

## Irradiation Effect on the Diffusion Capacitance of Parallel Vertical Junction Silicon Solar Cell under Static Regime and Monochromatic Illumination

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**Abstract** In this article, we have made a theoretical study of a parallel vertical junction solar cell under monochromatic illumination in static mode and under irradiation.

The resolution of the continuity equation which governs generation, recombination and electron diffusion process in the base, allowed us to establish the expression of the electron density and thereby deduce the expression diffusion capacitance depending on the wavelength  $\lambda$ , the recombination velocity at the junction  $S_f$  and the irradiation parameters.

We have studied the influence of irradiation parameters on the diffusion capacitance, the short-circuit diffusion capacitance, the open-circuit diffusion capacitance and the efficiency of the capacitance.

**Keywords:** vertical junction- wavelength -irradiation – diffusion capacitance-efficiency

### 1. Introduction

We will make, through this paper, a theoretical study of a parallel vertical junction solar cell under monochromatic illumination in static mode and under irradiation.

The resolution of the continuity equation will allow us to establish the expression of the density of minority charge carriers in the base and deduce the expression of the diffusion capacitance.

The expressions of short-circuit and open-circuit capacities will be subsequently deduced. In this article, we will study the impact of the change in coefficient of damage and the irradiation energy on the above listed capacities and the efficiency of the diffusion capacitance.

### 2. Theory

We consider a  $n^+p$ -p parallel vertical junction solar cell whose structure can be represented as follows:

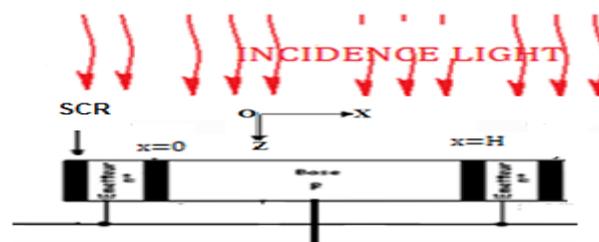


Figure 1: Parallel Vertical Junctions of a Solar Cell

When the solar cell is illuminated, there is a creation of electron-hole pairs in the base.



The behaviour of the minority carriers in the base (the electrons) is governed by the continuity equation which integrates all the phenomena causing the variation of the density of the electrons according to the width  $x$  of the base, its depth  $z$ , the recombination velocity at the junction, of the wavelength and irradiation parameters.

The resolution of this equation will enable us afterwards to express on the one hand the density minority charge carriers from the base and deduce on the other hand the diffusion capacitance.

The continuity equation in static mode is presented in the form below:

$$D \cdot \frac{\partial^2 \delta(x)}{\partial x^2} - \frac{\delta(x)}{\tau} = -G(z, \lambda) \quad (1)$$

$\delta(x)$  describes the density of minority carriers in photo-generated charge.

$D$  is the coefficient diffusion.  $\tau$  is the average lifetime of carriers.

$G(z, \lambda)$  is the overall generation rate of the minority charge carriers according to the depth  $z$  of the base.

The continuity equation can be written again as follows:

$$\frac{\partial^2 \delta(x)}{\partial x^2} - \frac{\delta(x)}{L^2} + \frac{G(z, \lambda)}{D} = 0 \quad (2)$$

$L(kl, \phi) = \frac{1}{\sqrt{kl \cdot \phi + \frac{1}{L_o^2}}}$  is the diffusion length [1].  $L_o$  is the diffusion length with the absence of irradiation;

$kl$  and  $\phi$  indicate the coefficient of damage and the irradiation energy.

The expression of the overall generation of minority charge carriers' rate is of the form: [2]

$$G(z, \lambda) = \alpha_t (1 - R(\lambda)) \cdot F \cdot \exp(-\alpha_t \cdot z) \quad (3)$$

$R(\lambda)$  is the monochromatic reflection coefficient;  $F$  is the flux of incident photons resulting from a monochromatic radiation.  $\alpha$  is the coefficient of monochromatic absorption.

$$\frac{\partial^2 \delta(x)}{\partial x^2} - \frac{\delta(x)}{L^2} = -\frac{G(z, \lambda)}{D} \quad (4)$$

