Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

3-D MODELLING OF ELECTRICAL PARAMETERS' EFFECTS ON THE HEATING OF THE BASE OF AN INTENSE LIGHT ILLUMINATED POLYCRYSTALLINE SILICON PV CELL

B. Soro, M. Savadogo, B. Zouma, K. E. Tchedre, I. Sourabie, I. Zerbo, M. Zoungrana*, D. J. Bathiebo

Laboratoire d'Energies Thermiques Renouvelables (LETRE), UFR-SEA, Département de Physique, Université Joseph KI-ZERBO, Ouagadougou, Burkina Faso

Received: 05 August 2020 / Accepted: 13 August 2021 / Published online: 01 September 2021

ABSTRACT

Performances of a solar cell are significantly influenced by the heating of the base. Two phenomena contribute to the heating of the base of a PV cell: the heat due to the transfer by conduction of the solar energy radiation received by the surface of the PV cell and the heat generated inside the solar cell by various phenomena related to the movement of photogenerated electrons and holes.

Thus, even if the increase of the quantity of carriers leads to improve the PV cell electrical parameters, this phenomenon also leads to the increase of some internal phenomena like thermalization, carriers braking and the carriers collisions which are sources of heating of the base of the solar cell

Indeed, electrical parameters (photocurrent, photovoltage, electric power) are physical quantities related to the movement of charge carriers and also to the illumination mode, this means that changing of electrical parameters during the operation of the PV cell leads to a variation of the temperature inside the base of the PV cell.

This work presents the effects of the increase of some electrical parameters (photocurrent, photovoltage, electric power) on the behaviour of the temperature of the base of a silicon PV cell under intense light illumination.

Key words: Intense illumination, Photocurrent, Photovoltage, Electrical power, Fill Factor.

Author Correspondence, e-mail: zmartial2003@yahoo.fr

doi: http://dx.doi.org/10.4314/jfas.v13i3.15

1. INTRODUCTION

Current research on solar cells aims to improve the efficiency, which is a good indicator of the performance of a PV cell. The performance of a PV cell is related to internal factors (temperature of the base, recombination, grains sizes ...) and external factors (electric field, magnetic field …) given by Pelanchon et al. [1], Zoungrana et al. [2], Soika et al. [3]. Many studies of illumination, temperature, grains recombination boundaries effects on solar cell have been made by Gupta et al. [4], Miyakawa [5], Diatta [6], Agroui [7], O'Donnell [8], Soro et al. [9]. Some studies have also been carried out on 3D modelling by Soro et al. [9], Samb et al. [10], Mane et al. [12], Dugas [13]. They were mainly made on the effect of the light's intensity on the density of photogenerated carriers by Pelanchon et al. [1], Zoungrana et al. [2]; on the solar cell photocurrent and photovoltage by Gupta et al. [4], Agroui et al. [14] and also its efficiency and fill factor by Miyakawa [5].

The results of these studies have shown that increasing the intensity of illumination increases the performance of solar cells. Also, the influence of temperature on the performances of a PV cell has already made the topic of numerous studies such as the study of the influence of the temperature on: the density of charge carriers done by Diatta [6]; the photocurrent and photovoltage done by Agroui [7], Essalam et al. [15], Merahi et al. [16]; the electric power done by Agroui [7], Merahi et al. [16], Belhadj et al. [17]. It should be noted that all these studies were made with monofacial or bifacial monocrystalline, polycrystalline and multicrystalline silicon solar cells or InGaAs. Moreover, studies done by O'Donnell [8] and Sze et al. [18], have shown that increase of the temperature of the base leads to decreasing of the gap energy of the semiconductor material.

It has been proved also by the study done by Mane et al. [12] that, there is a relationship between the movement of charge carriers (mobilities and diffusion coefficient) and the temperature of the base. Indeed, according the study done by Soro et al. [9], mobility and diffusion parameters of electrons and holes decrease while the temperature inside the base increases. Since, the recombination parameters of the PV cell (recombination velocity at the rear side Sb and dynamic velocity at the junction Sf) and the electrical parameters (photocurrent Jph, photovoltage Vph, electric power Pel ...) depend on the mobility and the diffusion coefficient which are also depending of the temperature. In this work, we propose a 3-D modelling of the effect of electrical parameters on the increase of the temperature of the base of a PV cell induced by charge carriers thermalization, braking and collision.

