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LIGHT CONCENTRATION SOLAR CELL: TEMPERATURE PROPER AND DYNAMIC EFFECTS ON ELECTRICAL PARAMETERS DETERMINED BY USING J-V AND P-V CHARACTERISTICS

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ABSTRACT

The solar cell is assumed to be under light concentration (C=50 Suns) which leads us to take into consideration the electric field induced by electrons concentration gradient. We also take into consideration temperature influence on electron and hole diffusion parameters, on carrier generation rate, on carrier intrinsic concentration and on silicon energy gap. It emerges from results analysis that increase in temperature leads to decrease of open-circuit voltage and the photovoltaic parameters at the maximum power point (MPP) such as electric power, photo-voltage and photocurrent with however a slight increase of short-circuit photocurrent density. It also appears that temperature has a double effect on electrical parameters. The temperature dynamic effect which is characterized by parameters variations linked to operating point displacement caused by temperature variations. And the temperature proper effect which is characterized by parameters variation with temperature at a given operating point. Thus, the combination of these two effects represents temperature effective effect.

KEYWORDS: Light Concentration, External Load Resistance, Dynamic Junction Velocity, Temperature Dynamic Effect, Temperature Proper Effect, Temperature Effective Effect.

INTRODUCTION

Several authors have studied temperature's impact on photovoltaic parameters and have shown that temperature increase causes a drop of cell's performance [1-4]. Many other authors have studied temperature's impact on silicon devices and have shown a strong dependence of internal parameters on temperature [5-9].

Among these internal parameters which strongly depend on temperature variations, we can cite: charge carrier diffusion parameters, the carriers' intrinsic concentration, the rate of carriers thermal generation as well as silicon energy gap. It also emerges from these works that it is mainly the strong dependence of internal parameters on temperature which is the basis of the cell performance loss when this one is subjected to increasing temperatures.

In the basic principle of concentrated photovoltaic systems (CPV), the incident light is previously concentrated using parabolic mirrors or Fresnel lenses. This concentration of light causes cells heating if a cooling device such as a radiator is not associated to the installation [10, 11, 12].

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In a previous work we have studied heating impact on cell operating mode and efficiency [13]. In these previous works, the photocell is submitted to an intense light, thus the electric field induced by carriers concentration gradient is taken into consideration to determine continuity equation. For determination of carrier's density and photovoltaic parameters, the temperature influence on electron and hole diffusion parameters, on carrier generation rate, on carrier intrinsic concentration and on silicon energy gap are also taken into consideration.

In this present article which represents the continuation of our previous works [13], we will determine for different temperature, the photovoltaic parameters of silicon photocell, submitted to a concentrated illumination by using the both J-V and P-V characteristics. We will then study temperature impact on these parameters. Subsequently to analyze and better understand temperature influence on photovoltaic parameters of a silicon photocell under intense light concentration, we will decompose temperature effect of into two components.

THEORY

Expression of carrier density

We consider a monofacial photocell of type (n^+-p-p^+) operating under a concentrated multispectral light (C=50 Suns). The emitter contribution is neglected so the analysis was limited to the base thickness H [14]. The incident light is concentrated; this leads us to take into consideration the electric field induced by electrons concentration gradient [13, 15].