## 2.1. Solution of the Continuity Equation

### Special Solution

$$\delta_1(x) = \frac{L^2}{D} \alpha_t (1 - R(\lambda)) \cdot F \cdot \exp(-\alpha_t \cdot z) \quad (5)$$

-solution of the second member equation:

$$\delta_2(x) = A \cosh\left(\frac{x}{L}\right) + B \sinh\left(\frac{x}{L}\right) \quad (6)$$

-thus the general solution is:

$$\delta(x, z, \lambda, Sf, kl, \phi) = \left[ A \cosh\left(\frac{x}{L(kl, \phi)}\right) + B \sinh\left(\frac{x}{L(kl, \phi)}\right) + \frac{L^2(kl, \phi)}{D} \cdot \alpha(\lambda)(1 - R(\lambda)) \cdot F \cdot \exp(-\alpha_t z) \right]$$

## 2.2. Find the coefficients A and B:

- The boundary conditions:

-Therefore, in the junction ( $x = 0$ ) we have:

$$D \cdot \frac{\partial \delta(x, z, \lambda, kl, \phi)}{\partial x} \Big|_{x=0} = Sf \cdot \delta(x, z, \lambda, kl, \phi) \Big|_{x=0} \quad (8)$$

$Sf$  is the recombination velocity at the junction. This is a phenomenological parameter that describes how the base minority carriers go through the junction. It can be divided into two terms [3].



We have  $Sf = Sf_o + Sf_j$

$Sf_o$  induced by the shunt resistance, is the intrinsic recombination velocity. It depends only on the intrinsic parameters of the solar cell.

$Sf_j$  reflects the current which is imposed by an external charge and thus defining the operating point of the solar cell

-At The middle of the base ( $x = \frac{H}{2}$ ). The structure of the solar cell, with two similar junctions on either side of the base, portends the equation (9) below:

$$D \cdot \frac{\partial \delta(x, z, kl, \lambda, \phi)}{\partial x} \Big|_{x=H/2} = 0 \tag{9}$$

H is the thickness of the solar cell's base

### 3. Results and Discussion

#### 3.1 Expression of the diffusion capacitance

The diffusion capacitance of the solar cell is considered as the capacitance resulting from the variation of the charge during the process of diffusion within the solar cell.

The storage charge on both sides of the base-emitter junction transforms the space charge area in a plane capacitor whose capacitance depends on the intrinsic and extrinsic parameters of the solar cell.

The expression capacitance of this capacitor is given by the following relationship: [4]

$$C = \frac{dQ}{dV} = q \frac{d\delta(x=0)}{dV} = q \frac{d\delta(x=0)}{dSf} \times \frac{1}{\frac{dV}{dSf}} \tag{10}$$

From where:

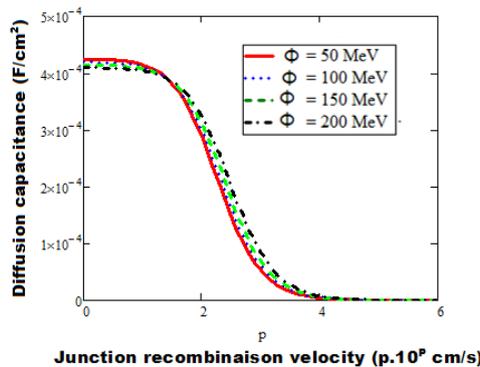
$$C = q \frac{n_o^2}{V_T \cdot N_B} + q \frac{\delta(x=0)}{V_T} \tag{11}$$

The first term refers to the darkness capacitance  $C_0$ ; it depends on the nature of the material (substrate) through ( $n_0$ ), doping through ( $N_b$ ) and temperature through ( $V_T$ ) which is thermal voltage.

Whereas the second term depends on the temperature ( $V_T$ ), the illumination, the operating point  $Sf$ , the depth  $z$  of the solar cell and irradiation parameters.

#### 3.2. Diffusion capacitance profile

Figures 2a and 2b show the profile of the diffusion capacitance according to the recombination velocity at the junction for respectively different values of the irradiation energy and the coefficient of damage.