2. INFLUENCE OF ELECTRICAL PARAMETERS ON THE TEMPERATURE IN THE BASE

2.1. Effect of photocurrent density increase on the heating of the base

In this study, according to the assumption made by Zoungrana et al. [2], Soro et al. [9], Essalam et al. [15], the contribution of the emitter is neglected and the study is conducted in the theory of the Quasi Neutral Base (QNB). Under these conditions, the expression of the photocurrent density $J_{ph}(T)$ is according Soro et al. [9], Merahi et al. [16]:

$$J_{ph}(T) = \frac{q.D^{*}(T)}{g_x g_y} \int_{-\frac{g_x}{2}}^{\frac{g_x}{2}} \int_{-\frac{g_y}{2}}^{\frac{g_y}{2}} \left[\frac{\partial \delta(x,y,z,T)}{\partial z} \right]_{z=0} dxdy \qquad (1)$$

The curve of the figure 1 shows the effect of the increase of the density of photocurrent on the behaviour of the temperature of the base of the PV cell.

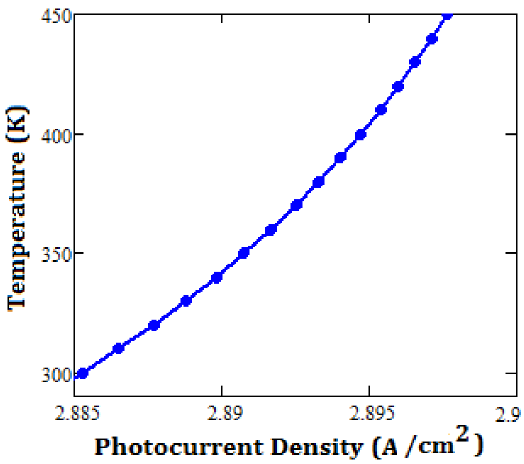

Fig.1. Temperature versus photocurrent density

(C=50 suns ; $g_x=g_y=3.10^{-3}$cm ; $S_{gb}=10^2$cm/s ; $S_f=4.10^4$cm/s ; $S_b=10^3$cm/s)

We observe on the curve of figure 1 that the increase of the density of photocurrent leads to an increase of the temperature inside the base of the solar cell. In fact, the increase of the photocurrent is characterized by an increase of the quantity of photogenerated electrons and holes in the base and therefore the quantity of electrons crossing the junction. According the study done by Soro et al. [9], the increase of the quantity of electrons and holes photogenerated is accompanied by an increase of the quantity of energy released by thermalization, by collision between charge carriers and braking by the electric field due to the gradient of electrons and holes concentration. The increase of the energy released by these three phenomena leads to an increase of the temperature in the base of the solar cell.

2.2. Effect of the photovoltage increase on the heating of the base

The photovoltage expression is given by the following Boltzmann law in the study of Dugas [13]:

$$V_{ph}(T) = V_T \ln\left[1 + \frac{N_B}{n_i^2}\int_{-\frac{g_x}{2}}^{\frac{g_x}{2}}\int_{-\frac{g_y}{2}}^{\frac{g_y}{2}} \delta(x,y,0,T)dxdy\right] \qquad (2)$$

With $V_T = \frac{K_B.T}{q}$ (V_T is the thermal voltage) n_i is the intrinsic concentration of electrons; N_B is the doping rate of the base.

The curve of the figure 2 illustrates the effect of the increase of the photovoltage on the behaviour of the temperature of the base of the PV cell.

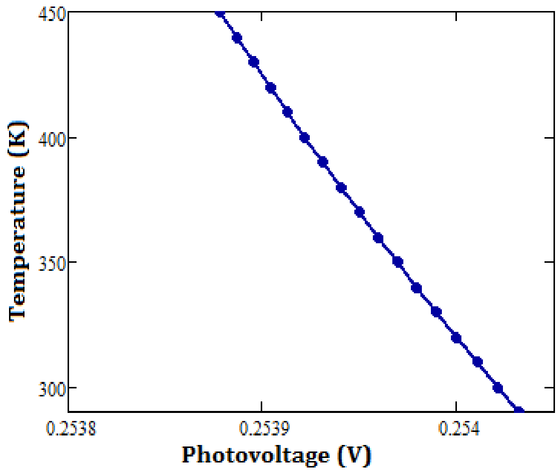

Fig.2. Temperature versus photovoltage

(C=50 suns ; g_x=g_y=3.10^{-3}cm ; S_{gb}=10^{2}cm/s ; S_f=4.10^{4}cm/s ; S_b=10^{2}cm/s)

