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EFFECT OF THE ELECTRIC FIELD ON THE DIFFERENT ELECTRICAL PARAMETERS OF A SOLAR CELL

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Abstract

In this article, we studied the influence of an external electric field applied in the base of a solar cell on its various electric parameters when it is illuminated by a monochromatic light. We have taken into account the actual values of intrinsic recombination velocities at the junction and the back face. This study revealed that when the electric field increases, the excess minority carrier density décreuses; on the other side, photocurrent, phototension, power, and capacitance increase with it. The application of the electric field in the base could improve the efficiency of the solar cell.

Keywords: *solar cell, recombination velocities, electric field, open-circuit, short-circuit*

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1. INTRODUCTION

Silicon is currently the most used material for making photovoltaic cells. These cells have a low efficiency hardly exceeding 20%.

The improvement of the solar cells efficiency requires necessarily the control of the various electric parameters. That is why, our group is interested in the effect of an external electric field on the different electrical parameters, in static mode, when the solar cell is illuminated by a monochromatic light.

A new approach involving both the intrinsic junction recombination velocity and the back side surface recombination velocity is used.

2. THEORY

2.1 Presentation of the Solar Cell

We consider an n^+-p silicon solar cell presented in figure 1

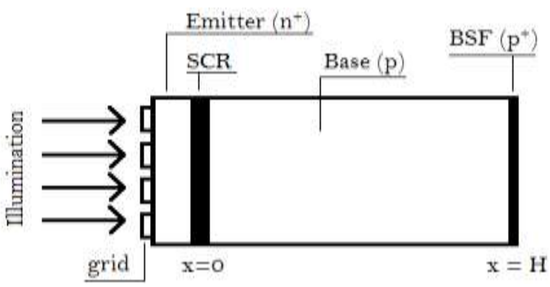

Fig 1: Schematic of a mono-facial n+-p silicon solar cell

H is the base thickness and SCR the space charge region

2.2 Excess Minority Carrier Density

The interaction between the front face of the solar cell and the monochromatic light leads to the creation of a pair electron-hole in the base where electrons correspond to the excess minority carriers. We give a brief description of these minority carriers generated in the base of the solar cell through the following equation[1]:

$$\frac{\partial^2 \delta(x)}{\partial x^2} + \frac{\mu_n E}{D}\frac{\partial \delta(x)}{\partial x} - \frac{\delta(x)}{L^2} = -\frac{G(x)}{D} \qquad \textbf{(1)}$$

Where $\delta(x)$ is excess minority carrier density in the base, L the excess minority carrier diffusion length, D the diffusion coefficient in the base, E the electric field and G(x) represents the minority carriers' generation rate in the base for monochromatic incident light. The expression of G(x) is given by

$$G(x) = \alpha(1-R)\phi_0 \exp(-\alpha x) \qquad \textbf{(2)}$$

α is the absorption coefficient associated to the wavelength, R is the reflexion coefficient and Φ_0 the incident photon flux.

The solution of the equation (1) can be written as follows:

$$\delta(x) = A.\exp(-\beta_n + \gamma_n)x + B.\exp(-(\beta_n + \gamma_n)x) + K\exp(-\alpha x) \qquad \textbf{(3)}$$

$$2\beta_n = \frac{\mu_n E}{D} \qquad \textbf{(4)}$$

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$$K = -\frac{\alpha L^2(1-R)\phi_0}{D(\alpha^2 L^2 - 2\beta_n \alpha L^2 - 1)} \quad \textbf{(5)}$$

$$\gamma_n = \frac{1}{2}\sqrt{4\beta_n^{\ 2} + \frac{4}{L^2}} \quad \textbf{(6)}$$

Coefficients A and B are determined sussing the boundaries conditions [2-6]:

At the emitter-base junction, x = 0:

$$D\frac{\partial\delta(x)}{\partial x}\bigg|_{x=0} = Sf \cdot \delta(0) \quad \textbf{(7)}$$

