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Research Article

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Wavelength's effects on the photocurrent photovoltage characteristic and the shunt resistance in the absence and in presence of the electric field

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Abstract In this paper, we propose a theoretical study of electric field effect in the base of a polycrystalline silicon bifacial solar cell on the photocurrent photovoltage characteristic and the shunt resistance when it is doubly illuminated in both faces by a monochromatic light. Starting from the continuity equation that governs photovoltaic conversion, we obtained the expression of the excess minority carriers density of charges. Of the density expression, we have obtained the photocurrent and the photovoltage. Then we studied the photocurrent photovoltage characteristic for different values of the electric field and for different values of the wavelength in the absence and in presence of electric field.

Finally, we studied the shunt resistance versus recombination velocity at the junction for different values of electric field and for different values of the wavelength in the absence and in presence of electric field.

Keywords solar cell, electric field, wavelength, photocurrent, photovoltage, shunt resistance

1. Introduction

The operation of a photovoltaic cell under illumination can be modeled by considering the equivalent electrical diagram established by Shokley. It is composed of a Jph current generator which models the conversion of the luminous flux into electrical energy, in parallel with a diode which models the PN junction, a shunt resistance Rsh modeling the leakage currents which short-circuit the junction and a series resistance Rs representing the various connection resistances [1,2]. The improving efficiency of the photovoltaic cell necessarily involves mastering its various electrical parameters. In our study, we are interested in the wavelength of the electric field on the photocurrent photovoltage characteristic. From the photocurrent-photovoltage characteristic and the equivalent electric model of the solar cell, we will determine the expression of the shunt resistance. Then we will study the wavelength'effects on this resistance in the absence and in presence of electric field.

2. Theory

2.1. Presentation of the solar cell

Fig 1 represents the simplified structure of a one-dimensional n-p-p+ bifacial solar cell illuminated by the two faces.

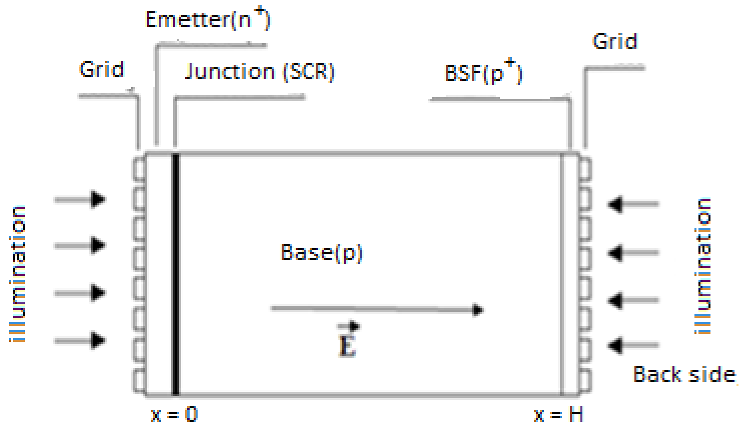

Figure 1: Schematic of a bifacial n-p-p+ silicon solar cell

H is the base thickness, SCR the space charge region and E the electric field in the base.

2.2. Excess minority carrier density

The excess minority carrier density in the base of the solar cell is given by the following equation [3-6]:

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

Where $\delta(x)$ is excess minority carrier density in the base, L the excess minority carrier diffusion length, D the diffusion coefficient in the base and G(x) represents the minority carrier's generation rate in the base for monochromatic incident light. The expression of G(x) is given by

$$G(x)=\alpha(1-R)\Phi_0\left[\exp(-\alpha x)+\exp\left(-\alpha(H-x)\right)\right] \quad (2)$$

α is the absorption coefficient associated to the wavelength, R is the reflexion coefficient and Φ_0 the incident photon flux.

A solution of the equation (1) can be written as:

$$\delta(x)=A.\exp\left(-\beta_n+\gamma_n\right)x+B.\exp\left(-(\beta_n+\gamma_n)x\right)+K_1\exp(-\alpha x)+K_2\exp(\alpha x) \quad (3)$$

With $$2\beta_n=\frac{\mu_n E}{D} \quad (4) \qquad \gamma_n=\frac{1}{2}\sqrt{4\beta_n^{\ 2}+\frac{4}{L^2}} \quad (5)$$

$$K_1=-\frac{\alpha L^2(1-R)\phi_0}{D\left(\alpha^2L^2-2\beta_n\alpha L^2-1\right)} \quad (6) \qquad K_2=-\frac{\alpha L^2(1-R)\phi_0.\exp(-\alpha H)}{D\left(\alpha^2L^2+2\beta_n\alpha L^2-1\right)} \quad (7)$$

Coefficients A and B are determined from the boundaries conditions [6-10]:

At the junction (x = 0) : $$\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=0}=\frac{Sf}{D}\delta(0) \quad (8)$$

$$Sf=Sf0+Sf(j) \quad (9)$$

Where Sf_0 is the intrinsic junction recombination velocity related to the shunt resistance.