It appears on the curve of figure 2 that the increasing of the photovoltage is follow by the reduction of the temperature in the PV cell's base. Indeed, the increase of the photovoltage corresponds to an increase of the rate of charge carriers blocked into the base. The blocking of carriers in the PV cell's base leads to a reduction of electrons and holes movement and collision in the base, and then, to a reduction of the quantity of energy released by thermalization, collision and braking. The reduction of the quantity of energy released by thermalization, collision and braking with the increase of the photovoltage is the consequence of the reduction of the temperature in the solar cell base.

2.3. Effect of the increase of electric power on the temperature in the base

The output power of the PV cell is the result of multiplying the photocurrent density and the photovoltage. As the photocurrent density and the photovoltage depend on the temperature in the base, the electric power will also depend on it. Its expression is given by Equation 3 :

$$P_{él}(T) = J_{ph}(T) \cdot V_{ph}(T) \qquad (3)$$

We illustrate on the curve of the figure 3, the behaviour of the temperature of the base with the increase of the output power of the PV cell.

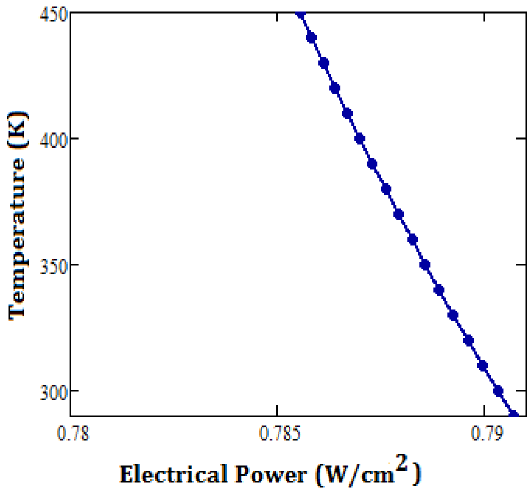

Fig.3. Temperature versus power output

C=50 suns ; g_x=g_y=3.10^{-3}cm/s ; S_{gb}=10^{2}cm/s ; S_b=10^{3}cm/s S_f=4.10^{4}cm/s

We observe on the curve of the figure 3 that the temperature of the base decrease with the increase of the power output delivered by the PV cell. This result is in accordance with those of figures 1 and 2. Indeed, it appears on these figures that the photocurrent density increase is accompanied by the increase of the temperature in the base while the temperature decreases with the increase of the photovoltage.

The electric power being the result of multiplying the photocurrent density and the photovoltage, the decrease of the temperature in the base with the increase of the power output, characterizes the fact that, with the increase of the photovoltage, the reduction of the temperature in the base is more sensitive than it increases with the one of the photocurrent density.

2.4. Influence of the temperature in the base on the fill factor

The fill factor or ideality factor is the ratio of the maximum output power (P_{max}) that can be extracted from a solar cell under the standard conditions to the theoretical maximum electric power (open circuit voltage V_{oc} multiplied by short current circuit density J_{sc}). Its expression is given by Equation (4):

$$FF(T) = \frac{P_{\max}(T)}{V_{co}(T).J_{cc}(T)} \qquad (4)$$

It appears in Equation (4) that the fill factor depends on the temperature in the PV cell’s base.

The curve of the figure 4 shows the influence of the heating of the base on the fill factor of the PV cell.

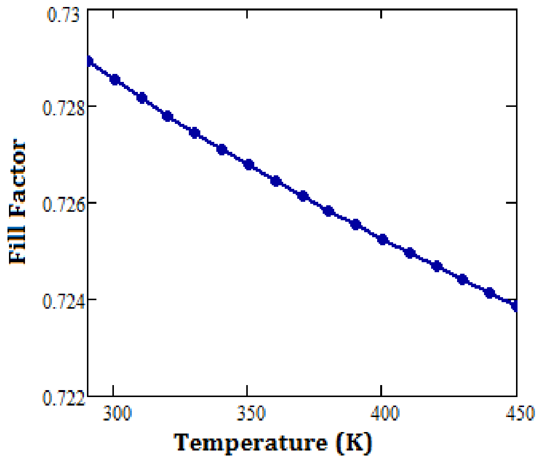

Fig.4. Fill factor versus temperature

C=50 suns ; $g_x=g_y=3.10^{-3}$cm ; $S_{gb}=10^2$cm/s ; $S_f=4.10^4$cm/s ; $S_b=10^3$cm/s

