DOI: https://dx.doi.org/10.4314/gjpas.v29i1.5

GLOBAL JOURNAL OF PURE AND APPLIED SCIENCES VOL. 29, 2023: 39-48
COPYRIGHT© BACHUDO SCIENCE CO. LTD PRINTED IN NIGERIA ISSN 1118-0579
www.globaljournalseries.com.ng, Email: globaljournalseries@gmail.com

COMPARATIVE STUDY OF THE EFFECTS OF SIMULATION MODELS ON THE ELECTRONIC AND ELECTRICAL PARAMETERS OF A SILICON PV CELL

KPÉLI ESSO-EHANAM TCHEDRE, MAHAMADI SAVADOGO, GUY SERGE TCHOUADEP, ISSA ZERBO AND MARTIAL ZOUNGRANA

(Received 22 June 2022; Revision Accepted 5 November 2022)

ABSTRACT

For silicon solar cells simulation studies, one dimensional (1D), two dimensional 2D) and t hree dimensional (3D) models are used. Depending of model proposed and assumptions done for the study, the electronic and electrical parameters and then the performance of the solar cell can be influenced.
This situation raises the problem of the relevance of the choice of the study model and the quality of the resulting results. This work, propose comparative study of the electronic and electric parameters of 1D model, 3D analytical model and 3D empirical model. In this study, continuity equations of excess minority electrons are solved for 1D and 3D models and analytical expressions of electronic parameters (density of electrons δ, intrinsic junction recombination velocity Sf_0 and recombination velocity at back surface S_b) and electric parameters (J_{sc}, V_{oc}, η) are derived. The influence of the model chosen on the electric and electronic parameters of the PV cell have been presented.
It appears in this study that the choice of the simulation model has a large influence on the electronic and electrical parameters the PV cell. The one-dimensional formulation (1D) overestimates the solar cell efficiency comparatively to the three-dimensional (3D) formulations. The study put in evidence also that for the same grain size, the solar cell efficiency resulting of 3D classical formulation is overestimates than one resulting of 3D empirical formulation.

KEYWORDS: Silicon PV cell, simulation, study models, electronic parameters, electric parameters.

INTRODUCTION

In the earth's crust, silicon is the second most abundant element with nearly 28%, just after oxygen (47%). This preference for silicon is also justified by the numerous studies which have led to the improvement of the efficiency and to the reduction of the production costs of photovoltaic energy.

Among these research works on the polycrystalline silicon PV cell, there are simulation studies that are carried out using one-dimensional [1,2], two-dimensional [3,4] or three-dimensional [5,6,7] models. In 3D model, studies are also proposed in empirical [7,8] and analytical [5,6] assumptions and for parallelepipedic [5,6] and cylindric [9,10] grain models and grain size assumptions. The transition

Kpéli Esso-Ehanam Tchedre, Laboratoire d'Energies Thermiques Renouvelables (L.E.T.RE). Université Joseph KI-ZERBO, Ouagadougou, BURKINA FASO
Mahamadi Savadogo, Laboratoire d'Energies Thermiques Renouvelables (L.E.T.RE). Université Joseph KI-ZERBO, Ouagadougou, BURKINA FASO
Guy Serge Tchouadep, Laboratoire d'Energies Thermiques Renouvelables (L.E.T.RE). Université Joseph KI-ZERBO, Ouagadougou, BURKINA FASO
Issa Zerbo, Laboratoire d'Energies Thermiques Renouvelables (L.E.T.RE). Université Joseph KI-ZERBO, Ouagadougou, BURKINA FASO
Martial Zoungrana, Laboratoire d'Energies Thermiques Renouvelables (L.E.T.RE). Université Joseph KI-ZERBO, Ouagadougou, BURKINA FASO

from one model to another one, requires approximations that can influence the values of electronic and electric parameters and therefore the performance of the PV cell.

In 3D models, some experimental data such as diffusion coefficient and diffusion length of minority charge carriers which vary with the crystal type should therefore vary with the grain size. The work conducted by Imaizumi et al. [7], devoted to this subject, proposed an empirical formula which links some diffusion parameters of minority charge carriers to the grain size.

