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External Electric Field Influence on Series And Shunt Resistance Bifacial Silicon Solar Cell

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Abstract:

In this paper, we propose a study on the electric field effect resulting from the external polarization on the electrical parameters of solar cell. From the excess minority carrier's density in the solar cell, the photocurrent density and the photovoltage are determined. From the I-V characteristic, the series and shunt resistances are determined for different values of applied electric field.

Keyword: Solar cell - electric field - photocurrent – photovoltage – series and shunt resistance -.

1. Introduction

The photovoltaic effect is conversion of sunlight energy directly from into electrical energy from a devise know as photovoltaic cell or solar cell. Because of their modest performance, many research studies have been conducted in order to improve the manufacturing technology **[1-3]** of the solar cell under static condition or dynamic regime **[4, 5]**. Our contribution in this work is to study the effect of the electric field resulting from the solar cell external polarization on its electrical parameters.

2.Theory

In this study, we consider a n^+-pp^+ type solar cell [6], whose structure is represented in figure1.

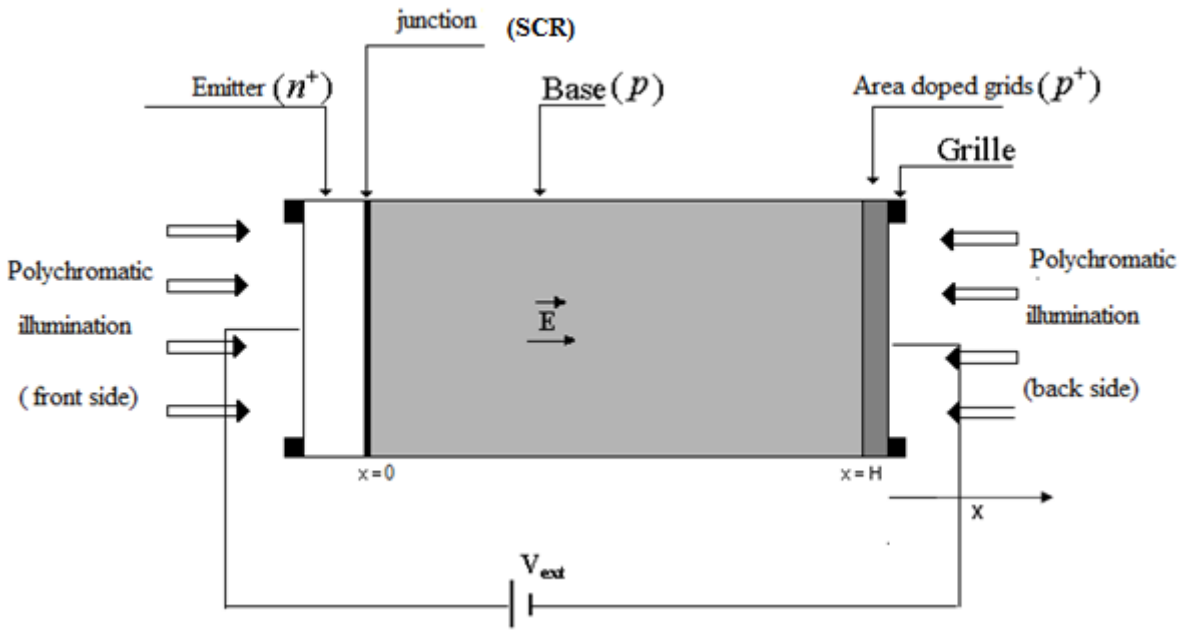

***Figure 1*: Bifacial solar cell structure to the n^+-pp^+ type under electric polarization and polychromatic illumination.**

The solar cell is illuminated by its front face of polychromatic illumination and is under external polarization by applying a voltage. Therefore, we will study the effect of external electric field resulting from the polarization behavior of the minority carriers in the base volume and we work in the quasi-neutral base theory **[7]**

2. Excess minority carrier's density

The external polarization creates an internal electric field $\vec{E}$ that influences the movement of minority carriers. This electric field is the sum of the external electric field resulting from the polarization and the solar cell internal electric field ($\vec{E} = \vec{E}_{ext} + \vec{E}_{\text{int}}$). Under these conditions, the equation of minority carrier's distribution in the base volume is given by:

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

With D being the diffusion coefficient, L the diffusion length, G(x) is the carrier generation rate of the minority carrier in the base **[8]** given by:

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

Where a_i and b_i are coefficients from modeling of the generation rate overall radiations in the solar spectrum **[9].**

The excess of minority carrier's density is obtained from equation (1) resolution and is given by:

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

With:

$$c_i = -\frac{a_i \cdot L^2{}_n}{D_n \cdot [L^2{}_n \cdot b^2{}_i - L_E \cdot b_i - 1]} \quad ; \quad \alpha = \frac{(L^2{}_E + 4 \cdot L^2{}_n)^{\frac{1}{2}}}{2 \cdot L^2{}_n} \quad ;$$

$$\beta = \frac{-L_E}{2 \cdot L_n^2} \quad \text{and} \quad L_E = \frac{\mu . E . L_n{}^2}{D_n}$$

A and *B* are obtained with the boundary condition at the emitter – base junction and at the back surface of the cell **[9, 10]** :

-at the junction *(x=0)* :

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

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

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

Sf and Sb are respectively excess minority carriers recombination velocities at the junction and at the back surface **[10, 11]**.

