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Investigating the Impact of Base Heating and External Electric Field on PV Cell Performance under Intense Illumination

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Abstract

The characterization of the performances of a PV cell is linked to intrinsic factors of this cell. It is therefore important for us to identify the favorable or unfavorable conditions that affect the performance of PV cells. It is from this perspective that it seems judicious to us to study the simultaneous influence of the heating of the base and an external electric field on the performance of a PV cell under intense illumination of 50 suns. Two phenomena contribute to the heating of the base of a PV cell which is heating due to the transfer by conduction of solar radiation energy received by the surface of the PV cell and the heat generated inside the PV cell by various phenomena linked to the movement of photogenerated charged carriers. In this study, we take into account the heating linked to the movement of the charged carriers in the base. After a mathematical modeling of the PV cell considered, some hypotheses are formulated and the expressions of the electrical parameters are established as a function of the electric field and base temperature. Subsequently, we use numerical simulation to highlight the behavior of theses parameters as a function of temperature and of the intensity of the electric field. The results show that for any given temperature, the orientation of the electric field as considered in our work improves the performance of the PV cell while high temperatures degrade these performances. Furthermore, the analysis of the curves shows that the harmful effect of temperature on the performance of a PV cell is more accentuated at large values of electric field.

Keywords

Collisions, Thermalization, Braking, Electric Strength, Base Temperature

1. Introduction

Currently research in PV cell is oriented towards improving performance of PV cells for which the conversion efficiencies remain relatively weak. Studies show that concentrated PV cells have higher efficiencies (up to 47.1%) than ordinary PV cells [1]. But taking into account the mode of illumination, concentrated PV cells operate under high temperatures. Thus, some authors have shown, through studies, that the elevation of temperature causes a drop in the performances of PV cells [2] [3]. Other authors are interested in the effect of light intensity on the performance of PV cells and observed that increasing the intensity of incident light improves performance of PV cell [2] [4]. In addition, studies on the effect of an external magnetic field [5] [6] and of a protons irradiation on the performance of PV cells [7] have been made and it appears that the Magnetic fields as well as protons degrade performances of PV cells. The multiplicity of sources of electromagnetic fields (development of telecommunication systems) and the operating conditions of PV cells under concentration of light (high temperatures) give us the opportunity to investigate the behavior of the electrical parameters of a PV cell under illumination of 50 suns in function of the heating of the base and the intensity of an external electric field. The aim of this study is to demonstrate the simultaneous effect of base heating and an external electric field on a PV cell.

2. Mathematical Modeling

In our study, we used a polycrystalline silicon PV cell under illumination of 50 suns as shown in **Figure 1** below.

$\overrightarrow{E_0}$ is the external variable electric field acting on the PV cell. It is supposed to be uniform in all the space around the PV cell.

$\vec{E}(x)$ is concentration gradient electric field [8].

$$E(x)=\frac{D_p-D_n}{\mu_n+\mu_p}\cdot\frac{1}{\delta(x)}\cdot\frac{\partial\delta(x)}{\partial x} \tag{1}$$

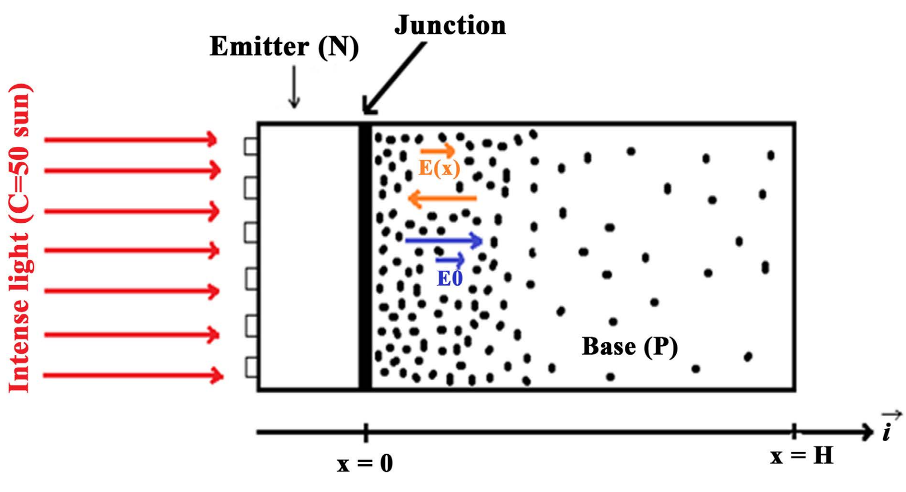

Figure 1. PV cell under concentrated illumination and under external electric field.

