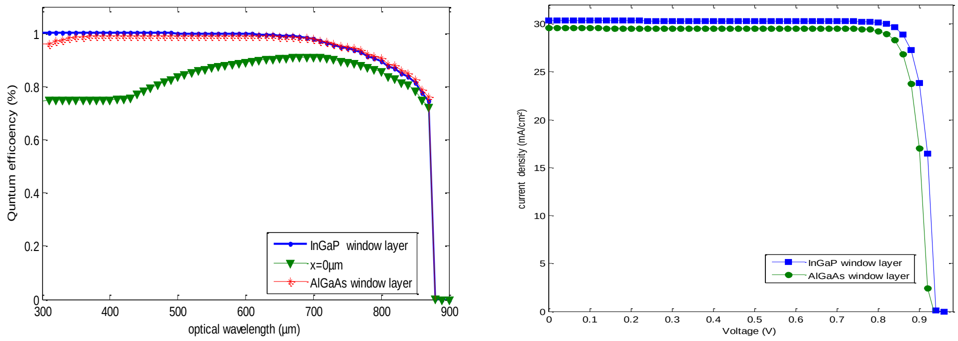
Fig. 3. (a) Current density and (b) Conversion efficiency of GaAs solar celsl at different values of thickness for $In_{0.5}Ga_{0.5}P$ window layer and $Al_{0.2}Ga_{0.8}As$ window layer

The photovoltaic parameters of each optimized cell are summarized in Comparative Table 2. Our simulations as can be seen in Table 2 are in good agreement with the experimental values reported in the literature [13,14], while a noticeable difference was assigned to resistive losses.

Table 2. Photovoltaic parameters of each optimized cell.

Photovoltaic parameters	GaAs solar cell with $In_{0.5}Ga_{0.5}P$ Window layer (x=0.1μm)	GaAs solar cell with $Al_{0.2}Ga_{0.8}As$ window layer (x=0.04μm)
$I_{sc}(mA)$	30.87	29.54
$V_{co}(V)$	0.96	0.95
FF(%)	87.40	87.36
η (%)	25	24.86

In order to make a comparison between the two window layers, the spectral response of the GaAs cells with the $In_{0.5}Ga_{0.5}P$ and $Al_{0.2}Ga_{0.8}As$ window layers and without window layers is traced. The response for optimum thicknesses of window layers is shown in Fig. 4 a. We note that the cell with $In_{0.5}Ga_{0.5}P$ window layer represents the best spectral response because of the good absorption of light in this layer, the $In_{0.5}Ga_{0.5}P$ can minimize recombination at the surface of the GaAs cell and make the solar cell sensitive to high energy photons. Fig. 4 b shows the comparative current-voltage characteristics of the two optimized solar cells, we can see that the InGaP window layer better affect the characteristic of GaAs solar cell then $Al_{0.2}Ga_{0.8}As$ layer.



(a) *(b)*

Fig. 4. (a) Spectral response of the tree GaAs cells (with $In_{0.5}Ga_{0.5}P$ window layer and $Al_{0.2}Ga_{0.8}As$ window layer and without window layer), (b) comparative electrical characteristics of optimized GaAs solar cells.

4.2. The doping window layer effect

Doping is one of the various parameters that can affect the functioning of the cell. After optimizing the thickness of the window layer, we studied the effect of the doping of the window layer on the performance of the cell by keeping the optimal thickness of each window layer.

The conversion efficiency in term of the doping is represented in Fig. 5, the efficiency of the cell with an $In_{0.5}Ga_{0.5}P$ window layer increases slightly with the doping up to a doping of 4.10^{18} and then becomes constant. In the cell with $Al_{0.2}Ga_{0.8}As$ window, the efficiency increases with the doping then undergone a decrease for a doping higher than 10^{18}. Because the effect of the series resistance is not taken into account in our simulation, the variation in conversion efficiency is not significant because the doping of the window layer can reduce the resistive losses.

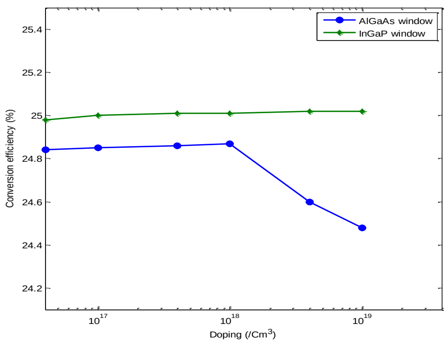


Fig. 5. Conversion efficiency of GaAs solar cells in term of doping of $In_{0.5}Ga_{0.5}P$ window layer and $Al_{0.2}Ga_{0.8}As$ window layer.

5. Conclusion

In this work we simulated GaAs thin-film cells using the 1D SCAPS one-dimensional programs. The GaAs cell performance is optimized using $In_{0.5}Ga_{0.5}P$ and $Al_{0.2}Ga_{0.8}As$ window layers. The structure of the cell and the material choice play an important role in the performance of the solar cell.

In this study a considerable improvement in the short-circuit current density and in the conversion efficiency with the introduction of the window layers was obtained. These window layers allowed to minimize the recombination speed and to reduce the series resistance. for the realization of the window layers, the InGaP material has excellent properties by providing AlGaAs material[15,16] it has no defects related to the incorporation of oxygen during its growth and has a low rate of recombination on the surface.

It has been found that the best performance is obtained for the $In_{0.5}Ga_{0.5}P$ layer cell with an optimum thickness of 0.1 µm and a doping value of 4.10^{18} (η = 25.02%), for a window layer of $Al_{0.8}Ga_{0.8}As$ the maximum of the efficiency is obtained for a thinner thickness (0.04µm) and a month doping of 10^{18} with a corresponding value of 24.87%.

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