$Sf(j)$ is the dynamic junction velocity related to the external load and quantifies how excess carriers flow through the junction in a real operating condition.

At the backside surface of the base (x = H): $$\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=H}=-\frac{Sb}{D}\delta(H) \quad (10)$$

Sb is the minority carrier recombination velocity at the backside surface.

We obtained:

$$A = \frac{K_1[\theta_1.\chi_2.\exp(-\alpha H) - \Theta_2.\chi_1.\exp(-(\gamma_n + \beta_n)H)] + K_2[-\xi_1.\chi_2\exp(\alpha H) + \xi_2.\chi_1.\exp(-(\gamma_n + \beta_n)H)]}{2.\exp(-\beta_n.H)[\Psi_1.sh(\gamma_n.H) + \Psi_2.ch(\gamma_n H)]} \quad (11)$$

$$B = \frac{K_1.[\Theta_1.\chi_4.\exp(-\alpha H) - \Theta_2.\chi_3.\exp((\gamma_n - \beta_n)H)] + K_2.[-\xi_1.\chi_4.\exp(\alpha H) + \xi_2.\chi_3.\exp((\gamma_n - \beta_n)H)]}{2.\exp(-\beta_n.H).[\Psi_1.sh(\gamma_n.H) + \Psi_2.ch(\gamma_n.H)]} \quad (12)$$

$$\chi_1 = \gamma_n.D + \beta_n.D - Sb \quad (13) \qquad \chi_2 = \gamma_n.D + \beta_n.D + Sf \quad (14)$$

$$\chi_3 = \gamma_n.D - \beta_n.D + Sb \quad (15) \qquad \chi_4 = \gamma_n.D - \beta_n.D - Sf \quad (16)$$

$$\Theta_1 = \alpha D - Sb \quad (17) \qquad \Theta_2 = \alpha.D + Sf \quad (18)$$

$$\xi_1 = \alpha.D + Sb, \quad (19) \qquad \xi_2 = \alpha.D - Sf \quad (20)$$

$$\Psi_1 = \gamma_n{}^2.D^2 - \beta_n{}^2.D^2 + \beta_n.D.Sb - \beta_n DSf + Sf.Sb \quad (21) \qquad \Psi_2 = D.\gamma_n(Sb + Sf) \quad (22)$$

2.3. Recombination parameter's determination

When $Sf(j) \geq 10^5 cm/s$, the photocurrent density tends to its maximum value which is the short-circuit-current [7, 8].Thus, we have the relationship [7, 8]:

$$\left.\frac{\partial J_{PH}}{\partial Sf}\right|_{Sf \geq 10^5 cm.s^{-1}} = 0 \quad (23)$$

The resolution of the equation (10) gives the effective value of the back side surface recombination velocity Sb which is expressed as:

$$Sb = D\frac{K_1[\alpha \Upsilon_1 + \Psi_4 sh(\gamma_n.H)] - K_2[\alpha \Upsilon_2 - \Psi_3 sh(\gamma_n H)]}{K_1[\Upsilon_1 + (\alpha - \beta_n)sh(\gamma_n H)] + K_2[\Upsilon_2 - (\alpha + \beta_n)sh(\gamma_n H)]} \quad (24)$$

With

$$\Upsilon_1 = \gamma_n(e^{(\beta_n - \alpha)H} - ch(\gamma_n H)) \quad (25) \qquad \Upsilon_2 = \gamma_n(e^{(\beta_n + \alpha)H} - ch(\gamma_n H)) \quad (26)$$

$$\Psi_3 = \gamma_n{}^2 - \beta_n{}^2 - \alpha\beta_n \quad (27) \qquad \Psi_4 = \gamma_n{}^2 - \beta_n{}^2 + \alpha\beta_n \quad (28)$$

Sb depends on the wavelength and the electric field

When we plotted the photocurrent density versus Sb, we then remarked that it is minimal and constant for $Sb \geq 10^5 cm/s$ as shown in [7, 8].We then set the relation [7, 8]:

$$\left.\frac{\partial J_{PH}}{\partial Sb}\right|_{Sb \geq 10^5 cm.s^{-1}} = 0 \quad (29)$$