3. Photocurrent – Photovoltage characteristic (I-V)

The photocurrent density and the photovoltage depend on the junction recombination velocity Sf. By use of this concept of recombination velocity, we plot on figure 2 the solar cell I(Sf)-V(Sf) characteristic curves for different values of electric field [12].

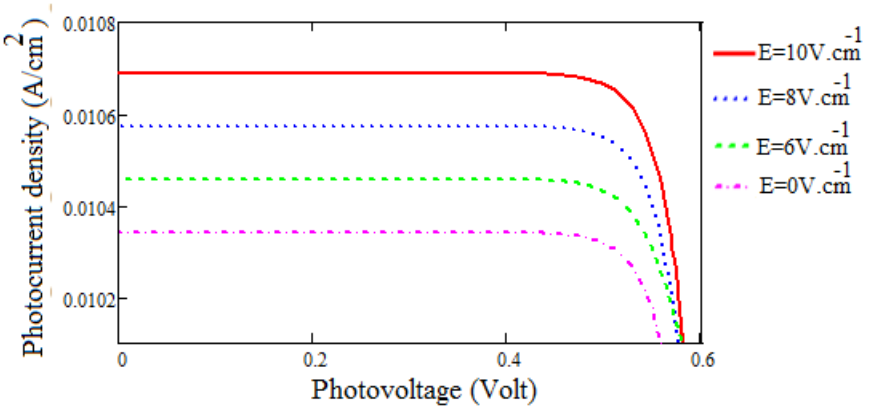

Figure 2: I-V characteristic for different values of electric field
($\mu=10^3 cm^2V^{-1}s^{-1}$, L=0.02cm, H=0.03, $D=26cm^2.s^{-1}$)

We notice two extreme positions: the open circuit situation and the short circuit situation. Between these two situations, there is the solar cell operation point variation determined by a variation of the junction recombination velocity. We observe that the electric field increases the photocurrent. Indeed, when the electric field increases, the minority carrier are accelerated, which enables them to acquire a sufficient energy to cross the junction and to take part in the photocurrent production. That's why we observe high photocurrent density for low junction recombination velocity i.e. in the open circuit condition (figure 3). The decrease of the open circuit voltage with the increase of the electric field is observed [12], because the electric field supports the flow of the minority carriers through the junction what decrease the quantity of minority carriers stored in the junction.

While keeping the solar cell under open circuit and short-circuit conditions, series and shunt resistances are respectively determined through out equivalent circuits.

4. Series resistance:

The series resistance is caused by the movement of electrons through the emitter and base of solar cell, the contact resistance between the metal contact and silicon and the resistance of metal grids at the front and the rear of the solar cell **[12, 13]**. The open circuit of the solar cell behaves like an ideal voltage generator (vertical characteristic). However, in experimental I-V curves, one can observe that beyond the open circuit operating point, the photocurrent decreases with the increase of the photo voltage. Beyond the open circuit, the I-V characteristic is not vertical but oblique. Thus, to the neighborhood of the open circuit the solar cell behaves like a real voltage generator i.e. a voltage source in series with the solar cell series **[14-19]:**

