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A method to determine the transient capacitance of the bifacial solar cell considering the cylindrical model of the grain and the dynamic junction velocity (Sf)

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Abstract

In this paper, we present a new technic based on the dynamic junction velocity (Sf) concept for the evaluation of the transient diffusion capacitance of the bifacial solar cell considering cylindrical model of the grains. Associating (Sf), the back surface recombination velocity (Sb) and the grain boundary recombination velocity (Sgb), we resolved the continuity equation in the base of the solar cell under monochromatic illumination. We calculated and plotted the solar cell's transient diffusion capacitance profile which decreases with the dynamic junction velocity (Sf), the back surface recombination velocity (Sb), the grain boundary recombination velocity (Sgb) and the high wavelength. The study shows also that the transient diffusion capacitance increases with the grains size (R).

Keywords: Grain Size, Grain Boundary Recombination Velocity, Polycrystalline, Solar Cell, Junction Recombination Velocity, Wavelength, Capacitance.

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1. Introduction

The choice of a model constitutes the basis of any modeling study leading to simulations and therefore to the results which enable to the physicist to make his scientific reading. For the characterization of solar cells, the one dimension (1D) [1, 2] and the columnar grains [3-4-5] models are widely used. Hence, combined to the dynamic junction velocity (SF), some methods are proposed to determine the diffusion length and the lifetime of the excess minority carriers in the base of the solar cell [6]. These two models permit also to calculate the excess minority carriers density, the photocurrent I [5], the phototension V [5], the solar cell's power (P), the I-V and P-V characteristics [5], the intrinsic junction recombination velocity (Sf0) [1,2], the real

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back side recombination velocity (Sb) [1,2], the series and shunt resistances [5] and the diffusion capacitance solar cell's efficiency. Considering these two dimensions, effects of magnetic and electric fields and the irradiation on the electrical solar cell parameters are also studied [7, 8].
In [3], authors used the columnar grains model and concluded that the solar cell's junction could be considered as a plane capacitor with two identical plane electrodes separated by an extension region width which depends on the dynamic junction velocity (SF), the grain size, the grain boundary recombination velocity and the wavelength. In this study, the primary role of Sf which related to the operating point of the solar cell is demonstrated.
However, the columnar approach of the grains of the solar cell which gives good results is not the only method to allow the characterization and must be improved. The cylindrical orientation can also be considered in order to better refine the control of the parameters of the solar cells.

That is why, this paper aims at presenting the behavior of the transient diffusion capacitance of an N^+P-P^+ bifacial solar cell. The capacitance is studied using the cylindrical orientation of the grains of the solar cell. We take into account of the dynamic junction velocity Sf [9], the grain radius (R) and the grain boundary recombination velocity (Sgb).

2. Theory

We present in figure 1 an isolated cylindrical grain of the bifacial silicon solar cell under monochromatic illumination.

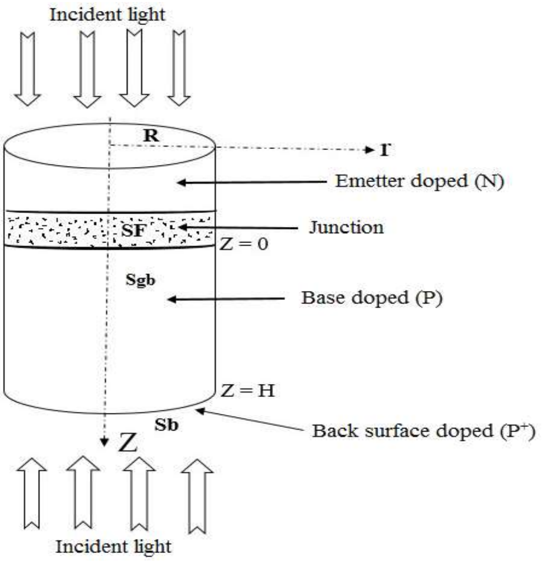

Figure 1. Isolated cylindrical grain

The bifacial solar cell is assumed to have four zones: the emitter doped N^+, the base doped P, the junction N^+P which is setted between the emitter and the base, and the back contact where another junction is created by a thin film strongly doped P^+. This second junction is the seat of the very intense electric field which returns the minority carriers towards the base [3-5]. This electrical field limits the recombination at the back side of this type of solar cell which are more efficient than the conventional solar cell [3-5].
According to [10], the transfer phenomenas in the base of the solar cell are modeled by the equation of continuity in cylindrical coordinates:

$$\frac{\partial^2\delta(r,\theta,z)}{\partial r^2}+\frac{\partial^2\delta(r,\theta,z)}{\partial z^2}+\frac{1}{r^2}\cdot\frac{\partial^2\delta(r,\theta,z)}{\partial\theta^2}+\frac{1}{r}\cdot\frac{\partial(r,\theta r,\theta}{\partial r}-\frac{\delta(r,\theta,z)}{L^2}=-\frac{G(z)}{D} \quad (1)$$

