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Influence of Temperature on the Serial and Shunt Resistance of a Silicon Solar Cell under Polychromatic Illumination in Static Mode

Babou DIONE[1#], Mountaga BOIRO[2], Mame Fadiamé THIAM[3]

[123]Physical Department, University Cheikh Anta Diop of Dakar, 5005 Dakar, Senegal.

[#]corresponding author

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Babou DIONE /0000-0002-5367-0839

ABSTRACT

This work presents a study of the influence of temperature on the series and shunt resistance of a silicon solar cell under polychromatic illumination. First, a theoretical study allowed us to give the expression of the density of minority carriers. From this expression of the minority carrier density, we determined the expression of the current density and the photovoltage. The expressions of the short circuit current density and the open circuit voltage were also determined. Under polychromatic illumination and temperature, we find that the short circuit current Icc and the open circuit voltage Vco have quasi-linear behaviour. The results obtained show that the series resistance Rs is of the type with a positive temperature coefficient, while the shunt resistance Rsh is of the type with a negative temperature coefficient.

Keywords: Silicon solar cell, temperature, Resistors series and shunt.

Introduction

The use of solar cells as converters of solar energy has created the need to study these systems to optimize them. The optimization and quality of a solar cell can be defined by the measurement of the phenomenological parameters involved in the recombination process of minority carriers. Several studies have indicated that the operation of solar cells depends strongly on several parameters: internal [1,2,3] (related to the device itself; the technology of elaboration of the photovoltaic device) and external [4,5] (related to the surroundings of the operation: illumination, temperature, etc.). The study of the influence of these different parameters on the operation of solar cells is possible through the knowledge of the influence of each parameter on the I-V characteristic of the cell [6,7].

In this paper, we study a silicon solar cell under polychromatic illumination and the effect of temperature on the main parameters: the short-circuit photocurrent density Icc, the open-circuit photovoltage Vco and on the series and shunt resistance.

Temperature is a critical parameter in the behaviour of solar cells. It has a great influence on the electrical parameters of the solar cell such as the series and shunt resistance [8, 9, 10, 11].

Hence, the importance of studying the influence of temperature to optimize the performance of solar panels since they are exposed to radiation.

Theoretical

The type of photostack is n+-p-p+ and its structure is shown in Figure 1 [12].

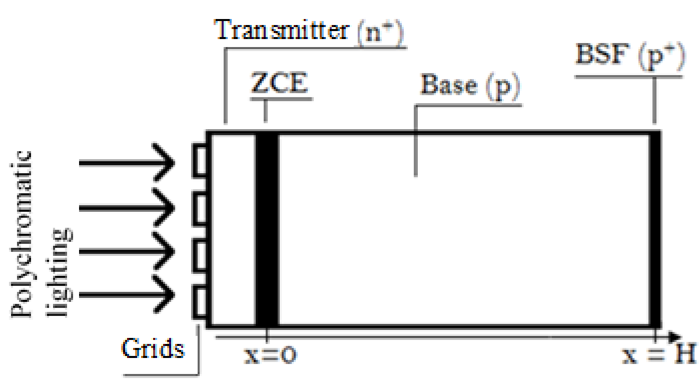

Figure 1: Structure of a silicon solar cell n+-p-p+

The transfer of the minority holders of photogenerated charges is the fundamental principle of the photopile. The continuity equation of these carriers at one dimension is given by the following equation [13,14]:

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

With δ (x) is the density of the generated electrons in the base at the x position
G(x) is the generation rate of minority holders at position x of the base [15] given by:

$$G(x) = \sum_{i=1}^{3} a_i e^{-b_i x} \quad (2)$$

:

The coefficients ai and bi is obtained from the tabulated values of the A.M1,5 [16]. These coefficients are given by:

a_1=6.13.10^{20} cm^{-3}/s; a_2=0.54.10^{20}cm^{-3}/s; a_3=0.0991.10^{20}cm^{-3}/s; b_1=6630cm^{-1}; b_2=1000cm^{-1}; b_3=130cm^{-1},

$$\left(L(T)\right)^2 = \tau D(T) \quad (3)$$

L is the diffusion length of electrons in the base, it depends on the temperature, τ and is the lifetime of electrons in the base.

$$D(T) = \mu(T)\frac{k_b}{q}T \quad (4)$$

D is the diffusion coefficient of electrons in the base [17].

$$\mu(T) = 1{,}43.10^9 T^{-2{,}42}\ cm^2V^{-1}s^{-1} \quad (5)$$

$\mu(T)$is the electron mobility coefficient [18], kb is the Boltzmann constant, and q is the elemental charge of the electron.

