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RESEARCH ARTICLE

EFFECTS OF LIGHT INTENSITY LEVEL, ILLUMINANCE DEPTH AND TEMPERATURE ON THE PARAMETERS OF A SILICON SOLAR CELL IN CURRENT- GENERATING MODE

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Abstract

The influence of the light intensity level, of illuminance depth and of temperature on some parameters of a silicon solar cell operating in the vicinity of the short-circuit has been the subject of our study.Starting from the continuity equation, then from the equation of the density of minority charge carriers where the effects were studied, we have analyzed the performance parameters according to a temperature range from $298-350K$ and under an illumination from 0.2 to 1 Sun.The results indicate that the illumination intensity has a dominant effect on the current parameters.The photocurrent density and the short-circuit current increase with increasing light intensity level whereas the shunt resistance is more sensitive to temperature variations.

Introduction:-

When solar cells are utilized for indoor applications or integrated into a building, they are exposed to variable irradiance intensity [1]. By definition, the irradiance intensity on a solar cell is called the number of sun , where 1 sun corresponds to standard illumination at $AM1.5$ solar spectrum or $1kwatt/m^2$ [2],[3]. Changing the light intensity incident on a solar cell changes all solar cell parameters ,including the short circuit current (Jsc) ,the open circuit voltage (Voc) ,the fill factor (ff) ,the efficiency (η) , the maximum power $(P\max)$ and the impacts of series and shunt resistances $(Rs\ ;\ Rsh)$.

Knowing that the performance of a solar cell is influenced by the variation of irradiance and environmental parameters, we will focus our study on the $n+pn+$ parallel vertical junction silicon solar cell [4],[5] in current generator operation , subject to a variation in the level of illumination according to a polychromatic light and this in static mode. The impacts of irradiance, illuminance depth and temperature will be examined on minority charge carrier's density, on photocurrent density, on short circuit current and on shunt resistance.

Theory :-

Presentation of the solar cell

Our study solar cell subjected to polychromatic illumination, a variation in the amount of sunshine and a variation in temperature is represented by figure 1 below :

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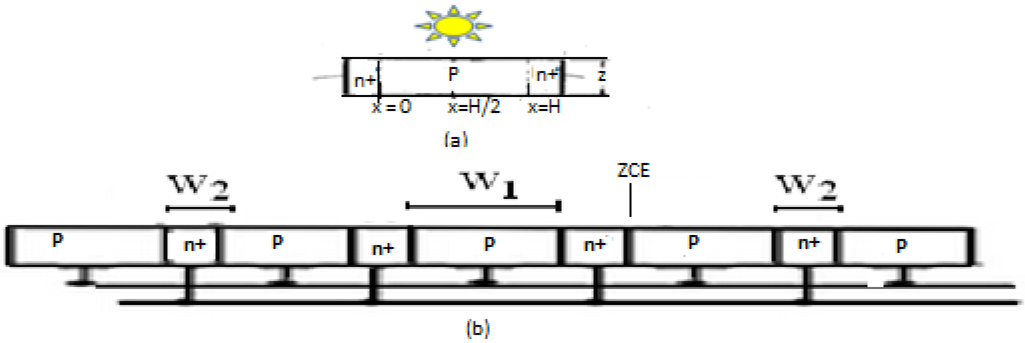

Figure 1:- (a) Single Vertical parallel junction cell (b) Vertical parallel junction cell configuration

For a simple modeling of the solar cell parameters, the following assumptions can be made:

1. No recombinations at the front side and the back side
2. No reflections on surfaces
3. Recombinations at the space charge zone are negligible
4. The generation rate is a function of the depth z
5. The diffusion of minority charge carriers is inidirectional (depending on the thickness x)

These assumptions make it possible to make a simple modeling of the solar cell parameters.
Thus, taking into account the physical phenomena that take place in the base of our illuminated solar cell (namely the absorption of photons of energy $h\upsilon \succ Eg$; the generation of electron-hole pairs, the diffusion and the recombination of minority charge carriers), we obtain the following continuity equation:

$$D(T)\frac{\partial^2\delta(x)}{\partial x^2}-\frac{\delta(x)}{\tau}+G(z)=0 \quad (1)$$

where:

$\delta(x)$; $D(T)$; $G(z)$ and τ represent respectively : the density,the diffusion coefficient,the generation rate under polychromatic illumination and the lifetime of minority charge carriers.

