Silicon Solar Cell Emitter Extended Space Charge Region Determination under Modulated Monochromatic Illumination by using Gauss's Law

Massamba DIENG, Boureima SEIBOU, Ibrahima LY, Marcel Sitor DIOUF, Mamadou WADE, Grégoire SISSOKO

***Abstract:** In this paper, a method of determining the Emitter Extension space charge Region in a silicon Solar Cell Operating in short-circuit condition, is presented. The excess minority carrier's density versus base Depth is established in Dynamic Regime under monochromatic Illumination. Considering the junction as a plane capacitor, the emitter extension region X_{0e} is determined for various wavelengths,by using Gauss's law.*

***Keywords:** Silicon Solar Cell - minority carrier's density - monochromatic Illumination - Dynamic Regime - Gauss's Law - Emitter Extension Region*

I. INTRODUCTION

The junction of a diode is considered as a plane capacitor. There is a cathode side of the base and an anode -side emitter **[1].** The silicon solar cell, under illumination, presents a space charge region which can be considered as a plane capacitor whose capacitance is proportional to the area of the junction and inversely proportional to the width of the junction **[2]**. This extension region's width X_0 separating the cathode and the anode is the thickness of the junction. Based on the depletion model, Shockeley propose a determination of X_0 **[3],** valid for zero and opposite polarization. Taking into account the free carriers in the junction, J. J. Liou and F. A. Lindholm develop an appropriate model for all polarizations [4]. In this article, the Width Emitter Extension Region is determined by using Gauss's law there after studied in low frequency for various wave length.

II. THEORY

II.1. Description and operating of the solar cell

We consider a crystalline silicon solar cell (n + -p- p +) [5], [6] illuminated by the front side under monochromatic illumination under low frequency and we are working in quasi-neutral base theory [7]. The structure of this solar cell is represented in figure 1

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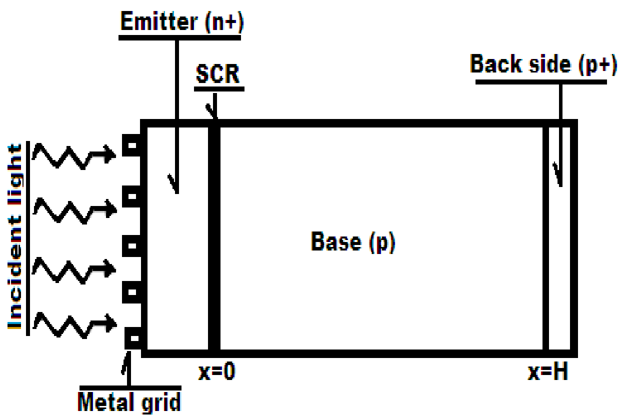

Figure 1: **An n+-p-p+ structure of a silicon solar cell.**

This solar cell has four main parts:

a) The emitter, highly doped n^+ (with a doping level of between 10^{17} and $10^{19}cm^{-3}$) and low thickness (0.5 à 1 µm).
b) The base, less p-doped (with a doping level of between 10^{15} and $10^{17}cm^{-3}$) and a much wider thickness than the emitter (up to 400 µm)
c) The space charge region which is the interface between the emitter and the base. In this region prevails a strong electric field which separate the electron-hole pairs created.
d) The rear area, highly type doped p^+ shows an electric field surface which returns the minority carriers generated in the rear region to the junction. it is the effect of the back field (or Back Surface Field : B.S.F) [8], [9].

The electrical contacts are provided by metal grids on both sides of the solar cell obtained by [10] chemical deposition of nickel on silicon, by screen printing a paste based on silver

II.2. Determination of the excess minority carrier's density

When the solar cell is illuminated, charge carriers are generated in the base. These charge carriers in the base undergo phenomena of diffusion and recombination. The variation in time and space of the excess minority carrier's density $\delta(x,t)$ in the base is governed by the continuity equation:

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

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In this equation, $D(\omega)$ represents diffusion coefficient which is a function of frequency. Its expression is given by:

$$D(\omega)=D\left[\frac{1+(\omega\tau)^2}{(1-\omega^2\tau^2)^2+(2\omega\tau)^2}+\omega\tau\frac{-1-(\omega\tau)^2}{(1-\omega^2\tau^2)^2+(2\omega\tau)^2}j\right] \quad (2)$$

τ is the minority carriers lifetime.

$G(x,t)$) is the global carrier generation rate at depth x in the base versus time t. Its expression is given by [11] [12] :

$$G(x,t)=g(x).e^{j.\omega.t} \quad (3)$$

With:

$$g(x)=\alpha.\phi.(1-R).e^{-\alpha.H} \quad (4)$$

α is the monochromatic absorption coefficient of the crystalline silicon.