From the analysis of Figure 5, it appears that as the studies of Gupta et al. [4], Zoungrana et al. [11] carried out that, when the temperature in the base increases, the fill factor of the solar cell decreases. In fact, the increase of the temperature in the base is the consequence of the increase of the collisions between electrons and holes and the braking which they undergo. Therefore, these phenomena lead to an increase of carriers losses in the bulk of the base and then to a reduction of the quantity of electrons which crosses the junction, and will have as consequence the reduction of the maximum power output delivered by the PV cell. The decrease of the fill factor with the increase of the temperature is then the consequence of the reduction of the maximum power output with the increase of the temperature.

2.5 Influence of the temperature on the efficiency of the PV cell

According to the studies done by Agroui et al**.** [14], Subhash Chander et al**.** [19], the expression of the efficiency of a PV cell is given by Equation (5):

$$\eta(T) = \frac{P_{\max}(T)}{P_{inc}} \qquad (5)$$

In the case of intense illumination, the incident power is given by the relation proposed by Subhash Chander et al. [19]: $P_{inc} = 0.072$ W/cm^2 × C; C being the number of suns.

In accordance with the study of Pelanchon et al**.** [1], in this study, C = 50 suns and then $P_{inc} = 3.6$ W / cm^2.

The influence of the temperature on the efficiency of the PV cell is illustrated in Figure 5:

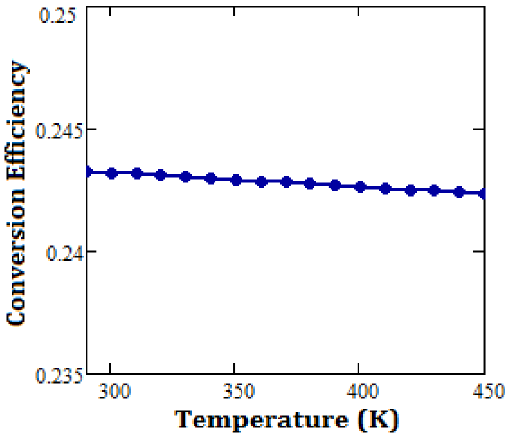

Fig.5. Conversion efficiency versus temperature

(C=50 suns ; $g_x=g_y= 3.10^{-3}$ cm ; $S_{gb} = 10^2$ cm/s ; $S_f = 4.10^4$ cm/s ; $S_b = 10^3$ cm/s)

We observe that in an intermediate operating point ($S_f = 4.10^4$ cm/s), the increase of the temperature in the PV cell's base results in a decrease of the efficiency. This result is in accordance with the decrease of the power output and the fill factor with the increase of the temperature in the base as observed previously.

3. CONCLUSION

In this paper, a 3-D modelling of the influence of electrical parameters on the temperature in the base of a polycrystalline silicon PV cell under light concentration was studied. It appears that the increase of the density of photocurrent is accompanied by an increase of the temperature in the base. On the other hand, the increase of the photovoltage is accompanied by a decrease of the temperature in the base. This study also shows that the increase of the power output provided by the PV cell leads to a decrease of the temperature in the base. This result put in evidence the fact that the low temperatures are the operating situations for a better performance of the solar cells. Indeed, it appears from the study that the increase of the temperature in the base leads to a decrease of the fill factor and the conversion efficiency, which are very important parameters to appreciate the performance of solar cells. These results also highlight the need to cool down the solar cells under intense illumination to optimize their performance.

4. ACKNOWLEDGEMENTS

The authors thank International Science Program (ISP) for funding their research group.

5. REFENCES

[1] Pelanchon F, Sudre C, Moreau Y. Solar cell under intense light concentration: Numerical and analytical approaches. 11th European Photovoltaic Solar Energy Conference, Montreux, Suisse, (1992).

[2] Zoungrana M, Zerbo I, Ouedraogo F, Zouma B, Zougmoré F. 3D modelling of magnetic field and light concentration effects on a bifacial silicon solar cell illumination by its rear side. IOP conf. Series: Materials Science and Engineering. 29 (2012).

[3] Soika E, Moller H.J. Magnetic field measurement and numerical simulation of the current distribution in the emitter region of solar cells. Journal of Magnetism and Magnetic Materials, 272: 667-668, (2004).