Equation (1) has a general solution :

$$\delta(x,T) = A\cosh\left(\frac{x}{L(T)}\right) + B\sinh\left(\frac{x}{L(T)}\right) + \sum_{i=1}^{3}\frac{a_i\left(L(T)\right)^2}{D(T)\left[\left(L(T)\right)^2(b_i)^2-1\right]}e^{-b_i x} \quad (6)$$

Expressions of A and B are determined from the following boundary conditions [19]:

i) At the junction (x = 0) :

$$\left.\frac{\partial\delta(x,T)}{\partial x}\right|_{x=0} = \frac{S_f}{D(T)}\delta(x,T)|_{x=0} \quad (7)$$

ii) Rear (x = H) :

$$\left.\frac{\partial\delta(x,T)}{\partial x}\right|_{x=H} = -\frac{S_b}{D(T)}\delta(x,T)|_{x=H} \quad (8)$$

Sf refers to the recombinant speed of the minority load carriers at the base junction and also indicates the point of operation of the photostack [20,21] and Sb refers to the recombinant speed of the minority load carriers at the rear face of the base [22].

Results and Discussion

I-V Characteristic

The I-V characteristic being temperature dependent allows us to determine the variation of the photocurrent density as a function of the photovoltage for different points of operation of the photo battery. It is determined from the expressions of photocurrent and photovoltage for illumination by the front face.

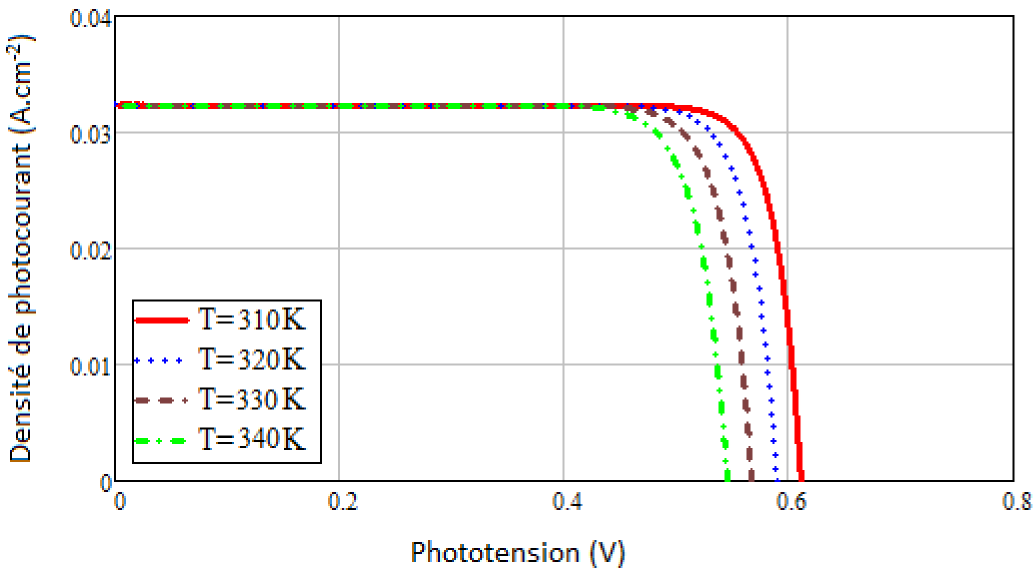

Figure 2 shows the photocurrent-photovoltage characteristic for different temperature values. We see that the short circuit photocurrent increases slightly when the temperature increases and that the photovoltage decreases when the temperature increases.