In this work, we propose a comparative study of the electronic parameters (electrons density (δ), intrinsic recombination velocity at junction (Sf_0), recombination velocity at back surface (S_b)) and the electric parameters (short circuit current density (J_{sc}), open circuit voltage (V_{oc}), and efficiency (η)) of 1D model, 3D analytical model and 3D empirical model. The study models and assumptions are presented, and for each model, the continuity equation of excess electrons is solved. Analytical expressions of electronic parameters (δ, Sf_0, S_b) and electric parameters (J_{sc}, V_{oc}, η) are derived. Through the comparison of the curves of electric and electronic parameters, the influence none the less of the chosen model but also of the grain size on the electric and electronic parameters of the PV cell have been presented. Through these comparisons, we propose the better model for the study in simulation. assumed, to be constituted by a parallel juxtaposition of identical grains separated by joints. This model led then to take into account the columnar grain size and then the possibility of carrier's losses at grain boundaries. The carriers losses at grain (g) boundaries is characterized by carriers recombination velocity at grain boundaries (S_{gb}).

The representation of the PV cell in three-dimensional (3-D) model is given by Figure 2.

MATERIALS AND METHODS

Analytical formulation

This study is based on a n-p-p^+ polycrystalline silicon PV cell under constant light illumination (AM 1,5). The representation of the PV cell in one-dimensional (1-D) model is given by Figure 1. In this model, the grain size is fixed and must be in the domain of monocrystalline silicon (monocrystalline silicon PV cell), multicristalline silicon (multicristalline silicon PV cell) or polycrystalline silicon (polycrystalline silicon PV cell). In the three-dimensional (3-D) model, with the columnar model approximation, the solar cell is

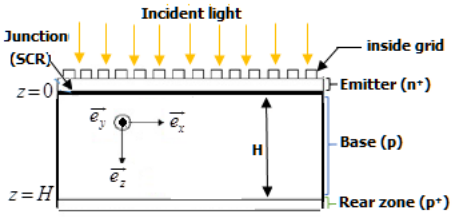

Figure 1: One-dimensional model of silicon **PV** cell under constant illumination

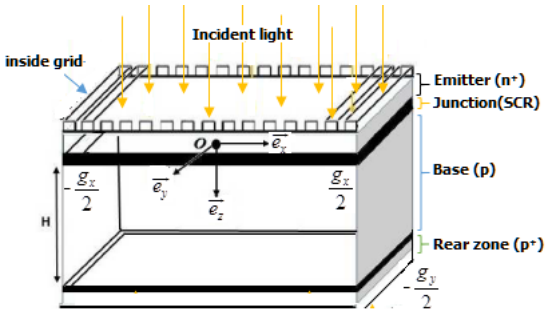

Figure 2: Three-dimensional model of a polycrystalline silicon PV grain under constant illumination

The following assumptions are used in this study:

- the PV cell is assumed to be in the theory of quasi-neutral basis hypothesis (QNB) [7-11],
- in the columnar model (3-D model) from which the grain is extracted, the grain boundaries are recombination planes perpendicular to the junction [5,6,11],
- for the two models, the origin of the coordinate system is taken at the junction,
- the contribution of the emitter is negligible

The continuity equation of excess electrons, in steady state, is given by equation (1) [5, 6,]:

$$D_n \vec{\nabla}^2 \delta - \frac{\delta}{\tau_n} + G_n = 0 \qquad (1)$$

In this expression τ_n and D_n represent respectively the lifetime and the diffusion length of electrons: $L_n{}^2 = \sqrt{D_n \cdot \tau}$, L_n is the diffusion coefficient of electrons. Introducing these coefficients in equation, we obtain equation (2) and (4) below:

- **for one-dimensional model:**

$$\frac{\partial^2 \delta(z)}{\partial z^2} - \frac{\delta(z)}{L_n{}^2} = -\frac{G(z)}{D_n} \qquad (2)$$

- **for three-dimensional model:**

$$\frac{\partial^2 \delta(x,y,z)}{\partial x^2} + \frac{\partial^2 \delta(x,y,z)}{\partial y^2} + \frac{\partial^2 \delta(x,y,z)}{\partial z^2} - \frac{\delta(z)}{L_n{}^2} = -\frac{G(z)}{D_n} \qquad (3)$$