We determine the intrinsic junction recombination velocities (Sf_0):

$$Sf0 = -D\frac{K_1.e^{-\alpha H}\{\alpha\gamma_n ch(\gamma_n H) + \Psi_4 sh(\gamma_n H)\} - K_2.e^{\alpha H}\{\alpha\gamma_n ch(\gamma_n H) - \Psi_3 sh(\gamma_n H)\} - \alpha\gamma_n e^{-\beta_n H}(K_1 - K_2)}{K_1\Omega_1 e^{-\alpha H} - K_2\Omega_2 e^{\alpha H} - \gamma_n e^{-\beta_n H}(K_1 + K_2)} \quad (30)$$

With

$$\Psi_3 = \gamma_n{}^2 - \beta_n{}^2 - \alpha\beta_n \quad (31) \qquad \Psi_4 = \gamma_n{}^2 - \beta_n{}^2 + \alpha\beta_n \quad (32)$$

$$\Omega_1 = (\alpha - \beta_n)sh(\gamma_n H) + \gamma_n ch(\gamma_n H) \quad (33) \qquad \Omega_2 = (\alpha + \beta_n)sh(\gamma_n H) + \gamma_n ch(\gamma_n H) \quad (34)$$

2.4. Photocurrent density

The solar cell's photocurrent density is obtained from the excess minority carrier density and calculated using the relation:

$$J_{ph} = q \cdot \left[D \cdot \left.\frac{\partial \delta(x)}{\partial x}\right|_{x=0} + \mu_n \cdot \mathrm{E} \cdot \delta(0) \right] \quad (35)$$

2.5. Photovoltage

The photovoltage of the solar cell is given by Boltzmann's relation:

$$Vph(Sf) = V_T . \ln\left(\frac{\delta(0, Sf)Nb}{n_i^2} + 1\right) \quad (36)$$

Where *Nb* is the base doping density, ni the intrinsic carriers density and V_T is the thermal voltage

3. Results and Discussions

3.1. Photocurrent photovoltage characteristic

3.1.1. Electric field effect

In fig 2, we present the profile of the photocurrent photovoltage characteristic for different values of the electric field.

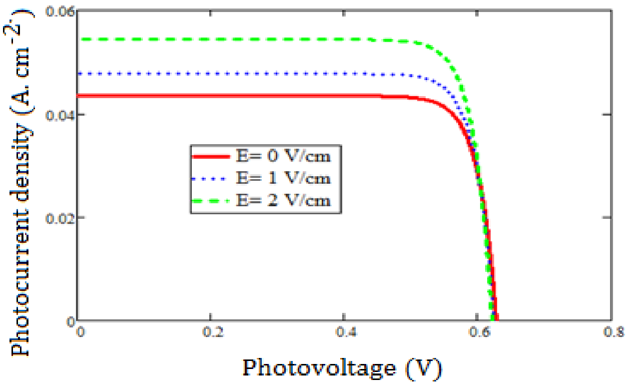

Figure 2: Photocurrent photovoltage characteristic for different values of the electric field
(λ = 0,7 µm, D = 26 cm^2.s^{-1}, L = 0,01cm,H = 0,03 cm)

These curves show that when the photovoltage delivered by the solar cell is minimum, the photocurrent is maximum: the solar cell operates in the vicinity of the short circuit. Inversely, when the voltage delivered by the solar cell is maximum, the photocurrent is minimal: the solar cell operates in the vicinity of the open circuit. Otherwise, these curves show the influence of the electric field on the current and the voltage delivered by the solar cell. When the electric field increases, the short-circuit current increases, the open circuit voltage decreases.

3.1.2. Wavelenght effect

In fig 3, we present the profile of the photocurrent photovoltage characteristic for different values of the wavelenght in the absence and in presence of electric field.

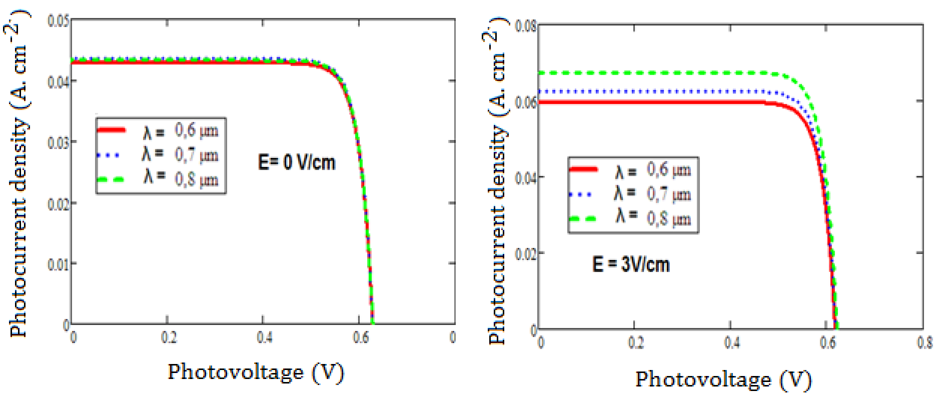

Figure 3: Photocurrent photovoltage characteristic for different values of the wavelength
(D = 26 cm^2.s^{-1}, L = 0,01 cm, H = 0,03 cm)

