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Research Article

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Effect of the Electric Field on the Bifacial Solar Cell for Illumination by the Back Face

Fakoro Souleymane Dia[1,2], Alioune Badara Dieng[1], Senghane Mbodji[2], Birame Dieng[2], G. Sissoko[1]

[1]Faculty of Science and Technology, University Cheickh Anta Diop, Dakar, Senegal
[2]Physics Department, Alioune Diop University, Bambey, Senegal

Abstract In this paper, we studied the influence of an external electric field applied in the base of a bifacial solar cell on its various electric parameters when it is illuminated by a monochromatic light on the back face. We have taken into account the actual values of intrinsic recombination velocities at the junction and the back face. These actual values of the velocities depend on the wavelength and the electric field. After making a brief presentation of the solar cell, we have made a detailed study of the carrier density starting from the continuity equation.

From density expression, we studied photocurrent, phototension and power of the solar cell as a function of the recombination velocity at the junction under or without the influence of the electric field. This study shown that these different electrical quantities increase with the electric field but this increase is less important compared to an illumination by the front face.

Keywords solar cell, recombination velocities, electric field, open-circuit, short-circuit, carrier density, photocurrent, phototension, electric power

1. Introduction

Figure 1 shows the simplified structure of a one-dimensional solar cell n-p-p$^+$ in the depth of the base illuminated by the back face.

Photovoltaic solar energy is the electricity produced by transforming part of the solar radiation with a solar cell. Generally, this solar cell manufactured based on monocrystalline or polycrystalline silicon has a low efficiency. The improvement of the solar cells efficiency requires necessarily thecontrol of the various electric parameters. That is why, our group is interested in the effect of an external electric field on the different electrical parameters, in static mode, when the solar cell is illuminated on the back face.

2. Theory

2.1. Presentation of the solar cell

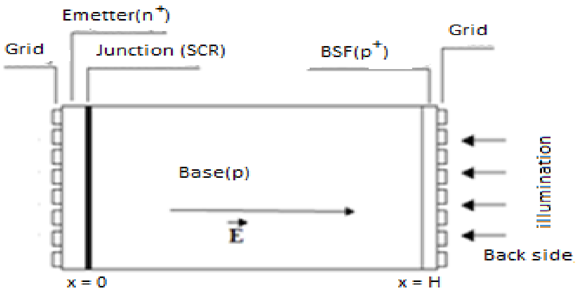

Figure 1: Schematic of a bifacial n-p-p$^+$ silicon solar cell

H is the base thickness and SCR the space charge region

2.2. Excess minority carrier density

When the solar cell is illuminated by the back face, the minority carriers are generated in the base. Excess minority carrier density is given by the following continuity equation [1]:

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

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, E the electric field and G(x) represents the minority carriers' generation rate in the base for monochromatic incident light. The expression of G(x) for illumination by the back face is given by

$$G(x)=\alpha(1-R)\Phi_0\exp(-\alpha(H-x)) \quad (2)$$

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

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

$$\delta(x)=A_2\exp(-\beta_n+\gamma_n)x+B_2\exp(-(\beta_n+\gamma_n))+K_2e^{\alpha x} \quad (3)$$

With: $2\beta_n=\frac{\mu_n E}{D}$ (4)

$$K_2=-\frac{\alpha L^2(1-R)\phi_0.\exp(-\alpha x)}{D(\alpha^2L^2+2\beta_n\alpha L^2-1)} \quad (5)$$

$$\gamma_n=\frac{1}{2}\sqrt{4\beta_n{}^2+\frac{4}{L^2}} \quad (6)$$

Coefficients A_2 and B_2 are determined sussing the boundaries conditions [2-6]:

At the junction (x = 0): $\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=0}=\frac{Sf}{D}\delta(0)$ (7)

$$Sf=Sf0+Sf(j) \quad (8)$$

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

$Sf(j)$ is 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): $\left.\frac{\partial\delta(x)}{\partial x}\right|_{x=H}=-\frac{Sb}{D}\delta(H)$ (9)