2a)  $kl = 10 \text{ cm}^2/\text{s}$

Figure 2a: Variation of the diffusion capacitance according to the recombination velocity at the junction for different values of irradiation energy

$\lambda = 0.5 \text{ }\mu\text{m}$ ;  $H = 0.03 \text{ m}$ ;  $Z = 0,0001\text{cm}$ ;  $L_o = 0,01\text{cm}$



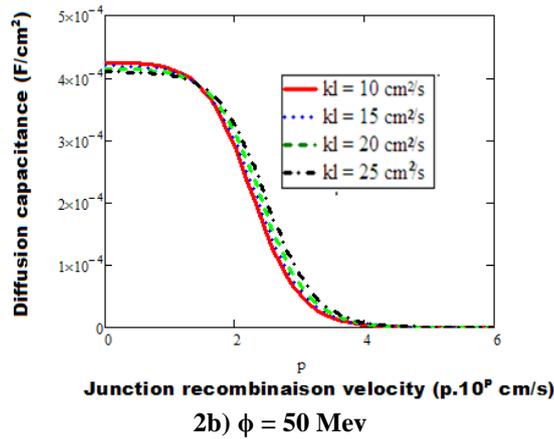


Figure 2b: Variation of the diffusion capacitance according to the recombination velocity at the junction for different values of the coefficient of damage

$\lambda = 0.5 \mu\text{m}$ ;  $H = 0.03 \text{ m}$ ;  $Z = 0,0001\text{cm}$ ;  $L_o = 0,01\text{cm}$

Figures 2-a and 2-b show us that the capacity of diffusion is constant and maximum for the low values of the recombination velocity at the junction corresponding to the operation of the solar cell in open circuit.

It is almost zero for large values of  $S_f$  corresponding to the state of short circuit.

In open-circuit and short-circuit conditions, irradiation decreases the amount of charges stored on either side of the junction by reducing the diffusion length of the photo-generated carriers, which increases the recombination rate and causes decrease the diffusion capacitance.

In these two operation modes of the solar cell, the decrease of the diffusion capacitance corresponds to an enlargement of the space charge zone since:

$$C(\lambda, kl, \phi, z, Sf) = \frac{\epsilon S}{X(\lambda, kl, \phi, z, Sf)} \tag{12}$$

with X the width of the space charge zone.

In fact by boosting the recombination rate, the irradiation increases thus the width of the zone devoid of mobile charges which is the space charge zone.

In intermediate operation, we notice that diffusion capacitance increases the with irradiation parameters.

Irradiation participates in the generation of charge carriers and increases the thermal diffusion velocity of the carriers generated by the overheating of the material.

The quantity of carriers which reach the junction will therefore increase, which results in the behavior the diffusion capacitance.

### 3.3. Profile of short-circuit capacitance

Figures 3a and 3b show the profiles of the short-circuit capacity according respectively to the irradiation energy and coefficient of damage.

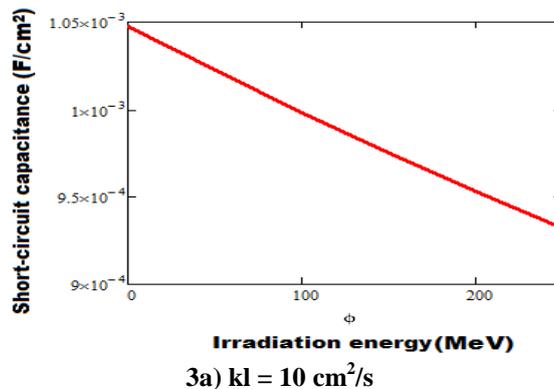


Figure 3a: Variation of the short-circuit capacitance according to irradiation energy

$H = 0.03 \text{ cm}$ ,  $Z = 0.0001 \text{ cm}$ ,  $S_f = 6.10^6 \text{ cm/s}$ ,  $L_o = 0.01 \text{ cm}$ ,  $\lambda = 0.5 \mu\text{m}$