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

Where :

$\mu(T)$ represents the mobility of minority charge carriers as a function of temperature.Hisexpression is worded as follows $[6]$:

$$\mu(T)=1.43\times10^{9}\times T^{-2.42}cm^{2}V^{-1}s^{-1} \quad (3)$$

K_B is the Boltzmann constant $K_B = 1.38\times10^{-23} J/K$

$$G(z)=n\sum_{i=1}^{3}a_i e^{-b_i z} \quad (4)$$

The coefficients a_i and b_i are tabulated values of solar radiation under $AM1.5$ $[7],[8]$.

n is the number of Sun.It makes it possible to link the real incident power to a reference power for a given solar spectrum.In the space field, the $AM0$ solar spectrum serves as a reference. In the field of terrestrial applications of photovoltaic solar energy, the reference is the spectrum $AM1.5$.

Density of minority charge carriers

Solving the continuity equation leads to the following minority charge carrier’s density expression:

$$\delta(x,Sf,T,n,z) = A(Sf,T,n,z)\sinh(\frac{x}{L(T)}) + B(Sf,T,n,z)\cosh(\frac{x}{L(T)}) + n\tau\sum_{i=1}^{3} a_i e^{-b_i z} \quad (5)$$

With:

$$L(T) = \sqrt{\tau \times D(T)} \quad (6)$$

$L(T)$: the diffusion length of the minority charge carriers.

The coefficients A and B are obtained using the following boundary conditions [9]:

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

$$D(T)\frac{\partial\delta(x)}{\partial x}\Big|_{x=0} = Sf\delta(0) \quad (7)$$

- **at the middle of the base** $(x = \frac{H}{2})$:

$$D(T)\frac{\partial\delta(x)}{\partial x}\Big|_{x=\frac{H}{2}} = 0 \quad (8)$$

Sf is the junction recombination velocity of minority charge carriers. His expression and overall definition can be found in the article by Ba and al [10].

Photocurrent Density

Fick's law allows us to obtain the expression of the photocurrent density. This expression is given by the following equation:

$$Jph(Sf,T,n,z) = 2qD(T)\frac{\partial\delta(x,Sf,T,n,z)}{\partial x}\Big|_{x=0} \quad (9)$$

Short circuit current density

It corresponds to the maximum current that our solar cell can deliver.It is expressed as follows:

$$Jsc(T,n,z) = \lim_{Sf\to\infty} Jph(Sf,T,n,z) \quad (10)$$

$$Jsc(T,n,z) = 2q\frac{D(T)}{L(T)}\left[n\tau\sum_{i=1}^{3} a_i e^{-b_i z}\right] \quad (11)$$

Shunt resistance

Depending on the operating neighborhood considered, our solar cell operates as a current generator, in parallel with a shunt resistance and all in series with a load resistance as shown in the following figure:

The mesh law applied to this circuit makes it possible to establish the following relationship:

$$Vph = Rsh(Jph - Jsc) \quad (12)$$

$$Rsh(j,T,n,z) = \frac{Vph(j,T,n,z)}{Jph(j,T,n,z) - Jsc(T,n,z)} \quad (13)$$

This relationship remains valid only in the domain of large values of the junction recombination velocity $(Sf \geq 4\times10^4 cm/s)$ .Throughout our work, we fix Sf $(Sf = 5\times10^5 cm/s)$.

Vph is the potential difference across the terminals of the illuminated solar cell.

$$Vph(Sf,T,n,z) = \frac{K_B T}{q}\ln\left[1 + \frac{Nb}{(n_0(T))^2}\delta(0,Sf,T,n,z)\right] \quad (14)$$