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

We obtained:

$$A_2=K_2\frac{F_1'(\gamma_nD+\beta_nD+Sf)\exp(\alpha H)-F_2'(\gamma_nD+\beta_nD-Sb)\exp(-(\gamma_n+\beta_n)H)}{2.\exp(-\beta_nH)\{\Psi_n.sh(\gamma_nH)+D.\gamma_n(Sb+Sf).ch(\gamma_nH)\}} \quad (10)$$

$$B_2=K_2\frac{F_1'(\gamma_nD-\beta_nD-Sf)\exp(-\alpha H)-F_2'(\gamma_nD-\beta_nD+Sb)\exp((\gamma_n-\beta_n)H)}{2.\exp(-\beta_nH)\{\Psi_n.sh(\gamma_nH)+D.\gamma_n(Sb+Sf).ch(\gamma_nH)\}} \quad (11)$$

$$F_1^{'} = -\alpha.D - Sb \quad (12)$$

$$F_2^{'} = -\alpha.D + Sf \quad (13)$$

$$\Psi_n = (\gamma_n^{\ 2} - \beta_n^{\ 2}).D^2 + (Sb - Sf)\beta_n.D + Sf.Sb \quad (14)$$

2.3. Photocurrent density

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

$$J_{ph} = q \cdot \left[D \cdot \left.\frac{\partial \delta(x)}{\partial x}\right|_{x=0} + \mu \cdot \mathrm{E} \cdot \delta(0) \right] \quad (15)$$

2.4. 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. Thus, we have the relationship [3,4]:

$$\left.\frac{\partial J_{PH}}{\partial Sf}\right|_{Sf \geq 10^5 cm.s^{-1}} = 0 \quad (16)$$

The resolution of the equation (16) gives the effective value of the back side surface recombination velocity which Sb is expressed as:

$$Sb = D \frac{\alpha.\gamma_n.e^{(\beta_n+\alpha)H} + \left(\gamma_n^{\ 2} - \beta_n^{\ 2} - \alpha.\beta_n\right)sh(\gamma_n.H) + \alpha.\gamma_n.ch(\gamma_n.H)}{(-\alpha - \beta_n)sh(\gamma_n.H) - \gamma_n.ch(\gamma_n.H) + \gamma_n e^{(\beta_n+\alpha)H}} \quad (17)$$

The intrinsic junction recombination velocity Sf_0 is determined by setting, $Sb=10^m$ ($m \geq 0$). 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. We then set the relation [3, 4]:

$$\left.\frac{\partial J_{PH}}{\partial Sb}\right|_{Sb \geq 10^5 cm.s^{-1}} = 0 \quad (18)$$

We determine the intrinsic junction recombination velocities

$$Sf_0 = D \frac{\left(\gamma_n^{\ 2} - \beta_n^{\ 2} - \alpha.\beta_n^{\ 2}\right)e^{(\beta_n+\alpha)H} sh(\gamma_n H) - \alpha.\gamma_n.\left(e^{(\beta_n+\alpha)H} ch(\gamma_n H) - 1\right)}{(\beta_n + \alpha)e^{(\beta_n+\alpha)H}.sh(\gamma_n H) - \gamma_n\left(e^{(\beta_n+\alpha)H} ch(\gamma_n H) - 1\right)} \quad (19)$$

2.5. Photovoltage

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

$$Vph(Sf) = V_T.\ln\left(\frac{\delta(0,Sf)Nb}{n_i^{\ 2}} + 1\right) \quad (20)$$

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

2.6. Solar cell electric power

The electric power delivered by the solar cell base to an external load circuit is expressed by the following relation

$$P(Sf) = I(Sf)..V_{Ph_u}(Sf) \quad \textbf{(21)}$$

With

$$I(Sf) = q.Sf(j).\delta(0) \quad (22)$$

I (Sf) is the photocurrent that crosses the external load resistance.

3. Results and discussions

3.1. Electric field effect on the minority density carrier charge

In fig 2, we present the profile of the minority density carrier charge carriers in the base of the solar cell in a situation of open-circuit and short-circuit respectively. These curves highlight the influence or not of electric field.

