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WAVELENGTH'S EFFECTS ON RECOMBINATION VELOCITIES AND ON DIFFUSION CAPACITANCE EFFICIENCY

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Abstract

We present in this paper, the wavelength effect on the space charge's extension region width corresponding to the open circuit and short-circuit real operating points of when the silicon solar cell illuminated by a monochromatic light. In this study, we have taken into account the intrinsic recombination velocity (Sf0) at the junction and the back side surface recombination velocity (Sb). It is showed that these two velocities, Sf0 and Sb, depend on the wavelength absorption coefficient. The efficiency of the solar cell's junction capacity with the wavelength is then studied by using the extension of space charge region width's model.

Keywords: *- Solar cell, recombination velocities, wavelength, space charge region*

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1. INTRODUCTION

The mono-facial silicon solar cell under constant monochromatic light has a space charge region which could be considered as a plane capacitor that is proportional to the area S and inversely proportional to the extension of the space charge region width [1]. This extension of the solar cell's junction space charge region width is a very important parameter for the generation of the photocurrent and depends on the junction recombination velocity. Our group has a long-standing interest in the study of the wavelength effect on the extension region width and on the efficiency of the solar cell's junction capacitance.

A new approach involving both the intrinsic junction recombination velocity and the back side surface recombination velocity, is used. This allows us to determinate the extension of the space charge region width and the solar cell's junction capacitance efficiency.

2. THEORY

2.1 Presentation of the Solar Cell

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

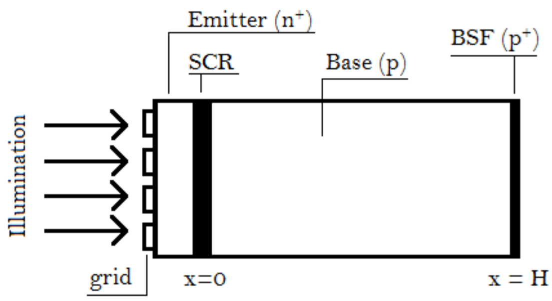

Fig 1: Schematic of a mono-facial n+-p silicon solar cell

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 by the following equation [2]:

$$\frac{\partial^2 \delta(x)}{\partial x^2} - \frac{\delta(x)}{L^2} = -\frac{G(x)}{D} \quad \textbf{(1)}$$

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 and G(x) represents the minority carrier's generation rate in the base for monochromatic incident light. The expression of G(x) is given by

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

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

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

$$\delta(x) = \left[A.\cosh\left(\frac{x}{L}\right) + B.\sinh\left(\frac{x}{L}\right) - \frac{\alpha(1-R)\phi_0.L^2}{D.(\alpha^2 L^2 - 1)} \exp(-\alpha x) \right] \quad \textbf{(3)}$$

Coefficients A and B are determined sussing the boundaries conditions [3-8]:

-At the emitter-base junction (x= 0):

$$D\left.\frac{\partial \delta(x)}{\partial x}\right|_{x=0} = Sf \cdot \delta(0) \quad \textbf{(4)}$$

-At the backside surface of the base (x = H):

$$D\left.\frac{\partial \delta(x)}{\partial x}\right|_{x=H} = -Sb.\delta(H) \quad \textbf{(5)}$$

Equation **(4)** uses the concept of junction recombination velocity Sf that describes how the minority carrier flow through the junction [5, 7, 9]. Sf can be written as [5, 7, 9]:

$$Sf = Sf(j) + Sf_0 \quad \textbf{(6)}$$

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:

$$A = \frac{\alpha(1-R)\phi_0 L^3 \left\{ D(Sb - \alpha D)\exp(-\alpha H) + (Sf + \alpha D)\left(D.\cosh\left(\frac{H}{L}\right) + L.Sb.\sinh\left(\frac{H}{L}\right)\right)\right\}}{D(\alpha^2.L^2 - 1)\left\{ L.D(Sb + Sf)\cosh\left(\frac{H}{L}\right) + (L^2 Sb.Sf + D^2)\sinh\left(\frac{H}{L}\right)\right\}}$$

(7)

And

$$B = \frac{\alpha(1-R)\phi_0 L^3 \left\{ L.Sf(Sb - \alpha D)\exp(-\alpha H) - (Sf + \alpha D)\left(D.\sinh\left(\frac{H}{L}\right) + L.Sb.\cosh\left(\frac{H}{L}\right)\right)\right\}}{D(\alpha^2.L^2 - 1)\left\{ L.D(Sb + Sf)\cosh\left(\frac{H}{L}\right) + (L^2 Sb.Sf + D^2)\sinh\left(\frac{H}{L}\right)\right\}}$$

