# Numerical Study of the Impact of Junction Depth and the Surface Recombination Velocity on Electrical Parameters of GaAs-Solar Cell

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RESEARCH ARTICLE

# Numerical Study of the Impact of Junction Depth and the Surface Recombination Velocity on Electrical Parameters of GaAs-Solar Cell

**Abdelkader Baghdad Bey[1,2], Abbassia Talbi[2], Mourad Hebali[3*], Mohammed Berka[1,4], Frédérique Ducroquet[5]**

[1] *Department of electrical engineering, University of Mascara, 29000 Mascara, Algeria*
[2] *Laboratory AMEL, University of Sidi-Bel-Abbes, 22000 Sidi-Bel-Abbes, Algeria*
[3] *Department of Electrical Engineering, ENP Oran-MA, Laboratory CaSiCCe, 31000 Oran, Algeria*
[4] *Laboratory E.P.O, University of Sidi-Bel-Abbes, 22000 Sidi-Bel-Abbes, Algeria*
[5] *University of Grenoble Alpes, Grenoble INP, IMEP-LaHC, 38000 Grenoble, France*

**ABSTRACT:** Solar energy based on the solar cell is the most promising source among renewable energy sources. The photocurrent ($I_{ph}$), open circuit voltage ($V_{oc}$), maximum voltage ($V_m$), form factor (*FF*) and efficiency ($\eta$) of the solar cell are the most important parameters that can define the quality of this cell. In this work, we study the impact of the junction depth *Xj* and the surface recombination velocity *Sn* on these parameters in both external and internal cases of the solar cell in Arsenic gallium (*GaAs)* technology using the MATLAB software as a tool. Results show that in order to obtain high-performance of *GaAs*-solar cells must be the surface recombination velocity value is low, and the junction depth in submicron scale. Numerical results gave higher values of efficiencies 19.21 % and 30.1 % in external and internal cases respectively, and best electrical parameters of the *GaAs*-solar cell when the junction depth and the surface recombination velocity are equal to 0.2 µm and $10^2$ cm/s respectively.

**KEYWORDS:** Solar cell, GaAs, Efficiency, Electrical parameters.

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## 1. INTRODUCTION

Solar energy, which is available in most of the areas over the world, is the most promising supply of renewable energy sources [1]. This energy is virtually limitless which make it become an ideal energy source in theory. Photovoltaic (PV) is obtained by direct conversion of sunlight into electricity [2-4], by means of PV cells. This electricity has a potential interest in recent years in scientific and economic terms. This interest is due to the growing demand for energy in most industrial sectors, but also to environmental obligations. Photovoltaic cells are at the heart of the electricity production chain [5]. In the last years, The Gallium Arsenide (*GaAs*) is among the most important materials that have proven their worth in the manufacture of solar cells, because the efficiency of *GaAs*-solar cells has reached 29.1% under concentrated sun light [6]. This is what makes these cells are highly efficient devices.

Competition over optimizing and increasing the efficiency of solar cells, leads researchers to find numerical methods to determine the parameters of these cells as types of efficiency [7]. The efficiency is considered as the most important parameter of the solar cell in addition to the rest of the electrical parameters, so that this parameter defines the quality of the cell.

In this work, we studied the different electrical parameters of the solar cell in *GaAs* technology, according to the impact of two important technological parameters. To realize our study, we presented the structure of this cell, then on the basis of the different mathematical equations of the electrical parameters (the photocurrent ($I_{ph}$), open circuit voltage ($V_{oc}$), maximum voltage ($V_m$), form factor (*FF*) and efficiency ($\eta$)) of the *GaAs*-solar cell. We have calculated the impact of junction depth and the surface recombination on these parameters in both internal and external cases. We have also studied in the ranges of the junction depth *Xj* and the surface recombination velocity *Sn* ranging from *Xj* = 0.2 µm to 1 µm and ranging from $S_n$ = $10^2$ cm/s to $10^8$ cm/s respectively. In this study, we used MATLAB software as a calculation tool.

## 2. STRUCTURE OF GAAS-SOLAR CELL

Figures 1 and 2 show the structure of the *GaAs*-solar cell proposed in this study, according to the different views and this cell in the case of lighting respectively. The ohmic contact of the forehead is in the form of lines and fingers so that the electron is rapidly collected and for a large part of the incident wave penetrated into the solid. The surface of the end of the base is completely covered by an ohmic contact. Table 1 shows the different important dimensions of the structure of the *GaAs*-solar cell proposed.