[4] Gupta B, Shishodia P. K, Kapoor A, Mehra R.M, Soga T, Jimbo T, Umeno M. Effect of illumination intensity and temperature on the i-v characteristics of n-c/p-si heterojunction. Solar Energy Materials and Solar Cells. 73: 261-267 (2002).

[5] Miyakawa H, Tanaka Y, Kurokawa T. Photovoltaic cell characteristics for high-intensity laser light. Solar Energy Materials and Solar Cells. 86: 253-267 (2005).

[6] Diatta I, Diagne I, Sarr C, Faye K, Ndiaye M, Sissoko G. Silicon solar cell capacitance: Influence of both temperature and wavelength. IPASJ International Journal of Computer Science. 3,12 (2015).

[7] Agroui K. Etude du comportement thermique de modules photovoltaïques de technologie monoverre et biverre au silicium cristallin. Rev. Energ. Ren. pp. 7-11 (1999).

[8] O'Donnell K. P, Chen X. Temperature dependence of semiconductor band gaps. Appl. Phys. Lett. 58, 25 (1991).

[9] Soro B, Zoungrana M, Zerbo I, Savadogo M, Bathiébo D. J. 3-D Modeling of Temperature Effect on a Polycristallin Solar Cell Under Intense Light Illumination. Smart Grid of Renewable Energy. 8 pp. 291-304 (2017).

[10] Gupta B, Shishodia P.K, Kapoor A, Mehra R.M, Tetsuo S, Takashi J, Masayoshi U, 2002. Effect of illumination intensity and temperature on the I2V characteristics of n-C/p-Si heterojunction. Solar Energy Materials & Solar Cells, 73: 261–267.

[11] Zoungrana M, Zerbo I, Savadogo M, Tiedrebéogo S, Soro B, Bathiebo D.J. Effect of light intensity on the performance of siliconsolar cell. Global journal of pure and applied sciences. 23, pp. 123-129 (2017).

[12] Mane R, Ly I, Wade M, Datta I, Douf M S, Traore Y, Ndiaye M, Tamba S, Sissoko G. Minority Carrier Diffusion Coefficient D^*(B, T): Study in Temperature on a Silicon Solar Cell Under Magnetic Field Energy and Power Engineering. 9, pp1-10 (2017).

[13] Dugas J. 3-D modeling of a reverse cell made with improved multicrystalline silicon wafer Solar Energy Materials & Solar Cells, 32 pp. 71-88 (1994).

[14] Agroui K, Belgachi A, Kadri S. Caractérisations électriques et thermiques d'un module PV au silicium multicristallin en milieu contrôlé et sur site saharien. Rev. Energ. Ren. ICPWE, pp 19-25 (2003).

[15] Essalam B. A, Mabrouk K. Development of a bond graph control maximum power point tracker for photovoltaic: Theoretical and experimental. Jordan Journal of Mechanical and Industrial Engineering. 7, 1 pp. 19-26 (2013).

[16] Zoungrana M, Zerbo I, Barro F. I, Sam R, Touré F, Samb M.L, Zougmoré F. Modélisation à 3D de l'influence de la taille des grains et de la vitesse de recombinaison aux joints de grain sur une photopile au silicium polycristallin sous éclairement concentré. Revues des Energies Renouvelables, 14, 4 pp. 649-664 (2011).

[17] Belhadj M, Benouaz T, Cheknane A, Bekkouche S.M.A. Estimation de la puissance maximale produite par un générateur photovoltaïque. Revue des Energies Renouvelables. 13, 2 pp. 257-264 (2010).

[18] Khan F, Singh S.N, Husain M. Effect of illumination intensity on cell parameters of a silicon solar cell. Solar Energy Materials & Solar Cells, 94: 1473–1476.

[19] Subhash Chander, A. Purohit, Anshu Sharma, Arvind, S. P Nehra, and M. S. Dhaka. A study on photovoltaic parameters of mono-crystalline silicon solar cell with cell temperature. Energy Reports, 1 :104-109, 2015.

How to cite this article:
Soro B, Savadogo M, Zouma B, Tchedre KE, Sourabie I, Zerbo I, Zoungrana M, Bathiebo DJ. 3-D modelling of electrical parameters' effects on the heating of the base of an intense light illuminated polycrystalline silicon pv cell. J. Fundam. Appl. Sci., 2021, *13(3), 1380-1388.*