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Determination of the Recombination and Electrical Parameters of a Vertical Multijunction Silicon Solar Cell

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Abstract: A theoretical study of a vertical parallel junction under constant multispectral light has been made. By using a new approach of the carrier generation rate we determine the recombination and electrical parameters. The photocurrent density J_{PH} is presented as a calibrated function, diffusion length dependent. It intercepts with the experimental short circuit current density J_{SC}, at the minority carriers diffusion length L value. The photo voltage as a calibrated function of surface recombination velocity intercepts the experimental open circuit voltage at the junction intrinsic recombination velocity. The shunt and series resistances are presented respectively as a calibrated function of the surface recombination velocity and it intercepts with the value of junction recombination velocity in short circuit SF_{SC} or in open circuit SF_{OC} at the experimental shunt and series resistances value.

Keywords: Electrical parameter, recombination parameter, vertical junction

INTRODUCTION

Diffusion length and recombination velocity at the junction are some recombination parameters which influence the efficiency of the solar cell a lot. Parameters which limit the diffusion length are impurities and defects in polycrystalline silicon solar cell. Hence many methods have been developed for determining these recombination parameters of minority carrier's in the base of solar cell in steady state or in transient one (Barro *et al*., 2004, 2008).

In this study, we use a 1D modeling of a polycrystalline silicon solar cell in order to determine diffusion length and the intrinsic recombination velocity at the junction. The considered cell is an n+-p-n+-p structure. It is a vertical multijunction under constant multispectral light.Theory which helps us to determine the expression of the excess minority carriers' density, the photocurrent and the photo voltage is followed by the simulation results.

METHODOLOGY

Theory: We consider a vertical and parallel multijunction silicon solar cell with n+-p-n+-p structure. Since the base has a greater contribution to photo conversion, the following analysis will be focused only on this region. The solar cell is illuminated from front side with a constant monochromatic light parallel to the face of a junction (Wise, 1970).

A 1D model (Arora *et al*., 1981) showed in Fig. 1 helps us to make calculations.

Assumption: This model has been treated by using the following assumptions (Dione *et al*., 2009; Diallo *et al*., 2008):

- The illumination is uniform. We then have a generation rate depending only with depth in the base
- The front side which receives the radiation is covered with an anti-reflecting coating
- The contribution of the emitter and space charge region is neglected, so this analysis is only developed in the base region and we can then use the cartesian coordinates

Continuity equation: The continuity equation for the excess minority carrier density n(x) photo-generated in the base is:

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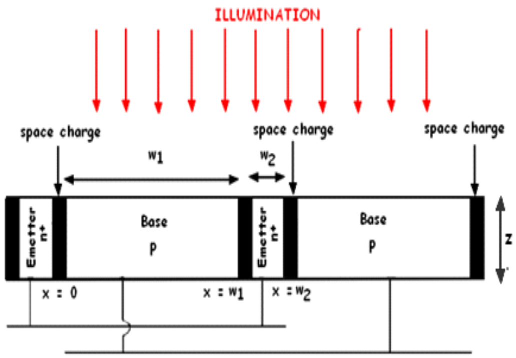

Fig. 1: Schematic structure of a vertical multijunction solar cell

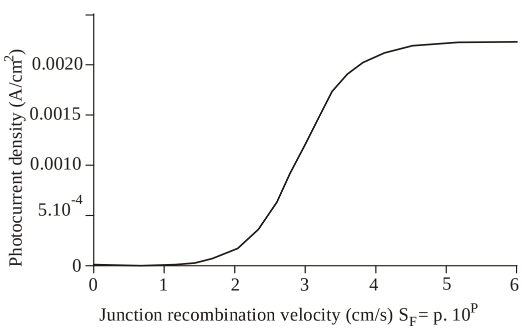

Fig. 2: Photocurrent density versus junction recombination velocity: Ln: 0.01 cm; w_1: 0.03 cm; Dn: 26 cm^2/s; z: 0.02 cm