***Corresponding Author:** *hebalimourad@yahoo.fr*
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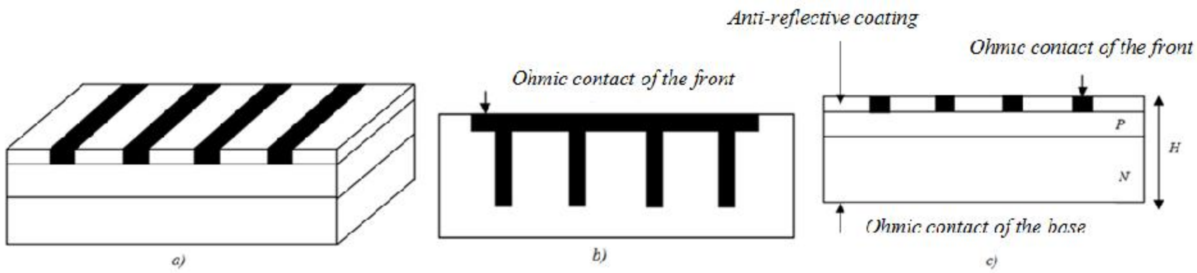


**Figure 1 Structure of the solar cell in, a) Perspective, b) View from above, c) View of section**

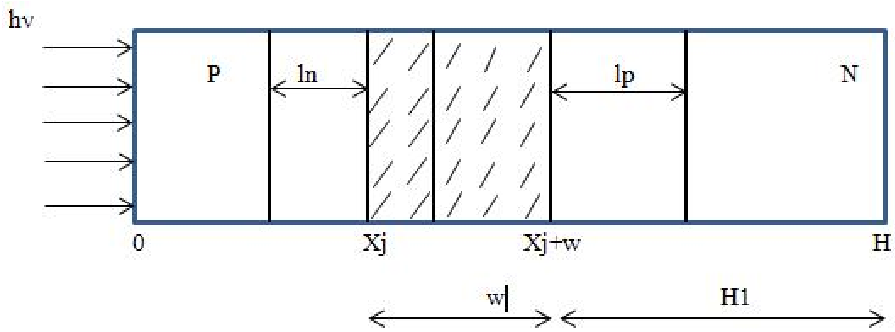


**Figure 2 Solar cell under illumination** [8]

**Table 1 Dimensions of the solar cell**

| Dimensions | Presentation | Values (µm) |
|---|---|---|
| *ln* | Electron diffusion length in the *P* region | 1.8 |
| *lp* | Hole diffusion length in region | 3.0 |
| *H* | Total cell width | 300 |
| *Xj* | Junction depth | 0.5 |
| *W* | Width of the space charge area | 0.09 |

## *3.* NUMERICAL METHOD

In the 1-D structure of the solar cell, the expressions for the electron and hole currents densities in the cases of *n/p* types base doping respectively and monochromatic illumination in light of absorption coefficient α are given by:

$$J_n = qD_n\frac{n_p}{dx} = \frac{qF(1-R)\alpha\, l_n}{\alpha^2 l_n^2 - 1}\left[\frac{\left(\frac{S_n\, l_n}{D_n} + \alpha\, l_n\right) - e^{-\alpha X_j}\left[\frac{S_n\, l_n}{D_n}ch\left(\frac{X_j}{l_n}\right) + sh\left(\frac{X_j}{l_n}\right)\right]}{\frac{S_n\, l_n}{D_n}.sh\left(\frac{X_j}{l_n}\right) + ch\left(\frac{X_j}{l_n}\right)} - \alpha\, l_n e^{-\alpha X_j}\right] \quad (1)$$

$$J_P = -qD_P \frac{P_n}{dx} = \frac{qF(1-R)}{\alpha^2 l_p^2 - 1} \alpha\, l_p e^{-\alpha(X_j+W)} \left[ \alpha\, l_p - \frac{\left(\frac{Sp\, l_p}{D_p}\right) - \left[ch\left(\frac{H_1}{l_p}\right) - e^{-\alpha H_1}\right] + sh\left(\frac{H_1}{l_p}\right) + \alpha\, l_p e^{-\alpha H_1}}{\frac{Sp\, l_p}{D_p} sh\left(\frac{H_1}{l_p}\right) + ch\left(\frac{H_1}{l_p}\right)} \right] \quad (2)$$

where $q$ the elementary charge, $Dn/Dp$ the electron/hole diffusion coefficient , $F$ the incident monochromatic photon flux density, $R$ is the reflection coefficient, α is the absorption coefficient, $S_n/S_p$ is the front surface recombination velocity and $ln/lp$ is the electron/ hole diffusion length.

