Capacitance determination of a Vertical Parallel Junction Solar Cell under Multispectral Illumination in Steady State

Ali Hamidou, Amadou Diao, Séré Ahmed Douani, ali Moissi, Moustapha Thiame, Fabé Idrissa Barro, Grégoire Sissoko

Abstract*— A theoretical study of a vertical junction silicon solar cell under multispectral illumination in steady state is presented. From the excess minority carrier's density in the base of the cell, the photocurrent density, the photovoltage, the diffusion capacitance and the dark capacitance were determined. All these parameters are studied according to the illumination level effect.

***Index Terms* — Vertical junction, solar cell, capacitance.**

I. INTRODUCTION

The solar cell is an essential device in the photovoltaic conversion chain so that any improvements in its conversion efficiency lead to general gain in energy production. Given their limited conversion efficiency [1] many studies have been made [2] to improve this efficiency; our contribution here will be a theoretical study of the capacitance of a vertical junction solar cell for various illumination levels.

II. THEORY

A. *Vertical parallel junction solar cell*

Vertical junction solar cells [3]-[5] are illuminated parallelly to the junction plane so that all the photogenerated carriers in a given plane are at the same distance to the junction. We present on fig.1 the structure of a typical parallel vertical junction solar cell [6], [7].

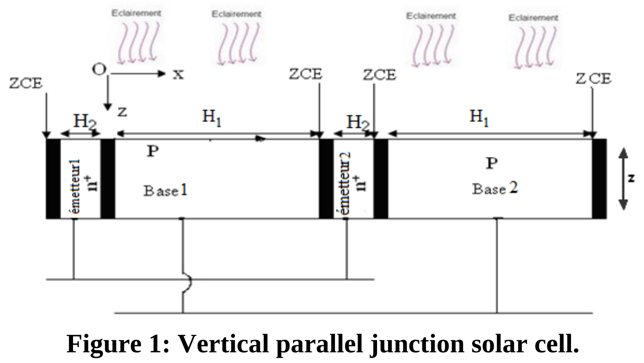

Figure 1: Vertical parallel junction solar cell.

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B. *Excess minority carrier's density*

When the solar cell is illuminated, there are photogenerated minority carriers in the base of the solar cell. Their diffusion in the base is governed by the continuity equation:

$$\frac{\partial^2\delta(x,z)}{\partial x^2} - \frac{\delta(x,z)}{L^2} + \frac{G(z)}{D} = 0 \qquad (1)$$

where is the excess minority carriers' density, D is the diffusion constant and L the diffusion length; G(z) is the carriers' generation rate for the multispectral light and is given by [8]:

$$G(z) = n\sum_{\lambda_0}^{\lambda g} F_0(\lambda).\alpha\ (1-R(\lambda))e^{-\alpha(\lambda)z} \qquad (2)$$

n is the illumination level as called sun number, is the absorption coefficient associated to the wavelength , is the reflexion coefficient and the incident photon flux. A solution of equation (1) can be written as:

$$\delta(x) = A.\cosh\left(\frac{X}{L}\right) + B.\sinh\left(\frac{X}{L}\right) + \sum_{\lambda_0}^{\lambda_g} K(\lambda)e^{-\alpha(\alpha)z} \qquad (3)$$

with $K(\lambda) = \frac{L^2}{D} n\sum_{\lambda_0}^{\lambda g} F_0(\lambda)\alpha(\lambda)(1-R(\lambda))$

Coefficients A and B is determined by the boundaries conditions:

- At the junction (x = 0):

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

- At the middle of the base (x=H):

$$D\cdot\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=\frac{H}{2}} = 0 \qquad (5)$$

Here the gradient of the carriers' density is supposed null [9]. Sf is the junction recombination velocity.

III. RESULTS AND DISCUSSION

A. *Excess minority carriers' density*

On figure 2, the excess minority carriers' density is represented according the base depth for various illumination levels.