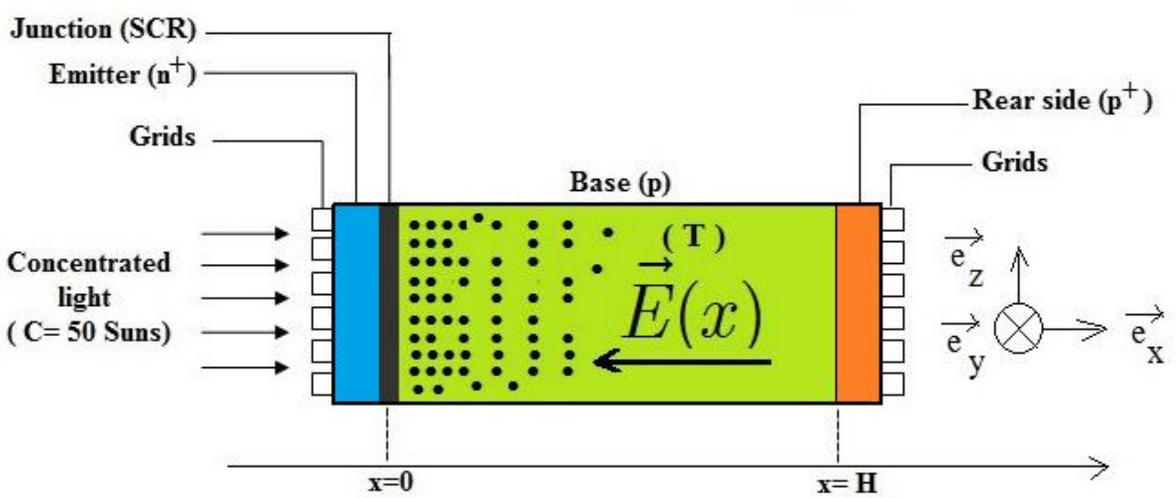

Figure 1: Temperature impact on a silicon photocell submitted to light concentration

By also taking into consideration temperature influence on electron and hole diffusion parameters, on carrier's generation rate, on carriers' intrinsic concentration and on silicon energy gap, we determine carrier's density given by Equation 1 [13].

$$d(x,T) = A\,ch(a(T)x) + B\,sh(a(T)x) + \sum_{i=1}^{3} K_i(T)\cdot e^{-b_i x} + \frac{(L^c(T))^2}{D^c(T)} C_{th} A_n^2 T^3 \exp\left(-\frac{Eg(T)}{kT}\right)$$

(1)

In above Equation (1) $K_i(T) = \frac{C}{D^c(T)} \frac{a_i (L^c(T))^2}{\left[1 - \left(b_i L^c(T)\right)^2\right]}$ and $a(T) = \frac{1}{L^c(T)}$; $D^c(T)$, $L^c(T)$ and $Eg(T)$ represent versus temperature T respectively diffusion coefficient, diffusion length and silicon energy gap [13]. C represents light concentration and coefficients a_i and b_i are obtained from modeling of carriers photo-generation rate considering solar radiation entire spectrum [13,15]. x represents the base depth and k the Boltzmann's constant [13,14,15]. C_{th} is proportionality coefficient on which depends carriers thermal-generation rate expression and A_n is a specific constant of material ($A_n = 3{,}87 \times 10^{16}$ for silicon) [13]. Coefficients A and B are determined through boundary conditions at the junction (x=0) and at the rear side (x=H) [13,14,15].

PHOTOCURRENT DENSITY

Equation 2 represents expression of current density [13, 14, 15, 16,17]:

$$J_{ph}(Sf,T) = q \cdot D^{c}(T) \cdot \left.\frac{\partial \delta(x,Sf,T)}{\partial x}\right|_{x=0} \quad (2)$$

where Sf is the junction dynamic velocity and q the elementary electric charge.

THE CELL PHOTO VOLTAGE

The cell photo voltage expression is given by Equation 3 [13, 14, 15, 16,17]:

$$V_{ph}(Sf,T) = V(T) \cdot \ln\left[\frac{\delta(x=0,Sf,T)}{n_0} + 1\right] \quad (3)$$

with $V(T)$ the thermal voltage versus the temperature T and n_0 carrier concentration at thermodynamic equilibrium [13].

RESULTS – DISCUSSIONS

Photocurrent Density-Photovoltage Characteristics (J_{ph}-V_{ph})

In Figure 2, we plot the J_{ph}-V_{ph} characteristic curve for various temperature.

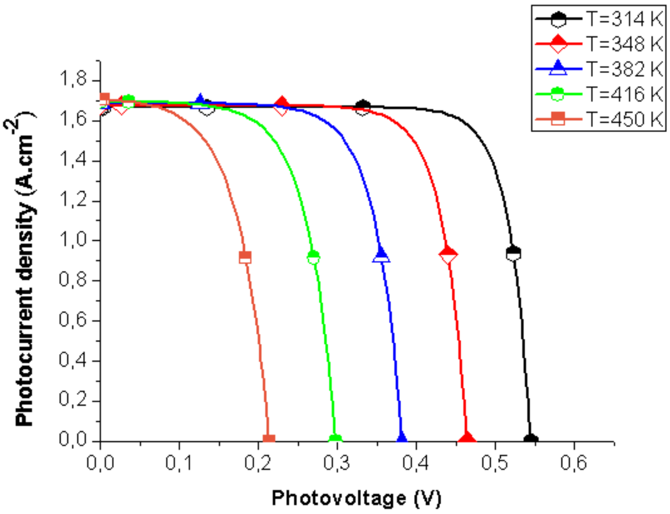

Figure 2: J_{ph}-V_{ph} Characteristic for different temperature (C= 50 Suns; H=0.03 cm; $S_b=10^2$ cm/s).