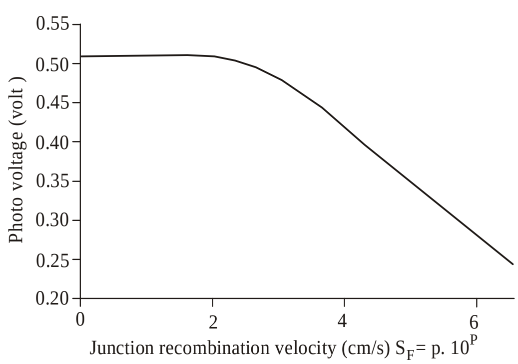

Fig. 3: Photo voltage versus junction recombination velocity: Ln: 0.01 cm; w_1: 0.03 cm; Dn: 26 cm^2/s; z: 0.02 cm

$$\frac{\partial^2 n(x)}{\partial x^2} - \frac{n(x)}{L_n^2} = \frac{G(Z)}{D_n} \qquad (1)$$

where, D_n represents the excess minority carriers diffusion constant and L_n their diffusion length. G(z) is the carrier generation rate for the multispectral light and is considered to be (Arora *et al*., 1981):

$$G(Z) = \sum_{\lambda_0}^{\lambda g} F_{0\lambda}.\alpha_\lambda.(1-r_\lambda).e^{-\alpha_\lambda.Z} \qquad (2)$$

α_λ and r_λ, are, respectively absorption and reflection coefficient, $F_{0\lambda}$ the incident photon flux for a given wavelength λ. λg (1.12 μm) is the cut off wavelength of the semiconductor and λ_0 (0.3 μm) is the minimum wavelength. These terms are to be summed up for the entire wavelength spectrum between λ_0 and λ_g.

Boundaries conditions: The continuity equation will be solved with the following boundaries conditions (Pernau and Bucher, 2002; Dione *et al*., 2009):
At the junction base-emitter:

$$D_n \left.\frac{\partial n(x)}{\partial x}\right|_{x=0} = SF.n(x)\Big|_{x=0} \qquad (3)$$

where, represent the recombination velocity at junction
The middle of the base:

$$\left.\frac{\partial n(x)}{\partial x}\right|_{x=\frac{w_1}{2}} = 0 \qquad (4)$$

with w_1 the thickness of base region.

RESULTS AND DISCUSSION

Photocurrent density: The electron photocurrent density can be written as:

$$J_{ph}(SF) = q.D_n.\left.\frac{\partial n(x)}{\partial x}\right|_{x=0} \qquad (5)$$

where, D_n is a constant defined above and q the elementary charge. It becomes if we take into the parallel character of the vertical junction (Dione *et al*., 2009):

$$J_{ph}(SF) = q.D_n.\left.\frac{\partial n(x)}{\partial x}\right|_{x=0} \qquad (6)$$

In Fig. 2 we have considered the current as a function of junction surface recombination velocity SF. The Fig. 2 shows that the photocurrent density is an increasing function of the junction recombination velocity. For large values of this velocity the photocurrent is a horizontal line which gives the short circuit current density J_{SC}. For low values of SF, any charge carrier crosses the junction and that corresponds to the open circuit condition, the photocurrent is zero.

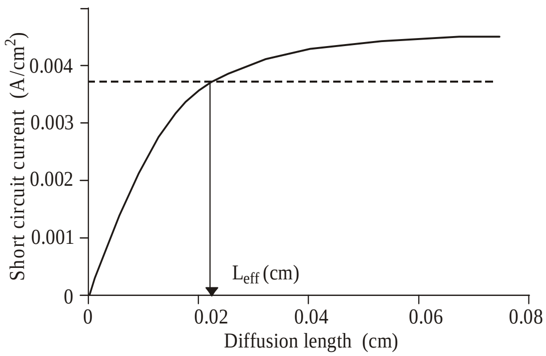

Fig. 4: Short circuit current versus diffusion length w_1: 0.03 cm; Dn: 26 cm^2/ s; z: 0.02 cm

