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Research Article

Influence of Temperature on the Electrical Parameters of a Vertical Parallel Junction Silicon Solar Cell under Polychromatic Illumination in Steady State

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Abstract: This study presents a theoretical study of a vertical parallel junction solar cell under multispectral illumination in steady state. Based on the diffusion equation, the excess minority carrier's density is expressed and both photocurrent density and photovoltage are determined. For all these parameters we showed the effect of external temperature with respect to the operating point of the solar cell through the junction recombination velocity.

Keywords: Photocurrent, photovoltage, solar cell, temperature, vertical junction

INTRODUCTION

From 100% of incident energy, a very small proportion is reflected by the surface of the solar cell and about 13% is extracted in the form of electrical energy; as a result it is more than 85% of the incident energy that must be dissipated as heat (Agroui, 1999**)**. This leads to an overheating of the solar cell and a decrease in the solar cell conversion efficiency given that electrical performance of a silicon solar cell is very sensitive to temperature (Agroui, 1999; Sze and Ng, 2007**)**. The aim of this study is to investigate the influence of temperature on electrical parameters such as: current density and photovoltage across the junction.

From the diffusion-recombination equation the excess minority carrier's density will be determined. Based on this excess carrier's density, the photocurrent density and the photovoltage are deduced. In the last part of this study we present our simulation results.

THEORY

This study is based on a vertical parallel junction silicon solar cell (Ly Diallo *et al*., 2012) presented on Fig. 1. The solar cell is illuminated along the z axis in steady state.
We assume that the following hypotheses are satisfied:

- The contribution of the emitter is neglected.
- Illumination is made with polychromatic light and is considered to be uniform on the z = 0 plane.

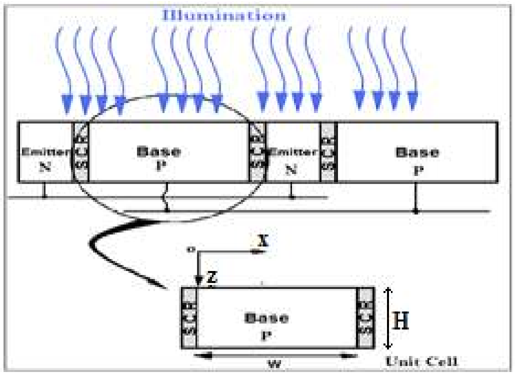

Fig. 1: Vertical parallel junction solar cell (H = 0.02 cm; W = 0.03 cm)

- There is no electric field without space charge regions.

Density of minority charge carriers: When the solar cell is illuminated, there are simultaneously three major phenomena that happen: generation diffusion and recombination.

These phenomena are described by the diffusion-recombination equation given by (Ly Diallo *et al*., 2012; Mbodji *et al*., 2011; Dione *et al*., 2009; Ly Diallo *et al*., 2008):

$$\frac{\partial^2 n(x)}{\partial x^2} - \frac{n(x)}{L^2} = -\frac{G(z)}{D} \tag{1}$$

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D is the diffusion constant and is related to the operating temperature through the relation (Francis Levy, 1995):

$$D = \mu.\frac{K}{q}.T \tag{2}$$

where,
q = The elementary charge
k = The Boltzmann constant
T = The temperature

G (z) is the carrier generation rate at the depth z in the base and can be written as (Furlan and Amon, 1985; Mohammad, 1987):

$$G(z) = \sum a_i e^{-biz} \tag{3}$$

where,
a_i and b_i : Obtained from the tabulated values of AM1.5 solar illumination spectrum and the dependence of the absorption coefficient of silicon with illumination wavelength
n(x), L, τ and μ : The excess minority carriers density, diffusion length, lifetime and mobility

The solution of Eq. (1) is:

$$n(x) = A\sinh(\frac{x}{L}) + B\cosh(\frac{x}{L}) + \sum \frac{a_i}{D} L^2 e^{-biz} \tag{4}$$

Coefficients A and B is determined through the following boundary conditions (Ly Diallo *et al*., 2012; Dione *et al*., 2009):

- At the junction (x = 0):

$$\left.\frac{\partial n(x)}{\partial x}\right|_{x=0} = \frac{S_f}{D} n(0) \tag{5}$$

This boundary condition introduces a parameter S_f which is called recombination velocity at the junction. Sf determines the charge carriers flow through the junction and is directly related to the operating point of the solar cell (Ly Diallo *et al*., 2012; Dione *et al*., 2009). The higher Sf is, the higher the current density will be.

