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INFLUENCE OF THE BASE DOPING RATE ON THE DIFFUSION AND ELECTRONIC PARAMETERS OF A SILICON PHOTOVOLTAIC CELL UNDER STRONG ILLUMINATION

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ABSTRACT

The characterization of the performance of a photovoltaic cell can be linked to factors intrinsic to this cell. It therefore seems necessary to identify the favourable or unfavourable conditions for the performance of photovoltaic cells. It is with this in mind that we think it is wise to study the influence of the base doping rate on the performance of a silicon PV cell under intense illumination of 50 suns. After a mathematical modelling of the PV cell considered and a few hypotheses formulated, the expressions of the diffusion parameters and the electronic parameters are established according to the doping rate of the database. Subsequently, we use digital processing to highlight the behaviours of these parameters according to the level of doping of the database. The results show that when the base doping rate increases, the diffusion and recombination parameters decrease. On the other hand, we see an increase in the density of load carriers when the doping rate of the base increases.

KEYWORDS: Base doping rate, diffusion parameters, recombination parameters, charge carrier density, strong illumination

1. INTRODUCTION

The The performance of a PV cell depends on internal factors such as grain size, recombination at the grain boundaries, base thickness, etc. This is because photovoltaic cell performance improves as grain size increases [1]. In addition, increasing the rate of recombination at the grain boundaries degrades the performance of photovoltaic cells [2]. Studies on the impact of base thickness on a photovoltaic cell under normal illumination show that increasing base thickness leads to lower performance [3]. Other studies show that external factors such as high temperatures and high-concentration lights also affect the performance of PV cells. Thus, high temperatures are unfavourable for the proper functioning of a photovoltaic cell [4, 5]. In addition, increasing the concentration of incident light improves the performance of a PV cell [6,7]. In order to continue the research on the characterization of photovoltaic cells, we are investigating the impact of the base doping rate on the performance of a photovoltaic cell under intense illumination of 50 suns.

2. MATHEMATICAL MODELING

In this study, we use a monofacial photovoltaic cell made of polycrystalline silicon and under illumination of 50 suns as shown in Figure 1 below:

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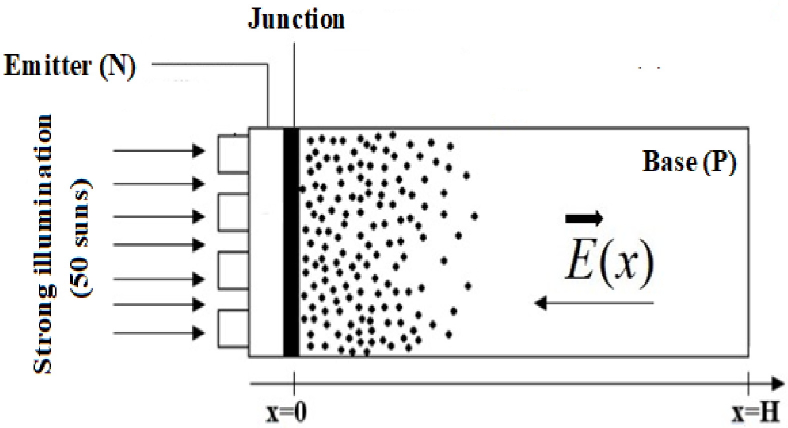

Figure 1: Modeling of the monofacial photovoltaic cell using polycrystalline silicon and under strong illumination

The study is made in one dimension; $\vec{E}(x)$ denotes the electric field of concentration gradient and its expression is [8]:

$$E(x) = \frac{D_n - D_p}{\mu_n + \mu_p} \frac{1}{\delta(x)} \frac{\partial \delta(x)}{\partial x} \qquad (1)$$

D_n , D_p , μ_n , μ_p are respectively the electron scattering coefficient, hole scattering coefficient, electron mobility and hole mobility.
$\delta(x)$ is the density of the photogenerated charge carriers at a position x in the base.