Φ is the incident photon flux.

R is the coefficient of monochromatic reflection

ω is the angular frequency of the excitation

Posing:

$$L(\omega)^2=\tau.D(\omega) \quad (5)$$

we obtain

$$L(\omega)=\sqrt{\tau\cdot D}\cdot\sqrt{\frac{1-j\omega\tau}{1+(\omega\tau)^2}} \quad (6)$$

$L(\omega)$ is the complex diffusion length

Equation (1) became:

$$\frac{\partial\delta(x,t)}{\partial x^2}-\frac{1}{D(\omega)}\cdot\frac{\partial\delta(x,t)}{\partial t}-\frac{\partial\delta(x,t)}{L(\omega)^2}=\frac{G(x)}{D(\omega)} \quad (7)$$

The solution for equation (7) is given by:

$$\delta(x)=A\cosh\left(\frac{x}{L(\omega)}\right)+B\sinh\left(\frac{x}{L(\omega)}\right)-\frac{\alpha.I_0.(1-R).L(\omega)^2.e^{-\alpha x}}{D(\omega).(\alpha^2.L(\omega)^2-1)} \quad (8)$$

A and B to be determined by means of the boundary conditions

a) at the junction x = 0

$$D(\omega)\cdot\frac{\partial\delta(x)}{\partial x}\Big|_{x=0}=Sf\cdot\delta(0) \quad (9)$$

b) at the rear side of the base (x = H)

$$D(\omega).\frac{\partial\delta(x)}{\partial x}\Big|_{x=H}=-Sb.\delta(H) \quad (10)$$

Sf is the junction recombination velocity. It is equal to the sum of the intrinsic recombination velocity Sfo (induced by resistance shunt and depending only on the intrinsic parameters of the photovoltaic cell) and the recombination velocity Sfj which shows the leakage current induced by the external load and which defines the operating point of the photovoltaic cell [15] - [17]..

$$Sf=Sfo+Sfj \quad (11)$$

Sb is the back surface minority carrier recombination velocity. It is related to the rate at which excess minority carriers are lost at the back surface of the cell. [15] - [17].

Figure 2 presents the profile of the excess minority carrier density versus base depth for various wave length λ.

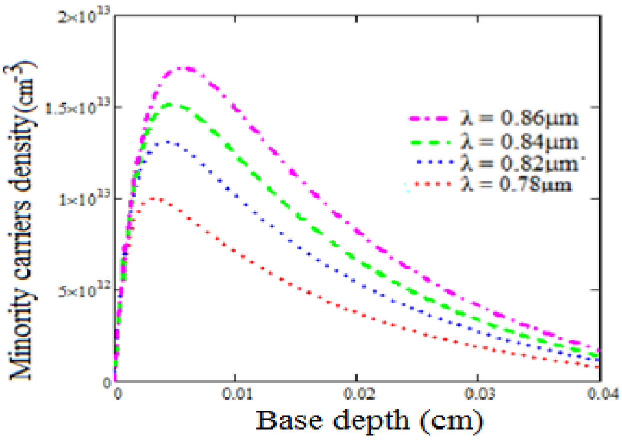

Figure 2 : minority carriers density versus depth X of the base for various wave length ($\omega=10^3$rad/s, Sf= 6.10^6cm/s,)

Figure 2 shows that excess minority carrier's density increases to a maximum corresponding to a X_{0b} depth in the base and for a value of the depth of the upper base to X_{0b} , minority carrier's density decreases. Thus, in the base of we note two areas bounded by X_{0b}

i) The domain where x< X_{0b} : in this region, The gradient of minority carriers density in the base is positive and minority carriers in it, can cross the junction and contribute to the photocurrent. This domain is assimilated at a extension of the space charge region **[18]**.

ii) The domain where x> X_{0b}: the minority carriers density minority decreases in the base, thus implying a negative gradient. The minority carriers are stored in this area and undergo recombination in volume and surface.

We note that at the X_{0b} depth, the gradient of the carrier density is null; there is no electron which cross the junction. X_{0b} thus defines the extension of the space charge region in depth in the base. We also observe that the of minority carriers density increases with the wave length and that the maximum density position X_{0b} moves towards the base.

II. 3. Gauss's law application

The Gauss's law is expressed as [19]:

$$\Phi=\oiint_{\Omega}\vec{E}.\vec{dS}=\frac{Q}{\varepsilon} \quad (12)$$

Ω is the Gauss surface, Q is the bulk global charge contained in the surface Ω and $\varepsilon=\varepsilon_0.\varepsilon_r$ with ε_0 =8.85.10^{-14} F.cm^{-1}is the permittivity for the vacuum and ε_r =12 is the relative dielectric constant of the semiconductor.