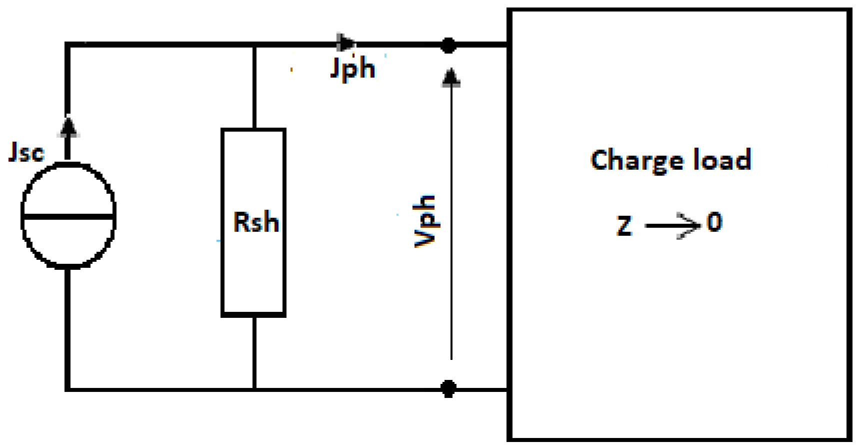

Figure 2 :- Equivalent electrical circuit of a solar cell operating in short circuit.

Nb is the doping density in the base . $n_0(T)$ is the intrinsic carrier's density, function of temperature whose explicit expression is given in these articles [11], [12].

Results And Discussions:-

Effects of irradiance or illumination intensity level, temperature and illuminance depth on:

1. Density of minority charge carriers
2. Photocurrent density
3. Short circuit current density
4. Shunt resistance

We present below the respective profiles of these variations (figures 3,4,5,6).

From the figures $3(a,b,c,d)$ above, we obtain the maximum of the density of the minority charge carriers in the middle of the base $(x = \frac{H}{2})$. The amplitude of the density of the charge carriers is more important there for the maximum of the intensity of illumination $(1Sun)$ andfor maximum temperature $(T = 350K)$.

Indeed, when the illumination intensity increases, more charge carriers can be generated and the temperature, in turn will accentuate the mobility of these carriers.

When the illumination intensity decreases 0.4 Sun ($400W/m^2$)few charge carriers are generated, hence the reduction in the amplitude of the photocurrent density noted in the figures $4(a,b,c,d)$.

The short-circuit current density decreases with increasing temperature in the figures $5(a,b,c,d)$, on the other hand it increases with the intensity of illumination.

However, strong is to recognize that according to the depth, there is a strong attenuation of the incident light.The expression of the generation rate being a function of the exponential which varies with the depth z decreases when this one increases.