As, we have an azimuthal symmetry, the angle θ is not processed. Therefore the continuity equation becomes:

$$\frac{\partial^2\delta(r,z)}{\partial r^2}+\frac{\partial^2\delta(r,z)}{\partial z^2}+\frac{1}{r}\cdot\frac{\partial\delta(r,z)}{\partial r}-\frac{\delta(r,z)}{L^2}=-\frac{G(z)}{D} \quad (2)$$

δ(r;z) : minority carrier's density;
D: electron diffusion coefficient in the base (D = 26 $cm^2.s^{-1}$);
L: electron diffusion length in the base;
G(z): minority carriers generation rate at position z in the base [3]
While proceeding by the separation method of the variables used by [10], we put:

$$\delta(r,z)=\sum_{k\geq1}^{\infty}f_k(r)\cdot\sin(c_k\cdot z)+K_k \quad (3)$$

The solution of the equation is given by:

$$\delta(r,z)=\sum_{k\geq1}^{\infty}\left[\begin{array}{l}A_k\cdot r+\frac{2\cdot\alpha\cdot(1-R)}{H\cdot D}\cdot\frac{L_k^2\cdot c_k}{c_k^2+\alpha^2}\cdot G(H)-\\ \frac{2K_k}{L^2\cdot H}\cdot\frac{1-\cos(c_k\cdot H)}{c_k}\end{array}\right]\cdot\sin(c_k\cdot z)+K_k \quad (4)$$

Coefficients $A_{k,u}$ and $K_{k,u}$ are obtained from the boundaries conditions of the solar cell:

- At the junction (z=0) [3,5]:

$$\left.\frac{\partial\delta(r,z,T)}{\partial z}\right|_{z=0}=\frac{Sf}{D}\cdot\delta(r,z=0) \quad (5)$$

- At the grain boundary (r=R) :

$$\left.\frac{\partial f(r,T)}{\partial r}\right|_{z=R}=-\frac{Sgb}{D}\cdot f(R) \quad (6)$$

3. Capacitance

The bifacial solar cell's transient diffusion is given by [5]:

$$C(Sf,Sb,Sgb,\lambda)=\frac{q}{V_T}\cdot\left[\begin{array}{l}\delta(z=0,Sf,Sgb,Sb,\lambda)\\ +\frac{n_i^2(T)}{N_b}\end{array}\right] \quad (7)$$

q represents the electron's charge.

4. Results and Discussions

In figures 2, 3 and 4, we plotted the transient diffusion capacitance versus the junction recombination velocity. Figure 2 shows effects of grain boundary recombination velocity. As for the influence of the grain size and wavelength (λ), we considered various radius (R) and wavelength (λ) in figures 4 and 5, respectively.

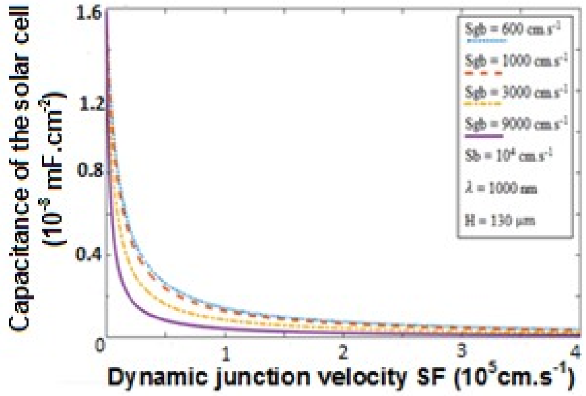

Figure 2. Capacitance of the illuminated solar cell versus SF for various Sgb: R= 0.01 cm.