The parameters τ_n, L_n and D_n above represent respectively the lifetime, the diffusion length and the diffusion coefficient of electrons. For both 1D and 3D models, the generation rate is given by equation (4) [12,13]:

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

The resolution of the continuity equations (2) and (3) led to the expressions of the density of excess electrons photogenerated for each model:

- For one-dimensional model

$$\delta_1(z) = A_1 ch\left(\frac{z}{L_n}\right) + B_1 sh\left(\frac{z}{L_n}\right) + \sum_{i=1}^{3} k_i e^{-b_i z}\ , \qquad \text{with } k_i = \frac{a_i L_n{}^2}{D_n\left(1 - L_n{}^2 b_i{}^2\right)} \qquad (5)$$

- For three-dimensional model

$$\delta_2(x,y,z,g) = \sum_j \sum_k \left[A_{2jk} ch\left(\frac{z}{L_{jk}}\right) + B_{2jk} sh\left(\frac{z}{L_{jk}}\right) + \sum_{i=1}^{3} K_i e^{-b_i z} \right] \cos\left(C_j x\right) \cos\left(C_k y\right) \qquad (6)$$

with: $K_i = \dfrac{a_i L_{jk}^2}{D_{jk}\left[1 - \left(b_i L_{jk}\right)^2\right]}$, $\quad L_{jk} = \left[C_j^2 + C_k^2 + L_n^{-2}\right]^{-1/2}$

and

$$D_{jk} = \frac{D_n\left[\sin(C_j \cdot g_x) + C_j \cdot g_x\right] \cdot \left[\sin(C_k \cdot g_y) + C_k \cdot g_y\right]}{16 \sin(C_j \cdot g_x / 2) \cdot \sin(C_k \cdot g_y / 2)}$$

In the three-dimensional models, the difference between analytical and empirical models results in the value of the diffusion length. Indeed, the analytical 3D model, like the one-dimensional model, assume the diffusion length (*L*) to be constant and then independent of grain size (g). However, for the empirical 3D model proposed by Imaizumi et al. [7], the diffusion length as given in equation (7) is assumed to be function of the grain size, and then allows it sensitive to the boundary's recombination.

$$\frac{1}{L_n(g)^2} = 1.11 \times 10^3 + 4.\frac{10^2}{g} \qquad (7)$$

As the carriers life time τ is function of diffusion length, in empirical 3D model [7], the carriers life time given by equation (8) will also be function of the grain size:

$$\tau(g) = L_n(g)^2 \big/ D_n \qquad (8)$$

In the empirical 3D model, and for the range of grain sizes considered ($10\,\mu m$-$300\,\mu m$) [8], the diffusion coefficient (D_n) and electron mobility (μ_n) do not vary with grain size [7,8], which is in accordance with the value used for both classical 1D and 3D analytical models.

In this work, the following values will be used $D_n = 26\ cm^2 \cdot s^{-1}$; $\mu_n = 1000\ cm^2 / Vs$ and $L_n = 0,015\ cm$. Specifically, for 3D models, the recombination velocity at the grain boundary is set to $S_{gb} = 5200\ cm/s$

EXPRESSIONS OF ELECTRIC PARAMETERS

- **Photocurrent density**

The application of Fick law at the junction of the PV cell, for one and three-dimensional models [11,14], leads to the expressions of the photocurrent density:

- for one-dimensional model, it is given by equation (9):

$$J_{ph1} = q \cdot D_n \left[\frac{B_1}{L_n} - \sum_i^3 k_i \cdot b_i \right] \qquad (9)$$

- **for three-dimensional model, it is given by equation (10):**

$$J_{ph2} = q \cdot D_n \sum_j \sum_k R_{jk} \left[\frac{B_{jk}}{L_{jk}} - \sum_i^3 k_i \cdot b_i \right] \qquad (10)$$

- **Photovoltage**

The hypothesis of Boltzmann approximation [11,14] lead**s** to the expressions of the photovoltage for one and three-dimensional models.