In addition, the diffusion coefficient and the lifetime of the electrons are a function of the doping rate of the base according to equations (5) and (6) below [9]: (2)

$$\tau_n = \frac{12}{1 + \frac{N_b}{5.10^{16}}} \qquad (3)$$

N_b being the doping rate of the base and V_T being the thermal voltage of photovoltaic cell.
The current density provided by the photovoltaic cell is a sum of a scattering current and a conduction current given by equation (4) below:

$$\vec{J_n} = qD_n \vec{\nabla}\delta - q\mu_n \vec{E}(x)\delta \qquad (4)$$

After replacing equation (1) in equation (4), we get:

$$J_n = qD_{np}(N_b)\frac{\partial \delta(x)}{dx} \quad \text{with} \quad D_{np}(N_b) = \frac{D_n\mu_p - D_p\mu_n + 2D_n\mu_n}{\mu_n + \mu_p} \qquad (5)$$

D_{np} is the overall scattering coefficient of the PV cell under intense illumination. On the other hand, we have:

$$D_n = \frac{k_B T}{q}\mu_n \quad \text{et} \quad D_p = \frac{k_B T}{q}\mu_p \qquad (6)$$

T is the temperature at which the photovoltaic cell operates and q is the elementary load.

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Because of the illumination mode, the photovoltaic cell operates at high temperature and we then assume that the temperature of the cell is T = 350 K. Indeed, for an operating temperature other than T_0 = 300K, the expressions of the mobilities are given by [10]:

$$\mu_n = \mu_{0n}\left(\frac{T}{T_0}\right)^{-1.5} \quad \text{et} \quad \mu_p = \mu_{0p}\left(\frac{T}{T_0}\right)^{-1.5} \tag{7}$$

with $\mu_{0n} = 1500 cm^2.V^{-1}.s^{-1}$; $\mu_{0p} = 475 cm^2.V^{-1}.s^{-1}$ et $T_0 = 300K$

$$\frac{\partial^2 \delta(x,N_b)}{\partial x^2} - \frac{1}{L_{np}^2(N_b)}\delta(x,N_B) = -\frac{C}{D_{np}(N_b)}\sum_{i=1}^{3} a_i e^{-b_i x} \tag{8}$$

C is the concentration of the incident light.

L_{np} is the overall diffusion length of the PV cell and is given by the following expression:

$$L_{np}^2(N_b) = \tau_n(N_b) D_{np}(N_b) \tag{9}$$

The coefficients a_i and b_i for the solar spectrum AM1.5 are given by [11]:

$$a_1 = 6.13.10^{20}\ ;\quad a_2 = 0.54.10^{20}\ ;\quad a_3 = 0.0991.10^{20}$$

$$b_1 = 6630\ ;\quad b_2 = 1000\ ;\quad b_3 = 130$$

The solution of differential equation (8) allows us to obtain the expression of the density of the carriers:

$$\delta(x,N_b) = A\cosh(\alpha x) + B\sinh(\alpha x) + \sum_{i=1}^{3} k_i e^{-b_i x} \tag{10}$$

$$\text{with} \quad \alpha = \frac{1}{L_{np}^2(N_b)} \quad \text{et} \quad k_i = \frac{C a_i}{D_{np}(N_b)(L_{np}^{-2} - b_i^2)} \tag{11}$$

The coefficients A and B are determined from the boundary conditions at the junction (x = 0) and at the back side of the base (x = H) [8].

According to the model of the PV cell used, the expressions for the recombination rates in the $S_B(N_b)$ base and at the $S_F(N_b)$ junction are given respectively by equations (12) and (13) below:

$$S_B(N_b) = D_{np}(N_b)\alpha \frac{\sum_{i=1}^{3} k_i(\alpha\sinh(\alpha H) + b_i\left[e^{-b_i H} - \cosh(\alpha H)\right])}{\sum_{i=1}^{3} k_i(\alpha\left[e^{-b_i H} - \cosh(\alpha H)\right] + b_i\sinh(\alpha H))} \tag{12}$$

$$S_F(N_b) = D_{np}(N_b)\alpha \frac{\sum_{i=1}^{3} k_i(\alpha\sinh(\alpha H) + b_i\cosh(\alpha H)\left[e^{-b_i H} - b_i\right])}{\sum_{i=1}^{3} k_i(\alpha - \left[\alpha\cosh(\alpha H) + b_i\sinh(\alpha H)\right]e^{-b_i H})} \tag{13}$$

In the rest of the work, we vary the doping rate from the base of the value 10^{15} atoms/cm^3 to the value 10^{17} atoms/cm^3 and we observe the behaviours of the diffusion parameters and the electronic parameters.

