International Journal of
Emerging Research in Management &Technology
ISSN: 2278-9359 (Volume-6, Issue-1)

Research Article

January 2017

Series Resistance Both Temperature and Wavelength Dependent in Silicon Solar Cell under Steady State

Ibrahima DIATTA[1], Ibrahima LY[2], Mamadou WADE[2], Marcel Sitor DIOUF[1], Youssou TRAORE[1], Mor NDIAYE[1], Senghane MBODJI[3] and Grégoire SISSOKO[1]
[1]Laboratoire des Semi-conducteurs et d'Energie Solaire, Faculté des Sciences et Techniques,
Université Cheikh Anta Diop, Dakar, Sénégal
[2]Ecole Polytechnique de Thiès, Thiès, Sénégal
3 Université Alioune DIOP de Bambey-Sénégal

DOI: 10.23956/ijermt/V6N1/101

Abstract:

The excess minority carrier junction recombination velocity limiting the open circuit Sfoc and the experimental series resistance of an exposed solar cell to temperature under monochromatic illumination in static regime were determined. It is determined by the photovoltage difference and the open circuit photovoltage Voc. Expression of junction recombination velocity limiting the open circuit has determined the experimental series resistance values. Expressions of photocurrent density and photovoltage are obtained from excess minority carrier density.

Keywords: solar cell - junction recombination velocity - open circuit – wavelength - series resistance - temperature.

I. INTRODUCTION

The series resistance is caused by electrons movement through the emitter and the solar cell base, the contact resistance between the silicon and the metal grids resistance at front and back side [1- 3].

In this paper, we study influence of both temperature and wavelength on series resistance of silicon solar cell in static regime under monochromatic illumination. This resistance and Sfoc are determined from the I-V characteristic. The experimental series resistance values are also determined from the series resistance curves calibration versus minority carrier junction recombination velocity Sf.

II. THEORY

The studied silicon solar cell is an n+pp+ BSF type. It is represented by the following figure:

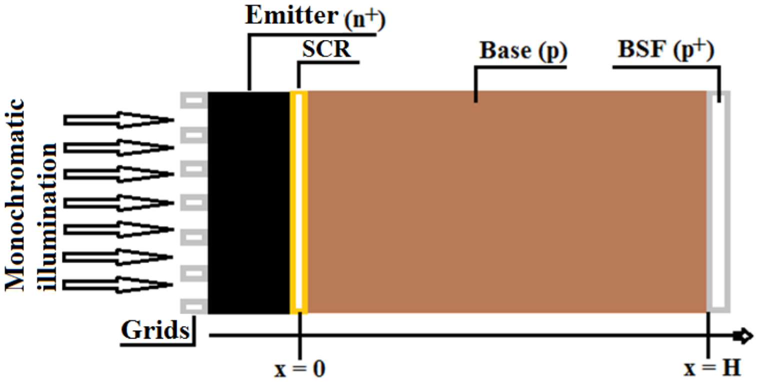

Figure 1 : Silicon solar cell n^+pp^+ type

When the solar cell is illuminated, there is electron-hole pairs generation in the base. The excess minority carrier density in the base is modeled by the following continuity equation:

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

With
$\delta(x)$ is the minority carrier density at the depth x in the base
g(x) is the carrier generation rate at the depth x in the base, it is expressed as:

$$g(x)=\phi(\lambda)\alpha(\lambda)(1-R(\lambda))e^{(-\alpha(\lambda)x)} \qquad (2)$$

Where $\alpha(\lambda)$ and $R(\lambda)$ represent respectively absorption and reflection coefficient of the material for a given wavelength λ;

$\phi(\lambda)$ Is the incident photons flux.

The minority carrier diffusion length in the base material is temperature dependent; it is expressed by the following equation.

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

τ is the minority carrier lifetime.

D(T) is the diffusion coefficient, it's temperature dependent. D(T) can be expressed by Einstein relationship:

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

$\mu(T)$ is minority carriers mobility [11], $\mu(T)=1,43.10^9 T^{-2,42} cm^2 V^{-1} s^{-1}$ (5)

Solution of equation (1) is given by the following terms:

$$\delta(x,\lambda,T) = A\cosh\left(\frac{x}{L(T)}\right) + B\sinh\left(\frac{x}{L(T)}\right) - \frac{\phi(\lambda)\alpha(\lambda)\left(L(T)\right)^2\left(1-R(\lambda)\right)e^{\left(-\alpha(\lambda)x\right)}}{D(T)\left[\left(L(T)\right)^2\left(\alpha(\lambda)\right)^2-1\right]} \qquad (6)$$