The mobilities of electrons and holes as a function of base temperature are given by [9]:

$$\mu_n(T) = \mu_{on}\left(\frac{T}{T_0}\right)^{-1.5} \quad \text{and} \quad \mu_p(T) = \mu_{op}\left(\frac{T}{T_0}\right)^{-1.5} \tag{2}$$

with $\mu_{on} = 1500\ \text{cm}^2\cdot\text{V}^{-1}\cdot\text{s}^{-1}$; $\mu_{op} = 475\ \text{cm}^2\cdot\text{V}^{-1}\cdot\text{s}^{-1}$ et $T_0 = 300$ K.

The diffusion parameter is related to mobility by the following equation:

$$D_n(T) = \frac{K_B \cdot T_0}{e}\mu_n(T) \quad \text{and} \quad D_P(T) = \frac{K_B \cdot T_0}{e}\mu_P(T) \tag{3}$$

K_B is the Boltzmann's constant and e is the elementary charge. According to our model, the current density is the sum of three currents. It is given by the following equation.

$$J_n(x,T,E_0) = e \cdot D_n(T) \cdot \frac{\partial \delta(x,T,E_0)}{\partial x} - e \cdot \mu_n(T) \cdot E(x) \cdot \delta(x,T,E_0) + e \cdot \mu_n(T) \cdot E_0 \cdot \delta(x,T,E_0) \tag{4}$$

$eD_n(T)\dfrac{\partial \delta(x,T,E_0)}{\partial x}$ is a diffusion current.

$-e\mu_n(T)E(x)\delta(x,T,E_0)$ is a conduction current induced by $\vec{E}(x)$.

$e\mu_n(T)E_0\delta(x,T,E_0)$ is a conduction current induced by $\overrightarrow{E_0}$.

The continuity equation of charged carriers for the cell is given by the following Equation (5):

$$\frac{\partial^2 \delta(x,T,E_0)}{\partial x^2} + \frac{L_{E_0}(T)}{L_{np}^2(T)} \cdot \frac{\partial \delta(x,T,E_0)}{\partial x} - \frac{\delta(x,T,E_0)}{L_{np}^2(T)} = -\frac{C}{D_{np}(T)} \cdot \sum_{i=1}^{3} a_i \cdot e^{-b_i \cdot x} \tag{5}$$

with:

$$D_{np}(T) = \frac{2 \cdot \mu_n(T) \cdot D_n(T) + \mu_p(T) \cdot D_n(T) - \mu_n(T) \cdot D_p(T)}{\mu_n(T) + \mu_p(T)} \tag{6}$$

$$L_{np}^2(T) = D_{np}(T) \cdot \tau \tag{7}$$

$$L_{E_0}(T) = \mu_n(T) \cdot E_0 \cdot \tau \tag{8}$$

a_i and b_i are tabulated coefficient given for AM 1.5, by [10].

$a_1 = 6.13 \times 10^{20}$	$a_2 = 0.54 \times 10^{20}$	$a_3 = 0.0991 \times 10^{20}$
$b_1 = 6630$	$b_2 = 1000$	$b_3 = 130$

The resolution of Equation (5), lead to the expression of the charged carriers generated in the base $\delta(x, T, E_0)$.

3. Results and Discussions

3.1. Photocurrent Density

The Equation (9) below lead to the determination of photocurrent density as a function of the temperature T of the base and the electric field E_0:

$$J_{ph}(T,E_0) = eD_{np}(T)\frac{\partial\delta(x,T,E_0)}{\partial x}\bigg|_{x=0} + e\mu_n(T)E_0\delta(0,T,E_0) \tag{9}$$

The expression of the photocurrent density is given by the following Equation (10)

$$J_{ph}(T,E_0) = \frac{eD_{np}(S_F+\mu_n E_0)}{\beta^2 D_{np}^2 + (\alpha D_{np}+S_B)(S_F-\alpha D_{np})} \times\left[\sum_{i=1}^{3} k_i\left[\frac{\beta(D_{np}b_i - S_B)\left(e^{-H(\alpha+b_i)} - \cosh(\beta H)\right)}{\sinh(\beta H)+\beta D_{np}(S_B+S_F)\cosh(\beta H)} + \frac{\left[\beta^2 D_{np} - (\alpha D_{np}+S_B)(b_i+\alpha)\right]\sinh(\beta H)}{\sinh(\beta H)+\beta D_{np}(S_B+S_F)\cosh(\beta H)}\right]\right] \tag{10}$$

with: $k_i = \dfrac{C\cdot a_i\cdot L_{np}^2}{D_{np}\cdot\left(1+L_{E_0}\cdot b_i-(b_i\cdot L_{np})^2\right)}$; $\alpha = -\dfrac{L_{E_0}}{2\cdot L_{np}^2}$ and $\beta = \dfrac{1}{2\cdot L_{np}}\cdot\sqrt{\left(\dfrac{L_{E_0}}{L_{np}}\right)^2+4}$.