3. RESULTS AND DISCUSSION

1- Diffusion parameters

Electrons diffusion coefficient

The influence of the doping rate on the diffusion coefficient is illustrated in Figure 2:

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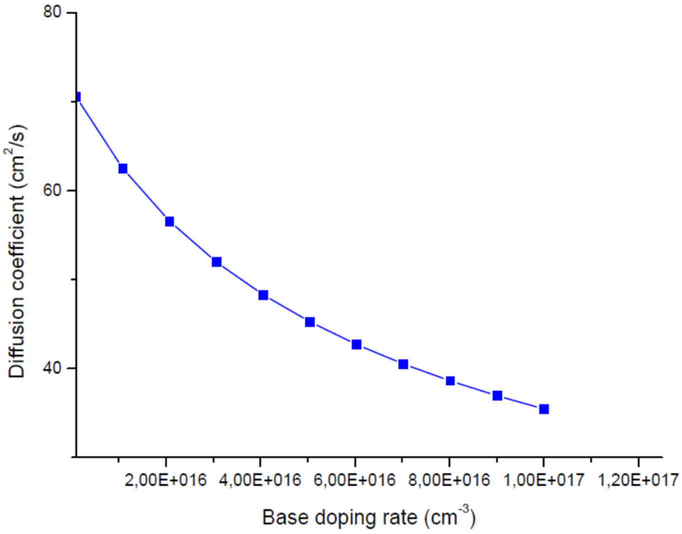

Figure 2*: *Variations of diffusion coefficient as a function of the doping rate of the base

The analysis in Figure 2 shows that the increase in the basic doping rate is accompanied by a decrease in the diffusion coefficient of the charge carriers. The decrease in the diffusion coefficient is explained by the fact that the increase in the doping rate leads to an increase in structural defects in the semiconductor material of the photovoltaic cell. This increases the possibility of blockage and collision of the charge carriers and consequently leads to a decrease in the diffusion coefficient.

Electron diffusion length

The evolution of the broadcast length as a function of the doping rate of the database is shown in the following Figure 3:

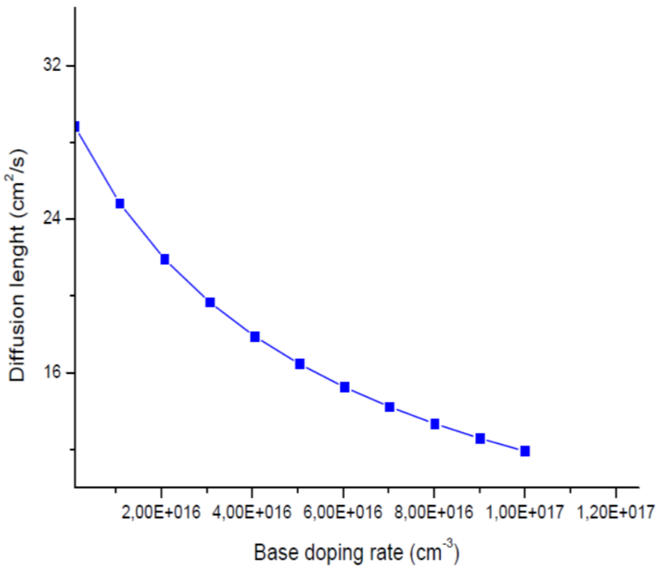

Figure 3*: *Variations of the diffusion length as a function of the base's doping rate

The analysis of the curve in Figure 3 shows that the diffusion length of the charge carriers decreases with the increase in the base doping rate. This result is in good agreement with that in Figure 2 above. Indeed, the diffusion

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length is proportional to the diffusion coefficient; A decrease in the diffusion coefficient then leads to a decrease in the scattering length of the electrons.

Electron mobility

The effect of the increase in the base doping rate on electron mobility is shown in Figure 4 below:

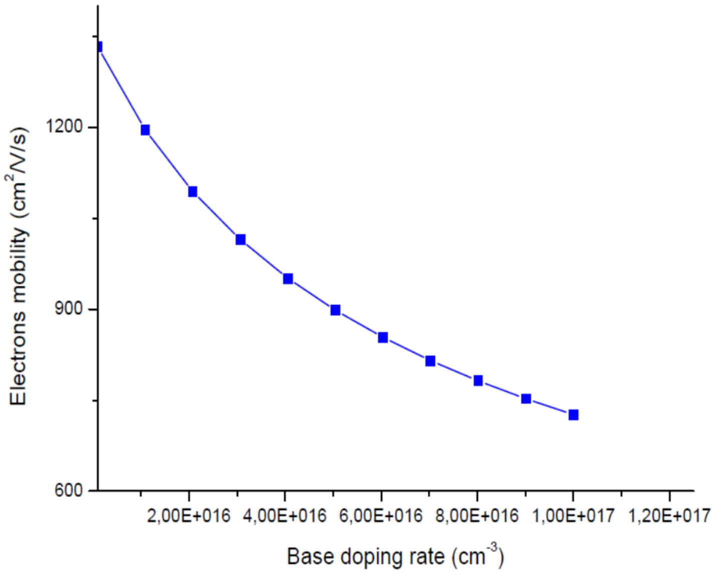

Figure 4: Variations of the electron mobility as a function of base doping rate

The analysis in Figure 4 shows that electron mobility decreases as the level of base doping increases. The decrease in electron mobility reflects a blockage of electrons in the base. Indeed, the increase in the doping rate improves the photogeneration of the charge carriers, but the sites of obstacles and blockages increase. These carriers therefore do not have enough space to move around due to their numbers and the increased possibility of collisions and blockages. Thus, the load carriers become less and less mobile in the base.

2- Electronic parameters

2.1- Charge carrier density

The variations in the density of carriers in short-circuit and open circuit situations, as a function of the doping rate of the base, are illustrated in figures 5 and 6 below, respectively:

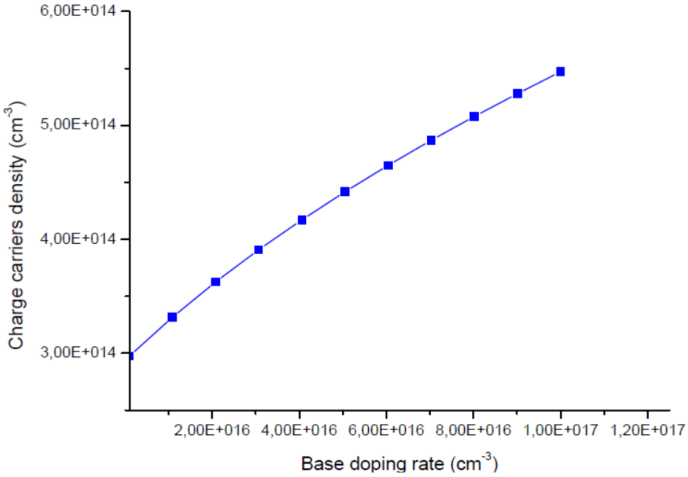

Figure 5*: Variations of the charge carriers density as a function of the base doping rate in short – circuit situation*

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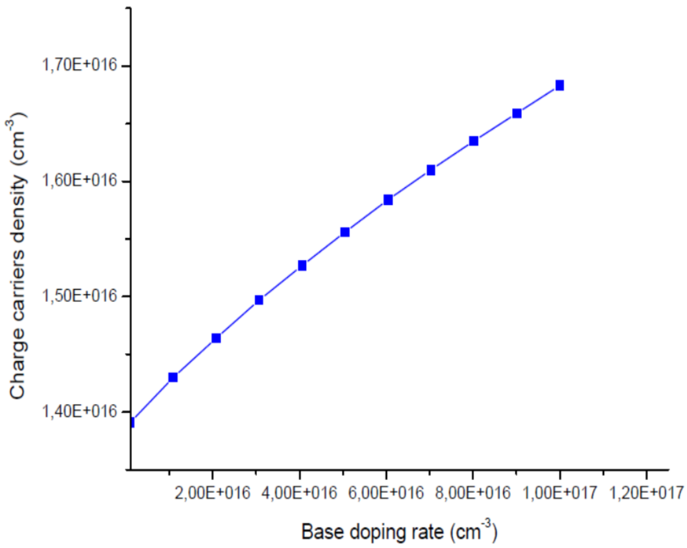

Figure 6*: Variations of the charge carriers density as a function of the base doping rate in open circuit situation*

The analysis of Figures 5 and 6 shows that the density of the charge carriers, both short-circuit and open-circuit, increases with increasing rate of doping of the base. This result is explained by the fact that base doping improves the electrical conductivity of the semiconductor material by reducing the energy gap required for an electron to pass from the valence band to the conduction band. Thus, with intense illumination, the number of photogenerated electrons in the base increases with the increase in the level of doping. In addition, we observe that, for a given doping rate, the density of charge carriers is higher in an open circuit situation. This is justified by the fact that, in an open circuit situation, the junction is blocked and the majority of the charge carriers are blocked in the base. This results in a higher density of charge carriers in an open circuit.