The constants A and B are determined from the boundary conditions:

- At the junction surface, x = 0 :

$$\mathrm{D(T)} \cdot \left.\frac{\partial \delta(x,\lambda,t)}{\partial x}\right|_{X=0} = \mathrm{Sf} \cdot \delta(0,\lambda,t) \qquad (7)$$

- At the back side surface, x = H :

$$\mathrm{D(T)} \cdot \left.\frac{\partial \delta(x,\lambda,t)}{\partial x}\right|_{x=H} = -\mathrm{Sb} \cdot \delta(H,\lambda,t) \qquad (8)$$

Sf is the minority carrier junction recombination velocity, expresses with two components which describe the solar cell operating point and the looses induced by shunt resistance[12,13].

Sb is the minority carrier surface recombination velocity [13], induced by a back surface fied.

III. DENSITE DE PHOTOCOURANT

The photocurrent density results from the minority carrier diffusion at the junction and it is given by:

$$J_{ph}(S_f,\lambda,T) = qD(T)\left.\frac{\partial \delta(S_f,\lambda,T)}{\partial x}\right|_{x=0} \qquad (9)$$

IV. PHOTOTENSION

The solar cell photovoltage is given by the Boltzmann relation.

$$V_{ph}\left(S_f,\lambda,T\right) = V_T \ln\left[\frac{N_b}{\left(n_i^2(T)\right)}\delta\left(0,S_f,\lambda,T\right)+1\right] \qquad (10)$$

Where V_T is the thermal voltage, it is defined as:

$$V_T = \frac{k_b}{q}T \qquad (11)$$

Nb is the doping level and ni, the intrinsic minority carrier density [14] expressed as follows:

$$n_i(T) = A.T^{\frac{3}{2}}\exp\left(-\frac{E_g}{2.k_b.T}\right) \qquad (12)$$

Eg is the energy gap, it's corresponds to the difference between the conduction and valence band energy expressed as: Eg = Ec - Ev. Eg = $1,12*1,6.10^{-19}$ J

A is a constant. A = $3,87.10^{16}$ cm^{-3} $K^{-3/2}$

V. I-V CHARACTERISTIC

V.1 Effect of temperature on I-V characteristic

The figure 2 represents the I(Sf)-V(Sf) characteristic of the solar cell under illumination for different temperature values[14].

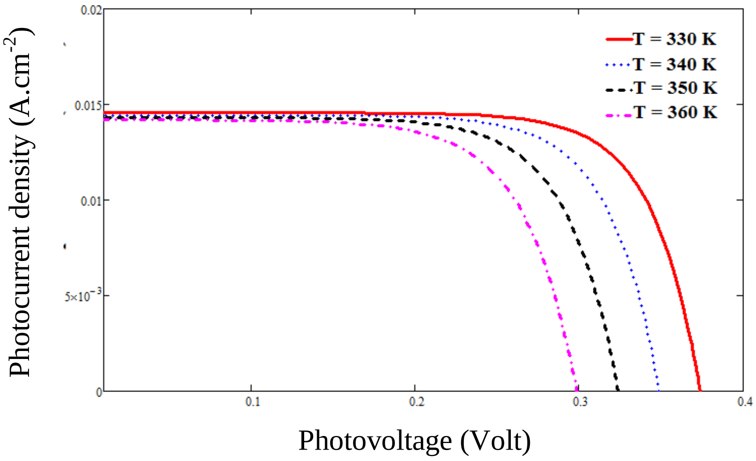

Figure 1: I-V characteristic for different temperature values

We observe that photocurrent density is maximum and constant for low value photovoltage. The maximum photocurrent density is called short-circuit photocurrent density Jphsc (λ, T). The maximum photovoltage is called open circuit photovoltage Vphoc (λ, T). For increasing temperature Jphsc (λ, T) and Vphoc(λ, T) decreases, slightly for the former and very sensitive for the second one.

V.2 Résistance série

We note in the I-V characteristic that near the open circuit, the voltage across the solar cell is independent of output current. The solar cell is considered as equivalent to a real voltage generator [15, 16]. We have presence of internal resistance called series resistance Rs. R_L is the external load resistance. The electrical equivalent circuit in open circuit situation is then represented [12, 17]:

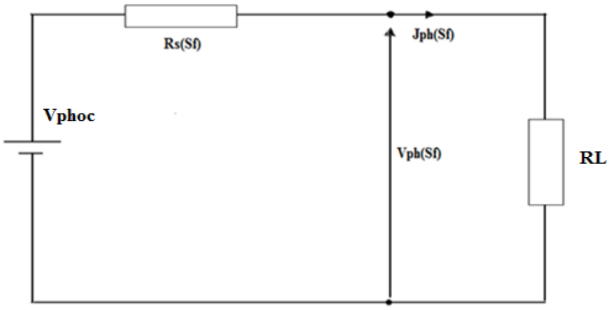

Figure 3: Electrical equivalent circuit in open circuit situation.