The variations of photocurrent density as a function of base temperature and external electric field are represented in the following Figure 2.

It appears on the curves of Figure 2 that the photocurrent yields by the PV cell increase with the increase of the intensity of electric field. This result is explained by the action of the electric strength which help electrons located in the vicinity of the junction across it, and participated to photocurrent.

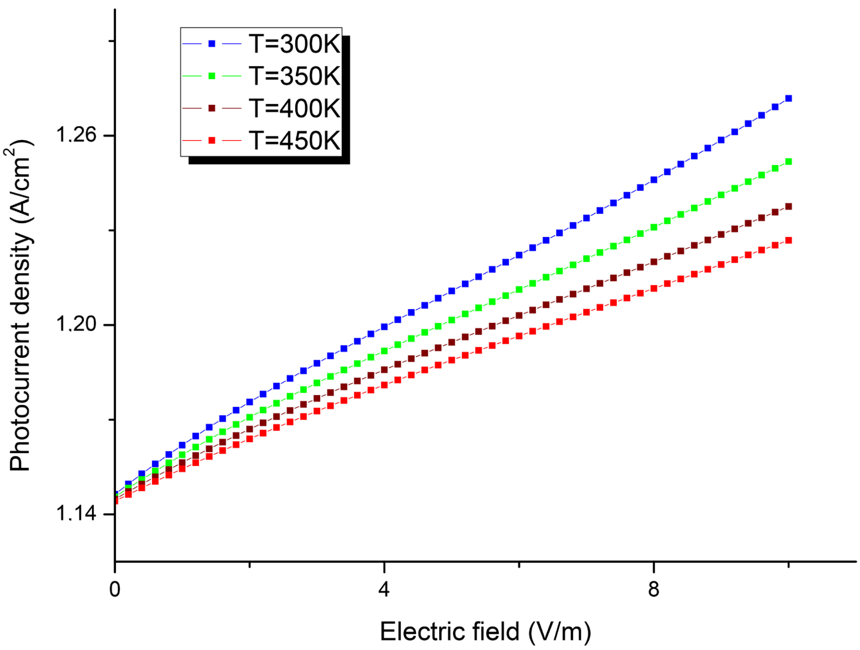

Figure 2. Variations of photocurrent versus electric field and the temperature of the base ($S_f = 5\times10^5$ cm/s; $S_b = 10^3$ cm/s; $H = 0.03$ cm; $C = 50$ suns).

From **Figure 2**, it also appears that, for a particular value of the electric field, the photocurrent decrease with the increase of the temperature of the base. This is explained by the fact that heating of the base is due to the movement of high number of charged carriers generated. Increasing of the photogenerated charged carriers is following by the increase of thermalization, collision between carriers and concentration gradient electric field $E(x)$.

Thermalization, collisions and braking produce thermal energy into the material of the PV cell. The electric field through the electric strength increases the possibility of collision between charged carriers. Hence, collision and breaking increase the loss of carriers and decrease of photocurrent.

We notice that decrease in photocurrent with increase of the temperature is more significant for high values of the intensity of the electric field. We explain that by the increase in electric strength for high values of electric field and therefore increase of collisions and loss of charged carriers.

3.2. Photovoltage

The expression of photovoltage delivered by the PV cell is given by the Equation (10) below:

$$V_{ph}\left(T,E_0\right)=V_T\ln\left[\frac{\delta\left(0,T,E_0\right)}{n_0}+1\right] \quad (11)$$

$$\text{With: } V_T=\frac{K_BT}{e} \text{ and } n_0=\frac{n_i^2}{N_B} \quad (12)$$