- **for one-dimensional model, the expression of the voltage is given by equation (11):**

$$V_{ph1} = V_T \ln \left[1 + \frac{N_B}{n_i^2} \left(A_1 - \sum_{i=1}^3 k_i \right) \right] \qquad (11)$$

- **for three-dimensional model, the expression of the voltage is given by equation (12):**

$$V_{ph2} = V_T \ln \left[1 + \frac{N_B}{n_i^2} \sum_j \sum_k R'_{jk} \left(A_{1jk} - \sum_{i=1}^3 K_i \right) \right] \qquad \text{With: } R'_{jk} = \frac{4 \sin\left(C_j \cdot \frac{g_x}{2} \right) \cdot \sin\left(C_k \cdot \frac{g_y}{2} \right)}{C_j \cdot C_k} \qquad (12)$$

1.1. Expressions of electronic parameters

- **Back surface recombination velocities**

For large value of the junction dynamic velocity (Sf ≥ 10^6 cm.s^{-1}) the curves of photocurrent density are constant [11,14]. So, the derivative of the photocurrent density with respect to the junction dynamic velocity is zero and leads to the expressions of the back-surface recombination velocity, for one dimensional and three-dimensional models.

- **for one-dimensional model:**

$$S_{b1} = D_n \sum_{i=1}^3 \frac{\frac{1}{L_n} sh\left(\frac{H}{L_n} \right) + b_i \left(e^{-b_i H} - ch\left(\frac{H}{L_n} \right) \right)}{e^{-b_i H} - ch\left(\frac{H}{L_n} \right) + L_n b_i sh\left(\frac{H}{L_n} \right)} \qquad \textbf{(13)}$$

- **for three-dimensional model**

$$S_{b2}(g) = D_n \frac{\sum_j \sum_k \left[\frac{R_{jk}}{L_{jk}} \cdot \sum_{i=1}^3 K_i \cdot \left[sh\left(\frac{H}{L_{jk}} \right) + b_i . L_{jk} \left(e^{-b_i H} - ch\left(\frac{H}{L_{jk}} \right) \right) \right] \right]}{\sum_j \sum_k \left[\frac{R_{jk}}{L_{jk}} \cdot \sum_{i=1}^3 K_i \cdot \left[e^{-b_i H} - ch\left(\frac{H}{L_{jk}} \right) + L_{jk} b_i sh\left(\frac{H}{L_{jk}} \right) \right] \right]} \qquad \text{With : } R_{jk} = \frac{4 \sin\left(C_j \cdot \frac{g_x}{2} \right) \cdot \sin\left(C_k \cdot \frac{g_y}{2} \right)}{g_x . g_y . C_j \cdot C_k} \qquad \textbf{(14)}$$

- **Intrinsic junction recombination velocity**

The curves of photocurrent density are also constant for large value of the back-surface recombination velocity (Sb ≥ 10^4 cm.s^{-1}) and their derivative with respect to the back-surface recombination velocity is zero and leads to the expressions of the intrinsic recombination velocity at junction [11,15], for one dimensional and three-dimensional models:

- **for one-dimensional model:**

$$S_{f01} = D_n \sum_{i=1}^{3} \frac{b_i - e^{-b_i H}\left[\frac{1}{L_n} sh\left(\frac{H}{L_n}\right) + b_i ch\left(\frac{H}{L_n}\right)\right]}{e^{-b_i H}\left[ch\left(\frac{H}{L_n}\right) + b_i L_n sh\left(\frac{H}{L_n}\right)\right] - 1} \qquad (15)$$

- **for three-dimensional model**

$$S_{f02}(g) = D_n \frac{\sum_j \sum_k R_{jk} \sum_{i=1}^{3} K_i \left[b_i - \left(\frac{1}{L_{jk}} \mathrm{sh}\left(\frac{H}{L_{jk}}\right) + b_i \,\mathrm{ch}\left(\frac{H}{L_{jk}}\right) e^{-b_i H}\right)\right]}{\sum_j \sum_k R_{jk} \sum_{i=1}^{3} K_i \left[\left(b_i L_{jk} \,\mathrm{sh}\left(\frac{H}{L_{jk}}\right) + \mathrm{ch}\left(\frac{H}{L_{jk}}\right) e^{-b_i H} - 1\right)\right]} \qquad (16)$$

RESULTS AND DISCUSSIONS

Effect of simulation model and grain size on the back-surface recombination velocity

Figure 3 presents the variations of recombination velocity at back surface as a function of the grain size for the two 3D models and for the 1D model.