At the backside surface of the base, x = H:

$$D\frac{\partial\delta(x)}{\partial x}\bigg|_{x=H} = -Sb.\delta(H) \quad \textbf{(8)}$$

Equation **(7)** uses the concept of junction recombination velocity Sf that describes how the minority carrier flows through the junction. Sf can be written as follow [4- 8]:

$$Sf = Sf(j) + Sf_0 \quad \textbf{(9)}$$

Where Sf_0 is the intrinsic junction recombination velocity related to the shunt resistance. Sf (j) is related to the external load and quantifies how excess carriers flow through the junction in a real operating condition.

Sb is the minority carrier recombination velocity at the backside surface. It is related to the rate at which the excess minority carriers are lost in the back side surface of the cell.

We obtained:

$$A = K\frac{F_1(\gamma_n D + \beta_n D + Sf)\exp(-\alpha H) - F_2(\gamma_n D + \beta_n D - Sb)\exp(-(\gamma_n + \beta_n)H)}{2.\exp(-\beta_n H)\{\Psi_n.sh(\gamma_n H) + D.\gamma_n(Sb+Sf).ch(\gamma_n H)\}}$$

(10)

And

$$B = K\frac{F_1(\gamma_n D - \beta_n D - Sf)\exp(-\alpha H) - F_2(\gamma_n D - \beta_n D + Sb)\exp((\gamma_n - \beta_n)H)}{2.\exp(-\beta_n H)\{\Psi_n.sh(\gamma_n H) + D.\gamma_n(Sb+Sf).ch(\gamma_n H)\}}$$

(11)

$$F_1 = \alpha.D - Sb \quad \textbf{(12)}$$

$$F_2 = \alpha.D + Sf \quad \textbf{(13)}$$

$$\Psi_n = \gamma_n^{\ 2}.D^2 - \beta_n^{\ 2}.D^2 + \beta_n.D.Sb - \beta_n DSf + Sf.Sb \quad \textbf{(14)}$$

2.3 Photocurrent Density

The photocurrent density of solar cell is obtained from the excess minority carrier density and calculated by using the relation below [9]**:**

$$J_{ph} = q\cdot\left[D\cdot\frac{\partial\delta(x)}{\partial x}\bigg|_{x=0} + \mu\cdot \mathrm{E}\cdot\delta(0)\right] \quad \textbf{(15)}$$

At the junction, x = 0:

$$D\frac{\partial\delta(x)}{\partial x}\bigg|_{x=0} = Sf\cdot\delta(0)$$

$$J_{ph}(Sf) = q\cdot[Sf + \mu_n\cdot \mathrm{E}]\delta(0) \quad \textbf{(16)}$$

2.4 Determination of the Recombination Parameters

When $Sf(j) \geq 10^6 cm/s$, the photocurrent density tends to its maximum value which is the short-circuit-current .Thus, we have the relationship [2, 3]:

$$\frac{\partial J_{PH}}{\partial Sf}\bigg|_{Sf\geq 10^6 cm.s^{-1}} = 0 \quad \textbf{(17)}$$

The resolution of the equation (17) gives the effective value of the back side surface recombination velocity Sb_{eff} which is expressed as follows:

$$Sb_{eff} = D\frac{\alpha.\gamma_n.e^{(\beta_n-\alpha)H} + (\gamma_n^{\ 2} - \beta_n^{\ 2} + \alpha.\beta_n)sh(\gamma_n.H) - \alpha.\gamma_n.ch(\gamma_n.H)}{(\alpha-\beta_n)sh(\gamma_n.H) - \gamma_n.ch(\gamma_n.H) + \gamma_n e^{(\beta_n-\alpha)H}}$$

(18)