By applying the Kirchhoff laws for the previous equivalent circuit, we deduce Rs expression.

$$R_s(S_f,\lambda,T)=\frac{V_{phco}(\lambda,T)-V_{ph}(S_f,\lambda,T)}{J_{ph}(S_f,\lambda,T)} \qquad (13)$$

V.2.1 Temperature effect on series resistance

Figure 4 shows series resistance versus minority carrier junction recombination velocity Sf for different temperature values.

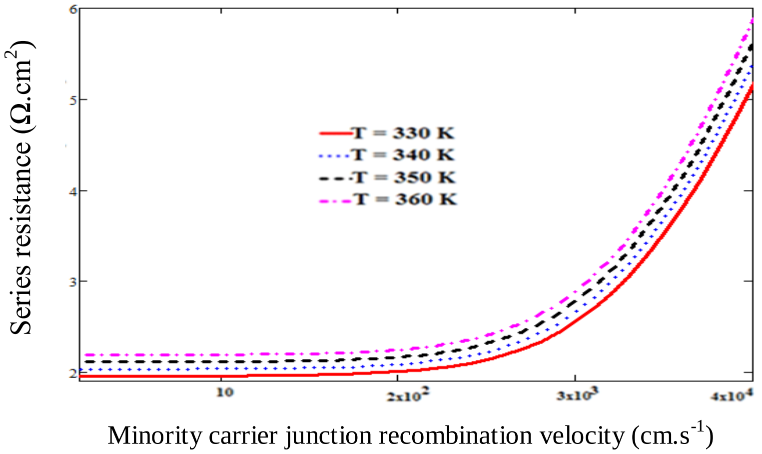

Figure 4: Series resistance versus minority carrier junction recombination velocity Sf for different temperature values.

We observe a bearing series resistance for low Sf values. The series resistance increases exponentially with Sf. And for increasing temperature, the series resistance increases either.

V.2.2 Wavelength effect on series resistance

Figure 5 shows series resistance versus minority carrier junction recombination velocity Sf for different wavelength values.

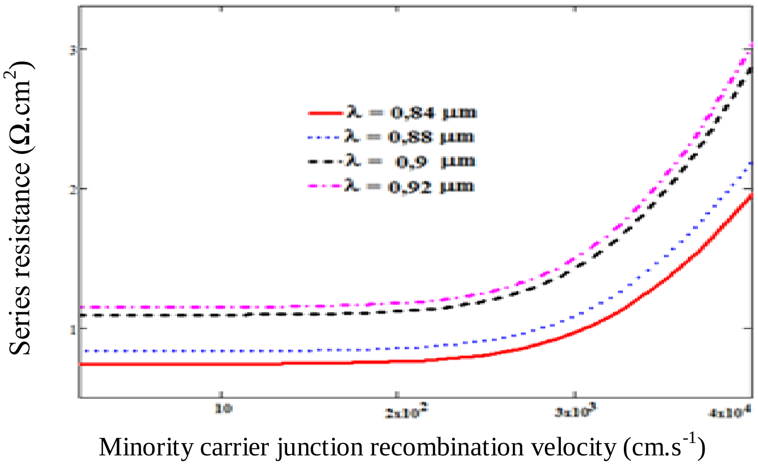

Figure 5: series resistance versus Sf for different wavelength values.

We note that at open circuit situation, series resistance increases gradually with minority carrier junction recombination velocity. We also observe an increase of the series resistance with wavelength: It is explained by the material increasing resistivity.

Figure 6 shows series resistance versus temperature for different wavelength values.