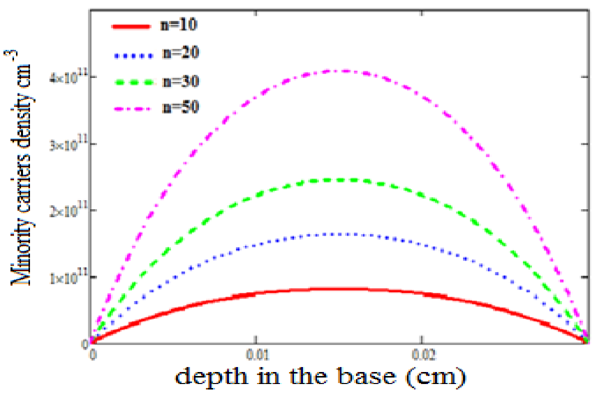

Figure 2: Excess carriers' density versus base depth for various illumination levels. (D=26cm²/s, Sf=7.10^{7}cm/s, H=0.03cm, z=0,0225cm, L=0,001cm).

One can observe that from the middle of the base, carriers flow towards the two junctions; that's why a very remarkable decrease of the excess minority carriers' density to the vicinity of the junction. With an illumination level increase, the incident photons flux increase too, that's also lead to greater photogenerated carriers in the solar cell and consequently the increase of the excess minority carriers' density in base.

B. Photocurrent density

The photocurrent density expression is given by:

$$Jph = 2.q.D.\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=0} \tag{6}$$

q is the elementary charge. The coefficient 2 results from the two junctions.

We illustrate on fig.3 the photocurrent density profile for various illumination levels.

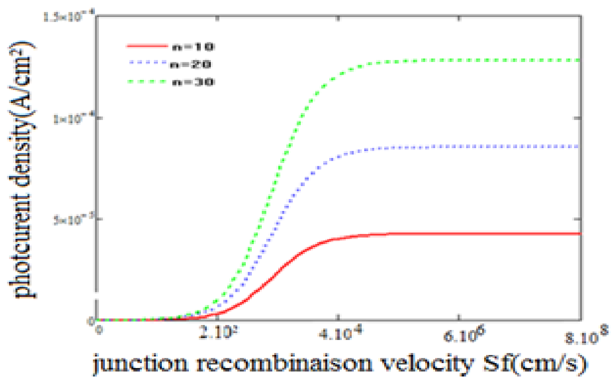

Figure 3: Photocurrent density versus junction recombination velocity for various illumination levels. (D=26cm²/s, H=0.03cm, z=0,0225cm, L=0,001cm).

Fig.3 shows that the photocurrent increases according to the junction recombination velocity Sf. One can note that an increase of Sf implies an increase of carriers flow though the junction and so, more minority carriers are collected to generate more current.

When the illumination level increases, the incident photons flux also increase enhancing photogenerated carriers and leading to an increase of the photocurrent. Effectively, for increasing illumination levels, a part of photogenerated carriers fills the recombination centers so that the remainder can easily diffuse and cross the junction.

C. Photovoltage

The photovoltage across the junction is obtained by the Boltzmann relation as:

$$Vph = V_T \ln\left(1 + \frac{Nb}{n_i{}^2}\delta(0)\right) \tag{7}$$

VT is the thermal voltage; ni the intrinsic carriers' concentration; Nb the base doping density.

On fig.4, the photovoltage is represented versus junction recombination velocity for various illumination levels.

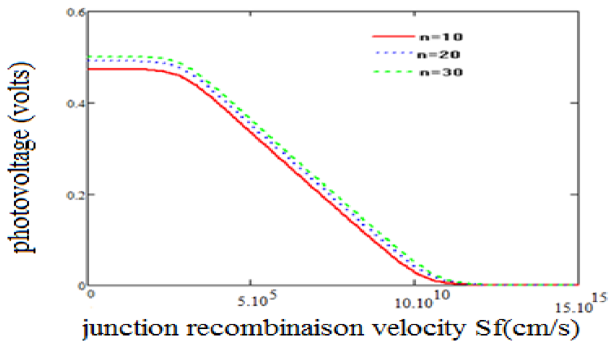

Figure 4: Photovoltage versus junction recombination velocity for various illumination levels: (D=26cm²/s, H=0.03cm, z=0,0225cm, L=0,001 cm)

One can see that photovoltage decreases for increasing Sf values. When Sf increases, more and more minority carriers flow through the junction so that stocked carriers in the base are drastically reduced. This situation leads to the reduction of the photovoltage.