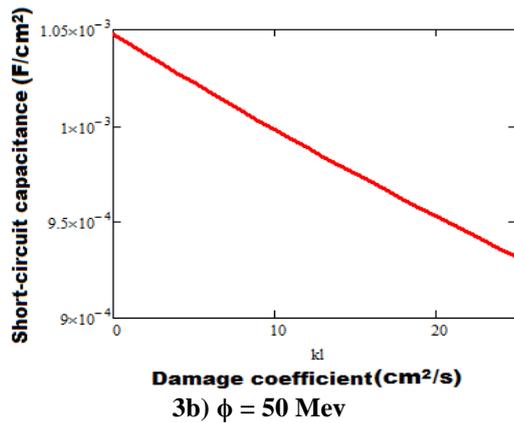


Figure 3b: Variation of the short-circuit capacitance according to the coefficient of damage

$H = 0.03$  cm,  $Z = 0.0001$  cm,  $Sf = 6.10^6$  cm/s,  $L_o = 0.01$  cm,  $\lambda = 0.5\mu\text{m}$

Figures 3a and 3b show that the capacitance in a short-circuit situation decreases with the irradiation energy and the damage coefficient.

When the irradiation energy or the coefficient of damage increases, the diffusion length of the charge carriers decreases, which results in an increase of the recombination rate and a decrease of the amount of charges stored on either side from the junction.

### 3.4. Profile of open circuit capacitance

Figures 4a and 4b show the profiles of the open circuit capacitance according respectively to irradiation energy and the damage coefficient.

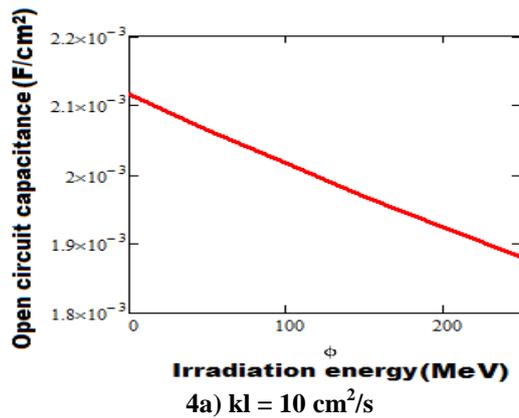


Figure 4a: Variation of the open circuit capacitance according to irradiation energy

$H = 0.03$  cm,  $Z = 0.0001$  cm,  $Sf = 10$  cm/s,  $L_o = 0.01$  cm,  $\lambda = 0.5\mu\text{m}$

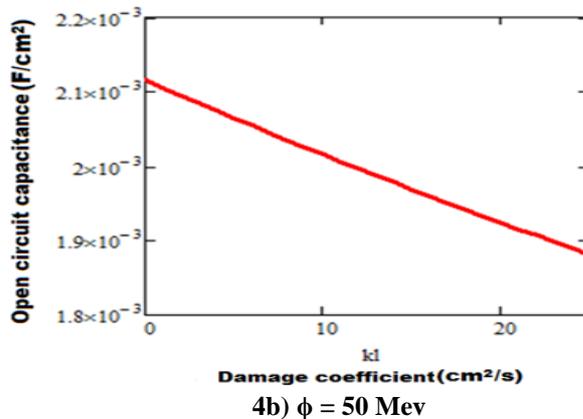


Figure 4b: Variation of the open circuit capacitance according to the coefficient of damage

$H = 0.03$  cm,  $Z = 0.0001$  cm,  $Sf = 10$  cm/s,  $L_o = 0.01$  cm,  $\lambda = 0.5\mu\text{m}$



Figures 4a and 4b show that the capacity in the open circuit situation decreases with the irradiation energy and the damage coefficient.

When the irradiation energy or the coefficient of damage increases, the diffusion length of the charge carriers decreases, which results in an increase of the recombination rate and a decrease of the amount of charges stored on either side from the junction.

This quantity of stored charges is greater in open-circuit situation than in short-circuit situation due to the low values of the recombination velocity at the junction.

### 3.5. Efficiency capacitance

#### 3.5.1. Expression

The expression of diffusion capacitance efficiency is presented in the form [5]

$$\eta(\lambda, kl, \phi, z) = 1 - \frac{C_{CC}(\lambda, kl, \phi, z)}{C_{CO}(\lambda, kl, \phi, z)} \quad (13)$$

Where  $C_{CC}$  is the short-circuit capacitance and  $C_{CO}$  open circuit capacitance.

This expression of efficiency will allow us to study its variation according to irradiation energy and coefficient of damage.