(8)

2.3 Photocurrent Density

The solar cell's photocurrent density is obtained from the excess minority carrier density and calculated using the relation [10]:

$$J_{PH} = qD\left.\frac{\partial \delta(x)}{\partial x}\right|_{x=0} \quad \textbf{(9)}$$

2.4. Recombination Parameter's Determination

When $Sf(j) \geq 10^5\, cm/s$, the photocurrent density tends to its maximum value which is the short-circuit-current [3, 4].Thus, we have the relationship [3,4]:

$$\left.\frac{\partial J_{PH}}{\partial Sf}\right|_{Sf \geq 10^5 cm.s^{-1}} = 0 \quad \textbf{(10)}$$

The resolution of the equation **(10)** gives the effective value of the back side surface recombination velocity Sb_{eff} which is expressed as:

$$Sb_{eff} = \frac{D}{L} \frac{\alpha \cdot L \cdot e^{-\alpha H} - \alpha \cdot L \cdot \cosh\left(\frac{H}{L}\right) + \sinh\left(\frac{H}{L}\right)}{\cosh\left(\frac{H}{L}\right) - \alpha \cdot L \cdot \sinh\left(\frac{H}{L}\right) - e^{-\alpha H}} \quad \textbf{(11)}$$

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 thenremarked that it is minimal and constant for $Sb \geq 10^5\, cm/s$ as shown in [3, 4]. We then set the relation [3, 4]:

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$$\left.\frac{\partial J_{PH}}{\partial Sb}\right|_{Sb \geq 10^5 cm.s^{-1}} = 0 \quad \textbf{(12)}$$

We determine the intrinsic junction recombination velocities (Sf_0):

$$Sf_0 = \frac{D}{L} \frac{\alpha \cdot L - \left(\sinh\left(\frac{H}{L}\right) + \alpha \cdot L\cosh\left(\frac{H}{L}\right)\right) \cdot e^{-\alpha H}}{1 - \left(\cosh\left(\frac{H}{L}\right) + \alpha \cdot L\sinh\left(\frac{H}{L}\right)\right) e^{-\alpha H}} \quad \textbf{(13)}$$

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3. RESULTS AND DISCUSSION

3.1 Profile of the Intrinsic Junction Recombination Velocity versus the Wavelength

We present in figure 2, the profile of junction intrinsic recombination velocity versus wavelength (λ).

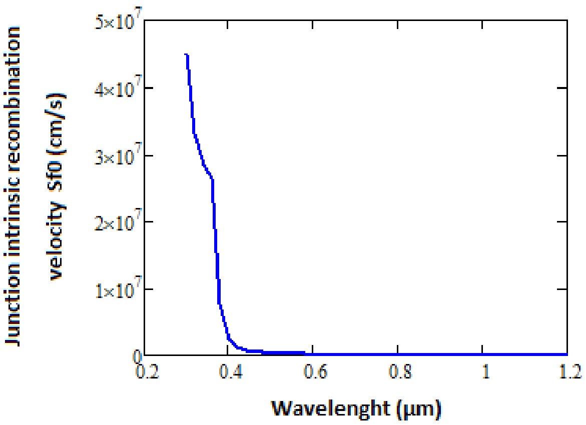

Fig 2: Intrinsic Junction recombination velocity (Sf0) versus wavelength (λ)

$$(D = 26cm^2 / s, L = 0.015cm, H = 0.003cm)$$

We noted in figure**2** that an increase of the wavelength results in a decrease of the intrinsic junction recombination velocity (Sf0) corresponding to the decrease of the losses at the junction.

In the range of the short wavelengths, the excess minorities' carriers are generated in the base near the junction, increasing the recombination at the junction. While in the range of the long wavelength, when the wavelength increases, the absorption coefficient decreases, the excess minorities' carriers are generated in the base, in depth, far from the junction, reducing the recombination at the junction.

3.2 Profile of the Backside Surface Recombination Velocity versus Wavelength

We present in figure**3**, the back side surface recombination velocity (Sb) versus wavelength (λ).