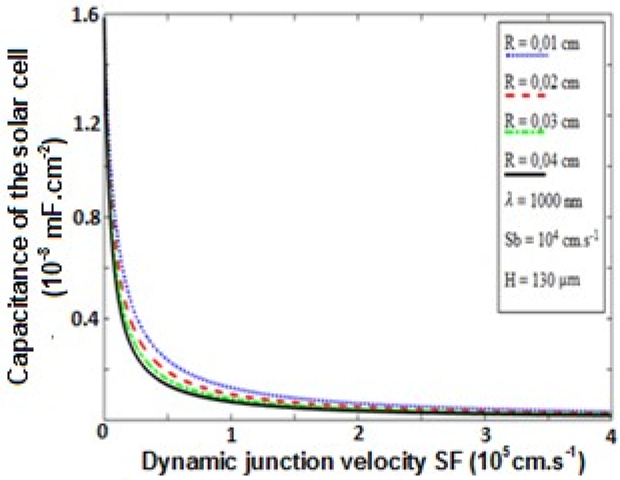

Figure 3. Capacitance of the illuminated solar cell by the front surface versus SF for various radius (R): L = 0.01 cm

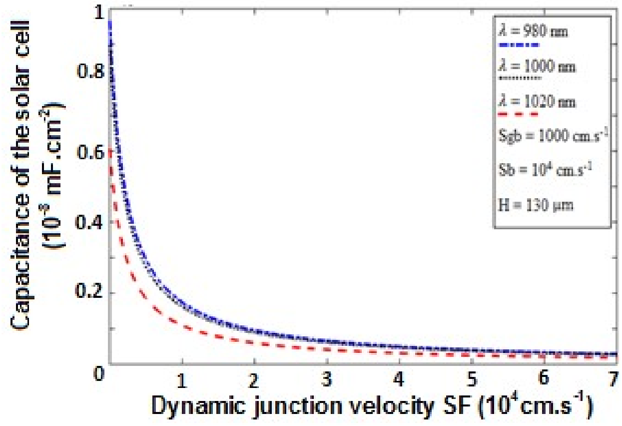

Figure 4. Capacitance of the illuminated solar cell versus SF for various wavelength: L = 0.01 cm and R= 0.01 cm

We remarked in figure 2, for a given solar cell, that:

- the open circuit transient diffusion capacitance is very brief. It can be seen here that there is a difference between the considered model and that of the cubic grains where the range of operating points of the open circuits is sufficiently long [4].
- the short circuit operating points zone is very important and there, the transient diffusion capacitance stretches toward zero ;
- a transient diffusion capacitance, depending on operating point which is related to SF, appears between the open circuit operating to the short – circuit operating points.

The increase of SF corresponds to an increase of the extension region width and hence to the increase of solar cell's photocurrent as shown by [3].
We also noted that the transient diffusion capacitance decreases with Sgb; meaning that increasing of Sgb leads to high recombination in the grain boundary of the solar. In figure 3, we noticed that the variation of the solar cell grain radius (R) leads to increase the transient diffusion capacitances.

Figure 4 shows that when the wavelength (λ) increases in the considered range between 980 to 1020 nm, the transient diffusion capacitance decreases. When the wavelength increases, the energy of incoming photons decreases and less excess minority carriers are extracted in the base of the solar cell.

In figure 5 we represented the solar cell's transient diffusion capacitance versus the dynamic junction velocity (SF) and the solar cell grain radius (R). Indeed, the solar cell's capacitance increases according to the grain radius (R) and decreases with the junction recombination velocity.