#### 3.5.2. Efficiency profile

Figures 5a and 5b show the efficiency capacitance profiles according to irradiation energy and the damage coefficient, respectively.

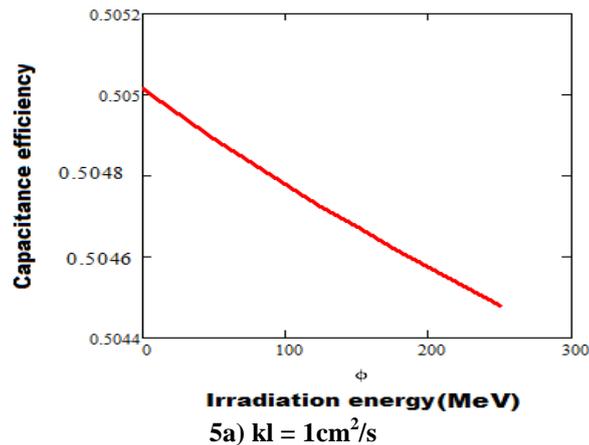


Figure 5a: Variation of the diffusion capacitance efficiency according to irradiation energy  
 $H = 0.03 \text{ cm}$ ,  $Z = 0.0001 \text{ cm}$ ,  $L_o = 0.01 \text{ cm}$ ,  $\lambda = 0.5 \text{ } \mu\text{m}$

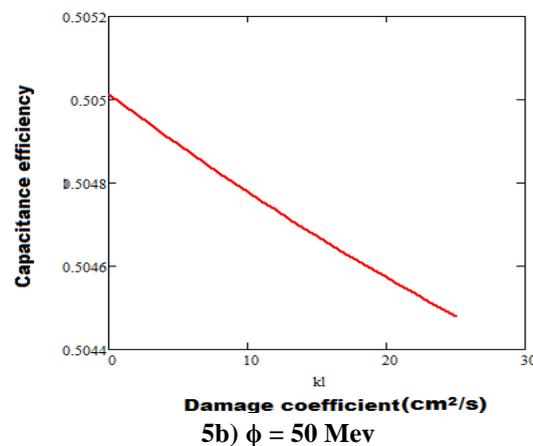


Figure 5b: Variation of the efficiency of the diffusion capacitance according to the damage coefficient  
 $H = 0.03 \text{ cm}$ ,  $Z = 0.0001 \text{ cm}$ ,  $L_o = 0.01 \text{ cm}$ ,  $\lambda = 0.5 \text{ } \mu\text{m}$



The efficiency of the capacitance decreases when the irradiation energy or the damage coefficient increases. In the vicinity of the open circuit, the amount of charges stored on both sides of the junction is greater than in the vicinity of the short circuit. The impact of irradiation on open-circuit capacitance is more pronounced on open-circuit diffusion capacitance than on short-circuit diffusion capacitance; the result is to reduce the efficiency of the diffusion capacitance.

Considering the expressions of the short-circuit and open-circuit diffusion capacitances

$$C_{CC}(\lambda, \phi, kl, z) = \frac{\varepsilon S}{X_{CC}(\lambda, \phi, kl, z)} \quad (14)$$

and

$$C_{CO}(\lambda, \phi, kl, z) = \frac{\varepsilon S}{X_{CO}(\lambda, \phi, kl, z)} \quad (15)$$

the efficiency of the capacitance depends on the extension of the space charge zone. Irradiation have the effect to increase the extension of this depletion zone.

This extension is more important in the vicinity of the short circuit than in open circuit, hence the reduction of the efficiency.

### Conclusion

The resolution of the continuity equation allowed us to obtain the expression of the electrons' density in the base and we deduced therefore that of the diffusion capacitance.

We studied in this paper the impact of the irradiation parameters variation on the diffusion capacitance, the open-circuit diffusion capacitance, the short-circuit diffusion capacitance and the efficiency of the diffusion capacitance.

In short-circuit and open-circuit operation, the study showed that irradiation reduces the diffusion capacitance because there is an accrual of the recombination centers.

The quantity of charges stored on either side from the junction decline according to recombinations. We have noticed an extension of the depletion zone caused by irradiation.

In intermediate operation, we have noticed some opposite phenomena.

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