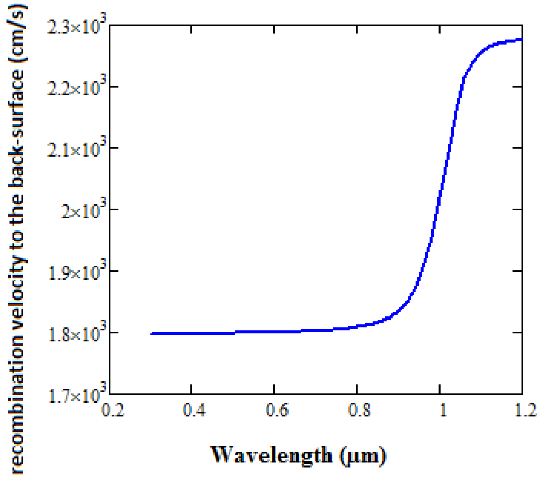

Fig 3: Back side-surface recombination velocity (Sb) versus wavelength (λ)

$$(D = 26cm^2 / s, L = 0.015cm, H = 0.003cm)$$

We remarked in figure**3** that Sb is minimal and constant in the range of short wavelengths corresponding to less recombination on the backside of the solar cell.

In the range of long wavelengths, Sb increases with wavelength because the electrons are generated in the base near the backside surface leading to a raise of the recombination velocity.

3.3 Profile of the Minority Density Carrier Charge versus Base Depth

In figure**4** and **5**, we present the profile of the excess minority densities in the base of the solar cell in two real operating conditions corresponding the open-circuit $(Sf(j) = 0)$ and short-circuit $(Sf(j) \to \infty)$ respectively. These curves highlight the influence of the wavelength.

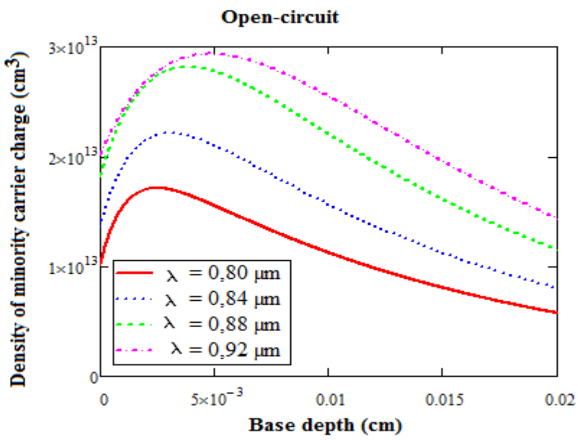

Fig 4: Open circuit excess minority carrier densities versus the base depth for different values of the wavelength

$$(D = 26cm^2 / s, L = 0.015cm, H = 0.003cm)$$

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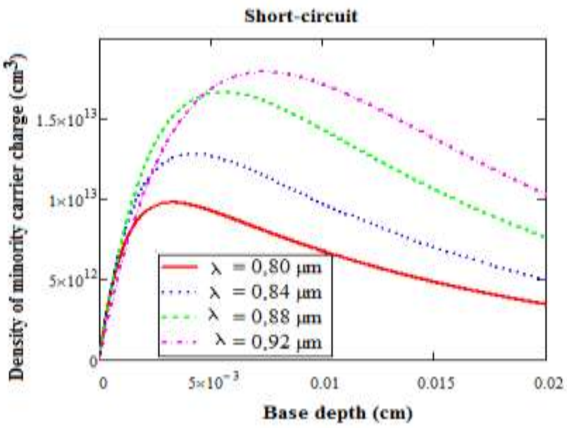

Fig 5: Short-circuit excess minority carrier's densities versus the base depth for different values of the wavelength $(D = 26cm^2/s, L = 0.015cm, H = 0.003cm)$

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

In open circuit, for low values of the junction recombination velocity there is storage of the carriers at the junction and the gradient of the excess minority carrier's density is positive. This shows the presence of a current leakage due to Sf0.

While in short circuit, for high values at the junction recombination velocity (figure**5**), 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.

We note that the carrier density in open circuit (low value Sf) is more important in short circuit (high value Sf): this is explained by the role played by the junction recombination velocity. When Sf increases, the electrons passing through the junction increase, causing a decrease of the carriers density.

In both conditions, the increase of wavelength leads to an increase of the density of minority carrier's and the maximum of the density moves in depth from the base. This is explained by an enlargement of the space charge region.

