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# Effect of wavelength on the electrical parameters of a vertical parallel junction silicon solar cell illuminated by its rear side in frequency domain

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ABSTRACT

The influence of the illumination wavelength on the electrical parameters of a vertical parallel junction silicon solar cell by its rear side is theoretically analyzed. Based on the excess minority carrier's density, the photocurrent density and photovoltage across the junction were determined. From both photocurrent and the photovoltage, the series and shunt resistance expressions are deduced and the solar cell associated capacitance and conversion efficiency are calculated.

The aim of this study is to show the influence of the illumination wavelength on the electrical parameters of the cell and the behavior of both parasitic resistances and capacitance versus operating point.


## Introduction

The knowledge of both microscopic and electrical parameters of solar cell is of great importance in order to improve solar cell fabrication process and materials, leading to the higher conversion efficiency. Various techniques [1,2] have been developed for that purpose; particularly, previous work done by [3,4] have shown that the behavior of silicon solar cells is dependent on the illumination wavelength. The purpose of this paper is to investigate the influence of monochromatic illumination wavelength on the electrical parameters of a vertical junction polycrystalline silicon solar cell.

## Theory

Fig. 1 represents parallel vertical junction solar cells under monochromatic light, in one dimensional model (Ox), where the studied p-base1 interacts with the two adjacent emitters.

We present on Fig. 2 a unit cell of a vertical junction's silicon solar cell under various wavelengths. $H$ is the base width, $\theta$ is the illumination incidence angle and $x$ is the depth in the base.

Given that the contribution of the base to the photocurrent is larger than that of the emitter [5] our analysis will only be developed in the base region (see Figs. 2 and 3).

Taking into account the generation, recombination and diffusion phenomena in the base, the equation governing the variation of the minority carrier's density $\delta(x,y,z,t)$ under modulation frequency [6–8] is:

$$D(\omega)\cdot\frac{\partial^2\delta(x,\theta,t)}{\partial x^2}-\frac{\delta(x,\theta,t)}{\tau}=-G(z,\theta,t)+\frac{\partial\delta(x,\theta,t)}{\partial t} \tag{1}$$

$D(\omega)$ [9] and $\tau$ are respectively, the excess minority carrier diffusion constant and lifetime.

The excess minority carriers' density can be written as:

$$\delta(x,t)=\delta(x)\exp(-j\omega t) \tag{2}$$

Carrier generation rate $G(z,\theta,t)$ is given by:

$$G(z,\theta,\lambda,t)=g(z,\theta,\lambda)\exp(-j\omega t) \tag{3}$$

where

$$g(z,\theta,\lambda)=\alpha(\lambda)(1-R(\lambda))\cdot\phi(\lambda)\cdot\exp(-\alpha(\lambda)\cdot z)\cdot\cos(\theta) \tag{4}$$

$x$ is the base depth along $x$ axis, $\omega$ is the angular frequency, $\theta$ is the incidence angle, $z$ the base depth according to the vertical axis; Sf is the junction recombination velocity and $\lambda$ the illumination wavelength.

If we replace Eq. (2) with Eq. (1), the temporary part is eliminated and we obtain:

$$\frac{\partial^2\delta(x)}{\partial x^2}-\frac{\delta(x,\theta,t)}{L(\omega)^2}=-\frac{g(z,\theta)}{D(\omega)} \tag{5}$$

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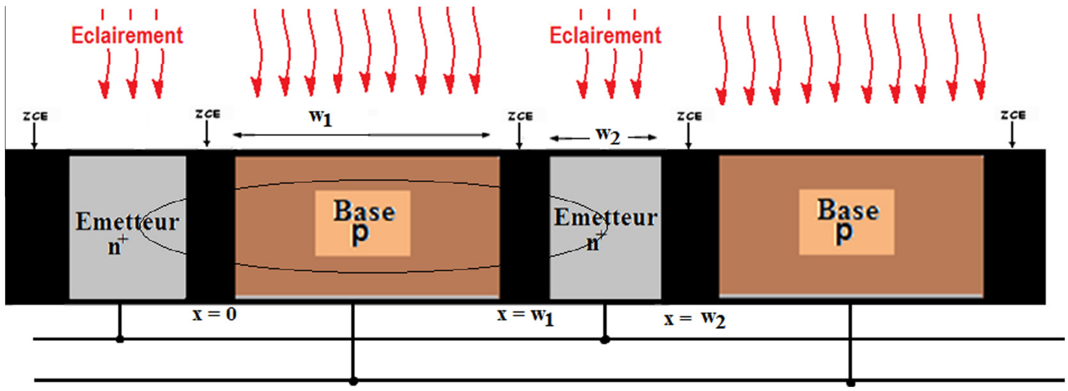


**Fig. 1.** Vertical parallel junction silicon solar cell.

The solution of this equation is:

$$\delta(x,\omega,\theta,z,Sf,\lambda) = A\cosh\left(\frac{x}{L(\omega)}\right) + B\sinh\left(\frac{x}{L(\omega)}\right) + \frac{L(\omega)^2}{D(\omega)} \cdot \alpha(\lambda)(1-R(\lambda))\cdot\phi(\lambda)\cdot\exp(\alpha(\lambda)\cdot z)\cdot\cos(\theta) \quad (6)$$

Coefficients A and B are determined through the following boundary conditions [10]:

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

$$D(\omega)\cdot\left.\frac{\partial\delta(x,\omega,\theta)}{\partial x}\right|_{x=0} = Sf\cdot\delta(x,\omega,\theta)|_{x=0} \quad (7)$$

$Sf$ is the excess minority carrier's recombination velocity at each junction [11].