For a given temperature, each curve is characterized by three remarkable points which are:

- the short-circuit where the photo voltage is null and where the current density is equal to the short-circuit current density (J_{sc});
- the open circuit where the current density is null and where the voltage is equal to open-circuit voltage (V_{oc});
- the MPP which is determined as illustrated by Figure 4 below where the power corresponds to the maximum (P_{max}) and where current density and voltage respectively correspond to current density (J_m) and voltage (V_m) so that:

$P_{max} = J_m.V_m$ (4)

It emerges from Figure 2 curves that the short circuit current density increases slightly while the open circuit voltage decreases strongly when temperature increases. It also emerges that increase in temprerature cause a rapid displacement of the MPP to low voltages while its displacement along current density axis is weak. This results in maximum power (P_{max}) decrease with temperature increase as already shown in our previous work [13].

It is so clearly emerges from equation 7 that cell temperature rise causes necessarily dinimution of external load's resistance.

Electric Power-Photovoltage Characteristics (P-V_{ph})

We plot in Figure 3 the P-V_{ph} characteristic curves for different temperature.

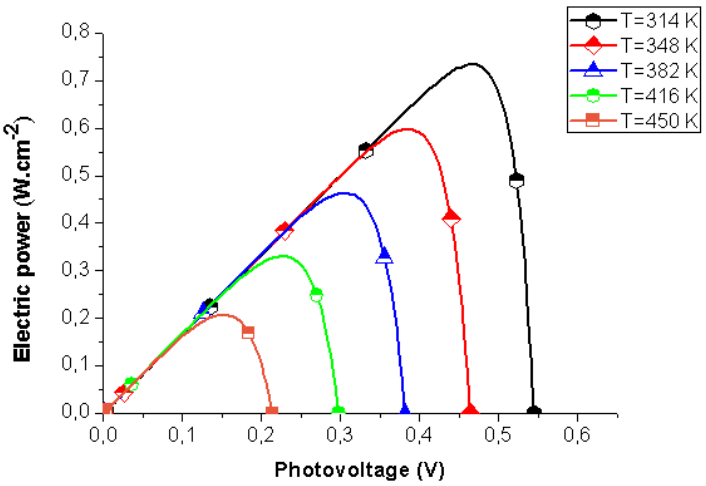

Figure 3 curves show that temperature rise causes maximum power dinimution as already shown above and in our previous work [13]. This diminution of maximum power is accompanied by a displacement of the MPP to low voltages.

Electrical Parameters Determination

We plot on the same axes system as show in Figure 4, J_{ph}-V_{ph} and P-V_{ph} characteristics for a given temperature. On the basis of these two curves, we determine solar cell electrical parameters at MPP: maximum power (P_{max}), photovoltage (V_m) and current density (J_m). We also determine values of short-circuit current density (J_{sc}) and open circuit voltage (V_{oc}).

We then calculate values of ideal power (P_{ideal}), fill factor (FF) and external load resistance at MPP (R_{MPP}) using following Equations 5, 6 and 7:

$$P_{ideal} = V_{oc} \times J_{sc} \quad (5)$$

$$FF = \frac{P_{max}}{P_{ideal}} \quad (6)$$

$$R_{MPP} = \frac{V_m}{J_m} \quad (7)$$

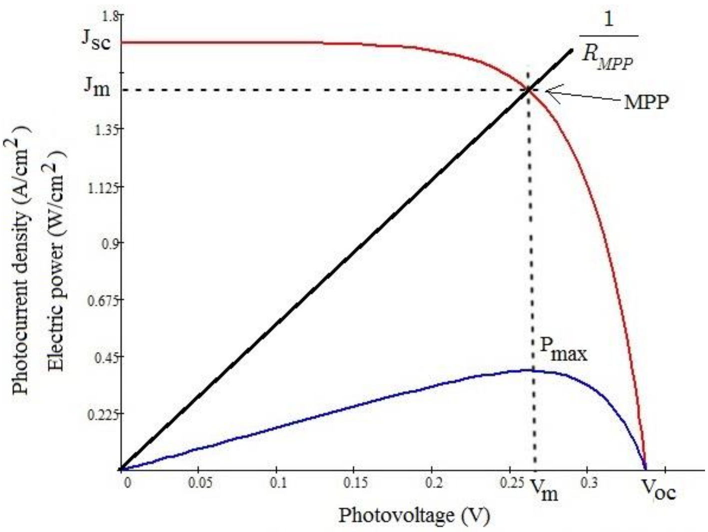

Figure 4: Electrical parameters determination using Jph-Vph and P-Vph characteristics.

Electrical Parameters Values

The Table 1 give the photovoltaics parameters determined by using J_{ph}-V_{ph} and P-V_{ph} characteristics.

Table 1: Electrical parameters of solar cell under intense light illumination for various temperature

Temperature	314 K	348 K	382 K	416 K	450 K
P_{max}(mW/cm^2)	734.46	598.79	464.06	331.20	206.89
V_m(mV)	466.40	385.28	303.91	230.37	149.79
J_m(mA/cm^2)	1574.70	1554.20	1526.90	1437.70	1381.30
V_{oc} (V)	544.93	464.36	381.87	298.16	213.68
J_{sc} (mA/cm^2)	1666.50	1674.30	1685.10	1693.30	1704.20
P_{ideal} (mW/cm^2)	908.13	777.48	643.49	504.87	364.15
FF	0.81	0.77	0.72	0.66	0.57
R_{MPP}(Ω.cm^2)	0.30	0.25	0.20	0.16	0.11

The results of Table 1 confirm a significant decrease of open-circuit voltage (V_{oc}) and a slight increase of short-circuit current density (J_{sc}) with temperature increasing.
It appears a decrease of ideal power (P_{ideal}) with temperature increasing. This decrease is linked to the rapid decrease of open circuit voltage (V_{oc}). Short-circuit current density (J_{sc}) increase is very slow, so it doesn't have a great influence on ideal power.
Table 1 results show that at MPP, maximum power (P_{max}) and voltage (V_m) decrease consequently while the current density (J_m) decreases very slightly with temperature rise.
The cell fill factor (FF) decreases with increasing temperature. This decrease means that loss in maximum power (P_{max}) is greater than loss in ideal power (P_{ideal}). This result reflects a loss in performance of a cell submitted to light concentration under temperature effect.
The external load resistance at MPP (R_{MPP}) decreases with temperature increasing. This result to the fact that at MPP, the voltage (V_m) decreases rapidly while current density (J_m) decreases very slightly.
For various temperature, Table 2 gives corresponding maximum power (P_{max}) and external load resistance at MPP (R_{MPP}). Table 2 also contains our previous work results which gives for each temperature, corresponding maximum power (P_{max}) and those of dynamic velocity at the MPP [13].
For each value of temperature, maximum power value determined in the previous work exactly correspond to that in this article.

Table 2: Temperature, corresponding maximum power (P_{max}), external load resistance (R_{MPP}) and dynamic velocity (Sf_{MPP}) at the MPP.

Temperature	314 K	348 K	382 K	416 K	450 K
P_{max} (mW/cm^2)	734.460	598.790	464.060	331.200	206.890
R_{MPP} (Ω.cm^2)	0.30	0.25	0.20	0.16	0.11
Sf_{MPP} (cm/s)	4.00×10^4	3.10×10^4	2.40×10^4	1.43×10^4	1.11×10^4

It emerges from Table 2 that both external load resistance (R_{MPP}) and dynamic velocity (Sf_{MPP}) decrease with temperature increasing. This result is in disagreement with Sow et al [16] who showed that dynamic velocity and external load resistance at the MPP evolve in reverse senses.
For a good understanding of this disagreement, we split temperature effect into two components which are:

- The temperature dynamic effect which is linked to displacement of operating point of the cell. Table 2 shows that the MPP moves towards open circuit which corresponds to a diminution of Sf_{MPP}. To study this dynamic effect on current density and on voltage, temperature assumed to be fixed (at T = 314 K).
- Temperature proper effect which is not linked to operating point displacement. When the operating point is fixed, temperature variation also causes solar cell's parameters variation. Thus we shown that temperature rise leads to short circuit current density increase and open circuit voltage decrease. Study of temperature proper effect on current density and on voltage supposes that dynamic velocity at the MPP is constant ($Sf_{MPP} = 4.10^4$ cm.s^{-1}).