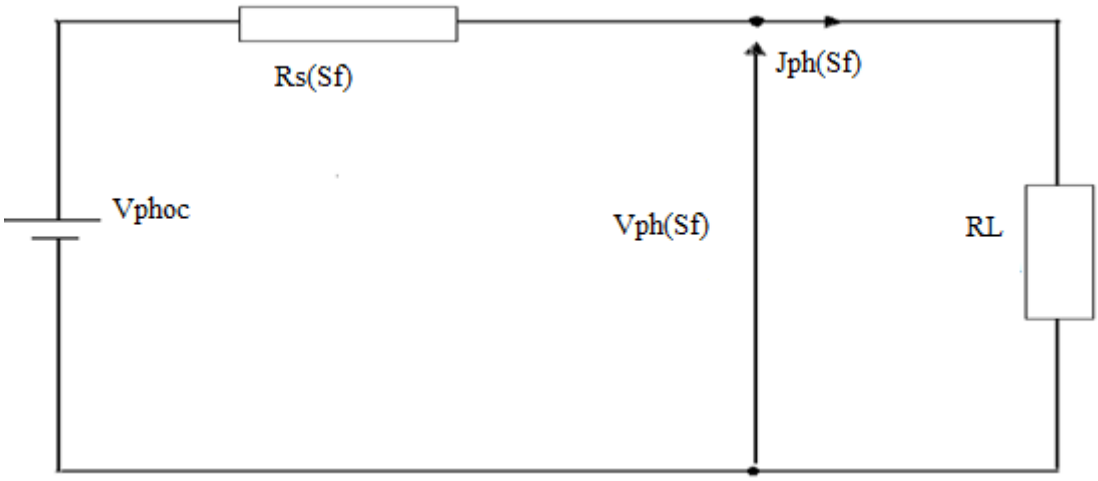

Figure 3: Equivalent electric circuit of the solar cell operating in open circuit condition

Using the circuit of figure 3, the series resistance can be expressed:

$$Rs(E,Sf) = \frac{Vph_{oc}(E) - Vph(E,Sf)}{Jph(E,Sf)} \tag{8}$$

We note that the series resistances depend on the parameters such as the open circuit voltage, photovoltage, photocurrent density: the junction recombination velocity and the applied Felectric field.

The curve of series resistance versus junction recombination velocity is plotted in figure 4 for different values of the electric field.

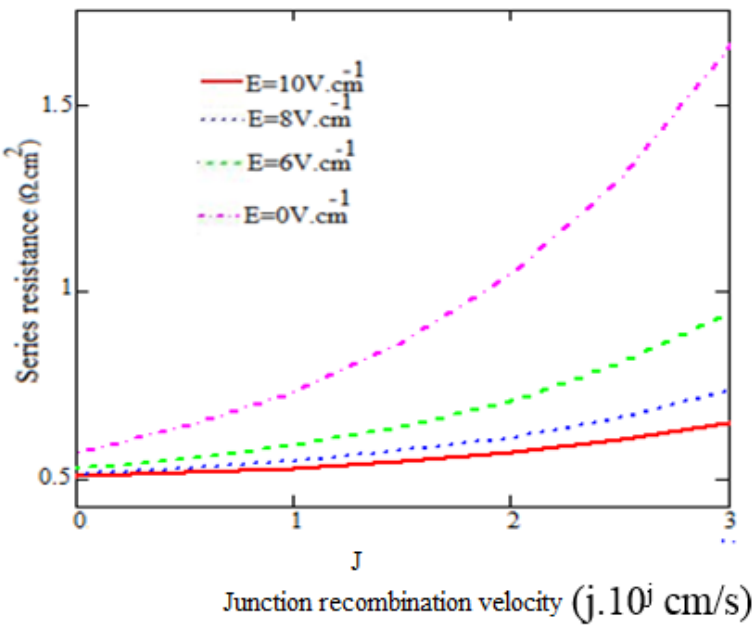

Figure 4: Series resistance versus junction recombination for different values of the electric field.
($\mu=10^3 cm^2V^{-1}s^{-1}$, L=0.02cm, H=0.03cm, $D=26cm^2.s^{-1}$)

Curves of figure 4 are increasing function of junction recombination velocity. Indeed, when Sf increases, more minority carriers cross the junction thus emptying the base. This reduction of the minority carriers entrained a reduction in dynamic conductivity in the base that yields an increase of resistivity and thus series resistance. We observe a decrease of the series resistance with the increase of the electric field, consequently a reduction of ohmic drop voltage with an increase of the photocurrent appears.

5. Shunt resistance

The shunt resistance is due to manufacturing defects and also lightly by poor solar cell design. It corresponds to an alternate current path for the photocurrent **[12, 13].**

It appears on the curves of figure 5 that near the short circuit the solar cell behaves like an ideal current generator (horizontal characteristic). The neighborhood of the short circuit, the solar cell behaves like a real current generator i.e a current source in parallel with the solar cell shunt resistance **[14, 15-19]:**

