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Thermal behavior of a parallel vertical junction Silicon photocell in static regime by study of the series and shunt resistances under the effect of temperature.

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Abstract

This work 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 the characteristic current-voltage, series resistance ant shunts resistance are determined. For all these parameters we showed the effect of external temperature.

Keywords: Vertical junction - temperature – series resistance- shunts resistance.

I Introduction

The aim of this work is to investigate the influence of temperature on electrical parameters such as: series resistance and shunt resistance. These two parasitic parameters enable us to come out with the performance of a photovoltaic cell.

From the diffusion-recombination equation the excess minority carrier's density, the photocurrent density and the photovoltage will be determined. Based on these parameters characteristic current-voltage, shunts resistance and series resistance are deduced. In the last part of this work we present our simulation results.

II. Theory

This study is based on a vertical parallel junction silicon solar cell [1]-[2]-[3] presented on figure 1. The solar cell is illuminated along the z axis in steady state.

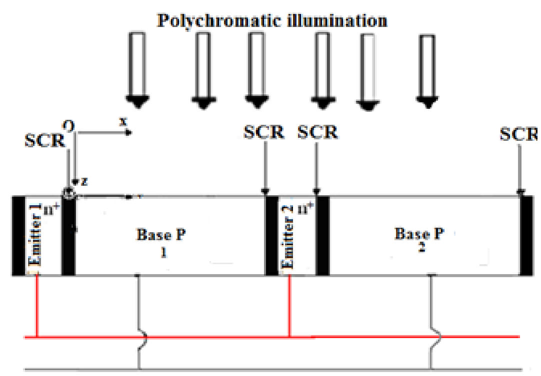

Figure 1: Vertical parallel junction solar cell
H =0,02cm; W =0,03cm

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.
- ❖ There is no electric field without space charge regions.

II.1 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 [3]-[4]-[5]-[6].

$$\frac{\partial^2 n(x)}{\partial x^2} - \frac{n(x)}{L^2} = -\frac{G_n}{D} \qquad (1)$$

D is the diffusion constant and is related to the operating temperature through the relation [7].

$$D = \mu . \frac{K}{q} . T \quad (2)$$

with q the elementary charge, k the Boltzmann constant and T the temperature.

Gn= g(z)+gth is the carrier generation rate.

g(z) is the carrier generation rate at the depth z in the base and can be written as **[1]**

$$g(z) = \sum a_i e^{-biz} \quad (3)$$

a_i and b_i are obtained from the tabulated values of AM1.5 solar illumination spectrum and the dependence of the absorption coefficient of silicon with illumination wavelength.

gth is the carrier thermal generation rate. It is given by:

$$g_{th} = c.n_i^2 \quad (4)$$

with

$$n_i = A_n . T^{\frac{3}{2}} . \exp(\frac{Eg}{2KT}) \quad (5)$$

n_i refers to the intrinsic concentration of minority carriers in the base **[7]**, A_n is a specific constant of the material (**A_n=3.87x10^{16}** for silicon) and N_b is the base doping concentration in impurity atoms.

And $\tau = \frac{1}{C.Nb}$ (6)

n(x), L, τ, and μ are respectively the excess minority carriers density, diffusion length, lifetime and mobility and C is the proportionality coefficient.

The solution of equation (1) is:

$$n(x) = A\sinh(\frac{x}{L}) + B\cosh(\frac{x}{L}) + \sum \frac{a_i}{D} L^2 e^{-biz} + \frac{L^2}{D} C.A_n.T^3.\exp(\frac{Eg}{KT}) \quad (7)$$

Coefficients A and B are determined through the following boundary conditions [2]-[3]-[5] at the junction (x=0):

$$\left.\frac{\partial n(x)}{\partial x}\right|_{x=0} = \frac{S_f}{D} n(0) \quad (8)$$

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 [2]-[3]-[5]. The higher Sf is, the higher the current density will be.

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

$$\left.\frac{\partial n(x)}{\partial x}\right|_{x=\frac{w}{2}} = 0 \quad (9)$$

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 (figure 1).

II.2 Photocurrent density

The photocurrent Jph is obtained from the following relation given that there is no drift current [2]-[8].

$$J_{ph} = qD \left.\frac{\partial n(x)}{\partial x}\right|_{x=0} \quad (10)$$

II.3 Photovoltage

The photovoltage derives from the Boltzmann relation [2]-[8].

$$V_{ph} = \frac{k.T}{q} \cdot \ln\left(Nb.\frac{n(0)}{n_i^2} + 1\right) \quad (11)$$

II.4 Characteristic current-voltage

La characteristic current –voltage is represented by the following curve:

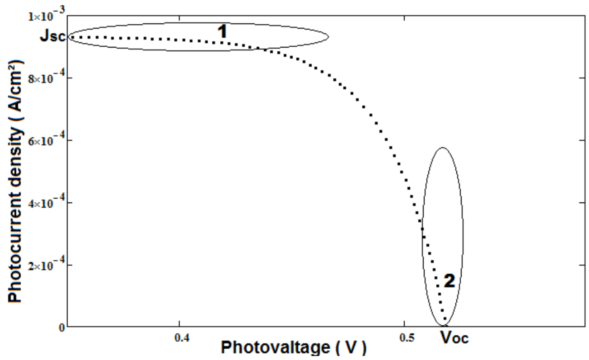

Figure 2: Current versus voltage

This characteristic presents two areas very important [9]:

- ✓ Area1 is has a current generator Jsc of admittance that can be modeled par :

$$\frac{1}{Rsh}$$

The corresponding electrical circuit is:

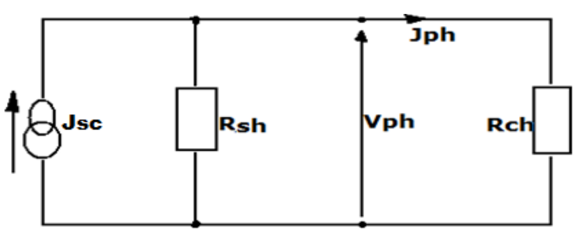

Figure 3: Electric equivalent circuit of the photocell operation by short-circuiting

Jsc : short circuit current densité,

Rsh : shunt resistance per unit area

Jph et Vph: density current et photovoltage.

Rch : Load resistance

The law of mesh applied to the circuit of figure2 (area1) gives:

$$Vph = Rsh\,(Isc - Jph) \quad (12)$$

This relationship; It draws the Rsh expression that is written in the form **:**

$$Rsh = \frac{Vph}{Isc - Jph} \quad (13)$$

- ✓ Area 2 is similar to a generator voltage Voc of equivalent resistance internal impedance Rs series

The model of equivalent electrical circuit of a photocell operating in open circuit is represented by the following figure:

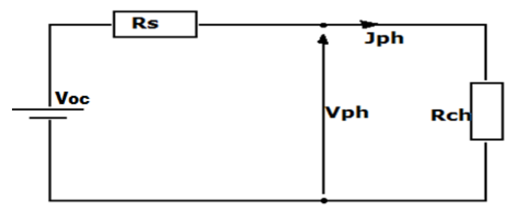

Figure 4: Electric equivalent circuit of the photocell in open circuit operation

Vco : open circuit voltage,

Rs : Résistance série par unité de surface

Vph : voltage

Applying the law of mesh to the circuit of figure2 (area2) , we get

$$V\ ph = V\ oc - R\,s \cdot I\ ph \quad (14)$$

We then deduce the series resistance expression as

$$R\,s = \frac{V\ oc - V\ ph}{I\ ph} \quad (15)$$

III. Results and discussion

The two resistors model internal losses [9] :

- Series Resistance Rs: models the ohmic losses in the material.

- Shunts Resistance Rsh: models the parasitic currents traversing the cell

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

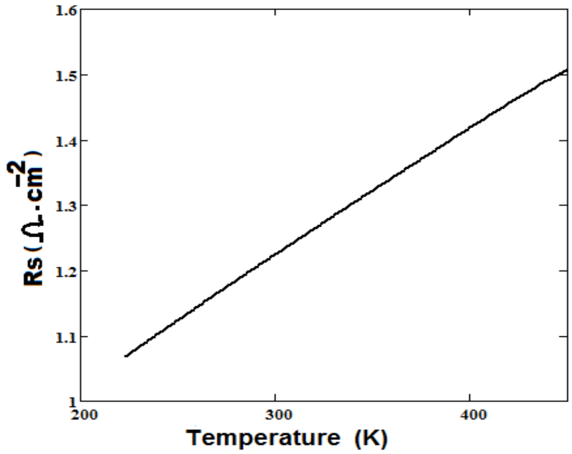

Figure 5: Séries Résistance versus temperature
Sf=10^2 cm.s^{-1}, z=10^{-2}cm

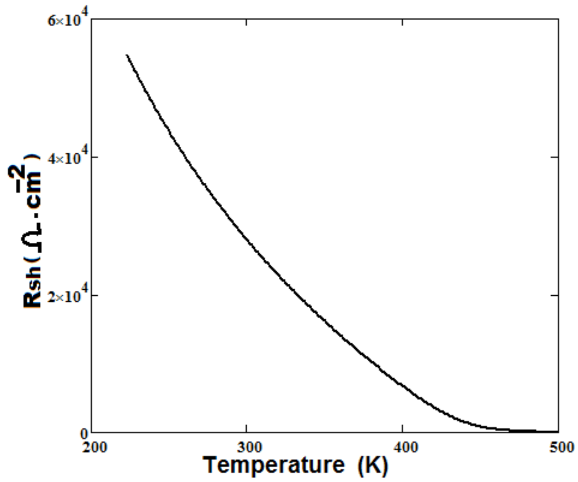

Figure 6 : Résistance versus temperature
Sf=10^6 cm.s^{-1}, z=10^{-2}cm

Series Resistance:

• Figure4 shows that the series Resistance increases the temperature of . In fact it increases temperature creates a followed warming of a dilation of metals. This phenomenon increases the ability of materials to resist the passage of electric current. Thus there for a positive temperature gradient is an increase in resistivity of semiconductor material, the constituent metal contacts the electrodes and the grid of the minority carrier collection.

• Figure 5 represents the profile of the series resistance depending on the speed of recombination for different temperature values.

This figure shows the series resistance believes on the basis of the recombination velocity at the junction. This increase of Rs is all the more important that the temperature rises.

Indeed when the recombination velocity increases, the diode characterizing the junction behaves as a resistance and opposes the passage of electric current [10].

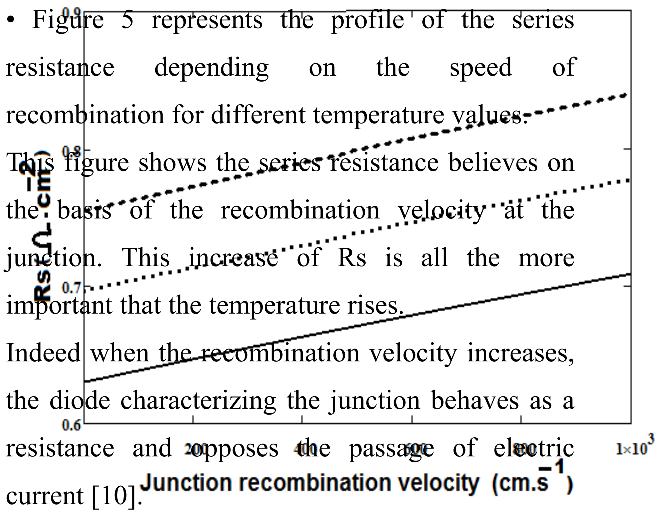

Fig.5: Séries Résistance versus junction recombination velocity for various temperatures z=10^{-2}cm

Shunts resistance:

• The figure 6 shows that the shunt resistance decreases with temperature. In fact the charge carriers photogeneses under the effect of temperature are equipped with great kinetic energy and put themselves in a chaotic movement [11]. This random motion causing much collusion between the carriers and the leakage current. Thus the diode current greatly increases. As a result the shunt resistance decreases with temperature.

• The figure7 represents the profile of the Shunt Resistance (Rsh) based on the recombination velocity at the junction for different values of the temperature.

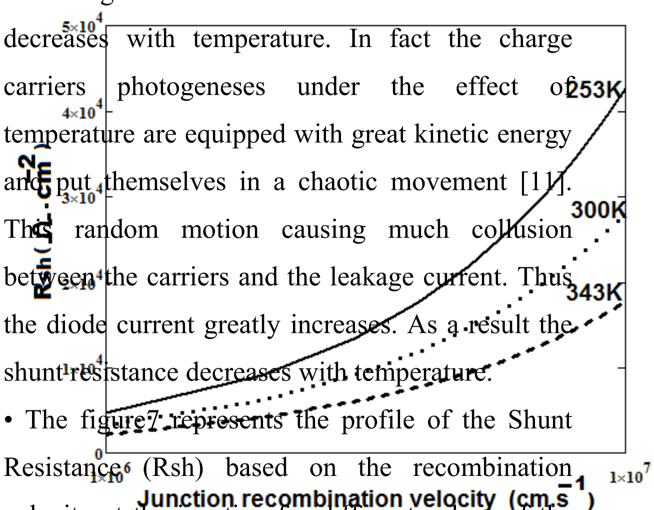

Fig.7: Shunt Résistance versus junction recombination velocity for various temperatures z=10^{-2}cm

This figure shows that the shunt Resistance believes based on the recombination velocity at the junction. This increase of Rsh is all the more important that the temperature is low.

Indeed when the recombination velocity increases, many carriers arrive at the junction. They thus cross the junction to participate in electric power. Thus the leakage current is reduced: it is said that the shunt resistance is high.

Conclusion:

In this simulation study, we found that the resistance series increases the temperature both drive the shunt resistance decreases.

The series resistance that characterizes the ohmic losses is smaller that the photocell is of good quality. The shunt resistance (Rsh) that characterizes the leakage current is greater that the photocell is of good quality.

It can be concluded that the increase in temperature in the material contributes significantly to the weakening of the performance of the photocell

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