- In the middle of the base (x = W/2):

$$\left.\frac{\partial n(x)}{\partial x}\right|_{x=\frac{w}{2}} = 0 \tag{6}$$

Equation (6) traduces the fact that excess carrier concentration reaches its maximum value in the middle of the base due to the presence of junction on both sides of the base along x axis (Fig. 1).

Photocurrent density: The photocurrent Jph is obtained from the following relation given that there is no drift current (Madougou *et al*., 2007):

$$J_{ph} = qD \left.\frac{\partial n(x)}{\partial x}\right|_{x=0} \tag{7}$$

Photovoltage: The photovoltage derives from the Boltzmann relation (Madougou *et al*., 2007):

$$\mathrm{V_{ph}} = \frac{k.T}{q} \cdot \ln\left(N_B \cdot \frac{n(0)}{n_i^2} + 1\right) \tag{8}$$

with,

$$n_i = A_n.T^{\frac{3}{2}}.\exp(\frac{Eg}{2KT}) \tag{9}$$

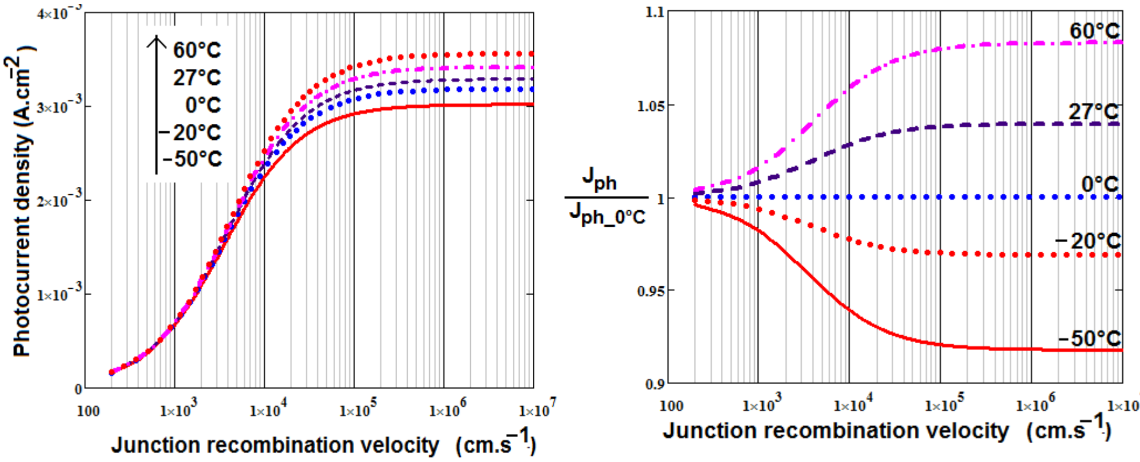
where,
n_i : The intrinsic concentration of minority carriers in the base (Francis Levy, 1995)
A_n : A specific constant of the material ($A_n = 3.87\text{x}10^{16}$ for silicon)
N_B : The base doping concentration in impurity atoms

RESULTS AND DISCUSSION

We present here some simulation results obtained from the previously described model.

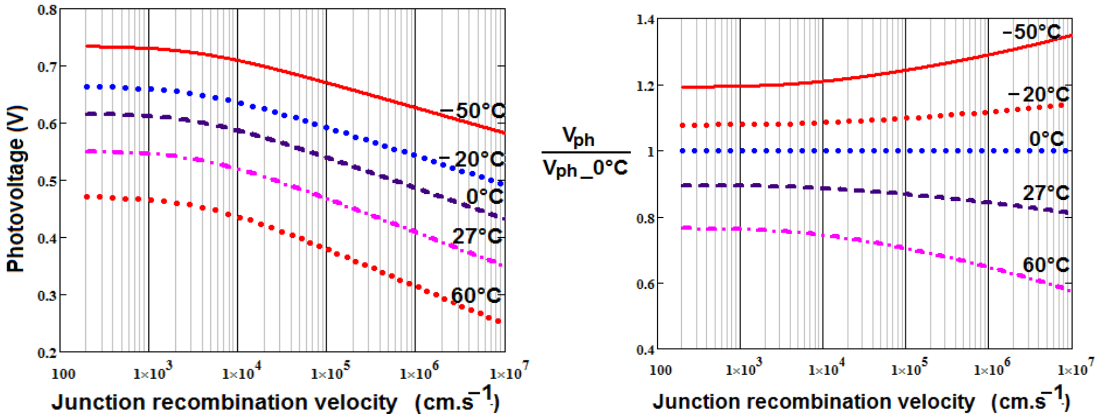
Photocurrent density: Figure 2a shows the photocurrent density profile versus junction recombination velocity for various operating temperatures.