Hence in the base and the emitter, the electric field is null. Equation (12) becomes:

$$\frac{e.S(X_{0b}.N_b-X_{0e}.N_e)}{\varepsilon}=0 \quad (13)$$

X_{0e} represents the emitter extension region X_{0e}, N_e is the emitter doping density. Its values range from 10^{17} to 10^{19} cm^{-3}[20]; N_b is the base doping density and the doping ranges 10^{15} to $10^{17}cm^{-3}$ [20]; e = 1.6 $\cdot 10^{-19}$C is the elementary charge.

From equation (13), we deduce the expression:

$$X_{0e} = \frac{N_b}{N_e} \cdot X_{0b} \quad (14)$$

X_{0b} is determined by using the study of minority carriers density versus depth X of the base for various wave length (figure 2):

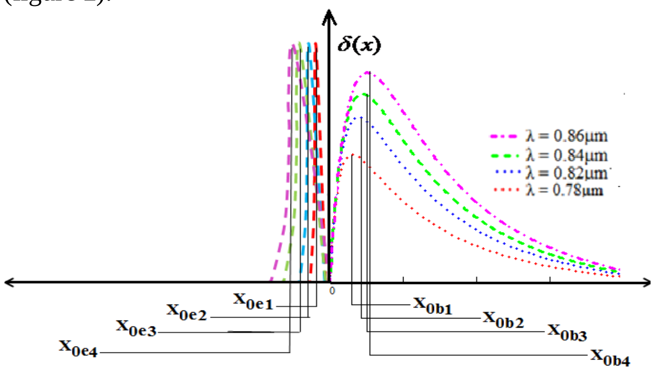

Figure 3 : Determination of X_{0b} for different wavelength values. ($\omega = 10^3$ rad.s^{-1}, Sf = 10^6 cm.s^{-1})

III. RESULTS AND DISCUSSIONS

From figure 3 the depth X_{0b} in the base is determined for various wave length. Thus the emitter extension region X_{0e} using equation (14) for various wave length. The results are represented in the table 1

Table 1: X_{0e} and X_{0b} values for different wave length

ʎ(µm)	N_b x10^{13} (cm^3)	N_e x 10^{17} (cm^3)	X_{0b}(cm)	X_{0e} (nm)
0.78	0,99478	1,5	0.0033	208
0.82	1,3115	1,5	0.0040	349
0.84	1,513	1,5	0.0045	453
0.86	1,7115	1,5	0.0053	604

Considering the results obtained, we plot in figure 4 the profile of the emitter extension region versus wave length.

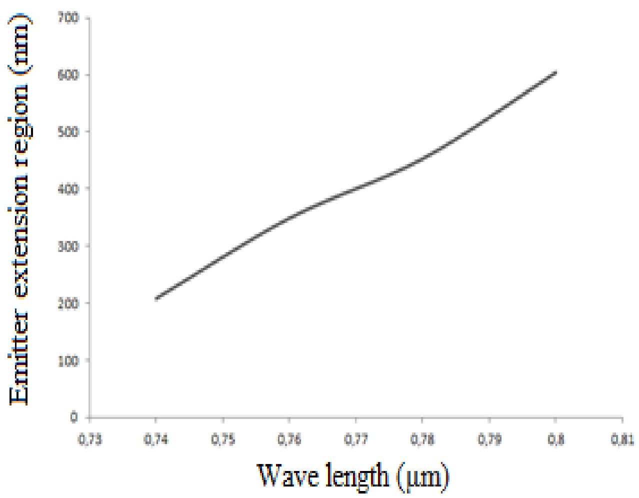

Figure 4: Emitter extension region versus wave length

Figure 4 shows that the emitter increases with the wave length. Indeed, the diffusion capacitance and the crossing of minority charge carriers at the junction depend of the space charge region extension [21]. If the carrier diffusion is limited, the photocurrent is low and the efficiency of the solar cell decreases. To improve the solar cell performance, minority carriers must have a certain energy that allows them to diffuse [21]. This may be related to an increase in wavelength. The extended space charge zone is favored by this diffusion phenomenon. This situation is observed in Table 1 by it increase with wavelength. When the wavelength increases the photogene rated carriers in the base increase. Thus, diffusion of minority charge carriers becomes large with the increase of the wavelength because these minority carriers will have sufficient energy which allows them to move

IV. CONCLUSION

The minority carriers density in base load is determined from the continuity equation then is studied for various values of the wavelength**.** Using Gauss's law the relationship between the emitter extension region and of the base is established. Thus, the study of emitter extension region depending on the wavelength is proposed and showed that the emitter extension region increases with the wavelength.

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