The photocurrent (Jph) of a solar cell usually increases slightly with increasing temperature. This increase is due to the decrease in the width of the forbidden band (Eg) of the semiconductor material. While for the photovoltage we can see that the increase in temperature leads to a decrease of Vco. So that means that a rise in temperature leads to a slight increase in the creation of electron-hole pairs.

Shunt Resistance Expression and Series

Shunt Resistance

One can translate the shunt resistance by the leakage currents within a photostack. The shunt resistance thus translates the leakage of current between the materials that make up the photopile, by the recombination of the minority carriers by the interface states. Thus the photobattery is similar to an ideal current generator that flows a Jphcc current in parallel with an Rsh resistance [23,24].

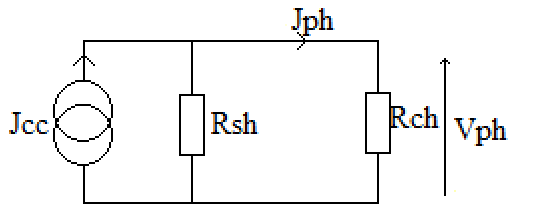

Figure 3 Equivalent electrical model

$$Rsh(Sf) = \frac{Vph\,(Sf)}{Jcc - Jph\,(Sf)} \qquad (9)$$

The following figure represents the shunt resistance profile as a function of the recombinant velocity of the minority carriers at the junction.

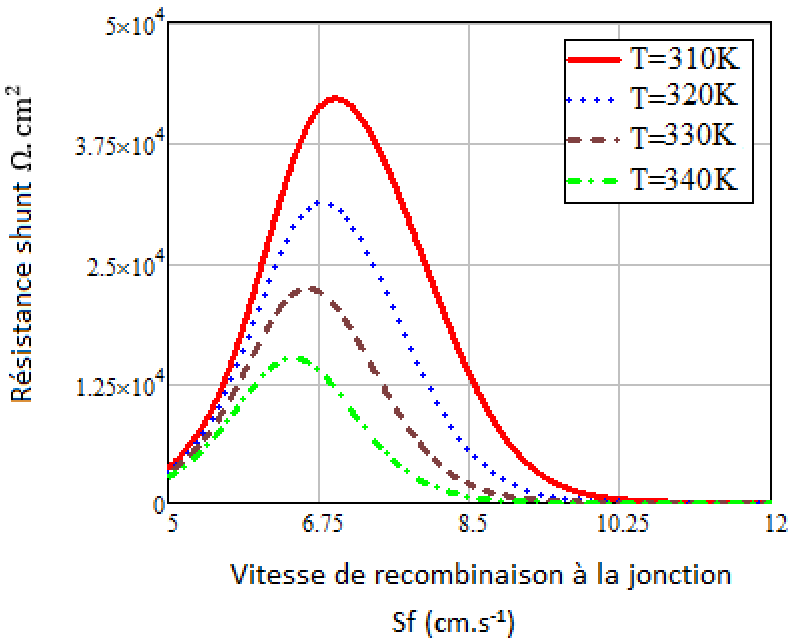

Figure 4 Shunt resistance curve as a function of recombinant velocity Sf for different temperature values; H=0.03 cm

We notice that shunt resistance increases rapidly as recombination speed increases. It reaches a peak and decreases with increasing recombination speed for different temperatures. We also see that the maximum point of shunt resistance moves when the temperature rises. This means that the shunt resistance decreases as the temperature rises.

Indeed, the temperature decreases the leakage currents within the photostack. This results in a decrease in shunt resistance.

