Thermal behavior of parasitic resistances of polycrystalline silicon solar cells

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Abstract – *In this work, we investigate the influence of temperature on the series and shunt resistances of polycrystalline silicon solar cells and then to determine the specific expressions of both parasitic resistances as function of temperature. We have exploited the current-voltage characteristics of polycrystalline silicon solar cell at different temperatures and under constant illumination (1000 W/m^2). The obtained results show that the series resistance,* R_s *, is a positive temperature coefficient type; however, the shunt resistance,* R_{sh} *, is a negative temperature coefficient type.*

Résumé - *Dans ce travail, nous étudions l'influence de la température sur les résistances série et shunt des cellules solaires au silicium polycristallin. Nous déterminons les expressions spécifiques des deux résistances parasites en fonction de la température. A ce propos, nous avons exploité des caractéristiques courant-tension d'une cellule solaire au silicium poly cristallin à différentes températures et sous un éclairement constant (1000 W/m²). Les résultats obtenus montrent que la résistance série,* R_s *, est du type à coefficient de température positif, cependant la résistance shunt,* R_{sh} *, est du type à coefficient de température négatif.*

Keywords: Polycrystalline silicon solar cell - Series resistance - Shunt resistance - Temperature.

1. INTRODUCTION

The current–voltage characteristic of the solar cell can be presented by a single diode model [1]. At a given temperature and illumination, the current density–voltage relation for a solar cell is given by:

$$J = J_{ph} - J_s \left[\exp\left(\frac{q(V + J \times R_s)}{n \times k \times T} \right) - 1 \right] - \frac{V + J \times R_s}{R_{sh}} \qquad (1)$$

where J_{ph} , J_s , q , R_s , n , k , T and R_{sh} being the photo generated current density, the diode saturation current density, electron charge, series resistance, ideality factor, Boltzman's constant, absolute [†]temperature and shunt resistance respectively.

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Both resistances have an important effect on the characteristic of the solar cell and consequently on the performances of the device [2].

The series resistance models the grid, contact, sheet, base and back contact resistances; however, the shunt resistance models any high conductivity path through the solar cell or on the edge caused by crystal damage in the junction or a metallization spike through the p-n junction [2].

Several authors have proposed number studies concerning the effects of the environmental conditions on both parasitic resistances of solar cells.

Khan *et al.* [3] have studied the effect of illumination intensity on silicon solar cell parameters and they observe that R_s decreases continuously with illumination, however R_{sh} increases slightly with illumination at lower intensity and becomes constant at higher intensity illumination values.

Radziemska [2] studied the influence of temperature on the behavior of series resistance of single crystalline silicon solar cells at dark condition, and found a decreasing of the series resistance with temperature increasing. Furthermore, the author mentioned that the shunt resistance varies exponentially with temperature.

Karatepe *et al.* [4] presented a neural network based approach for the solar cell model. The obtained artificial neural network results show that the series resistance R_s increases with temperature, however the shunt resistance R_{sh} decreases with increasing temperature.

In the above-mentioned works, no explicit expression explains the relationship between temperature and the concerned resistances. Based on the fact that the output power of a solar cell monotonically decreases with its temperature.

Ding *et al.* [5] have investigated for a silicon solar cell the specific expression of the series resistance. To the best of our knowledge, a similar theory expression of R_{sh} is still unknown and has not been clearly disclosed in previous research.

Therefore, the purpose of the paper is to explorer the effects of temperature on both parasitic resistances in the order to determine a specific theory expression of the shunt resistance and in the same time to apply the obtained expression by Ding *et al.* for series resistance in our case.

2. THEORY AND ANALYSIS

According to theory, there are only three types of thermal sensitive resistances [5]: conductor type, negative temperature coefficient type and positive temperature coefficient type:

i. Conductor type

$$R(T) = R_0(1+\alpha\times T) \tag{2}$$

where α is the conductor temperature coefficient ($\alpha > 0$) and R_0 is the initial condition resistance. The differential of the previous function gives:

$$\frac{dR}{dT} = \alpha\times R_0 > 0 \tag{3}$$

ii. Negative temperature coefficient type

$$R(T) = R_0 \exp\left(B/T\right) \quad (4)$$

where B is the semiconductor material coefficient $(B > 0)$ and R_0 is the initial condition resistance. The differential of the previous function gives:

$$\frac{dR}{dT} = -\frac{B \times R}{T_2} < 0 \quad (5)$$

iii. Positive temperature coefficient type

$$R(T) = R_0 \exp\left(B \times T\right) \quad (6)$$

where B is the semiconductor material coefficient $(B > 0)$ and R_0 is the initial condition resistance. The differential of the previous function gives:

$$\frac{dR}{dT} = B \times R > 0 \quad (7)$$

3. RESULTS AND DISCUSSION

In **Table 1**, extracted values of the series and shunt resistances from current-voltage characteristics of polycrystalline silicon solar cell at different temperatures under constant illumination (1 kW/m^2) are presented.

Note that Bouzidi *et al.* method [6] is used to extract the set of five parameters of the single diode lumped circuit model, including series and shunt resistances from experimental current-voltage data [6].

Table 1: Extracted values of R_s and R_{sh} for the considered polycrystalline silicon solar cell under (1 kW/m^2) of irradiance (using Bouzidi *et al.* [6] extractive method)

T (K)	288	293	298	303	308	313	318	323
R_s (Ωcm^2)	0.1825	0.1938	0.2150	0.2391	0.2715	0.3041	0.3294	0.3663
R_{sh} (kΩcm^2)	2.47	2.35	2.26	2.17	2.04	1.99	1.90	1.83

From the obtained results (**Table 1**) we have $(dR_{sh} / dT > 0)$. Therefore, R_s meets the first and third cases. Nevertheless, Ding *et al.* [5] confirm that the series resistance is a positive temperature coefficient type, so it is possible to make it under the form:

$$R_s(T) = R_{s0} \times \exp(B_s \times T) \quad (8)$$

where B_s is a coefficient specific to the semiconductor material $(B_s > 0)$ and R_{s0} is the initial condition resistance.