3.4 Diffusion Capacitance of the Solar Cell

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

$$C = \frac{q.n_0}{V_T}\exp\left(\frac{V_{pH}}{V_T}\right) \qquad \textbf{(14)}$$

V_T: is the thermal voltage

$$n_0 = \frac{n_i^2}{Nb}$$

Where Nb is the base doping density and n_i the intrinsic carriers density.

In figure**6**, we plotted the diffusion capacitance versus the junction recombination velocity (Sf) for different wavelengths (λ).

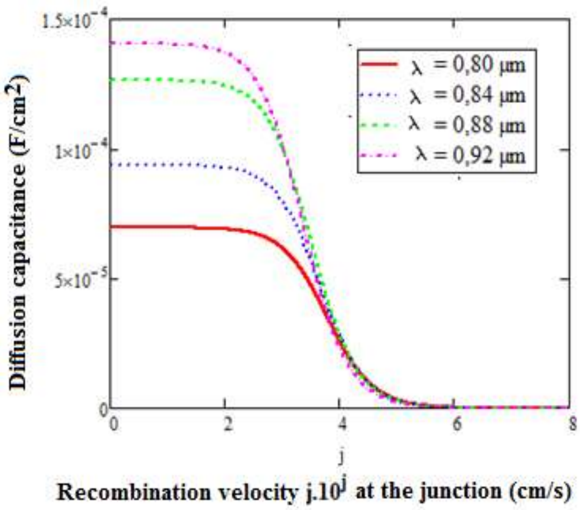

Fig 6: Diffusion capacitance versus junction recombination velocity (Sf) for different wavelengths (λ) $D = 26cm^2/s, L = 0.015cm, H = 0.003cm)$

The figure**6** 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 a reduction of the capacitance [12, 13]. We also note that the diffusion capacitance increases with the wavelength meaning that when wavelength increases, the excess minority carrier's density increases. Therefore the number of excess minorities' carriers stored in the junction increase.

3.5 Efficiency of the Diffusion Capacitance Solar Cell

The efficiency of the diffusion capacitance obtained by the model of the extension's space charge region width is given by the expression [9, 12]:

$$\eta = 1 - \frac{x_{OC}}{x_{SC}} \qquad \textbf{(15)}$$

x_{OC} is the extension width of the space charge region in open circuit

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x_{SC} is the extension width of the space charge region in short-circuit.

The figure **7** represents the efficiency of the diffusion capacitance solar cell versus the wavelength

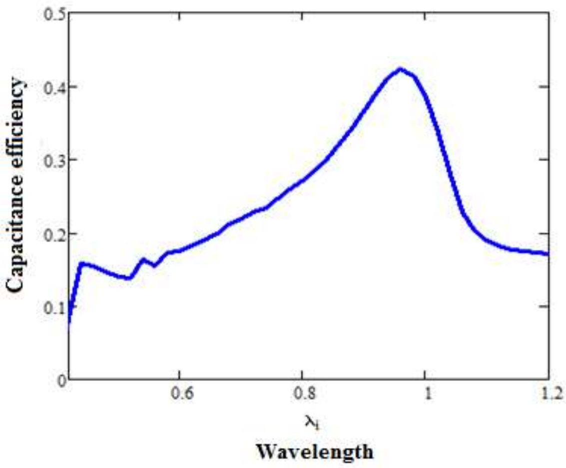

Fig 7: Efficiency of the diffusion capacitance solar cell versus wavelength

$$(D = 26cm^2 / s, L = 0.015cm, H = 0.003cm)$$

Figure**7** shows that the capacitance efficiency increases and reaches to a maximum value λ=0.96 µm and then decreases when the wavelength increases.

The values of the capacity efficiency are more important between 0.8 µm and 1µm. In this interval, the solar cell provides more energy because the silicon solar cell is very sensitive compared to infrared values of the wavelengths.

4. CONCLUSION

The paper dealt with the effect of wavelength on the intrinsic recombination velocity at the junction (Sf0), the back side surface recombination velocity (Sb), the extension of the space charge region width and the diffusion capacitance efficiency of the solar cell illuminated by a monochromatic light.

The study shows that an increase of the wavelength reduces recombination at the junction and increases recombination on the back side surface of the solar cell. We have also noted an enlargement of the space charge region when the wavelength increases corresponding to an increase of the diffusion capacitance efficiency for values of the wavelength less than 0.96 µm.

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