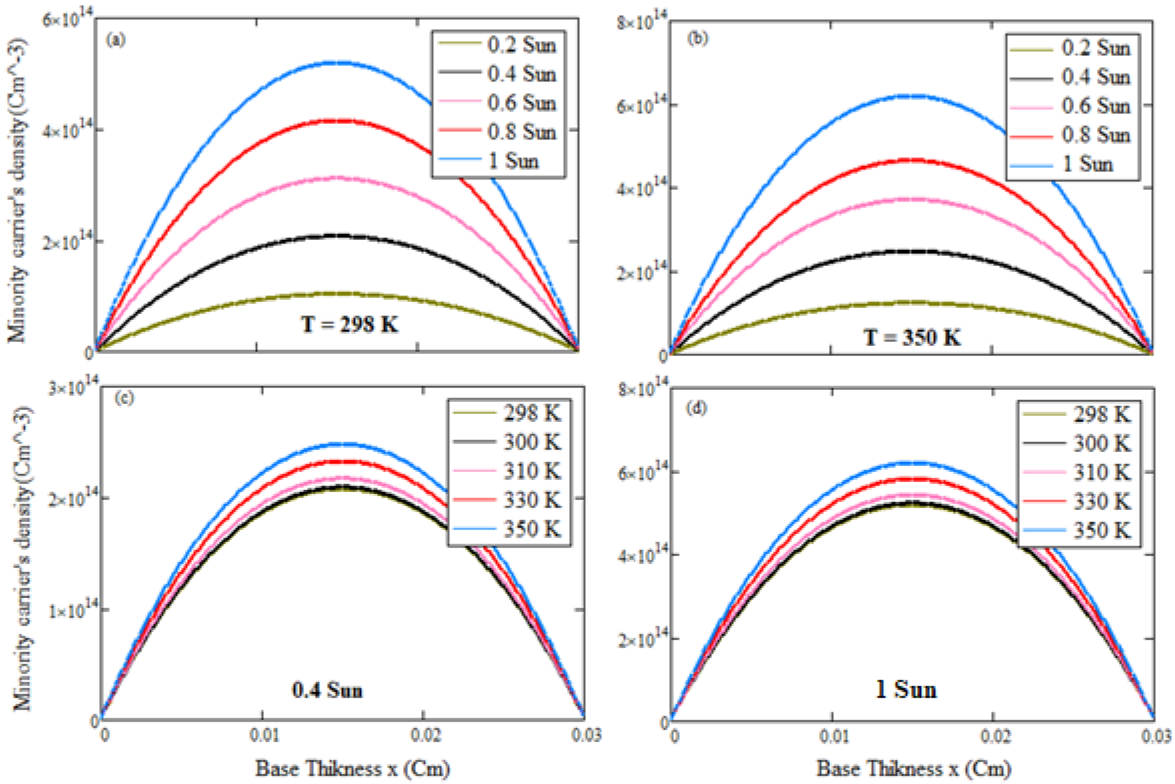

Figure 3 :- $\delta(x) = f(x)$ for various Sun and Temperatures with $z = 0.0002cm$.

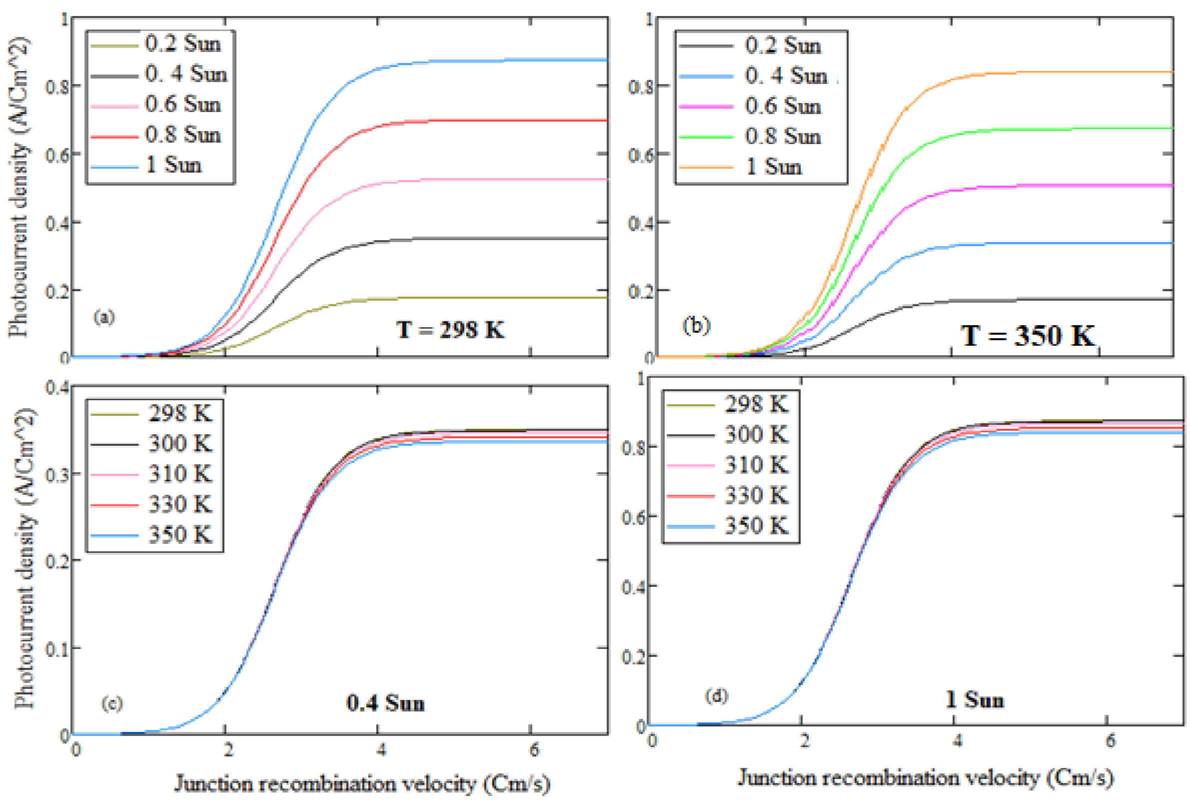

Figure 4 **:-** $Jph = f(Sf)$ for various Sun and Temperatures with $z = 0.0002cm$.