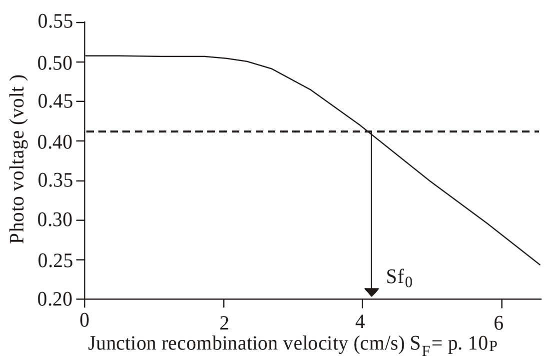

Fig. 5: Photo voltage versus junction recombination velocity: Ln: 0.01 cm; w_1: 0.03 cm; Dn: 26 cm^2/s; z: 0.02 cm

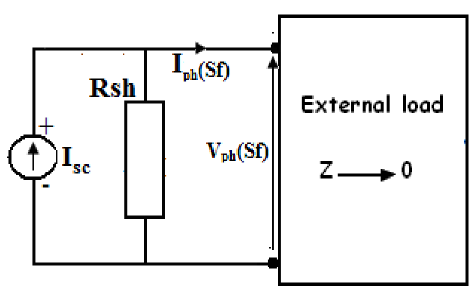

Fig. 6: Equivalent circuit of the solar cell in short circuit

Photo voltage: From Boltzmann law, the photo voltage can be written as:

$$V_{ph}(SF)=V_T.1n\left[1+\frac{N_B}{n_0^2}.n(x)\Big|_{x=0}\right] \qquad (7)$$

where, n_0, N_B and V_T, are, respectively the intrinsic carrier density at thermal equilibrium, the base doping density and the thermal voltage. Large value of SF, the voltage across the junction remains zero and for low values of this velocity the photo voltage is a horizontal line which corresponds to the open circuit voltage V_{OC}.

Table 1: Value of the effective diffusion length

Experimental short circuit current $J_{SC,ex}$ (A/cm²)	Effective diffusion length L_{EFF} (cm)
3.7×10^{-3}	0.022

Table 2: Intrinsic junction recombination value

Experimental open circuit current $V_{OC,ex}$ (V)	Intrinsic junction recombination SF_0 (cm/s)
0.412	9.983×10^{4}

Table 3: Junction recombination velocity in short circuit SF_{SC} and shunt resistance R_{SH} values

Value junction recombination velocity in short circuit SF_{SC}(cm/s)	Value shunt resistance R_{SH}(Ω .cm²)
7.388×10^{6}	1.969×10^{3}

Table 4: Junction recombination velocity in open circuit SF_{OC} and series resistance R_S values

Value junction recombination velocity in open circuit SF_{OC}(cm/s)	Value series resistance R_S(Ω.cm²)
2.747	3.184

Determination of recombination a parameter (Barro *et al*., 2004):

The effective diffusion length: In this method, we have used the expression of the short circuit photocurrent and the experimental values J_{scexp} of this parameter.We plotted both parameters versus the diffusion length in Fig. 4.We obtain the value of the effective minority carrier's diffusion length when the experimental short circuit current J_{SCex} intercepts with the calibrated function of J_{SC}.

The value of the effective diffusion length (L_{EFF}) and experimental short circuit current are presented in Table1.

The intrinsic recombination velocity: We represented in Fig. 5 the photo voltage as a calibrated function of surface recombination velocity and the experimental open circuit photo voltage value.

Using the same technique, the intrinsic junction recombination velocity is determined when the experimental open circuit voltage $V_{oc,ex}$ intercepts the calibrated photo voltage function.The result is given in Table 2.

Hence with these two different proposed methods, we have determined the values of the effective diffusion length and the intrinsic recombination velocity.

Determination of the electrical parameter: Series and shunt resistances are electrical parameters and their determination can be done by using many methods (Bashahu and habyarimana, 1995; El- adawi and al-nuaim, 2002).

The shunt resistance: Near the short circuit, the slope of I-V curve permits to determine the shunt resistance (Samb *et al*., 2010).