- at the middle of the base ($x = H/2$) [12]:

$$D(\omega)\cdot\left.\frac{\partial\delta(x,\omega,\theta)}{\partial x}\right|_{x=\frac{H}{2}} = 0 \quad (8)$$

The excess minority carriers in the base will flow to the two junctions by diffusion; the photocurrent density is given by the following expression:

$$J_{Ph} = 2\cdot q\cdot D(\omega)\cdot\left.\frac{\partial\delta(x,\omega,\theta)}{\partial x}\right|_{x=0} \quad (9)$$

where $q$ is the elementary charge.

Based on the excess minority carrier's density, we can determine the photovoltage across the junction, according to the Boltzmann relation, as inutile. The unit of cell can be represented as two cells mounted in parallel, composed of half of the base associated to emitter1 and 2. From Eq. (8) (see Fig. 3) each half of the base will act as ideal back surface field (recombination velocity at $H/2$ remained zero).

The photovoltage across the junction, according to the Boltzmann relation, is obtained as:

$$V_{Ph} = V_T\cdot\ln\left[1 + \frac{Nb}{n_0^2}\cdot\delta(0)\right] \quad (10)$$

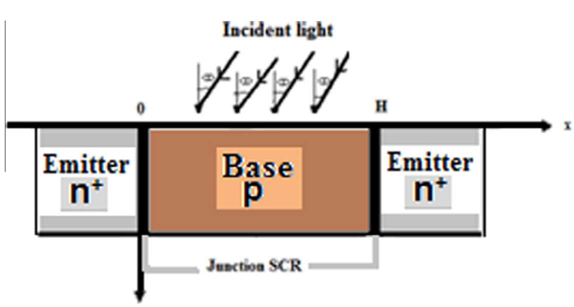


**Fig. 2.** Unit cell of a vertical parallel junction silicon solar cell.

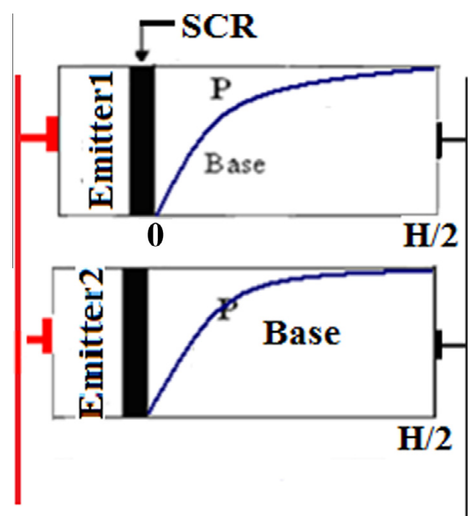


**Fig. 3.** Minority carrier distribution in the base.

with $V_T$ the thermal voltage, $Nb$ the base doping density, $n_i$ the intrinsic carriers' density.

The series and shunt resistances are given by the relations (10) and (11) [13–19]:

$$Rs(\omega,\theta,z,Sf,\lambda) = \frac{V_{co} - \mathrm{V_{ph}}(\omega,\theta,z,Sf,\lambda)}{\mathrm{J_{ph}}(\omega,\theta,z,Sf,\lambda)} \quad (11)$$

$$Rsh(\omega,\theta,z,Sf,\lambda) = \frac{\mathrm{V_{ph}}(\omega,\theta,z,Sf,\lambda)}{J_{cc} - \mathrm{J_{ph}}(\omega,\theta,z,Sf,\lambda)} \quad (12)$$

The charge variation in the base leads to a corresponding photovoltage variation across the junction; this gives rise to an associated capacitance. This capacitance is mainly due to the fixed ionized charge (dark capacitance) at the junction boundaries and the diffusion process (diffusion capacitance) [19–26]. The solar cell's capacitance can be defined by:

$$C = \frac{dQ}{dV} \quad (13)$$

with

$$Q = q\delta(x)|_{x=0} \quad (14)$$

Given the photovoltage expression (Eq. (10), the capacitance can be rewritten as:

$$C(\omega,\theta,z,Sf,\lambda) = \frac{q}{V_T}\cdot\left(\frac{n_i^2}{Nb} + \delta(0)\right) \quad (15)$$