The expression of photovoltage obtained from (11) is given by the equation (12)

$$V_{ph}\left(T,E_0\right)=V_T\times\ln\left[1+\left[\frac{D_{np}N_B\sum_{i=1}^{3}k_i\left[\beta\left(D_{np}b_i-S_B\right)\left(\mathrm{e}^{-H(\alpha+b_i)}-\cosh\left(\beta H\right)\right)\right]}{n_i^2\left[\left[\beta^2D_{np}^2+\left(\alpha D_{np}+S_B\right)\left(S_F-\alpha D_{np}\right)\right]\sinh\left(\beta H\right)+\beta D_{np}\left(S_B+S_F\right)\cosh\left(\beta H\right)\right]}\right.\right.$$
$$\left.\left.+\frac{\left[\beta^2D_{np}-\left(\alpha D_{np}+S_B\right)\left(\alpha+b_i\right)\right]\sinh\left(\beta H\right)}{n_i^2\left[\left[\beta^2D_{np}^2+\left(\alpha D_{np}+S_B\right)\left(S_F-\alpha D_{np}\right)\right]\sinh\left(\beta H\right)+\beta D_{np}\left(S_B+S_F\right)\cosh\left(\beta H\right)\right]}\right]\right] \quad (13)$$

V_T is the thermal voltage, n_0 is the electrons density at the thermal equilibrium, N_B represent the doping rate of the base ($N_B = 10^{16}\ \text{cm}^{-3}$) and n_i is the intrinsic concentration of electrons ($n_i = 10^{10}\ \text{cm}^{-3}$). The photovoltage profile as function of electric field for different values of temperature is present on the following **Figure 3**.

Analysis of **Figure 3** shows that, for a particular value of a given temperature of the base, the photovoltage increase with the increase in electric field. This is explain by the fact that electric strength which act on the charged carriers increase with the increase in electric field. Thus the charged carriers photogenerated in rear side of the base are easily send in the zone near the junction. It then appear an accumulation of electrons in the zones near the junction and therefore

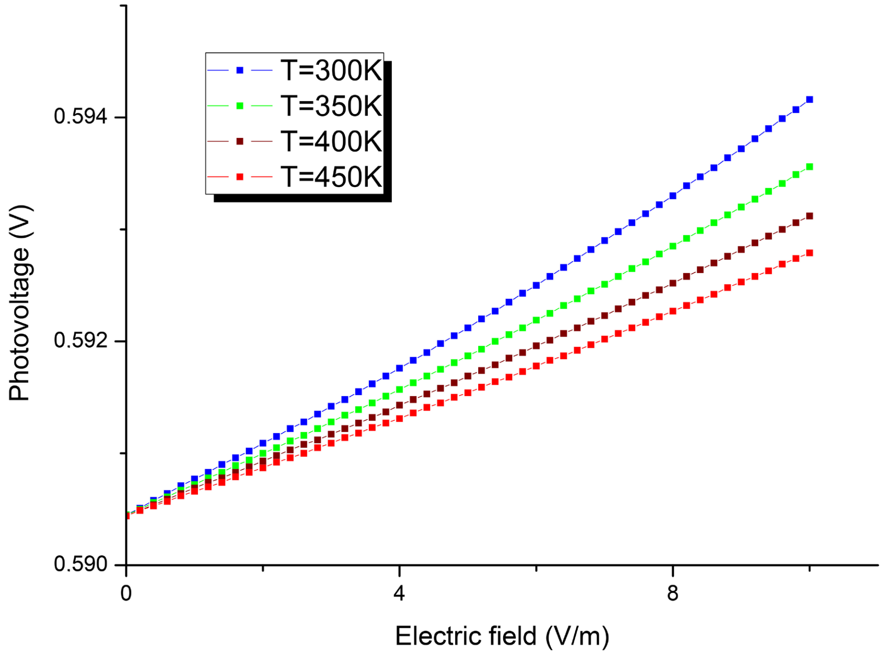

Figure 3. Evolution of the photovoltage versus electric field and the temperature of the base ($S_f = 5 \times 10^5$ cm/s; $S_b = 10^3$ cm/s; $H = 0.03$ cm; $C = 50$ suns).

an increase in photovoltage. In other hand, we notice that, for any given value of the intensity of the electric field, photovoltage decrease with the increase in the temperature of the base.

We explain this result by the fact that (champ electric du gradient de concentration) $E(x)$ induce an increase of thermalization, collisions between charged carriers, braking of charged carriers and consequently produce the heating of the base.

The presence of the electric strength increases the possibilities of collisions and losses of charged carriers into the bulk of the base of the PV cell. Consequently, photovoltage decrease. It appears on the curves of **Figure 3** that, decrease in photovoltage with increase in temperature is most significant for high values of electric field. This is the consequence of the increase in losses of charged carriers with the increase of collisions induces by the increase in electric strength.