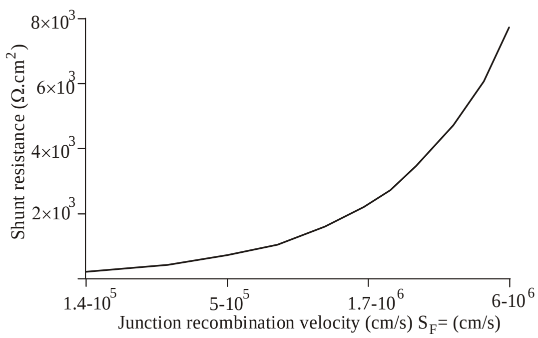

Fig. 7: Shunt resistance versus junction recombination velocity: Ln: 0.01 cm; w_1: 0.03 cm; Dn: 26 cm^2/s; z: 0.02 cm

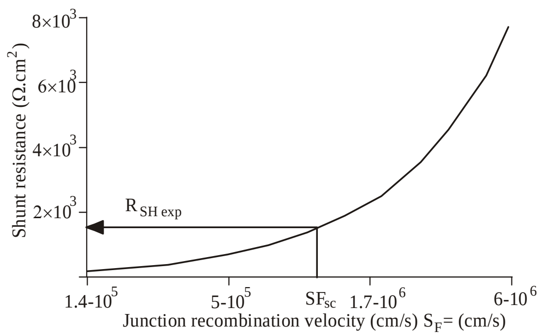

Fig. 8: Shunt resistance versus junction recombination velocity: Ln: 0.01 cm; w_1: 0.03 cm; Dn: 26 cm^2/s; z: 0.02 cm

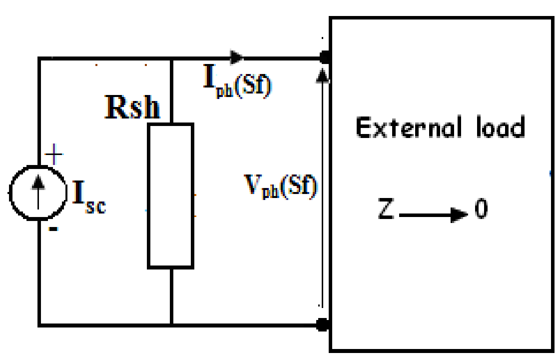

Fig. 9: Equivalent circuit of the solar cell in open circuit

This resistance is due to manufacturing defects and also lightly by poor solar cell design. It corresponds to an alternate current path for the photocurrent (Bashahu and habyarimana,1995; El- adawi and al-nuaim, 2002).

In Fig. 6 we propose the electrical equivalent model in short circuit of the solar cells and it is presented as current generator in parallel with the shunt resistance (Madougou *et al*., 2007; Barro *et al*., 2008; Mbodji *et al*., 2006). By using this circuit the expression of the shunt resistances can be written:

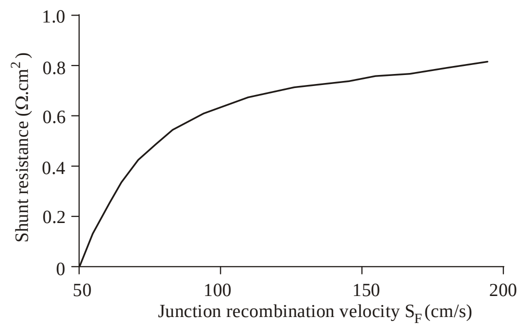

Fig.10: Series resistance versus junction recombination velocity: Ln: 0.01 cm; w_1: 0.03 cm; Dn: 26 cm^2/s; z: 0.02 cm