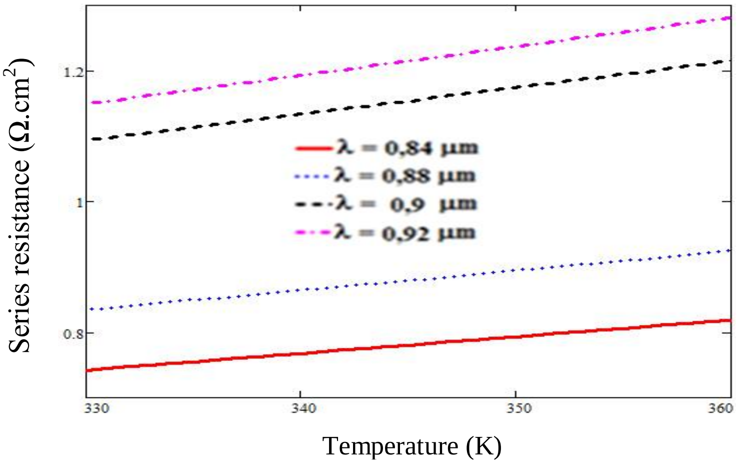

Figure 6: series resistance versus temperature for different high wavelength values (Sf= 10 cm/s)

For increasing temperature, the series resistance increases. It is more important for increasing wavelength values.

Figure 6 allows us to obtain the equation 14 who expressed series resistance versus temperature.

$$Rs_{\lambda}(T) = \beta T + \xi \qquad (14)$$

With,

β is the slope and ξ is the intercept and considered as resistance.

β and ξ values are presented for high wavelength by table 1

Table1: β and ξ for high wavelength

λ(µm)	**β(Ω.cm².K⁻¹)**	**ξ (Ω.cm²)**
0,84	$2{,}55.10^{-3}$	-0,10
0,88	$3{,}01.10^{-3}$	-0,160
0,9	$4{,}06.10^{-3}$	-0,247
0,92	$4{,}22.10^{-3}$	-0,238

V.3 Experimental determination of series resistance

Using the technique of the limiting recombination velocity at the junction Sfoc [18], the expression is derived from the equation 15, at Sf = Sfoc.

$Vph(S_f, \lambda, T) - Vphoc(\lambda, T) = 0$ (15)

After solving equation 15 we obtain Sfoc expression given as:

$$Sf_{oc}(\lambda,T) = \frac{D(T)L(T)[\beta(\lambda,T)+K(\lambda,T)D(T)\alpha(\lambda)]\cos\left(\frac{H}{L(T)}\right) + \left[D(T)^2\beta(\lambda,T) - L(T)K(\lambda,T)\alpha(\lambda)D(T)\right]}{D(T)L(T)[K(\lambda,T)-\beta(\lambda,T)]\cos\left(\frac{H}{L(T)}\right) + L(T)[K(\lambda,T)-L(T)\beta(\lambda,T)]\sinh\left(\frac{H}{L(T)}\right)} \quad (16)$$

Sfco depend on both wavelength and temperature.

With,

And

$$K(\lambda,T) = \frac{\phi(\lambda)\alpha(\lambda)L(T)^2\left[1-R(\lambda)\right]}{D(T)\left[L(T)^2\alpha(\lambda)^2 - 1\right]}$$

$$\beta(\lambda,T) = \frac{n_i(T)^2}{N_b}\left[e^{\left(\frac{Vco(\lambda,T)}{V(T)}\right)} - 1\right]K(\lambda,T)$$

K(λ,T) and β(λ,T) are coefficients, dependent of both wavelength and temperature.

Different temperature values introduced in Sfoc expression yield corresponding values.The calibration series resistance curve (Figure 4) at Sfoc values gives either the experimental Rs values who are given by Table 2

Table 2 : Sfoc and experimental Rs Values with their respective temperature for a given wavelength $\lambda = 0{,}94\ \mu m$.

T(K)	**Sfoc(cm/s)**	**Rs_{exp}(Ω.cm²)**
330	$6{,}3.10^{3}$	3
340	$6{,}1.10^{3}$	3,1
350	$5{,}7.10^{3}$	3,3
360	$5{,}5.10^{3}$	3,4

We note in table 2 that for a given wavelength value, Sfoc decreases for increasing temperature. And for increasing temperature, the experimental series resistance increases.

VI. CONCLUSION

In this study based on temperature effect, we ended up with some results:

- For a given wavelength value, temperature increases causes a reduction of photocurrent density and photovoltage.
- Theorical and experimental series resistance increases with increasing temperature and for these conditions the Junction surface recombination velocity limiting the open circuit decreases.
- The series resistance increases either with increasing wavelength.

REFERENCES

[1] M. Bashahu and A. Habyarimana, "Review and test of methods for determination of the solar cell series resistance", Renewable Energy 6(2) (1995) 129-138.

[2] M.K. El- Adawi and I.A. Al-Nuaim, "A method to determine the solar cell series resistance from a single I-V characteristic curve considering its shunt resistance-new approach", Vacuum 64 (2002) 33-36.