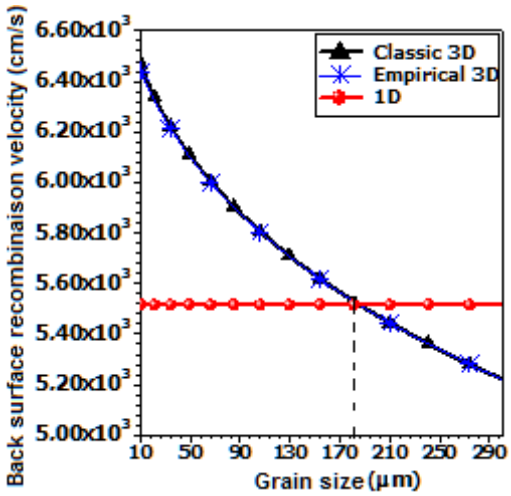

Figure 3: recombination velocity at back surface versus grain size and for different simulation models: $L_n = 0.015\ cm,\ H = 0.03\ cm.$

Curves of Figure 3 show that the values of recombination velocity at back surface are almost unchanged for the classical and empirical 3D models. Therefore, the empirical 3D model using a diffusion length varying with the grain size has the same values of recombination velocity at back surface as the classical 3D model. This result means that the influence of grain size on the recombination velocity at back surface is independent of 3D empirical or classical models.

Moreover, in the two 3D models, it appears a significant decrease of recombination velocity at back surface with the increase of the grain size. This means that the minority electrons losses near the back side of the base reduces with the increase of the grain size. Indeed, a decrease of grain size means an increase of grain boundaries and then traps in the silicon material. The increase of the traps leads to a decrease of electrons in the base, and then in the rear side. The 3D model, better reflects this electrons losses at the rear side of the PV cell.

We observe also that the back-surface recombination velocity for the 3D models correspond to ones of 1D models for grain size values of 185 μm. As the 1D model don't take into account the grain size, this study put in evidence the fact that, the 1D model simulation underestimates the back surface recombination velocity for small values of grain size ($g < 185\mu m$) and overestimates it for large values of grain size ($g > 185\mu m$).

Then, the 1D model simulation underestimates the recombination velocity at back surface for polycrystalline silicon PV cell with grain sizes $g < 185\mu m$ and overestimates it for grain sizes $g > 185\mu m$ and also for multicrystalline and monocrystalline silicon PV cells.

Effect of simulation models and grain sizes on minority electrons density

Figure 4 presents the effect of the simulation models on the minority electrons density profiles in the bulk of the PV cell base and in short circuit operation.

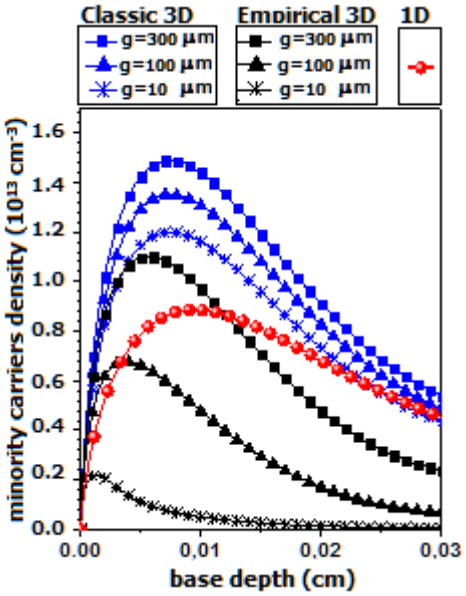

Figure 4: Minority Carrier density function of simulation models grain sizes: $S_f = 8.10^8\ cm/s$; $S_b = 10^2\ cm/s$.

The comparison of the 3D models shows that for the same grain size, at any depth of the base, the electrons density resulting of the classical model is significantly higher than that of the empirical model proposed by Imaizumi et al. [7]. We observe also that for the same grain size, the maximum of electrons density and the quantity of electrons that can cross the junction to participate to the photocurrent is bigger in classical formulation comparatively to the empirical formulation. It appears also on this Figure that the electrons gradient at the junction of the 1-D curves is smaller than that of the empirical 3-D curves, which in turn is smaller than that of the classical 3-D curves. This result means that for the same illumination level, the quantity of electrons that can cross the junction in 1D formulation is lower than those resulting of 3D empirical formulation, which are also lower than those of 3D classical formulation.