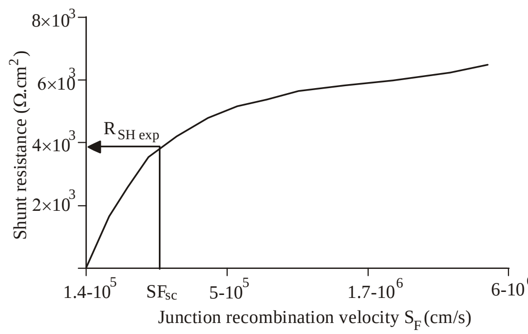

Fig.11: Series resistance versus junction recombination velocity: ln: 0.01 cm; w_1: 0.03 cm; dn: 26 cm^2/s; z: 0.02 cm

$$R_{SH}(SF)=\frac{V_{PH}(SF)}{J_{SC}-J_{PH}(SF)} \tag{8}$$

We presented in Fig. 7 the shunt resistance versusjunction recombination velocity SF. This Fig. 7 show that, the shunt resistance increases with SF meaning that, the photocurrent increases with SF because the space charge region is enlarged regarding an increase of the crossing of the electrons of the junction (Diallo *et al*., 2008; Madougou *et al*., 2007; Barro *et al*., 2008; Mbodji *et al*., 2006).

Determination of the value of shunt resistance (Dione *et al*., 2011): The shunt resistance is presented as a calibrated function of junction recombination velocity and it intercepts with the value of junction recombination velocity in short circuit SF_{SC} at the experimental shunt resistance value. And SF_{SC} is calculated by solving the following simple equation:

$$J_{PH}(SF)-J_{SC}=0 \tag{9}$$

where, $J_{PH}(SF)$ and J_{SC} represent respectively the photocurrent density and short circuit current density above defined. SF_{SC} is the solution of this equation.
This method is illustrated in Fig. 8.

The experimental value of shunt resistance is determined when the junction recombination velocity intercepts the R_{SH} calibrated function.The results is given in Table 3.

The series resistance: By using the slope of I-V curve and near the open circuit the solar cell can be presented as a photo voltage generator in series with the resistance and the external load (Samb *et al*., 2010).

This resistance is named series resistance and is caused by the movement of electrons through the emitter and base of the solar cell, the contact resistance between the metal contact and the silicon and the resistance of metal grids at the front and the rear of the solar cell (Bashahu and habyarimana, 1995; El- adawi and al-nuaim, 2002).

We show in Fig. 9 the electrical equivalent model in open circuit of the solar cell (Madougou *et al*., 2007; Barro *et al*., 2008; Mbodji *et al*., 2006).

The expression of the series resistance is given by:

$$R_S(SF) = \frac{V_{OC} - V_{PH}(SF)}{J_{PH}(SF)} \qquad (10)$$

The curve of series resistance versus junction recombination velocity is plotted in Fig. 10.

We note in Fig. 10 that the series resistance depends to junction recombination velocity and increase with SF. Increase of SF corresponds to an increase of the crossing of electrons at the junction leading to heat the metal grids in the front and the rear sides of the solar cell (Diallo *et al*., 2008; Madougou *et al*., 2007; Barro *et al*., 2008).

Determination of the value of series resistance (Dione *et al*., 2011): The series resistance as a calibrated function of surface recombination velocity intercepts SF_{OC} at the experimental value of series resistance. SF_{OC} represents the junction recombination velocity in open circuit and is the solution of the following equation:

$$V_{PH}(SF) - V_{OC} = 0 \qquad (11)$$

where, $V_{PH}(SF)$ and V_{OC} are, respectively the photo voltage and the open circuit voltage.We present this technique in the Fig. 11.

We obtain the value of the experimental series resistance when the junction recombination velocity in short circuit SF_{OC} intercepts the calibrated function of the series resistance R_S. The result is given in the following Table 4.

Hence with these different proposed methods, we have determined the values of the recombination and electrical parameters for a vertical parallel junction under constant multispectral light.

CONCLUSION

In this study we have presented a one dimensional modeling of a vertical parallel junction solar cell under constant multispectral light and in a real operating condition. From the calibrated function technique, such as:

- -Photocurrent density as a function of diffusion length, we have determined the effective diffusion length
- Photo voltage as a function of junction surface recombination velocity, we have determined the intrinsic recombination velocity
- Both shunt and series resistances as a function of junction surface recombination velocity, we have determined the values of shunt and series resistances

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