2.2- Recombination velocity in the base

The study of the impact of the doping rate on the behaviour of the recombination velocity in the base is presented in Figure 7:

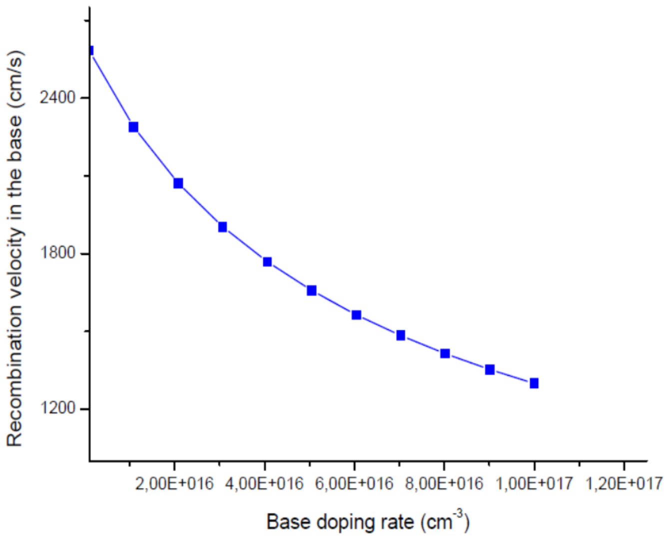

Figure 7: Variations of the recombination velocity in the base as a function of the doping rate

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The curve in Figure 7 shows that the recombination velocity in the base decreases as the level of doping increases. Indeed, the increase in the doping rate improves the photogeneration of the charge carriers and given the illumination mode, the number of charge carriers in the base becomes more and more important in relation to the losses of carriers. This manifests itself in the base as a decrease in recombinations. This result is in good agreement with those obtained on the density of charge carriers.

2.3- Dynamic velocity at junction

Figure 8 below shows the behaviour of the dynamic velocity at junction as a function of the base doping rate:

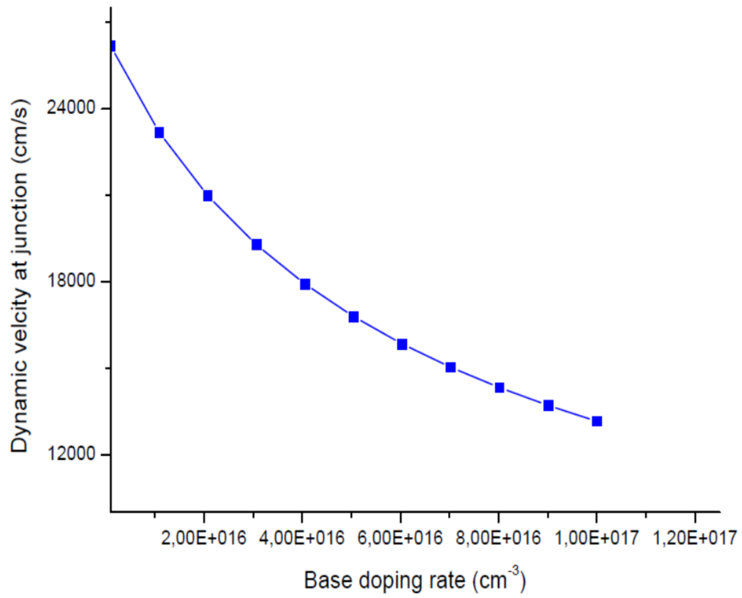

Figure 8: Variations of the dynamic velocity at junction as a function of the base doping rate

The analysis in Figure 8 shows that the dynamic velocity at junction decreases as the base doping rate increases. This result is interpreted by the fact that the diffusion of the charge carriers decreases with the increase in the rate of doping of the base, while the majority of photogenerated load carriers remain blocked in the base because of the structural defects caused by doping. Thus, the number of charge carriers capable of reaching the junction decreases. As a result, the dynamic velocity at junction decreases with the increase in the base doping rate.

4. CONCLUSION

This work allowed us to understand that the variation of the base doping rate influences the behavior of the diffusion parameters and the electronic parameters of a silicon photovoltaic cell and under intense illumination of 50 suns. From this study, it appears that the increase in the doping rate of the base is unfavourable to the diffusion and recombination parameters. However, we observe an improvement in the density of the load carriers when the base doping rate increases. In future work, our intention is to investigate the impact of the doping rate on the electrical parameters of the photovoltaic cell under high light concentration.

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