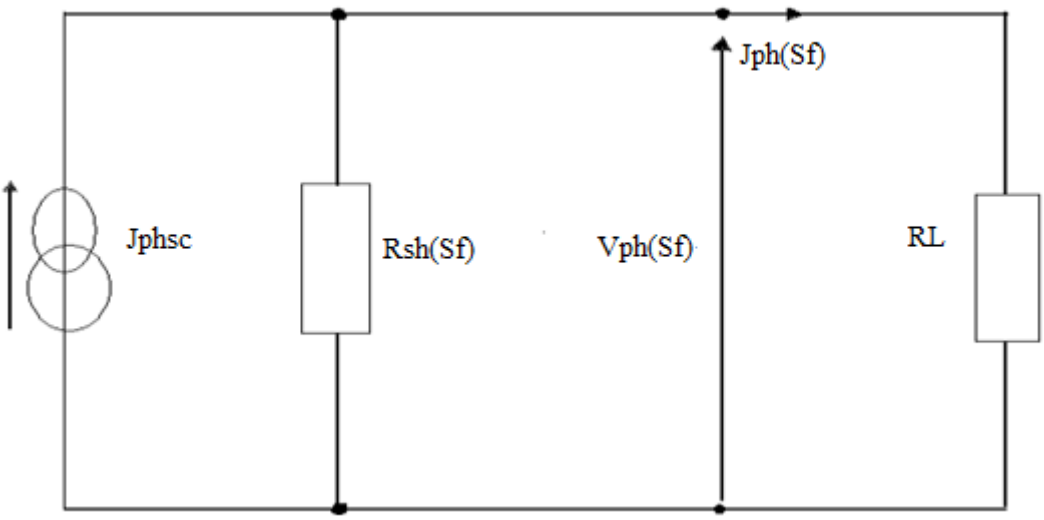

Figure 5: Equivalent electric circuit of the solar cell operating in short-circuit situation

Using the circuits of figure 5, the shunt resistances can be expressed as:

$$Rsh(E,Sf) = \frac{Vph(E,Sf)}{Jph_{sc}(E) - Jph(E,Sf)} \tag{9}$$

We note that the shunt resistance is function of photovoltage, short circuit current density, photocurrent density; the junction recombination velocity and the polarization electric field.

The curve of shunt resistance versus junction recombination velocity is plotted in figure 6 for different values of the electric field.

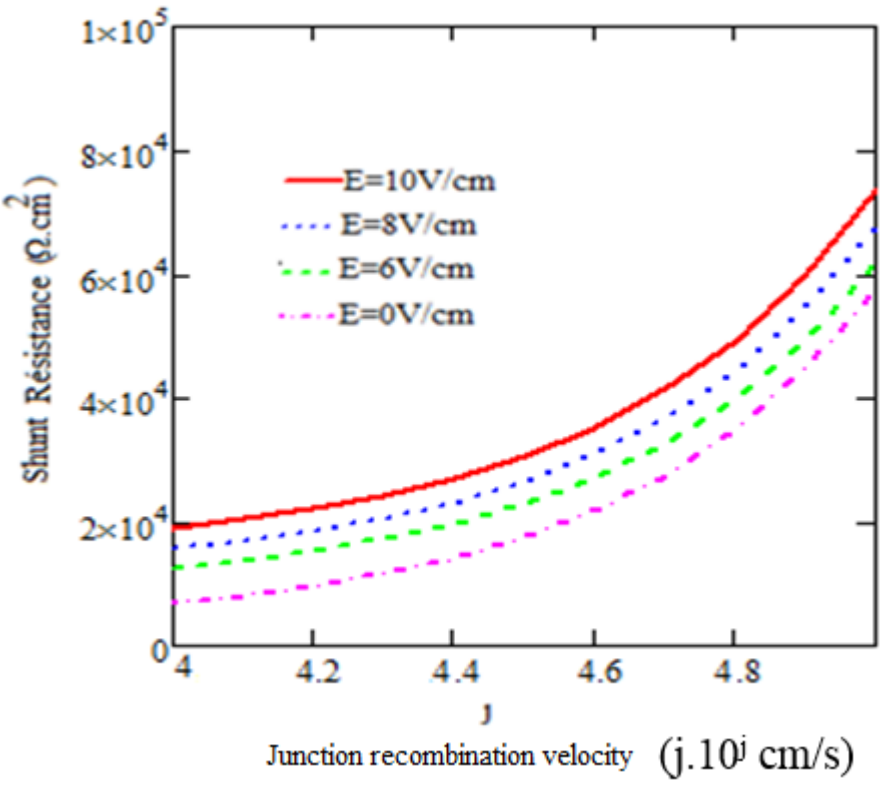

Figure 6: Shunt resistance versus junction recombination velocity for different values of the electric field. ($\mu=10^3 cm^2V^{-1}s^{-1}$, L=0.02cm, H=0.03cm, $D=26cm^2.s^{-1}$)

Curves of figure 6 are increasing function of junction recombination velocity. The increase of junction recombination velocity corresponds to an increase of minority carriers crossing the junction to participate to the photocurrent. We observe an increase of the shunt resistance with the electric field. Indeed, In the presence of the electric field, the minority carriers are accelerated enabling them to move in the base and escaping the recombination. One also notes from the equivalent circuit of the solar cell that an increase of shunt resistance permits to reduce the leak current tin this resistance (shunt resistance) and therefore permits to get an important photocurrent.

3. Conclusion

We showed the electric field resulting from the solar cell external polarization on its electrical parameters. From the excess minority carrier's density in the solar cell, the photocurrent density and the photovoltage are determined. From the I-V characteristic, the series and shunt resistance are determined then studied for different values of electric field. Series resistance decreases while shunt resistance increases with the applied electric field.

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