The intrinsic junction recombination velocity (Sf_0) is determined by setting, $Sb=10^m$ (m≥0). When we plotted the photocurrent density versus Sb, we then realized that it is minimal and constant for $Sb \geq 10^6 cm/s$ as shown in. We then set the relation [2,3]:

$$\frac{\partial J_{PH}}{\partial Sb}\bigg|_{Sb\geq 10^6 cm.s^{-1}} = 0 \quad \textbf{(19)}$$

We determine the intrinsic junction recombination velocities (Sf_0):

$$Sf0 = \frac{D}{L}\frac{\alpha\cdot L - \left(\sinh\left(\frac{H}{L}\right) + \alpha\cdot L\cosh\left(\frac{H}{L}\right)\right)\cdot e^{-\alpha H}}{1 - \left(\cosh\left(\frac{H}{L}\right) + \alpha\cdot L\sinh\left(\frac{H}{L}\right)\right)e^{-\alpha H}}$$

(20)

2.5 Photovoltage

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The photovoltage of the solar cell is given by Boltzmann's relation:

$$Vph(Sf) = V_T . \ln\left(\frac{\delta(0,Sf)Nb}{n_i^2} + 1\right) \quad \textbf{(21)}$$

Where Nb is the base doping density, $n_i$the intrinsic carriers density and V_T is the thermal voltage

2.6 Solar Cell Electric Power

The electric power delivered by the solar cell base to an external load circuit is expressed by the following relation

$$P(Sf) = I(Sf).V_{ph}(Sf) \quad \textbf{(22)}$$

With

$$I(Sf) = q.Sf(j).\delta(0) \quad \textbf{(23)}$$

$I(Sf)$ is the photocurrent that crosses the external load resistance.

2.7 Diffusion Capacitance of the Solar Cell

The diffusion of the capacitance, which originates from the transport of excess minority carriers in the base of the cell, can be expressed after calculating

$$C = \frac{q.n_i^2}{V_T Nb} \exp\left(\frac{V_{pH}}{V_T}\right) \textbf{(24)}$$

3. RESULTS AND DISCUSSION

3.1 Electric Field Effect on the Backside Surface Recombination Velocity

We present in figure**2**, the backside surface recombination velocity versus electric field

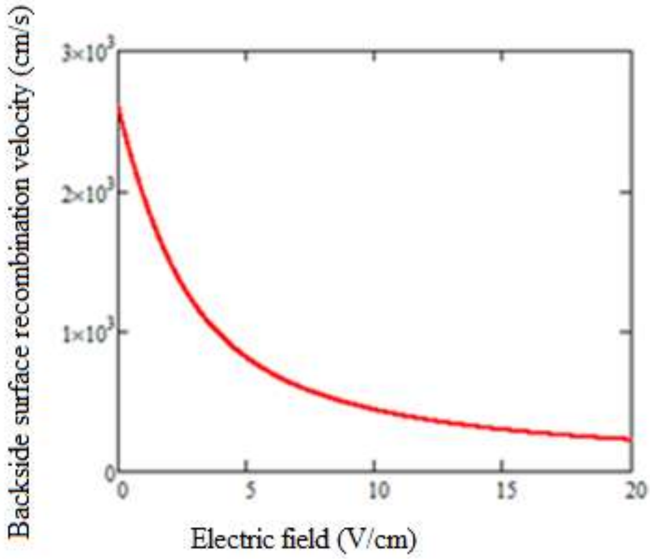

Fig 2: Backside Surface Recombination velocity (Sb) versus electric field (E) ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2 s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

We note in figure 2when the electric field increases, the backside recombination velocity decreases. The electric field reduces the losses in the load carrier in the rear area and improves the BSF effect.

3.2 Electric Field Effect on the Minority Density Carrier Charge

In fig 3 and fig 4, we present the profile of the minority density carrier charge carriers in the base of the solar cell in a situation of open-circuit $(Sf(j) = 0)$ and short-circuit $(Sf(j) \to \infty)$ respectively. These curves highlight the influence or not of electric field.

