Capacitance Voltage Characterization of Bifacial Silicon Solar Cell: Effect of External Electric Polarization

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Abstract In this paper, we propose a study on the electric field effect resulting from a silicon solar cell external polarization on the thickness diffusion capacitance. From both excess minority carrier density and photo voltage, the diffusion capacitance is carried out, either as function of the voltage or the junction surface recombination velocity. Electric polarization effects are shown through different C-V plots.

Keywords: silicon solar cell - electric field - capacitance - voltage - characterization.

I. INTRODUCTION

The solar cells are the basis of the conversion of sunlight energy into electrical energy. Because of their modest performance, it is advisable to improve their performance and to monitor all their qualities throughout their development. The quality of the solar cell is, however, limited by the recombination processes by volume [1-2] (Shockley-Read-Hall, and Auger Irradiative) and by surface related of the imperfections crystal lattice. So many studies have been conducted in order to minimize this recombination and raise the conversion efficiency. Related to the operating conditions, solar cell characterization methods lead to the electrical and recombination parameters (bulk and surfaces) [3, 4]. Then solar cell is either under steady state condition [5] or under dynamic state [6] (i.e. transient decay and frequency)

II. THEORETICAL ASPECT

We present in Figure 1 the solar cell structure of a type np-p +, under polychromatic illumination. In order to study the influence of an external electric field on the behavior of the charge carriers in the base, we polarize by applying a voltage, and work in theory quasi-neutral base (QNB). The solar cell was reverse biased, the resulting electric field oriented zone n to the p region, will provide additional energy to the charge carrier to push each other to the junction. This electric field is the sum of the external field resulting polarization and the solar cell internal electric field. Under these conditions, the equation of the charge carrier's distribution in the base is given by equation (1) below.
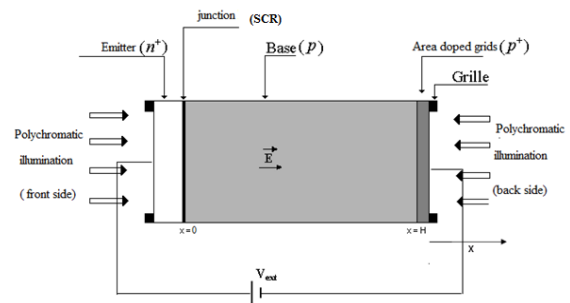

Figure 1: Bifacial solar cell structure to the n^+-pp^+ type under electric polarization and polychromatic illumination

$$\frac{\partial^2 \delta(x)}{\partial x^2} + \frac{\mu E}{D} \cdot \frac{\partial \delta(x)}{\partial x} + \frac{G(x)}{D} - \frac{\delta(x)}{L^2} = 0 \quad (1)$$

E represents the polarization electric field, μ carriers' mobility. D and L are respectively the diffusion coefficient and the diffusion length of minority carriers. $\delta(x)$ is the minority charge carriers density photogenerated in the base G (x) is the rate of generation given by [7]:

$$G(x) = \sum_{i-1}^{3} a_i \cdot e^{-b_i \cdot x} \quad (2)$$

a_i and b_i are coefficients from modeling of the generation rate overall radiations in the solar spectrum **[8]**. The expression of the minority carrier's density is given by equation (1) resolution:

$$\delta(x) = e^{\beta x} \cdot \left[A \cdot ch(\alpha \cdot x) + B \cdot sh(\alpha \cdot x) \right] + \sum_{i-1}^{3} c_i \cdot e^{-b_i \cdot x} \quad (3)$$

with:

$$c_i = -\frac{a_i \cdot L^2}{D \cdot [L^2 \cdot b^2_i - L_E \cdot b_i - 1]}$$

and

$$L_E = \frac{\mu.E.L^2}{D}$$

A and *B* are obtained with the boundary conditions at the emitter – base junction(x = 0) and at the back

surface(x = H) of the cell **[9, 10]** expressed as: -at the junction *(x=0)*:

$$Sf = \frac{D_n}{\delta(0)} \cdot \frac{\partial \delta(x)}{\partial x}\bigg|_{x=0} \qquad (4)$$

-at the back surface (*x=H*):

$$Sb = -\frac{D_n}{\delta(H)} \cdot \frac{\partial \delta(x)}{\partial x}\bigg|_{x=H} \qquad (5)$$