In the absence and in the presence of the electric field, the figure shows that the short-circuit current increases with the wavelength. But the variation wavelength doesn't influence the open circuit photovoltage.

3.2. Shunt resistance study

3.2.1. Expression of shunt resistance

To determine the shunt resistance of the solar cell, we consider in figure 4 the photocurrent photovoltage characteristic in the vicinity of the short circuit.

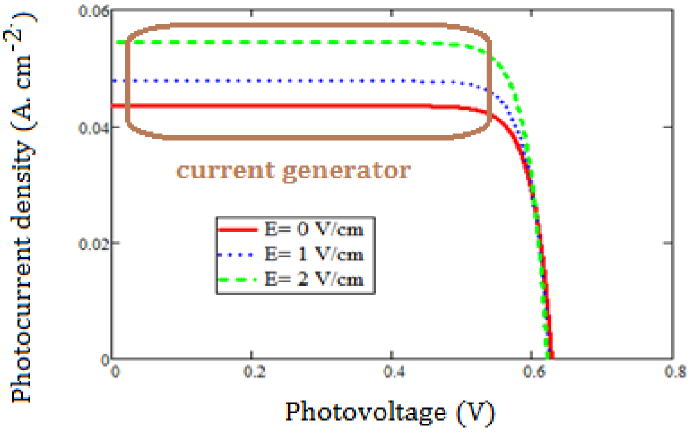

Figure 4: Photocurrent photovoltage characteristic in the vicinity of short circuit for different values of the electric field (λ = 0,7 μm, D = 26 $cm^2.s^{-1}$, L = 0,01cm, H = 0,03 cm)

We notice in the vicinity of the short circuit that the photocurrent-photovoltage characteristic is a horizontal straight line. The current started is almost independent of the voltage. This means in static mode, the solar cell behaves like an ideal current generator in the vicinity of the short circuit. If the solar cell was ideal the current delivered should remain constant whatever the value of the voltage. However we note a decrease in photocurrent at large phototension values. This behavior indicates that the solar cell can be considered as a real current generator: this is how the operation of a solar cell can be represented by the following electrical diagram [9,10].

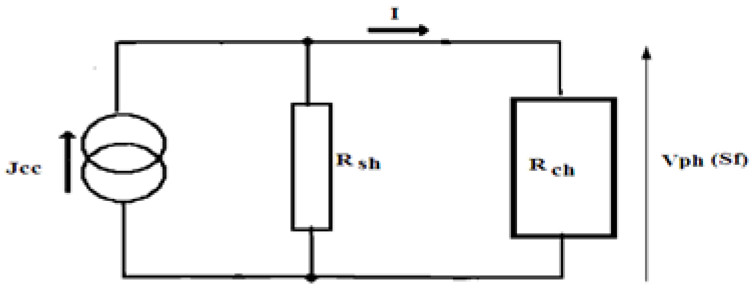

Figure 5: Equivalent circuit of a solar cell operating in short circuit

By applying the law of nodes from the figure, we get the expression of the shunt resistance which is given by the following relation.

$$Rsh(Sf) = \frac{Vph}{Jcc - I} \quad (37)$$

Rsh(Sf) is the shunt resistance
Vph is the photovoltage across the solar cell
Jcc is the short circuit current
I is the the current flowing through the load resistance
This expression allows us to study the effects of the electric field and wavelenght for simultaneous illumination of the solar cell.

3.2.2. Electric field effect of the shunt resistance

In figure 6, we plotted the shunt resistance versus the junction recombination velocity (Sf) for different values of the electric field.