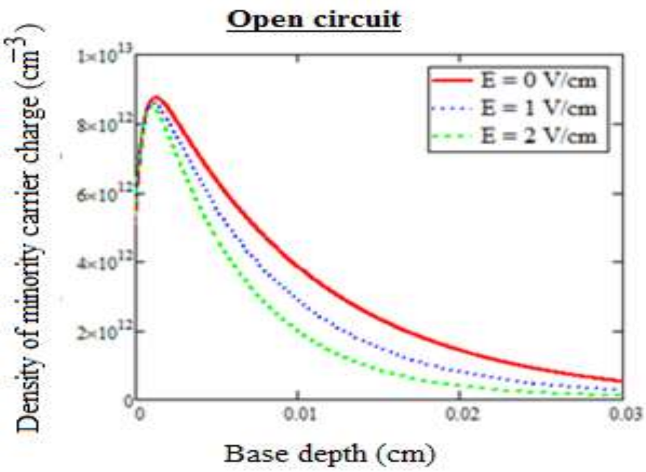

Fig 3: Open circuit minority carrier density versus the base depth for different values of the electric field. ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2 s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

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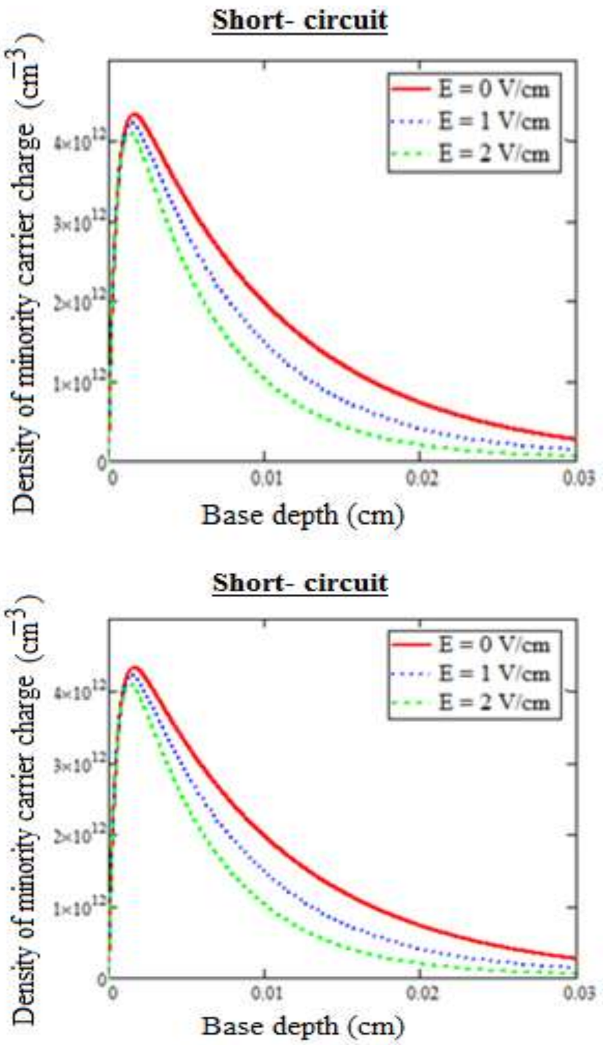

Fig 4: Short circuit minority carrier density versus the base depth for different values of the electric field. ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2 s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

The junction recombination velocity determines the operating point of circuit: open-circuit and short-circuit.

In open-circuit, there is storage of the carriers at the junction and the gradient of the density of the excess minority carrier is positive. This shows the presence of a current leakage due to Sf0.

While in short-circuit, there is no storage of the carriers at the junction and the gradient of the density of excess minority carriers is positive. The excess minority carrier goes through the junction and then participates in the photocurrent.

In open-circuit and in short-circuit, when the electric field increases, the density of minority carriers decreases. The electric field accelerates the excess minority carrier through the junction and reduces the density of minority carrier.

3.3 Electric Field Effect of the Photocurrent Density

In fig 5 we plotted the photocurrent density versus the junction recombination velocity (Sf) for different values of the electric field.