[3] K. Bouzidi, M. Chegaar and A. Bouhemadou, "Solar cells parameters evaluation considering the series and shunt resistance", Solar Energ. Mater. Solar Cells 91 (2007) 1647-1651.

[4] S. Mbodji, I. Ly, H. L. Diallo, M.M. Dione, O. Diassé and G. Sissoko "Modeling Study of N^{+}/P Solar Cell Resistances from Single I-V Characteristic Curve Considering the Junction Recombination Velocity (Sf)" Research Journal of Applied Sciences, Engineering and Technology 4(1) (2012) 1-7.

[5] D.T. Cotfas, P.A. Cotfas, S. Kaplanis, "Methods to determine the dc parameters of solar cells: A critical review", Renewable and Sustainable Energy Reviews 28 (2013) 588–596.

[6] E. Radziemska, "Dark I–U–T measurements of single crystalline silicon solar cells", Energy Conversion and Management 46 (2005) 1485–1494.

[7] J. Lauwaert, K. Decock, S. Khelifi, M. Burgelman **"**A simple correction method for series resistance and inductance on solar cell admittance spectroscopy**"**, Solar Energy Materials & Solar Cells 94 (2010) 966–970

[8] S. Kumar, P.K. Singh, G.S. Chilana, "Study of silicon solar cell at different intensities of illumination and wavelengths using impedance spectroscopy", Solar Energy Materials & Solar Cells 93 (2009) 1881–1884.

[9] P. Yadav, K. Pandey, B. Tripathi, C. M. Kumar, S. K. Srivastava, P.K. Singh, M. Kumar, "An effective way to analyse the performance limiting parameters of poly-crystalline silicon solar cell fabricated in the production line", Solar Energy 122 (2015) 1–10.

[10] G.Sissoko, C. Museruka, A. Corréa, I. GAYE, A. L. Ndiaye, "Light spectral effect on recombination parameters of silicon solar cell", World Renewable Energy Congress 3, 15-21 June Denver-USA (1996) 1487-1490.

[11] M. Kunst and A. Sanders, "Transport of excess carriers in silicon wafers", Semicond. Sci. Technol. 7 (1992) 51-59 in the UK.

[12] G. Sissoko, E. Nanema, Y. L. B. Bocandé, A. L. Ndiaye, M. Adj, "Minority Carrier Diffusion Length Measurement in Silicon Solar Cell Under Constant White Bias Light", World Renewable Energy Congress (1996) 1594-1597.

[13] H.L. Diallo, A. Seïdou. Maiga, A. Wereme, and G.Sissoko, "New approach of both junction and back surface recombination velocities in a 3D modelling study of a polycrystalline silicon solar cell", Eur. Phys. J. Appl. Phys. 42 (2008) 203–211.

[14] Babou Dione, Ousmane Sow, Mamadou Wade, L. Y. Ibrahima, Senghane Mbodji, Gregoire Sissoko, " Experimental Processus for Acquisition Automatic Features of I-V Properties and Temperature of theSolar Panel by Changing the Operating Point", Scientic Research Publishing -Circuits and Systems, 2016, 7, 3984-4000.

[15] G.Sissoko, C. Museruka, A. Corréa, I. GAYE, A. L. Ndiaye, "Light spectral effect on recombination parameters of silicon solar cell", World Renewable Energy Congress (1996) 1595-1597.

[16] G.Sissoko, E.Nanéma, A.Corréa, P.M.Bitéye, M.Adj, A.L. Ndiaye, "Silicon Solar cell recombination parameters determination using the illuminated I-V characteristic", World Renewable Energy Congress 3 (1998) 1848-1851.

[17] Th. Flohr and R. Helbig, "Determination of minority- measurements at different light wavelengths", J. Appl. Phys. 66 (7) (1989) 0360-3065.carrier lifetime and surface recombination velocity by Optical-Beam-Induced-Current.

[18] M.M. Dione, H. L. Diallo, M. Wade, I. Ly, M. Thiame, F.Toure, A. G. Camara, N. Dieme, Z. N. Bako, S. Mbodji, F.I. Barro and G. Sissoko, "Determination of the Shunt and Series Resistances of a Vertical Multijunction Solar Cell under Constant Multispectral Light", Proceedings of the 26 th European Photovoltaic Solar Energy Conference (2011) 250-254, DOI: 10.4229/26thEUPVSEC20111CV.3.6, Retrieved from: http: //www.eupvsec proceedings.com.