$$J_{dr} = qF(1-R)(1-e^{-\alpha W})e^{-\alpha X_j} \quad (3)$$

The spectral response ($SR$) is defined as the ratio of the photocurrent density $J_t$ of the solar cell to the incident photon flux [9] and expressed as follows in internal and external cases:

$$SR_{in} = \frac{J_t}{qF(1-R)} \quad (4)$$

$$SR_{ext} = \frac{J_t}{qF} \quad (5)$$

Photocurrent density expression of the solar cell is given by equation (6):

$$I_{ph}(E) = qF(E).SR(E) \quad (6)$$

In the illuminated solar cell, the total current as a function of the different currents is given by [10-11]:

$$I = I_{ph} - I_D - I_{sh} \quad (7)$$

For a solar cell, the I-V characteristic is described by the Shockley equation as follows [11].

$$I = I_{ph} - I_s\left(e^{\frac{q\,V}{nK_BT}} - 1\right) - \frac{V - IR_s}{R_{sh}} \quad (8)$$

where, $I_{ph}$ is the photocurrent, $I_s$ is the saturation current of the diode, $V$ is the voltage on the terminals of the cell, $n$ is the ideality factor, $K_B$ is the Boltzmann constant and $T$ is the absolute temperature, $R_s$ is the series resistance and $R_{sh}$ is the shunt resistance.

$$I_{ph} = q\, A_a \int_0^{\infty} F(E)\, SR(E).\, dE \quad (9)$$

where $A_a$ is the active area of the cell (in this work $A_a$ =1 cm²).
The short-circuit current $I_{sc}$ of the solar cell is obtained by ($I_{sc} = I(V = 0)$) and assuming that $R_s$ is negligibly small; thus,

$$I_{sc} = I_{ph} \quad (10)$$

The saturation current of the P-N junction of the solar cell is given by the following expression [8-12]:

$$I_S = q\, S\left(\frac{D_p}{l_P}\, p_{N0} + \frac{D_n}{l_n}\, n_{P0}\right) \quad (11)$$

where $S$ is the surface of the P-N junction, $p_{N0}$ and $n_{P0}$ are the concentration of the minority carriers (holes and electrons) at the equilibrium in the $N$ and $P$ regions respectively.

The Open-Circuit Voltage is the voltage at which no current flows through the external circuit. It is the maximum voltage that a solar cell can deliver [13]. $V_{OC}$ depends on the short circuit current and the saturation current. Assuming that the net current is zero, this voltage can be calculated from equation (12):

$$Voc = A_0 \frac{KT}{q} ln\left(\frac{I_{SC}}{I_S} + 1\right) \quad (12)$$

where $A_0$ is the coefficient of ideality (in this work $A_0$=1).

The solar cell form factor is a function of the maximum voltage, the short circuit current, the saturation current and its expression is given by equation (13):

$$FF = V_m \left[ \frac{1 - \frac{I_S}{I_{SC}}\left(e^{\frac{qV_m}{A_0 KT}} - 1\right)}{\frac{A_0 KT}{q} Ln\left(\frac{I_{SC}}{I_S} + 1\right)} \right] \quad (13)$$

The incident solar power $P_{in}$ can be determined by the following formula:

$$P_{in} = A_t \int_0^{\infty} F(E).dE \quad (14)$$

where $A_t$ is the total area of the cell (in this work $A_t$ =1 cm$^2$).
The important parameter defining the photovoltaic effect in the solar cell is the efficiency of power conversion; this parameter may be presented as the efficiency of conversion of light energy into electrical energy. This parameter is given by the equation:

$$\eta = \frac{FF\ V_{OC} I_{ph}}{P_{in}} \quad (15)$$

## 4. RESULTS AND DISCUSSION

### *4.1 Impact of junction depth $X_j$*

To study the impact of the junction depth $X_j$ on the different parameters of the *GaAs* solar cell, we vary this depth from 0.2 µm to 1 µm at the surface recombination velocity $S_n$ = 10$^8$ cm/s. From numerical calculations, we obtained the results which are represented in the following figures:

The results obtained show that when the junction depth is increased, the photocurrent ($I_{ph}$) and the open circuit voltage ($V_{OC}$) are decreased in both internal and external cases as shown in Figures 3-a) and 3-b) respectively. However, the open circuit voltage ($V_{OC}$) is not affected by the variation of junction depth in the range between 0.4 µm and 0.8 µm. In addition, both the photocurrent ($I_{ph}$) and the open circuit voltage ($V_{OC}$) have the highest value in the internal case compared to the external case. The maximum voltage ($V_m$) is not affected by the variation in the junction depth in the ranges from 0.4 µm to 1 µm and from 0.6 µm to 1 µm for the internal and external cases respectively as shown in the Fig. 3-c). As for the form factor (*FF*), it is not systematically affected as a function of the junction depth in the internal case.

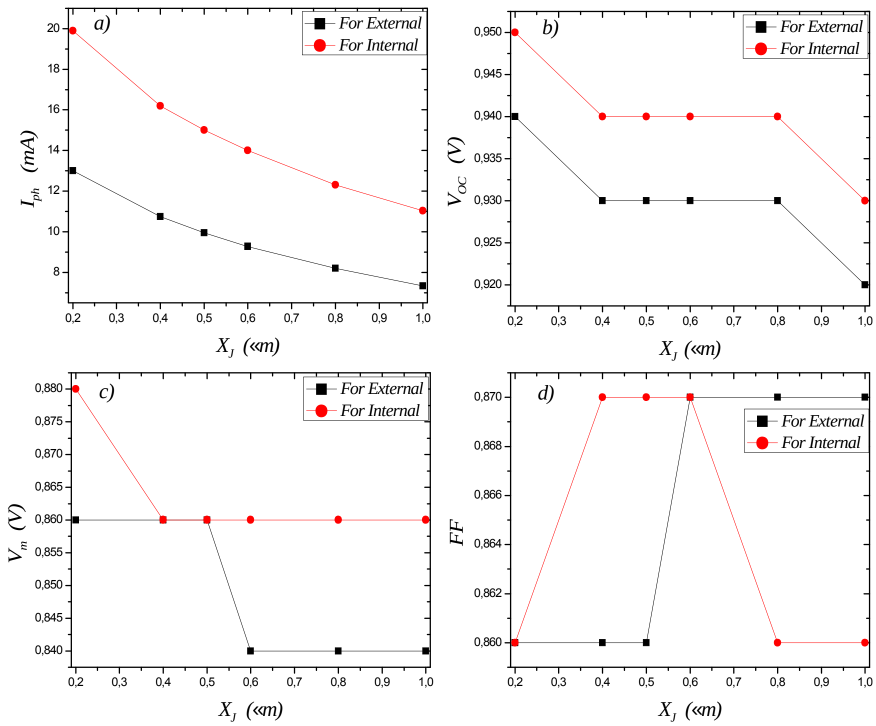


**Figure 3 Impact of junction depth on parameters, a) Photocurrent, b) Open circuit voltage, c) Maximum voltage, d) Form factor.**