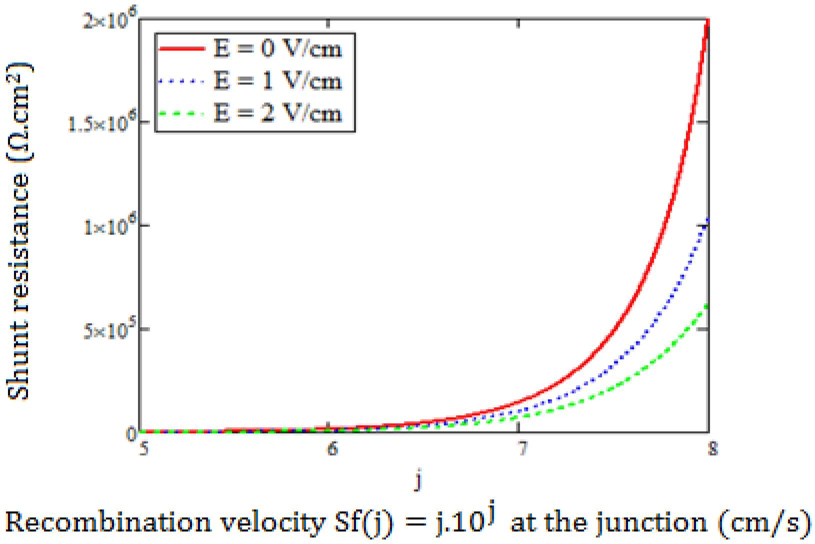

Figure 6: Shunt resistance versus recombination velocity at the junction for different values of the electric field (λ = 0,7 µm, D = 26 $cm^2.s^{-1}$, L = 0,01cm, H = 0,03 cm)

We notice that an increase in recombination velocity at the junction leads to an increase in shunt resistance. When Sf increases, the photocurrent increases so that the leakage current seems to decrease: everything happens as if Rsh increases with Sf.

We also observe that the shunt resistance of the solar cell decreases with the increase in the electric field. This behavior of the shunt resistance under the influence of the electric field is not advantageous for the solar cell. A drop in shunt resistance means that there are many recombinations within the solar cell and therefore an increase in leakage current.

3.2.3. Wavelength effect on shunt resistance

In fig 7, we represent the variation curves of the shunt resistance versus recombination velocity at the junction for different values of the wavelength in the absence and in presence of the electric field.

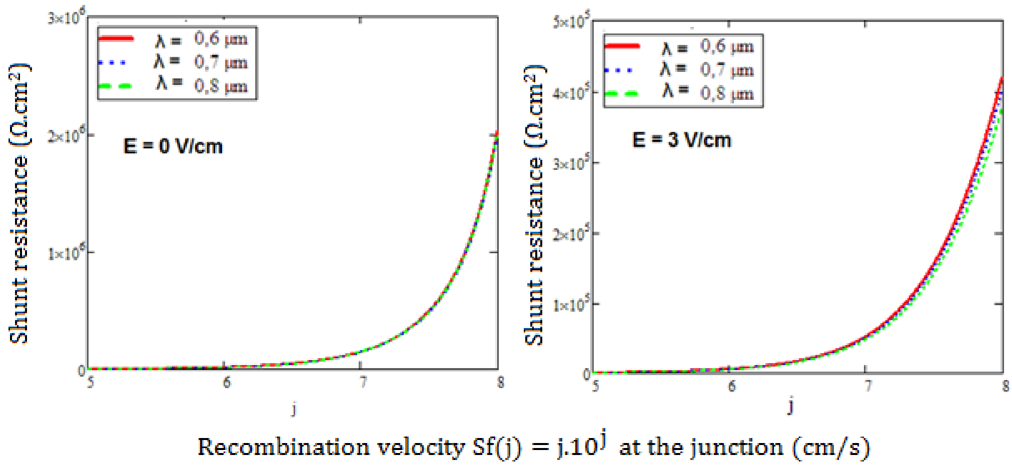

Figure 7: Shunt resistance versus recombination velocity at the junction for different values of the wavelength (D = 26 $cm^2.s^{-1}$, L = 0,01 cm, H = 0,03 cm)

In the absence of an electric field, the increase in wavelength has no effect on the shunt resistance. However, in presence of an electric field, the increase in wavelength favours the recombinations at the junction causing a decrease in shunt resistance.

4. Conclusion

In this paper, we study the wavelength effect on the photocurrent-photovoltage characteristic and on the shunt resistance in the absence and in presence of electric field when the bifacial solar cell is lit simultaneously by both faces.

The study showed when the electric field increases, the photocurrent in the vicinity of the short circuit increases but the photovoltage in the vicinity of the open circuit decreases. Then, when the wavelength increases, the photocourrent and the photovoltage increase in the presence and in absence of electric field.

The study also showed that the shunt resistance decrease when the wavelength increases in the presence of electric field.

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