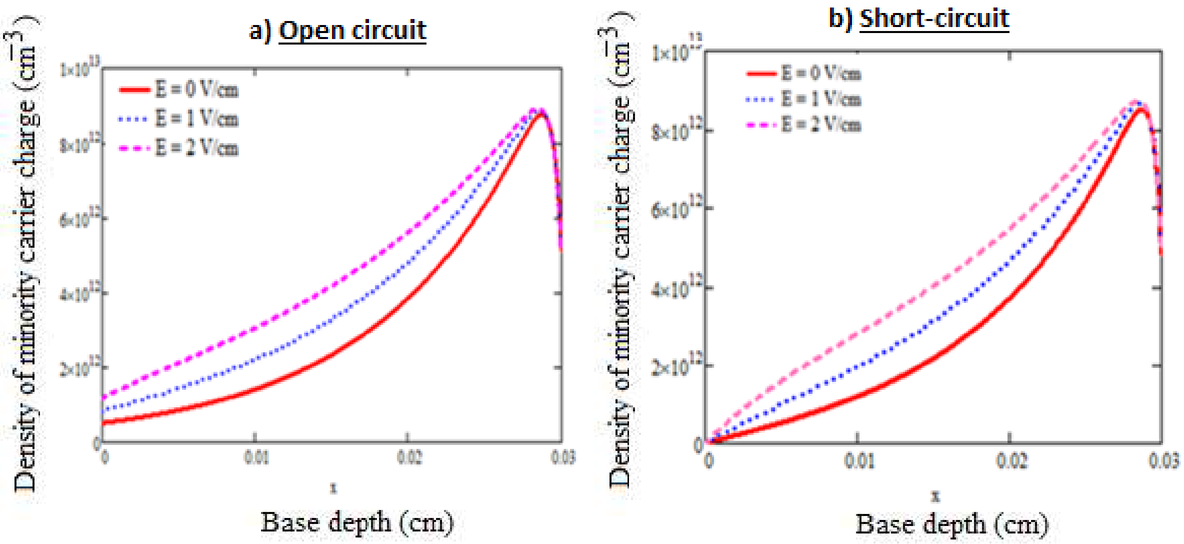

Figure 2: Minority carrier density versus the base depth for different values of the electric field (λ = 0,7μm, D = 26 $cm^2.s^{-1}$, L = 0,01cm, H = 0,03 cm)

Fig. 2 shows that the density of the carriers generated in the base of the photocell operating in open circuit or in short circuit is maximum near the back face because the illumination is done at this face.

In open-circuit, there is storage of the carriers at the junction; while, in short-circuit, the excess minority carrier goes through the junction and then participates in the photocurrent.

In open-circuit and in short-circuit, when the electric field increases, the density of minority carriers increases [7].

3.2. Electric field effect of the photocurrent density

In fig 3, we plotted the photocurrent density versus the junction recombination velocity (Sf) for different values of the electric field.

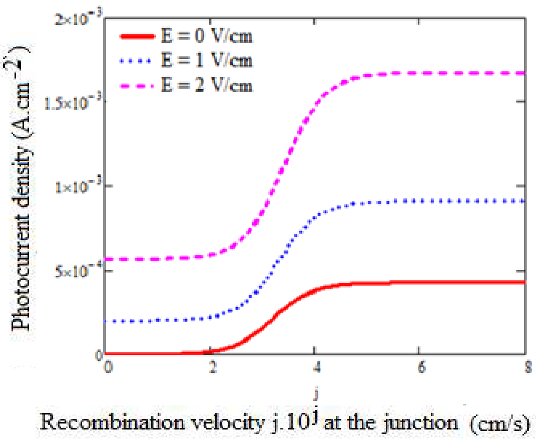

Figure 3: Photocurrent density versus junction recombination velocity (Sf) for different values of the electric field (λ = 0,7 μm, D = 26 $cm^2.s^{-1}$, L = 0,01cm, H = 0,03 cm)

In open circuit, the photocurrent density is minimal and constant: there is storage of the carriers at the junction. In short circuit, the photocurrent density is maximum and constant, there is not storage at the junction: the excess minority carrier goes through the junction and then participates in the photocurrent.
We also note when the electric field increases, the photocurrent increases but this current remains very low compared to an illumination by the front face [7].