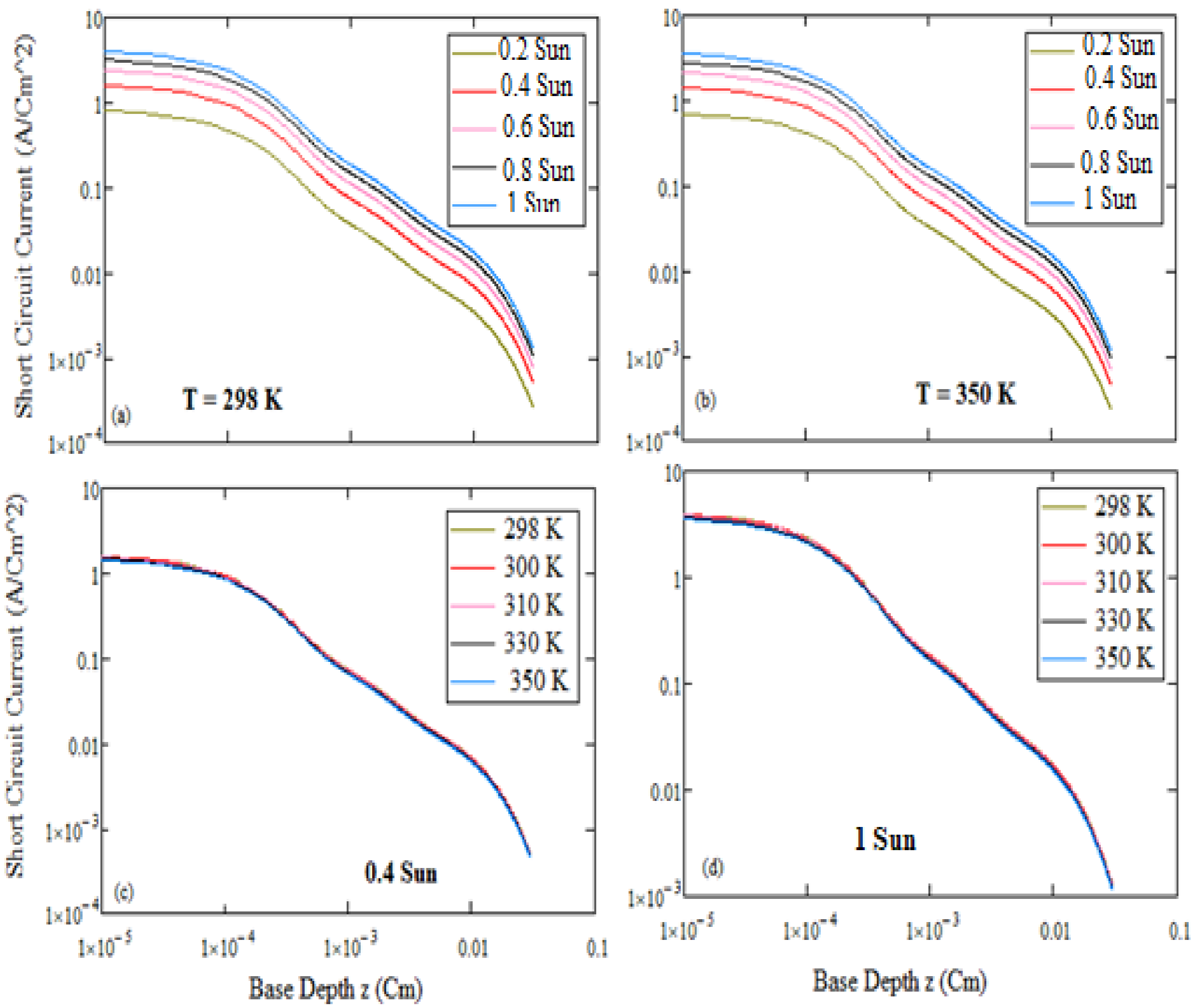

Figure 5:- $\log Jsc = f(\log z)$ for various Sun and Temperatures.

For the shunt resistance profiles (figures $6(a,b,c,d)$) , the amplitude is greater for a low number of sun, a low temperature and a great depth z ,shunt resistance increases there.Bestquality cells will have a high shunt resistance.

The table 1 below lists the data of the maximum amplitude of the parameters studied according to different levels of illumination intensity and temperature for a depth $z = 0.0002cm$ and junction recombination velocity $Sf = 5\times10^{5} cm/s$.