Fig. 1 shows the behavior of R_s as a function of temperature. We find that the temperature increase leads to an increase of the series resistance. These results are in agreement with those obtained by several authors [2, 4, 5].

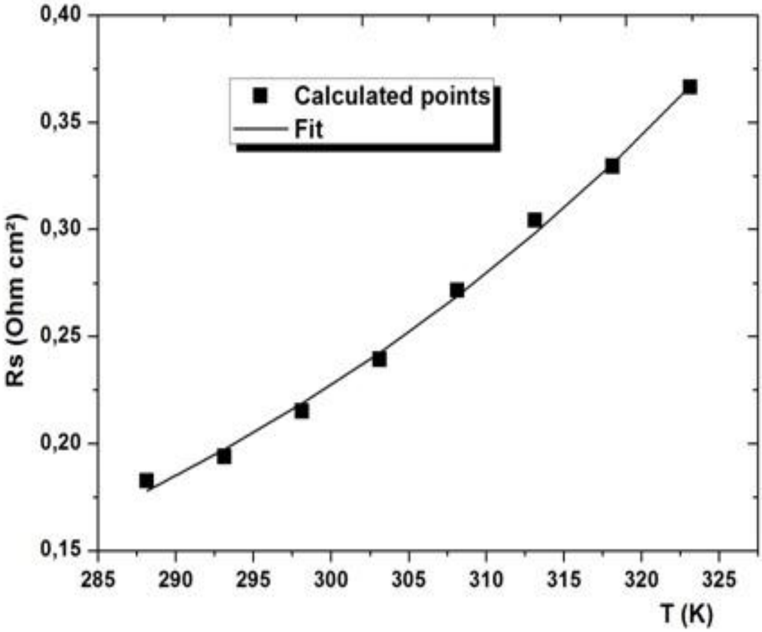

Fig. 1: Evolution of R_s with T calculated points were fitted using equation (8)

$$R_{s0} = 4.6 \times 10^{-4}\,\Omega cm^2 \quad , \quad \beta_s = 0.0207\ K^{-1}$$

Concerning R_{sh}, from **Table 1**, we have ($dR_{sh} / dT < 0$). Therefore, the shunt resistance meets the second case. So, it can be expressed as negative temperature coefficient type:

$$R_{sh} = R_{sh0} \times \exp\left(B_{sh} / T\right) \tag{9}$$

Where B_{sh} is a coefficient specific to the semiconductor material ($B_{sh} > 0$) and R_{sh0} is the initial condition resistance.

Fig. 2 shows the behavior of R_{sh} as a function of temperature. We find that the temperature increase leads to a decrease in R_{sh}. This is in agreement with the results of previous works [2, 4].

Fig. 2 shows also the fit of the calculated points from equation (9). Good agreement between the fit and calculations is observed.

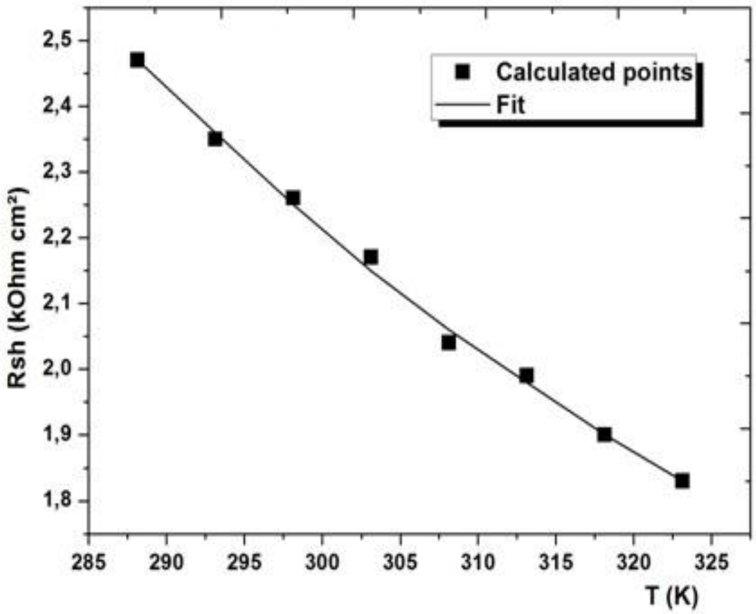

Fig. 2: Evolution of R_{sh} with T calculated points were fitted using equation (9)

$$R_{sh0} = 153.92\ \Omega.cm^2 \quad , \quad B_{sh} = 799.93\ K$$

4. CONCLUSION

We exploited extracted values of the series and shunt resistance, at different temperatures and constant illumination, for a polycrystalline silicon solar cell. For an illumination of (100 mW/cm^2), we found that, the series resistance (R_s) increases with temperature and it is of positive temperature coefficient type. However, the shunt resistance (R_{sh}) decreases with temperature and then it is of negative temperature coefficient type. Further work is to be on the parasitic resistances thermal behavior thin film based solar cells.

NOMENCLATURE

I : Current	k : Boltzmann's constant
V : Voltage	I_{sc} : Short circuit current
I_{ph} : Photo current	V_{oc} : Open circuit voltage
I_s : Saturation current	α : Conductor temperature coefficient
n : Ideality factor	β :Semiconductor material coefficient
R_s : Series resistance	R_0 : Initial condition resistance
R_{sh} : Shunt resistance	T : Absolute temperature
q : Electron charge	

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