One can note that photocurrent density increases rapidly with increasing junction recombination velocity until short circuit; given that junction recombination velocity traduces carrier flow through the junction, an increase of the former will induces an increase of the photocurrent density. High junction recombination velocity values are linked to short circuit operating point and very low Sf values arise near open circuit. For increasing operating temperature, Fig. 2a shows that the photocurrent density also increases. This can be well understood by the fact that the energy gap of the material decrease with respect to temperature (Sze and Ng, 2007; Karazhanov *et al*., 2010) leading to more minority charge carrier in the base and also that minority carrier in the base are accelerated due to increasing kinetic energy. Photocurrent density seems to be more sensitive to operating temperature for large Sf values (near short circuit) as can be seen on Fig. 2b where we plotted the ratio photocurrent density J_{ph} by



(a) (b)

Fig. 2: Photocurrent density versus junction recombination velocity for various temperatures ($z = 10^{-2}$ cm)



(a) (b)

Fig. 3: Photovoltage versus junction recombination velocity for various temperatures ($z = 10^{-2}$ cm)

photocurrent density at 0°C $J_{ph\_0°C}$. For the considered temperatures range, the net increase is about 8%.

Photovoltage: We present on Fig. 3a and b respectively the photo voltage V_{ph} across the cell and the ratio of photo voltage V_{ph} by photo voltage at 0°C $V_{ph\_0°C}$ both versus junction recombination velocity for various operating temperatures.

Figure 3a shows that the photovoltage decrease with junction recombination velocity Sf; when Sf increase, the carrier flow through the junction increase so that there is less and less carrier stored at the junction leading to a decrease of the photovoltage across the junction.

We also note that photovoltage decrease as operating temperature increase; effectively as we saw with photocurrent density, the bandgap energy decrease and minority charge carrier kinetic energy increase as temperature increase (Sze and Ng, 2007): this accelerate the carriers through the junction so that carriers could not be stored and photovoltage decrease.

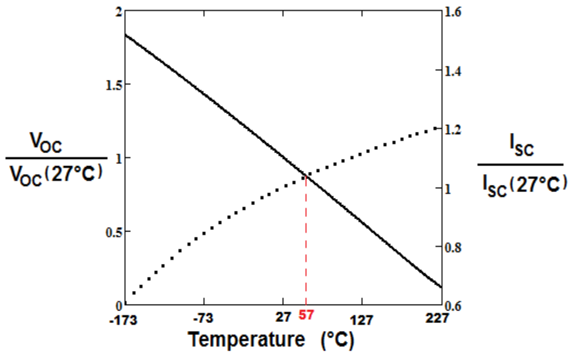


Fig. 4: Related short circuit current density and related open circuit voltage versus operating temperature

One can note that photovoltage is also more sensitive to temperature near short circuit Fig. 3b as previously noted on Fig. 2. The observed decrease in the photovoltage is lower than that of photocurrent and is about 3% for the same temperatures range.

We now plotted both short circuit current density Jsc and open circuit voltage Voc versus operating temperature (Fig. 4).

I_{SC} and V_{OC} are, respectively the maximum values of the photocurrent density and photovoltage. We have seen previously that the photocurrent and photovoltage vary in a manner contrary depending on the temperature. There is thus a temperature for which photocurrent density and photovoltage reach their possible maximum.

This temperature T_{cr} seems to be a threshold temperature that must never be exceeded otherwise solar cell performance will decrease significantly.

The critical temperature T_{cr} corresponds to the abscissa of the intercept point of the Jsc and Voc curves.

CONCLUSION

In the present study we presented a simulation study of a vertical parallel junction solar cell; we have shown that this kind of solar cell is also sensitive to operating temperature. We noted a significant increase on the photocurrent density of about 8% and a decrease of the photovoltage of about 3% for the considered range of temperature.

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