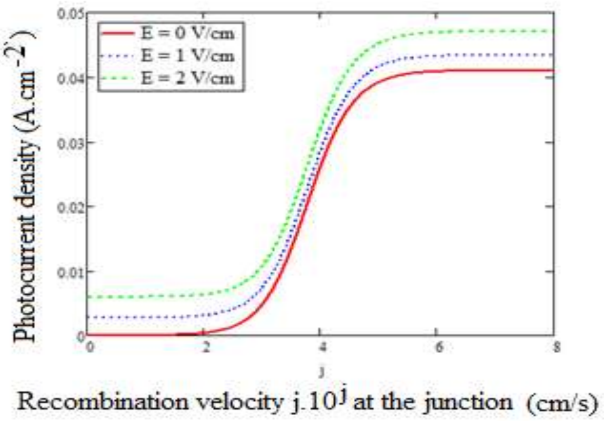

Fig 5: Photocurrent density versus junction recombination velocity (Sf) for different values of the electric field ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2 s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

For low values at the junction recombination velocity, the photocurrent density is minimal and constant. Then it increases versus junction recombination velocity. In short-circuit, When $Sf(j) \geq 10^6 cm/s$, the photocurrent density is maximum and constant. Sf(j) plays the pump electron role from the base to the junction. When Sf(j) increases, the number of excess minorities' carriers that crosses the junction increases therefore the photocurrent density increases.

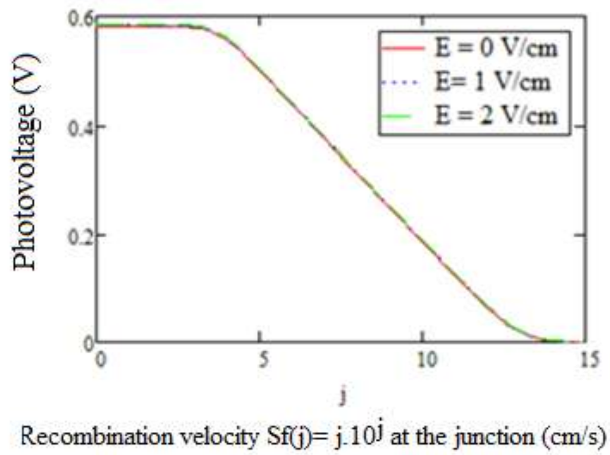

Fig 6: Photovoltage versus junction recombination velocity (Sf) for different values of the electric field ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2 s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

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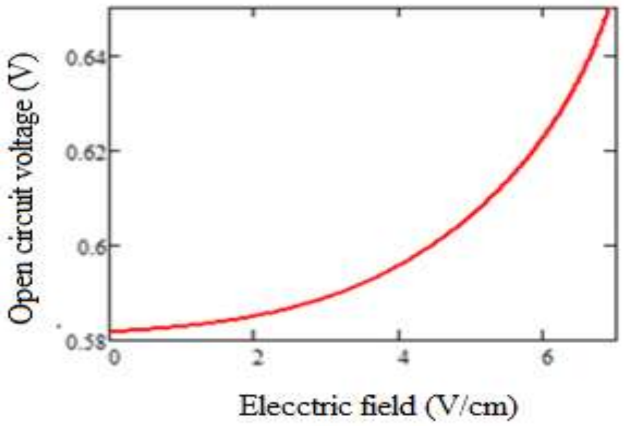

Fig 7: Open circuit photovoltage versus of electric field ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

For low values at the junction recombination velocity, the photovoltage is maximal and constant: there is storage of the carriers at the junction. Therefore it decreases when the recombination velocity at the junction increases.

The fig 7 shows, when the electric field increases, the open-circuit photovoltage increases.

3.4 Electric Field Effect of the Power

In fig 8, we plotted the power versus the junction recombination velocity (Sf) for different values of the electric field.