When illumination level increases, the photogenerated carriers' concentration in the base increase what also implies an increase of the photovoltage for a given operating point.

D. Capacitance

The diffusion capacitance of solar cell results from the diffusion process of minority carriers [10]. This capacitance can be expressed as:

$$C = \frac{dQ}{dV} = q\cdot\frac{d\delta(x=0)}{dVph} \tag{8}$$

Replacing the total charge Q by its expression, equation (8) becomes:

$$C = C_O + \frac{q\cdot\delta(0)}{V_T} \tag{9}$$

where C_O is the dark capacitance.

On fig. 5, the solar cell capacitance is plotted versus junction recombination velocity for various illumination levels.

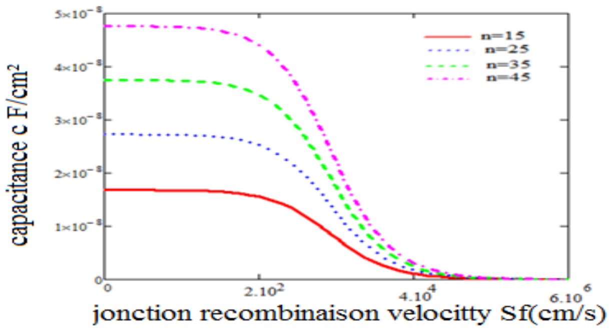

Figure 5: Capacitance versus junction recombination velocity for various illumination levels. (D=26cm²/s, H=0.03cm, z=0,0225cm, L=0,001cm).

Fig. 5 shows that near open circuit [0; 2.10^2 $cm.s^{-1}$], the solar cell capacitance decreases slightly. But above $2.10^2 cm.s^{-1}$ the capacitance decreases markedly: there are practically no stocked minority carriers near the junction because of the carriers flowing. For an increase illumination level, the capacitance increases too for a given operating point [11].

With equation (9), we obtain:

$$C = C_0 \exp\left(\frac{V_{ph}}{V_T}\right) \quad (10)$$

With the logarithmic function, equation (10) becomes:

$$\ln C - \ln C_0 = \frac{V_{ph}}{V_T} \quad (11)$$

A plot of the capacitance (log scale) versus photovoltage is presented on fig.6

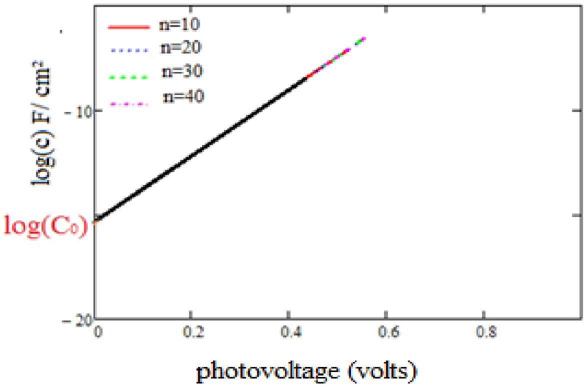

Figure 6: log(C) versus photovoltage for various illumination levels. (D=26cm²/s, Sf=7.107cm/s, H=0.03cm, z=0,0225cm, L=0,001cm).

Fig. 6 shows that the logarithm of the capacitance versus photovoltage is a straight line for any illumination level. The slope of this line is 1/VT. The intercept point obtained with the capacitance axis is the dark capacitance value of [12]. The obtained value with this method, is $C_0 = 0.20 \mu F/cm^2$.

IV. CONCLUSION

A theoretical study of a parallel vertical junction solar cell under multispectral illumination was done. The effect of illumination level on the electric parameters such as photocurrent, photovoltage, capacitance, has been presented. The dark capacitance of the solar cell was obtained for any illumination level.

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