Conclusion:-

At the end of this paper, and considering that our silicon solar cell is in current generator mode , we can say that: when temperature varies from $298-350K$, the obtained variation of parameters $(\delta(x)$; Jph; Jsc ; $Rsh)$ under illumination intensities from 0.2 to 1 Sun where respectively: $\delta(x)$ increases from 1.04×10^{14} to $5.433\times10^{14} cm^{-3}$; Jph decreases from 0.174 to $0.863 A/cm^{2}$; Jsc increases from 0.269 to $1.310 A/cm^{2}$ and Rsh decreases from 3.855 to $0.836\Omega\times cm^{2}$.

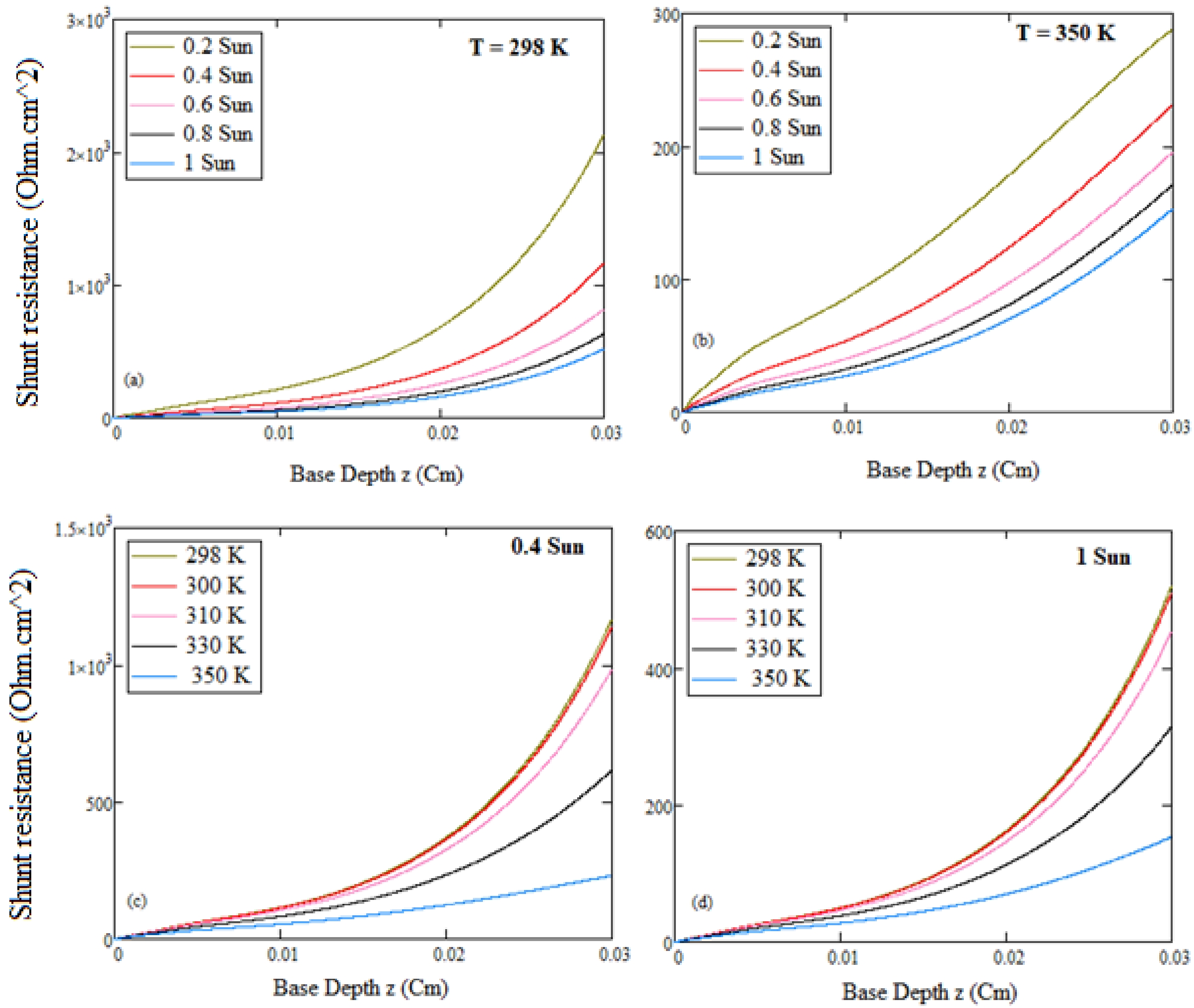

Figure 6 :- $Rsh = f(z)$ for various Sun and Temperatures.