3.3. Electric Power

Electric power delivered by a PV cell is given by the following equation:

$$P_{él}(T, E_0) = J_{ph}(T, E_0) \cdot V_{ph}(T, E_0) \quad (14)$$

Variations in electric power as a function of electric field intensity for different values of the base temperature are illustrated in **Figure 4** below.

From the analysis of **Figure 4**, it appears that, for any given temperature of the base, the electric power increases with increasing in electric field. Furthermore, for any values of electric field, the electric power decreases with the increase in the temperature of the base. These results are in good agreement with those obtained in the cases of photocurrent and photovoltage.

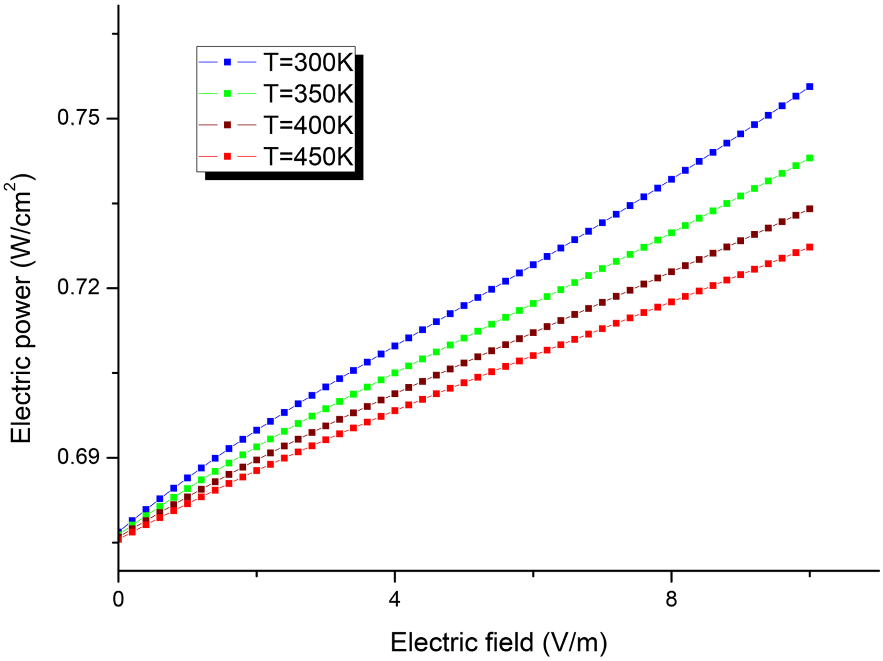

Figure 4. Variations of the electrical Power versus electric field and the temperature of the base ($S_f = 5 \times 10^5$ cm/s; $S_b = 10^3$ cm/s; $H = 0.03$ cm; $C = 50$ suns).

3.4. Fill Factor

The expression of fill factor of the PV cell is given by the following equation:

$$FF(T,E_0) = \frac{P_{él\max}(E_0,T)}{J_{cc}(T,E_0)\cdot V_{co}(T,E_0)} \tag{15}$$

The variation of the fill factor as a function of the intensity of the electric field for different values of the base temperature is presented in the following **Figure 5**.

The analysis of **Figure 5** shows that, for any given temperature of the base, the fill factor increases as the intensity of the electric field increases. Furthermore, for any given values of electric field, the fill factor decrease with the increasing of base temperature. These results are in good agreement with those obtained in the case of variations of the electric power, because the maximum electric power supplied by the PV cell changes from the same way as the electrical power delivered.

3.5. Conversion Efficiency

The expression of conversion efficiency is given by the following equation:

$$\eta(T,E_0) = \frac{P_{él\max}(T,E_0)}{P_{inc}} \tag{16}$$

The curves of conversion efficiency as a function of electric field for different values of base temperature are present in **Figure 6** below.

It emerges from the analysis of **Figure 6** that for any given value of the base temperature, the conversion efficiency of the PV cell increases with the increase