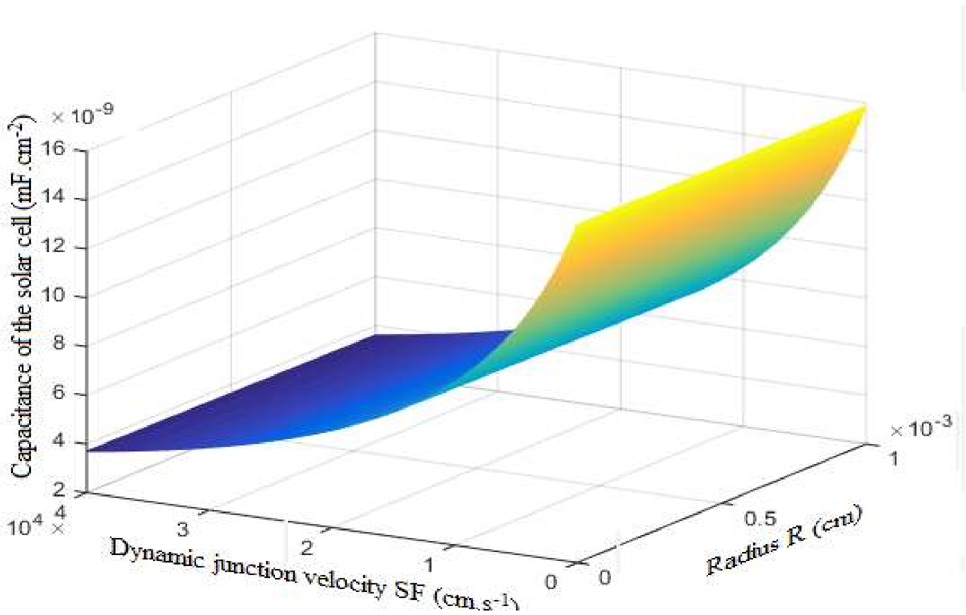

Figure 5. Capacitance of the illuminated solar cell by the front side versus SF and solar cell grain radius (R): λ=1000 nm, Sgb= 1000 cm.s^{-1}, Sb = 10000 cm.s^{-1}, L = 0.01 cm and H=130 µm.

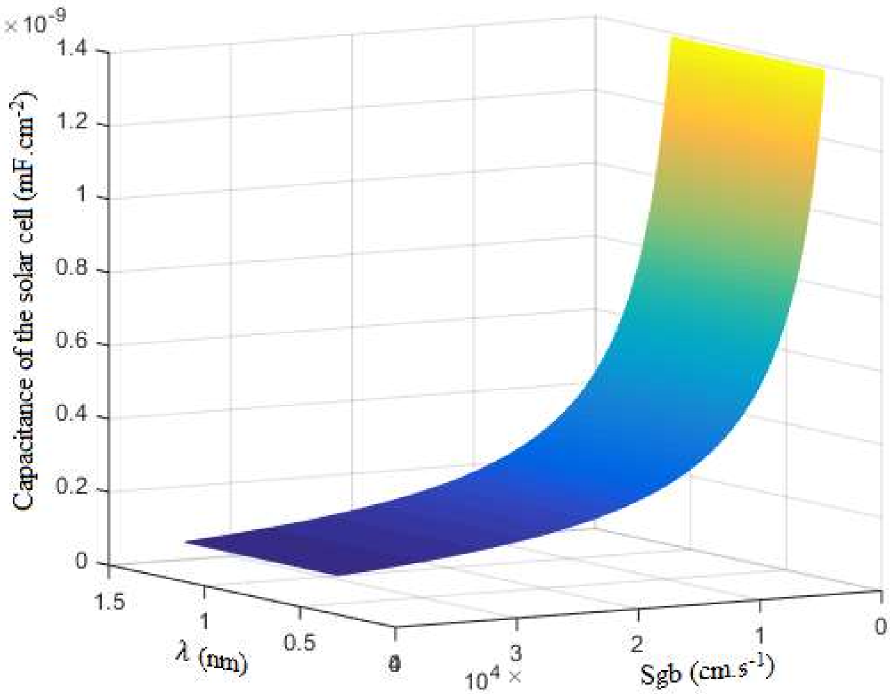

Figure 6. Capacitance of the illuminated solar cell by the front surface according to the grain boundary recombination velocity (Sgb) and wavelength (λ): Sb = 10^4 cm.s^{-1}, L = 0.01 cm, H=130 µm and R = 0.01 cm

In figure 6, we showed the variation of the capacitance according to Sgb and the wavelength (λ). These figures represent the bifacial solar cells transient diffusion capacitance for a fixed solar cell grain radius (R) and for various grain boundary recombination velocities (Sgb) and wavelengths (λ). Effects of these two parameters on the transient diffusion capacitance are the same as for the results of [3].

5. Conclusion

In this paper, we determined the transient diffusion capacitance using the cylindrical orientation of solar cell's grains. We have shown that, as for the columnar isolated grain model, the diffusion transient diffusion capacitance increases with solar cell grain radius (R) and with wave length. It decreases with the grain boundary recombination velocity and the dynamic junction velocity (SF). The approach confirms that best solar cells correspond to high grain radiuses (R) which lead to low grain boundary recombination velocity (Sgb).

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