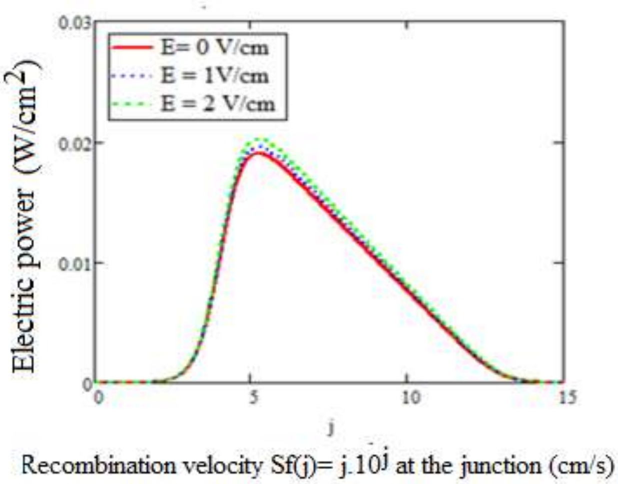

Fig 8: Power versus junction recombination velocity (Sf) for different values of the electric field ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

The figure shows that the electric power is equal to zero for low values at the junction recombination velocity (In open-circuit). Then it increases to reach its maximum value before decreasing linearly. The power is maximum for an intermediate operating point therefore it is undoubtedly interesting to place oneself on this point to make the most of the energy.

We also note when the electric field increases, the power increases. This is explained by the fact that as the electric field increases, the photocurrent and the photo-voltage increase therefore the electric power increases.

3.5 Electric Field Effect on the Diffusion Capacitance

In fig 9, we plotted the diffusion capacitance versus the junction recombination velocity (Sf) for different values of the electric field.

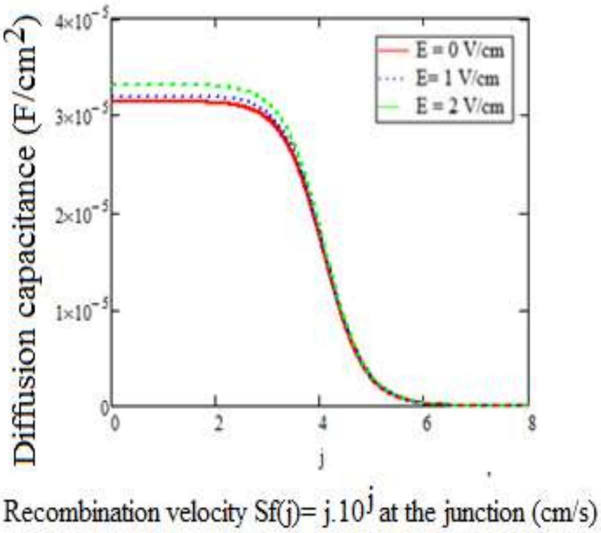

Fig 9: Diffusion capacitance versus junction recombination velocity (Sf) for different values of the electric field ($\lambda = 0{,}7\ \mu m, D = 26\ cm^2s^{-1}, L = 0{,}01 cm, H = 0{,}03\ cm$)

The fig 9 shows that the diffusion capacitance of the solar cell decreases when the junction recombination velocity increases. In open-circuit (low value of Sf), the diffusion capacitance is maximum because the electrons are stored in the junction. But, when the junction recombination velocity increases, the electrons cross the junction resulting in the reduction of the capacitance.

We also note that when the electric field increases, the diffusion capacitance increases.

4. CONCLUSION

In this paper, we dealt with the effect of electric field applied in the base of a solar cell on its various electric parameters when it is illuminated by a monochromatic light. The study showed that the presence of the electric field reduces the recombination at the back side and it has no effect on the recombination velocity at the junction. The study also showed that the presence of an electric field increases the photocurrent, the photovoltage, the electric power and the diffusion capacitance. Therefore, the application of the electric field in the base could improve the efficiency of the solar cell.

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