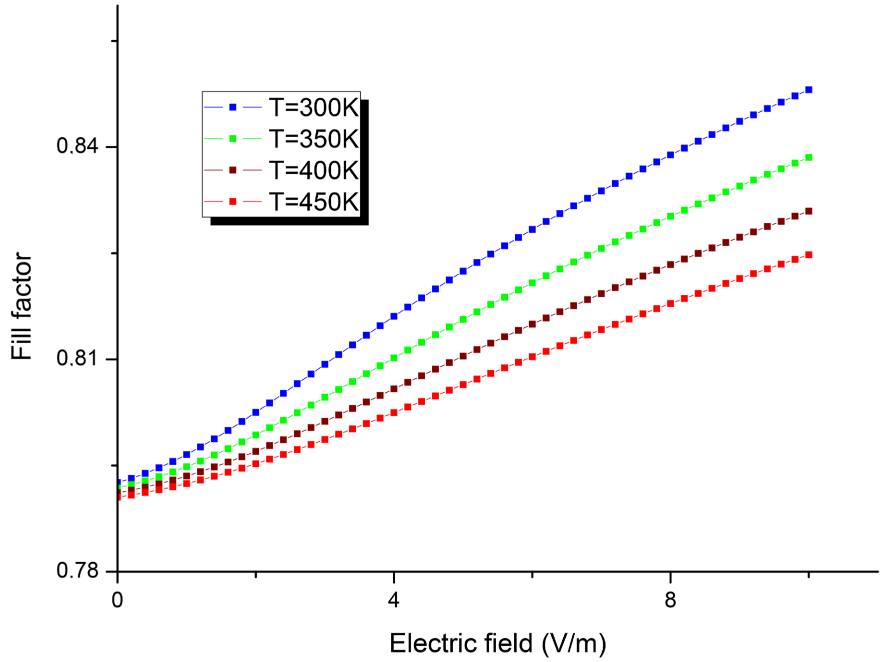

Figure 5. Variations of Fill Factor versus electric field and the temperature of the base ($S_f = 5 \times 10^5$ cm/s; $S_b = 10^3$ cm/s; $H = 0.03$ cm; $C = 50$ suns).

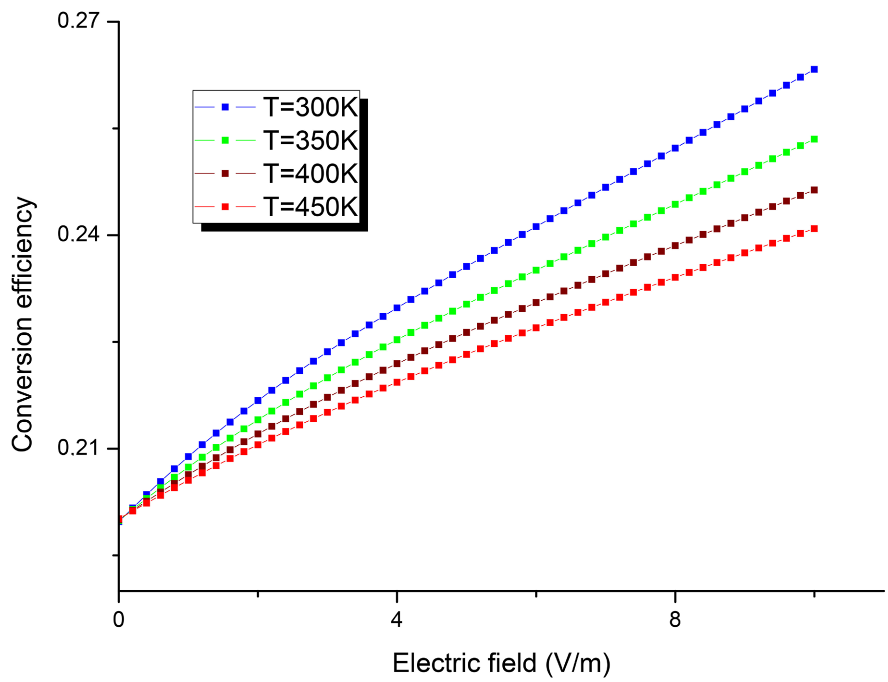

Figure 6. Variations of the conversion efficiency versus electric field and the temperature of the base ($S_f = 5 \times 10^5$ cm/s; $S_b = 10^3$ cm/s; $H = 0.03$ cm; $C = 50$ suns).

in the intensity of the electric field. Furthermore, for any given value of the electric field, the conversion efficiency decreases as the base temperature increases. These results are in good agreement with those obtained in the case of fill factor.

4. Conclusion

This work allowed us to establish the expressions of photocurrent density, electric power, fill factor and conversion as function of the base temperature and intensity of electric field. By numerical simulation, we plotted the curves of those different electrical parameters as function of temperature and electric field. The analysis of these curves shows that, for any given temperature, electrical parameters increase with the increase in electric field. It also appears that, the electrical parameters decrease with the increase in base temperature. The curves of electrical parameters reveal that harmful effect of the temperature is more important at large values of the electric field.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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