Sf and Sb are respectively the junction and back surface recombination velocity [10, 11]. To understand the electric field effect on extended junction space charge region, we illustrate in Figure 2 junction thickness extension under electric field effect Figure 2 shows a reverse polarization of the solar cell. The resulting electric field after this polarization is $E_0' = E_0 + E$. E_0 is the electric field in the space charge region without polarization and E is the electric field from the solar cell external polarization.
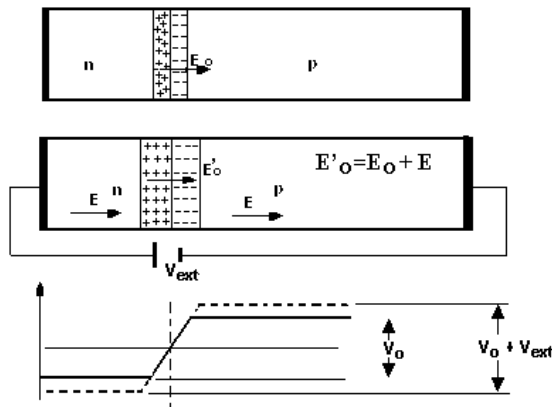

Figure 2: schematic illustration of the junction thickness extension under electric field effect

Vext and V_0 are respectively voltage from the space charge region in the absence of polarization and external circuit voltage. Thus, the minority charge carriers will be returned to the junction by the resulting electric field. These carriers reinforce the diffusion capacitance at the junction and contribute to junction thickness extension.

III. CAPACITANCE STUDY

Diffusing capacitance of the solar cell is considered as the ability of the resulting charge variation during the process of diffusion within the solar cell [11]. It is given by the following equation:

$$C = \frac{\partial Q}{\partial V} \qquad (6)$$

With:

$$Q = q\delta(x=0) \qquad (7)$$

By injecting (9) in (8), we have

$$C = q \times \frac{\partial \delta(x=0)}{\partial Vph} \qquad (8)$$

If we introduce the excess minority carrier recombination velocity at the junction in equation (8) we obtain following expression of the capacitance:

$$C = q \times \frac{\partial \delta(x=0)}{\partial Vph} = q \times \frac{\partial \delta(x=0)}{\partial Sf} \times \frac{1}{\frac{\partial Vph}{\partial Sf}} \qquad (9)$$

Or:

$$Vph = V_T \times \ln\left(1 + \frac{N_b}{n_i^2} \times \delta(0)\right) \qquad (10)$$

And:

$$\frac{\partial Vph}{\partial Sf} = V_T \times \frac{\frac{N_b}{n_i^2} \times \frac{\partial \delta(0)}{\partial Sf}}{\left(1 + \frac{N_b}{n_i^2} \times \delta(0)\right)} \qquad (11)$$

Therefore:

$$C = q \times \frac{\partial \delta(x=0)}{\partial Sf} \times \frac{1}{\frac{\partial Vph}{\partial Sf}}$$

$$= q \times \frac{\partial \delta(0)}{\partial Sf} \times \frac{1 + \frac{N_b}{n_i^2} \times \delta(0)}{V_T \times \frac{N_b}{n_i^2} \times \frac{\partial \delta(0)}{\partial Sf}}$$

$$= q \times \frac{\frac{n_i^2}{N_b}}{V_T} \times \left[1 + \frac{N_b}{n_i^2} \times \delta(0)\right] \qquad (12)$$

Thus,

$$C = q \times \frac{\frac{n_i^2}{N_b}}{V_T} \times \left[1 + \frac{N_b}{n_i^2} \times \delta(0)\right]$$

$$= \frac{q \times \frac{n_i^2}{N_b}}{V_T} + \frac{q \times \delta(0)}{V_T} \qquad (13)$$

Let:

$$Co = \frac{q \cdot \dfrac{ni^2}{Nb}}{V_T} \quad (14)$$

Co is the intrinsic capacitance under dark.
Replacing C_0 by its expression, equation (15) becomes:

$$C = Co + \frac{q \cdot \delta(0)}{V_T} \quad (15)$$

Considering the expression of the photo voltage from equation (10), solar cell capacitance can be expressed as:

$$C = C_0 \cdot \left[1 + \frac{N_b}{n_i^2} \cdot \delta(0)\right]$$
$$= C_0 \cdot \exp\left(\frac{Vph}{V_T}\right) \quad (16)$$

With equation (16), we obtain

$$\frac{C}{C_0} = \exp\left(\frac{Vph}{V_T}\right) \quad (17)$$

With the logarithmic function, equation (17) becomes:

$$\ln(C) - \ln(C_0) = \frac{Vph}{V_T} \quad (18)$$

The curve of the logarithm of the capacity versus the voltage is plotted in figure 3 versus photo voltage for different values of the bias electric field
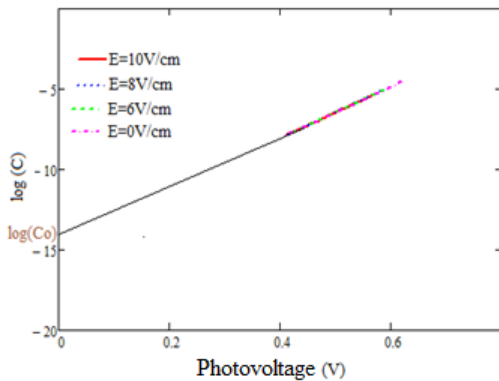