Speed of Recombination at the Sfcc Junction

The rate of recombination at the junction is derived from the following equation [25]:

$$J_{ph}\,(Sf) - J_{cc}\,(Sf) = 0 \qquad (10)$$

This equation (19) can be rewritten as follows:

$$q \times D \times \frac{\partial \delta(x,T)}{\partial x}|_{x=0} - Jcc = 0 \qquad (11)$$

by solving this equation we arrive at these equations to find Sfcc :

$$E(m,T) = L(T).(Sb(m) + \sum_{i=1}^{3} b_i D(T)).e^{-b_i.H} \qquad (12)$$

$$\varphi(m,T) = L(T) \times [\frac{J_{cc}(m,T)}{q.D(T)} - \sum_{i=1}^{3} b_i.K(i,T)] \qquad (13)$$

$$O(m,T) = L(T).Sb(m).\sinh\left(\frac{H}{L(T)}\right) + D(T).\cosh\left(\frac{H}{L(T)}\right) \qquad (14)$$

$$M(m,T) = L(T).Sb(m).\cosh\left(\frac{H}{L(T)}\right) + D(T).\sinh\left(\frac{H}{L(T)}\right) \qquad (15)$$

$$Sf_{cc}(m,T) = \frac{L(T).\sum_{i=1}^{3} K(i,T).L(T).E(m,T) - M(m,T).b_i.D(T) + \varphi(m,T).D(T).M(m,T)}{-L(T) \times (\varphi(m,T).O(m,T) + \sum_{i=1}^{3} K(i,T).M(m,T)} \qquad (16)$$

In the following table, we noted the value of different shunt resistors when the temperature:

Table 1. Variation of the shunt resistance for different temperature values

T (K)	310	320	330	340
Sfcc (cm/s)	$3{,}957 \times 10^5$	$3{,}793 \times 10^5$	$3{,}641 \times 10^5$	$3{,}498 \times 10^5$
Rsh (Ω/cm^2)	9836,2	7796,7	5328,7	2006,1

Shunt resistance decreases when the recombinant velocity of minority carriers at the junction decreases.

Serial Resistance

The sources of dissipation of the photoelectric energy are in general the metallic contacts, i.e. the collection grids of the photocurrent and in particular their interfaces with the semiconductor and the recombinations in volume. These sources of energy dissipation are characterized by a resistance called series resistance of the photocell. So the resistive losses within the photocell linked to the structure of the material and the metallization are represented by the series resistance.

Under the effect of the recombination rate at the junction, the increase of the series resistance leads to a decrease in the load voltage. This is related to strong recombination in the silicon material. The series resistance of the solar cell is determined when we are in an open circuit situation of the I-V characteristic where we have an oblique line, or for a generator of ideal voltage, the line should be vertical. This defect is symbolized by the series resistance. Therefore, for its determination, we adopt an equivalent electrical diagram of a solar cell that operates in the vicinity of the open circuit and is represented by the figure [26,27].