Table 1 **:-** Data under different light intensities levels and temperatures of parameters studies :

Light intensity $(n \times 1000 W/m^2)$	(number of Suns) n	$T(K)$	$\delta(cm^{-3}) \times 10^{14}$	$Jph(A/cm^2)$	$Jsc(A/cm^2)$	$Rsh(\Omega \times cm^2)$
200	0.2	298	1.04	0.174	0.269	3.855
		300	1.047	0.173	0.268	3.833
		310	1.086	0.172	0.262	3.702
		330	1.164	0.170	0.250	3.346
		350	1.240	0.167	0.240	2.852
400	0.4	298	2.079	0.348	0.539	2.021
		300	2.095	0.347	0.536	2.011
		310	2.173	0.345	0.524	1.954
		330	2.328	0.340	0.501	1.795
		350	2.480	0.335	0.481	1.569
1000	1	298	5.199	0.871	1.348	0.857
		300	5.238	0.869	1.341	0.854
		310	5.433	0.863	1.310	0.836

		330	5.820	0.850	1.254	0.782
		350	6.201	0.838	1.202	0.703

References:-

[1] Roth W.,Schmid J.8th EC Photovoltaic Solar Energy Conference,pp.26-39

[2] Singh,P.&Ravindra,N.M.,(2012).Temperature dependance of solar cell performance an analysis.Solar Energy Materials & Solar cells,101,pp: 36-45

[3] J.F.Randall, J.Jacot Is $AM1.5$ applicable in practice?Modelling eight photovoltaic materials with respect to light intensity and two spectra

[4] J.D.Arora,S.N.Singh and P.C.Marthur .(1981).Surface recombination effects on the performance of $n+p$ step and diffused junction silicon solar cell.Solid State Electronics,XXIV(8),pp : 739-747

[5] M.M.Dione,S.Mbodji,L.Samb,M.Dieng,M.Thiame,S.Ndoye ,F.I.Barro ,G.Sissoko .(2009).Vertical junction under constant multispectral light : Determination of recombination parameters. Proceedings of the 24th European Photovoltaic Solar Energy Conference, pp : 465-469

[6] M.Kunst and A.Sanders,(1992).Transport of excess carriers in silicon wafers.Semiconductor Science and Technoloy.Volume 7,Numero 1,pp.54-59

[7] J.Furlan and S.Amon . (1985).Approximation of the carrier generation rate in illuminated silicon. Solid State Electr. ,XVIII(12),pp :1241-1243,

[8] S.N.MOHAMMAD . (1987).An alternative method for performance analysis of silicon solar cells .J .Appl.Phys.61(2),pp :767 -772

[9] A.Hamidou,A.Diao,S.A.Douani,A.Moissi,M.Thiame,F.I.Barro and G.Sissoko. (2013). Determination of a vertical parallel junction solar cell under multispectral illumination steady state. International Journal of Innovative Technology Exploring Engineering (IJITEE),II(3),pp : 1-6

[10] Fatimata Ba,BoureimaSeibou,MamadouWade,MarcelSitorDiouf,Ibrahima Ly and GrégoireSissoko. (2016).Equivalent electric model of the junction recombination velocity limiting the open circuit of a vertical parallel junction solar cell under frequency modulation. IPASJ International Journal of Electronics & Communication (IIJEC),Volume 4 ,Issue 7,pp : 1-11 ,ISSN : 2321-5984

[11] C.D.Thurmond.(1975).The standar thermodynamic functions for the formation of electron and hole in Ge ,Si,GaAs and GaP.Journal of Electrochemical Society,122,8,pp: 1133-1144

[12] MohamadouSamassaNdoye,BoureimaSeibou,IbrahimaLy,MarcelSitorDiouf,MamadouWade,SenghaneMbodji,GregoireSissoko(2016).Irradiation effect on silicon solar cell capacitance in frequency modulation.International Journal of Innovative and Exploring Engineering (IJITEE),Volume 6 Issue 3,pp: 21-25.