The difference of the electrons density in the bulk of the base for the same grain size is the consequence of diffusion length dependence with the grain size in empirical formulation. Indeed, we observe that the diffusion length increases with the increase of grain size in empirical formulation while it is constant in classical formulation. But for the same grain size, the diffusion length resulting of empirical formulation is smaller than that of classical formulation. The small values of diffusion length characterize a high probability of electrons losses in the bulk of the base, and then a low electrons density for empirical formulation.

Figure 5 presents the effect of the simulation models on the minority electrons density profiles in the bulk of the PV cell base and in open circuit operation.

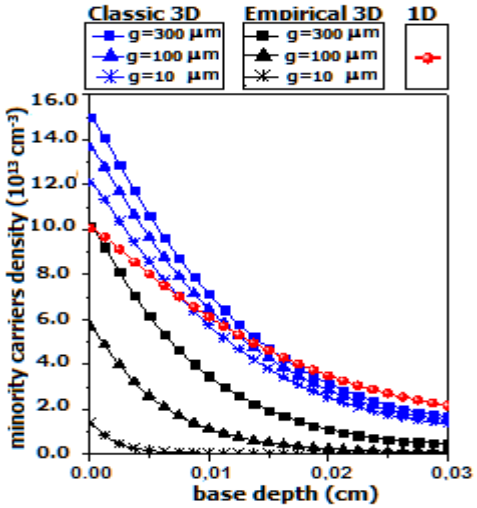

Figure 5: Minority Carrier density function of simulation models grain sizes: $S_f = 0\ cm/s$; $S_b = 10^2\ cm/s$.

We observe from Figure 5 that the electrons density near the junction for 1D formulation is bigger than the one of 3D empirical simulation but it is smaller than the one of 3D classical simulation.
It appears also that in rear side of the solar cell base, the electrons density in 3D empirical formulation is smaller than the one of 3D classical formulation which is also smaller than the one of 1D formulation. The 3D empirical formulation for which the diffusion length is function of grain size and then grain boundaries being as close as possible to reality, it appears through this curve that whatever the grain size, the 1D formulation and the 3D classical formulation overestimates electrons density near the junction. These two situations are also the consequence of taking into account the grain boundaries in 3D empirical formulation that leads to increase electrons losses in the bulk of the base.

Effect of simulation models and grain sizes on the intrinsic recombination velocity at junction
Figure 6 presents the effect of simulation model and the grain size on the intrinsic recombination velocity at the junction.

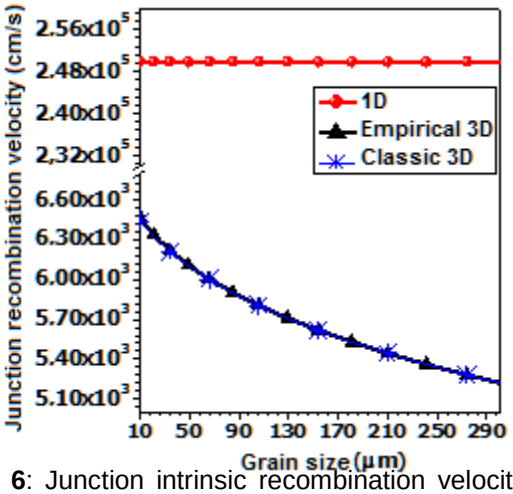

Figure 6: Junction intrinsic recombination velocity function of simulation model and grain sizes: $H = 0.03\ cm; L_n = 0.015\ cm.$

This Figure shows that the intrinsic recombination velocity at the junction of the silicon PV cell is none the less dependent of simulation model but also of the grain size for the 3D formulation. Indeed, it appears on this Figure that electrons' intrinsic losses in the solar cell junction are more important in 1D formulation than those of 3D models. This behavior means that in simulation studies, the choice of the 1D model overestimates the carrier's intrinsic losses in solar cell junction. It appears also on this Figure that in case of simulation with 3D model**s**, the choice of empirical model or classical model don't have influence on carrier's intrinsic losses in the solar cell junction. However, the increase of the grain size leads to a decrease of the intrinsic recombination velocity at the junction for all classical and empirical models. The decrease of the intrinsic recombination velocity at the junction with the increase of grain sizes is in line with the reduction of grain boundaries and then the decrease of carrier's intrinsic losses in the junction with the increase of grain size.