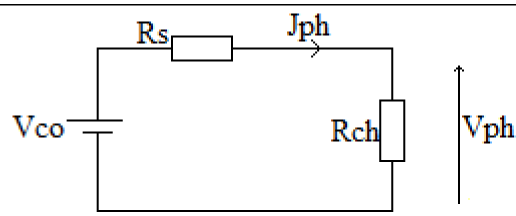

Figure 5 Equivalent electrical model

$$Rs(Sf) = \frac{V_{co} - Vph\,(Sf)}{J_{ph\,(Sf)}} \qquad (17)$$

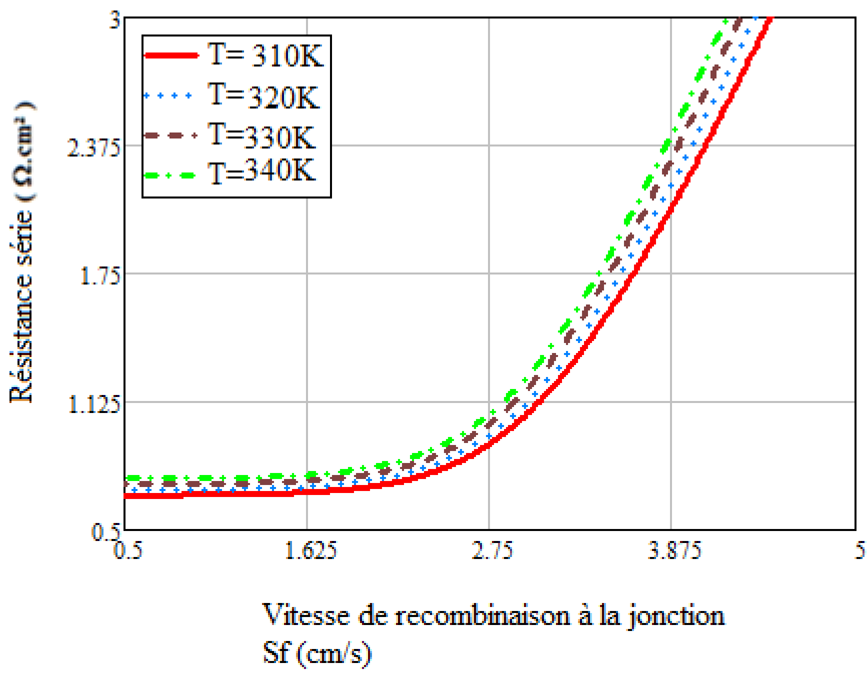

Figure 6 Serial resistance curve as a function of recombinant velocity Sf for different temperature values; H=0.03 cm (W/cm^2)

We note that for low values of the recombination velocity (Sf <10^{2}cm/s), the series resistance is constant and low. On the other hand, it grows exponentially with the recombination velocity at the junction. Increasing the series resistance at large (off-model) values of the junction recombination rate is not desirable for the photocell.

When the temperature increases the series resistance increases because the charge carriers are accelerated towards the junction thus increasing the voltage drop.

Speed of Recombination at Sfco Junction

The rate of recombination at the junction is derived from the following equation [28]:

$$Vph(Sf)-Voc(Sf)=0 \qquad (18)$$

By solving this equation we find:

$$\theta(Vco) = \frac{n^2{}_i}{N_b} \times (e^{\frac{Vco}{V_T}} - 1) + \sum_{i=1}^{3} K(i,T) \qquad (19)$$

$$\gamma(Sb,T) = D(T) \times (Sb - D(T).b_i) \times e^{-H.b_i} \qquad (20)$$

$$Y(Sb,T) = \frac{D(T)}{L(T)} \times \cosh(\frac{H}{L(T)}) + L(T) \times Sb \times \sinh(\frac{H}{L(T)}) \qquad (21)$$

$$N = \theta \times (D(T))^2 \sinh(\frac{H}{L(T)}) + L(T) \times Sb \times D(T) \times \theta \times \cosh(\frac{H}{L(T)}) \qquad (22)$$

$$N_1 = -\theta \times \left(L(T)\right)^2 \times Sb \times \sinh(\frac{H}{L(T)}) \qquad (23)$$

$$N_2 = \theta \times \left(L(T)\right)^2 \times Sb \times \cosh(\frac{H}{L(T)}) \qquad (24)$$

$$Sfco = \frac{N - L(T) \times \sum_{i=1}^{3} K(i,T) \times \gamma(Sb,T) - L(T) \times D(T) \times Y \times \sum_{i=1}^{3} K(i,T) \times b_i}{N_1 - N_2 + L \times Y \times \sum_{i=1}^{3} K(i,T)} \qquad (25)$$

Table 2.Variation of the serial resistance for different temperature values

T (K)	310	320	330	340
Sfco (cm/s)	$\mathbf{2.2 \times 10^2}$	$\mathbf{2.07 \times 10^2}$	$\mathbf{1.92 \times 10^2}$	$\mathbf{1.84 \times 10^2}$
Rs (Ω/cm^2)	3.064	2.791	2.487	2.137

The serial resistance decreases when the temperature increases, and at the same time, the recombination speed decreases at the junction for the open circuit.

Conclusion

The objective of this paper was to see the effect of temperature on the series and shunt resistances of the photocell. The knowledge of the values of the series and shunt resistances is important in the study of the quality of the material and in the improvement of the cells' efficiency.

We have noticed that the temperature has an influence on the electrical parameters by slightly increasing the short-circuit current and clearly decreasing the open-circuit voltage. So, we can say that the increase in the temperature leads to a slight increase in the creation of electron-hole pairs in the photovoltaic cell.

The temperature is a significant parameter in the behaviour of solar cells because the electrical performance of a solar cell is very sensitive to it.

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