Figure 3: Log(C) versus the photo voltage for different values of electric field ($\mu=10^3 cm^2 V^{-1} s^{-1}$, L=0.02cm, H=0.03cm, D=26cm^2.s^{-1})

In Figure 3, we see that whatever the capacitance under darkness Co is independent of the electric field polarization. The intercept point obtained with the capacitance axis is the dark capacitance value [11]. The obtained value with this method is:

$$Co = 1.8.10^{-15} \, (F/cm^2)$$

Equation (16) allows us to observe the capacitance evolution versus the photo voltage for different values of electric field. It is represented in Figure 6
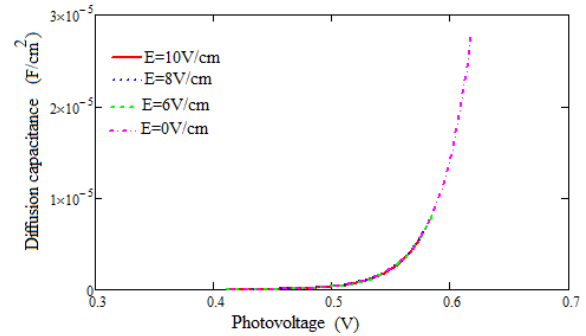

Figure 6: C-V characteristics for different values of electric field ($\mu=10^3 cm^2 V^{-1} s^{-1}$, L=0.02cm, H=0.03cm, D=26cm^2.s^{-1})

Figure 6 enables us to observe an increase of the capacitance when the photo voltage increases. Thus, for low values of the photo voltage (V< 0.5 volts), corresponding to operation of the solar cell in short circuit situation, the capacitance is very low. This is due to the massive crossing of minority charge carriers at the junction. Similarly , for large values of the photo voltage (V > 0.5 volts) , corresponding to operation of the solar cell in open circuit situation, the capacitance increases exponentially as a function of the photo voltage which is explained by a significant carrier storage at the junction . Thereafter, whatever the value of the electric field, we get the same value of the dark capacitance. We also observed an increase in the characteristic when the electric field decreases. Indeed, an increase in the electric field leads a reduction the minority carriers stored in the junction and therefore a decrease in diffusion capacitance. We represent in Figure 7 the capacitance versus junction recombination velocity for different values electric field:
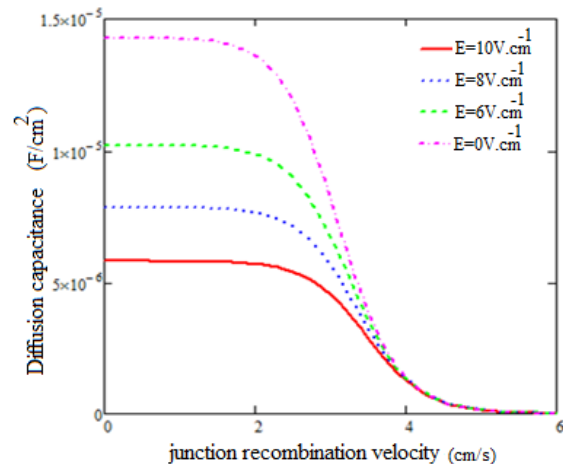

Figure 7: Capacitance verus junction recombination velocity for different values of electric field ($\mu=10^3 cm^2 V^{-1} s^{-1}$, L=0.02cm, H=0.03cm, D=26cm^2.s^{-1})

Figure 7 shows that the diffusion capacitance is a maximum at low values junction recombination. Minority charge carriers remain stored at the junction because they do not have enough energy to cross the junction. When the junction recombination velocity increases, the minority charge carriers begin to cross the junction and the diffusion capacitance. The diffusion capacitance is proportional to the width of the junction by the equation:

$$C = \frac{S.\varepsilon}{e} \qquad (20)$$

Where S is the surface area of the junction and e its thickness. ε represent the silicon dielectric constant. Under these conditions, the junction thickness is accompanied by a decrease in diffusion capacitance. The electric field promotes the flow of minority charge carriers across the junction and decreases the diffusion capacitance.

IV. CONCLUSION

This study showed a decrease in the density of minority charge carriers with the increase in the electric field. This phenomenon is accompanied by a moving of the excess minority carrier's density maximum to the junction who increases the quantity of minority carriers in the vicinity. We also showed that the electric field increases the photocurrent and decreases photo voltage and diffusion capacitance. This decreased of the solar cell capacitance is accompanied by the junction thickness.

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