3.3. Electric field effect of the photovoltage

In fig 4, we plotted the photovoltage versus the junction recombination velocity (Sf) for different values of the electric field.

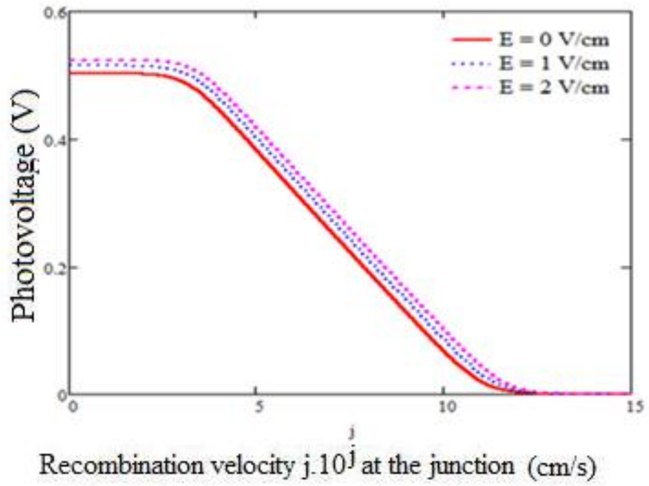

Figure 4: Photovoltage versus junction recombination velocity (Sf) for different values of the electric field (λ = 0,7µm, D = 26 $cm^2.s^{-1}$, L = 0,01cm,H = 0,03 cm)

In open circuit, the photovoltage is maximal and constant: there is storage of the carriers at the junction. Therefore it decreases when the recombination velocity at the junction increases because the carriers stored at the junction decrease.
We also note when the electric field increases, the photovoltage increases but this photovoltage is less important compared to an illumination by the front face [7].

3.4. Electric field effect of the power

In fig 5, we plotted the power versus the junction recombination velocity (Sf) for different values of theelectric field.

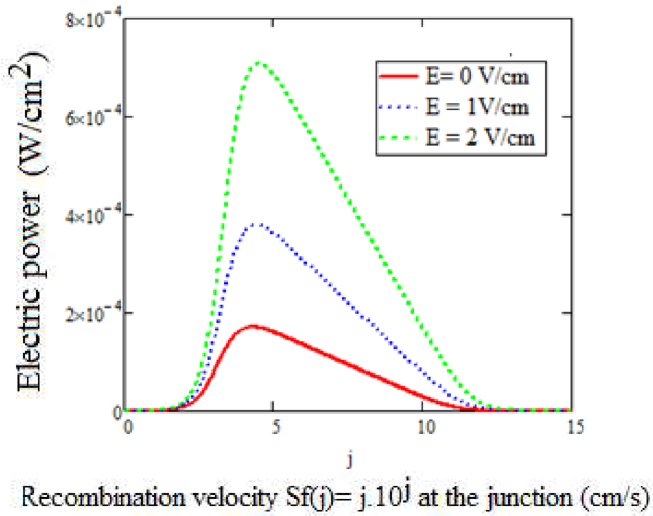

Figure 5: Power versus junction recombination velocity (Sf) for different values of the electric field (λ = 0,7µm, D =26 $cm^2.s^{-1}$, L = 0,01cm,H = 0,03 cm)

The power of the solar cell is zero in open circuit (Ioc = 0) and short circuit (Vsc = 0) but it is maximum for an intermediate operating point.This point is called the MPPT (Maximum Power Point Tracking) [8]. We notice that Power increases with the electric field but this power remains very low compared to an illumination by the front face [7].

4. Conclusion

We studied in this paper the effect of the electric field on the various electrical parameters of the solar cell. The study showed the presence of electric field influences the density of minority carriers in the base. The electric field accelerates the excess minority carriers towards the junction. So the photocurrent, the photovoltage, the electric power increase with the electric field when the solar cell is illuminated for the back face but this increase is less important compared to an illumination by the front face.

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