To determine temperature dynamic effect, we obtained Table 3 below which gives for each dynamic velocity value at the MPP, the corresponding values of current density and photovoltage, the temperature is supposed to be constant and equal to T = 314 K.

Table 3: Dynamic velocity at MPP, corresponding values of current density and voltage, temperature is considered to be constant at T = 314 K

Sf_{MPP}(cm/s)	4.00×10^4	3.10×10^4	2.40×10^4	1.43×10^4	1.11×10^4
J_m (mA/cm^2)	1574.74	1549.89	1518.86	1433.41	1376.63
V_m (mV)	466.41	472.90	479.29	491.66	497.56

It emerges from Table 3 that a decrease of Sf_{MPP} leads to current density J_m decrease and voltage V_m increase. Indeed, Sf_{MPP} characterizes carriers flux crossing the junction and its decrease corresponds to current density decrease and voltage increase. Current density decrease and voltage increase lead consequently to $R_{MPP} = \frac{V_m}{J_m}$ increase. In other words, when Sf_{MPP} increases then J_m increases while V_m decreases and the external load resistance at the MPP (R_{MPP}) decreases. So when we consider only the temperature influence on dynamic velocity then Sf_{MPP} value and that of external load resistance at the MPP evolve in reverse senses.

We also obtained the following table 4 which gives for each temperature, the corresponding values of current density and voltage, the dynamic velocity at the MPP being considered constant ($Sf_{MPP} = 4.10^4$ cm.s^{-1})

Table 4: Temperatures, corresponding values of current density and voltage when dynamic velocity is considered to be constant at Sf_{MPP}=4.00×10^4 cm/s

Temperature	314 K	348 K	382 K	416 K	450 K
J_m (mA/cm^2)	1574.74	1579.74	1586.59	1591.89	1600.65
V_m (mV)	466.41	378.10	288.31	197.29	107.34

Table 4 shows that when cell's temperature rise, it proper effect causes a very slight increase of J_m which goes from 1574.74 mA.cm^{-2} to 1600.65 mA.cm^{-2}. On another hand, its dynamic effect as shown by Table 3 leads to a relatively greater decrease in J_m which goes from 1574.74 mA.cm^{-2} to 1376.63 mA.cm^{-2}. The dynamic effect is predominant therefore temperature effective effect on J_m which corresponds to combination

The temperature effective effect causing a slight decrease in J_m and a strong decrease in V_m, the external load resistance at the MPP, $R_{MPP} = \frac{V_m}{J_m}$ necessarily decreases as we have already prouve in Table 1

CONCLUSION

Because of the high level of illumination, the electric field induced by electrons concentration gradient has been taken into consideration. We also took into consideration temperature influence on electron and hole diffusion parameters, on carrier generation rate, on carrier intrinsic concentration and on silicon energy gap.

On the basis of J_{ph}-V_{ph} and P-V_{ph} characteristics, electrical parameters were obtained for various temperature.

It emerges from results analysis that open circuit voltage, maximum power, voltage and current density at MPP, ideal power, fill factor and external load resistance at MPP decrease when an intense illumination photocell's temperature rise. However, a slight increase in short circuit current density appears when solar cell's temperature increases.

Because of the MPP displacement, It also emerges from results that a good understanding of electrical parameters variation requires decomposing temperature effect in two components which are the dynamic effect and the proper effect. The combination of these two effects gives temperature effective effect.

of these two effects causes a slight decrease in J_m as Table 1 have already shown.

Table 3 highlights a very slight increase in V_m due to dynamic effect (Sf_{MPP}) while table 4 shows a strong decrease in Vm due to temperature proper effect (T) which is then predominant. Therefore temperature effective effect causes a strong decrease of V_m as already prouve by Table 1 and as well by curves of Figures 2 and 3.

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