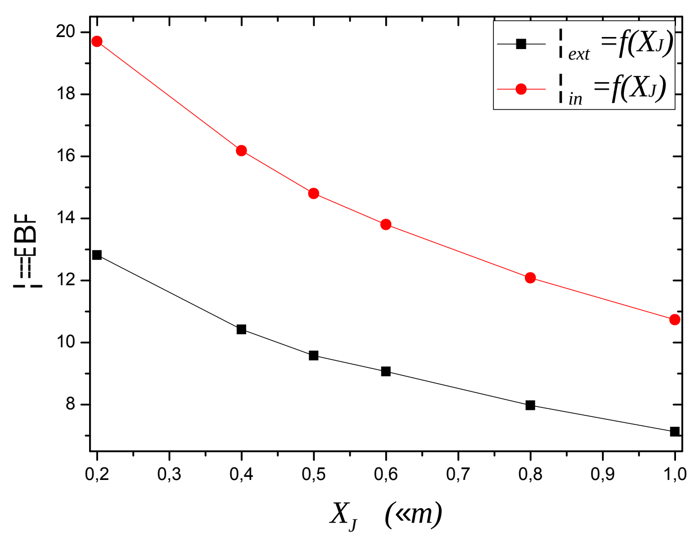


**Figure 4 Solar cell efficiencies as a function of the junction depth $X_J$**

Fig. 4 shows the evolution of the external $\eta_{ext}$ and internal $\eta_{in}$ efficiencies as a function of the junction depth $X_j$ at the surface recombination velocity $S_n$ = $10^8$ cm/s. The different types of efficiency are inversely proportional to the variation of the junction depth $X_j$. From this numerical simulation, our results of the evolution of the efficiencies as a function of the junction depth $X_j$ are very similar to the results that are present in the literature [1,14,15]. In addition, the internal efficiency is greater than the external efficiency for the different values of the junction depth $X_j$.
The numerical results of our work show that the external and internal efficiencies are characterized by better values in the case of the junction depth $X_j$ = 0.2 µm, for this we used this value to study the influence of the surface recombination velocity on the different parameters of *GaAs* solar cell. From these results, the front of the a solar cell must be thin enough to allow all created carriers to be collected so we must make a deep junction with $X_j$ low value.

### *4.2 Impact of surface recombination velocity Sn*

To study the impact of the surface recombination velocity $S_n$ on the different parameters of the *GaAs* solar cell, we varied the surface recombination velocity from $10^2$ cm /s to $10^8$ cm /s at the junction depth which is $X_j$ = 0.2 µm. The numerical results obtained are represented in the following figures:

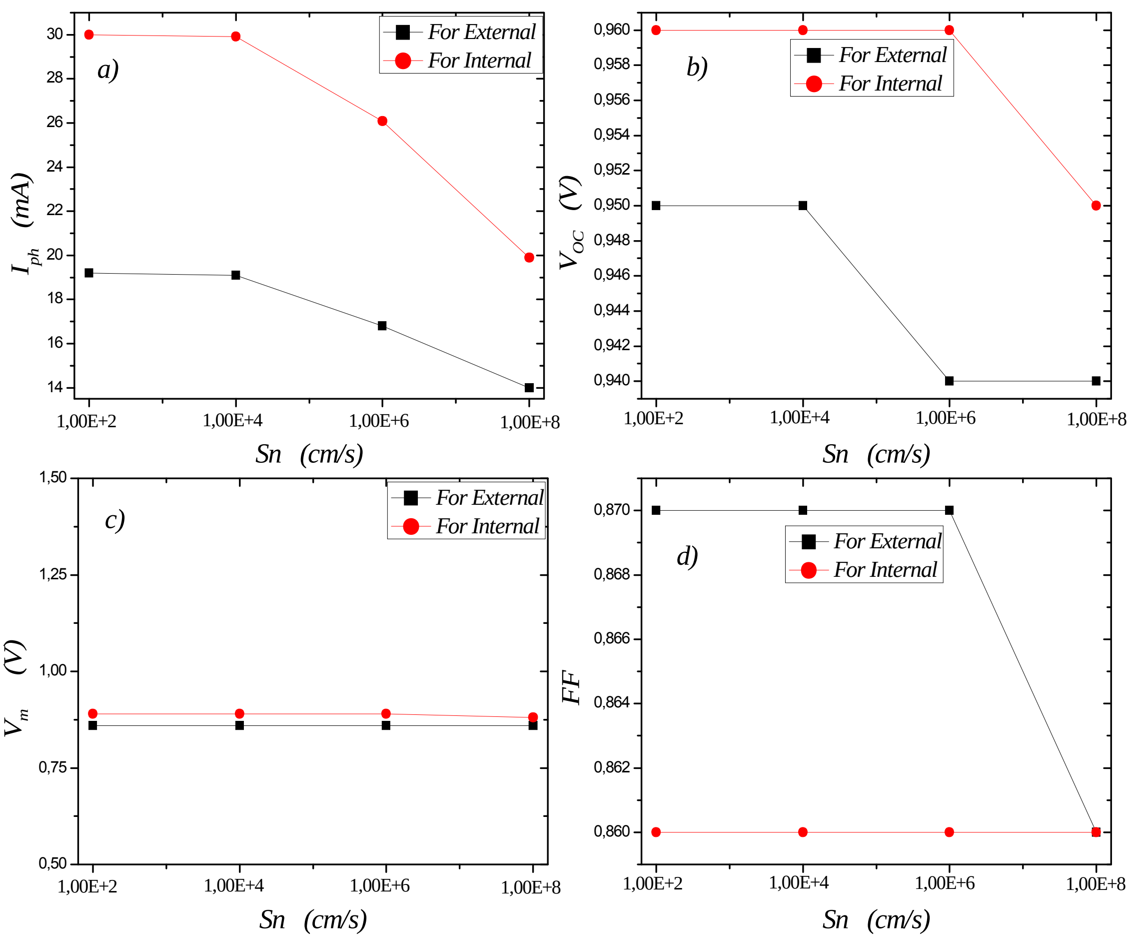


**Figure 5 Impact of surface recombination on parameters, a) Photocurrent, b) Open circuit voltage, c) Maximum voltage, d) Form factor.**

From the graphs that are shown in Fig. 5, we can see that when the surface recombination velocity is increased, the photocurrent ($I_{ph}$) and the open circuit voltage ($V_{OC}$) are decreased [12] in both internal and external cases, and form factor (*FF*) was decreased in external case. As for the maximum voltage ($V_m$) has not affected by the variation of the surface recombination velocity in both internal and external cases, as well as for form factor (*FF*) in internal case. In addition, the different electrical parameters of *GaAs*-solar cell in the internal case are characterized by large values compared to the external case, except for the form factor.

Fig. 6 shows the evolution of the external $\eta_{ext}$ and internal $\eta_{in}$ efficiencies as a function of the surface recombination velocity $S_n$. This figure shows that both types of efficiency decrease when the value of the surface recombination velocity $S_n$ increases; this is very similar to the results presented in the literature [15-18]. In addition, the internal efficiency value has small relative to the external efficiency value in the variation range of the surface recombination velocity.

The numerical results show that the different efficiencies are characterized by better values in the case of surface recombination velocity $S_n = 10^2$ *cm/s*. The ohmic contact of the front has well placed to reduce the rate of recombination on the surface, which gives us a good photocurrent for this value of the surface recombination velocity *Sn*.

The technological parameters must be chosen carefully, to find better values of electrical parameters of the *GaAs*-solar cell, in which the junction depth $Xj = 0.2\ \mu m$ and the surface recombination velocity $Sn = 10^2$ *cm/s.*

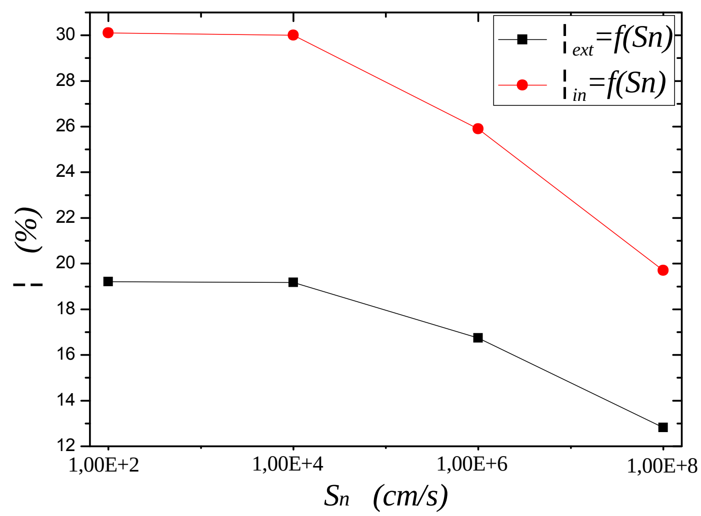


**Figure 6 Solar cell efficiencies as a function of surface recombination velocity $S_n$**

## 5. CONCLUSION

The impact of junction depth and the surface recombination velocity on electrical parameters of *GaAs*-solar cell are investigated in both internal and external cases using the MATLAB. The parameters of interest are photocurrent ($I_{ph}$), open circuit voltage ($V_{oc}$), maximum voltage ($V_m$), form factor (*FF*) and efficiency ($\eta$). The results obtained show that the different electrical parameters of the *GaAs*-solar cell are influenced by the variation of the junction depth and the surface recombination velocity in the two studied cases except some parameters has been presented in this work, and the different efficiencies are decreased according to the technological parameters thus indicated previously. This study has enabled us to propose the values of the technological parameters accurately to obtain a very high performance of *GaAs*-solar cells and has given us very satisfactory results in solar cell technology.

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