Effect of simulation models and grain sizes on J-V Characteristics

We present in Figure 7, the effects of simulation models and grain size on the J-V characteristics of the PV cell.

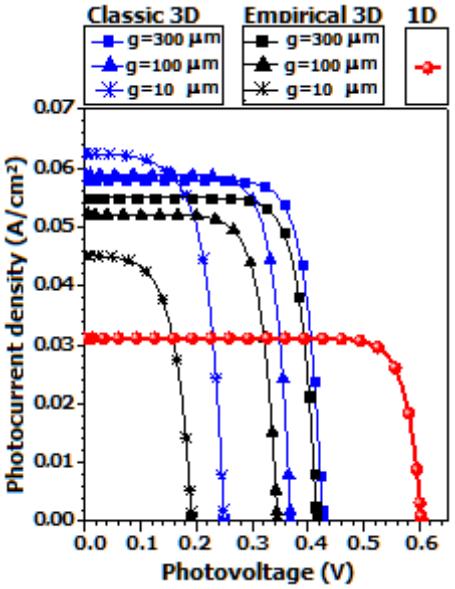

Figure 7: Simulation models and grain sizes effects on J-V characteristic**s**: $S_b = 10^3\ cm/s,\ H = 0,03\ cm,$

We observe on this Figure that the short circuit current density and the open circuit voltage are both function of simulation models and grain sizes. It appears on this Figure that the short circuit current density in the case of 1D formulation is smaller than those of 3D formulations. Also, for 3D formulations, the short circuit current density resulting of the 3D empirical formulation is smaller than that of 3D classical formulation. These results are in line with those of *section 3.2* (electrons density maximum and gradient at the junction variation with simulation models) and *section 3.3* (dependence of intrinsic recombination velocity with the simulation models). Indeed, it appears on Figure 4 that, near the junction the slope of the curves resulting of 3D classical formulation are bigger than those of 3D Empirical formulation which are also bigger than this of 1D formulation.

In Figure 6, we observe also that the intrinsic junction recombination velocity in 1D formulation is bigger than those of 3D formulation**s**. As the increase of slopes characterize**s** an increase of the quantity of carriers that can cross the junction, this result combined with the values of intrinsic recombination velocity at the junction justifies the evolution of the short circuit current density with the simulation model. It appears also on this Figure that the open circuit voltage in the case of 1D formulation is bigger than those of 3D formulations. For the same grain size, we observe also that the open circuit voltage of 3D classical formulation is bigger than that resulting of 3D empirical formulation. These results are also in line with those of Figure 4. Indeed, in 1D and 3D classical formulations, the effect of grain sizes and then grain boundaries is underestimated. In this case the carrier's recombination in the bulk of the base is less affected and then, in open circuit, the photovoltage will increase.

Effect of simulation models and grain sizes on the conversion efficiency

Figure 8 presents the effects of grain size and simulation models on the efficiency of the silicon PV cell.

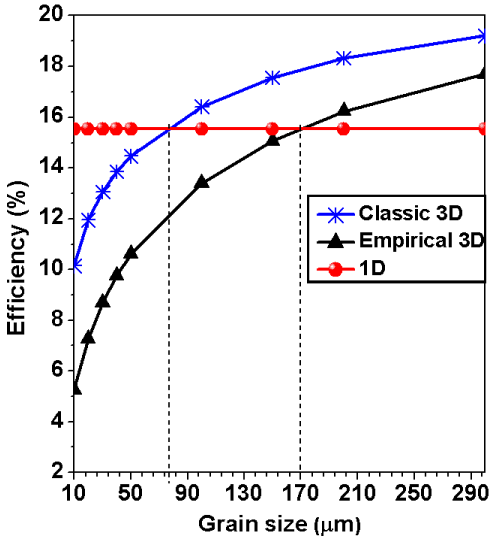

Figure 8: Effects of simulation models grain sizes on PV cell efficiency*:* $L_n = 0.015\ cm,\ H = 0.03\ cm,$

We observe on these curves that the efficiency is none the less dependent of grain size but also of simulation models. The comparison of the efficiency resulting of 1D formulation to those of 3D formulation shows that for small grain sizes ($g < 76\mu m$ for However, for the same grain size, we observe that the maximum value of the efficiency resulting of the This result is in accordance with those of the Figure 7 where it was observed that for the same grain size, the values of short circuit current density and open circuit voltage in the 3D classical formulation are bigger than those resulting of 3D empirical Indeed, with this assumption, we underestimate the grain boundaries and then boundaries recombination, that will lead to overestimate the maximum electric power of the PV cell and then its efficiency. As the 3D empirical formulation is close to the reality, we can say that 1D formulation overestimates the efficiency for small grain sizes ($g < 170\mu m$) and underestimates it for large grain sizes ($g > 170\mu m$). The comparison of the results of the 3D models shows that for the same grain size, the 3D classical formulation overestimates the PV cell efficiency.

CONCLUSION

In this work, a comparative study of the 1D, 3D classical and 3D empirical formulations effects on a silicon PV cell electronic parameters (electrons' density, recombination velocity at back surface, intrinsic recombination velocity at junction) and electric parameters (J-V characteristics and efficiency) have been done. It appears through this study that the choice of the study model and the grain sizes has a big influence on the values of the electronic and electric parameters. The analysis of the approximations made in the different models shows that the 3D empirical formulation, for which classical formulation and $g < 170\mu m$ for empirical formulation), the efficiency of 1D formulation is bigger than ones of 3D formulation. According to the 3D models, it appears that the efficiency increases with the increase of the grain size. 3D classical formulation is bigger than that of the 3D empirical formulation.
formulation. The difference of the efficiency values in the two 3D formulations is justified by the independence of the diffusion length with grain sizes in 3D classical formulation.

the diffusion parameters are dependent of grain sizes, and then take into account the recombination in grain boundaries during the carrier's diffusion is closest to the reality.

The comparison of the electronic and electrical parameters resulting to 1D formulation and 3D formulation shows that, for the 1D formulation, the recombination velocity at back surface is underestimated for values of grain sizes $g < 185\mu m$, and overestimated it for large grain sizes ($g > 185\mu m$) . It appears also through this comparison that for 1D formulation and the 3D classical formulations, the electrons density near the junction is overestimated. However, whatever the grain size, the 1D formulation overestimates the intrinsic recombination velocity at junction and the open circuit voltage and underestimates the short circuit current density.

The comparison of the efficiency resulting of 1D formulation to those of 3D formulation shows that 1D formulation overestimates the efficiency for small grain sizes ($g < 170\mu m$) and underestimates it for large grain sizes ($g > 170\mu m$).

According to the comparison of 3D classical and 3D empirical formulations, it appears that whatever the

grain size, the formulation model don't have any influence on the profiles of back surface recombination and junction intrinsic recombination velocities. For the same grain size, the 3D classical formulation overestimates the electrons' density maximums, the short circuit current density, the efficiency and the open circuit voltage comparatively to the 3D empirical formulation.

At the end of this study, it appears that for solar cells simulation studies, the choice of model has a great influence on simulation results reliability. The 3D empirical formulations for silicon solar cell electronic et electric characterization leads to better results than 1D and 3D classical ones.

ACKNOWLEDGMENT

The authors thank International Science Program (ISP) for funding **their** research group and allowing them to conduct this work

REFERENCES

Zerbo, M. Zoungrana, A. Ouedraogo, and D. J. Bathiebo, "Effect of jonction quality on the performance of a silicon solar cell," J. Fundam. Appl. Sci., vol. 1, no. 1, 2017.

Ngom, M.I., Zouma, B., Zoungrana, M., Thiam, M., Bako, Z.N., Camara, A.G. and Sissoko, G. "Theoretical Study of a Multi-Junction Silicon Cell under Multispectral Parallel Vertical Illumi Nation: The Influence of External Magnetic Field on the Electrical Parameters." International Journal of Advanced Technology and Engineering Research., vol. 2, no. 6, pp. 101–109, 2012.

M. Goldbach, R. Brendel, and U. Rau, "Two-dimensional Simulation of Thin-film Silicon Solar Cells with Innovation Device Structures," vol. 100, no. June 1998, pp. 85–100, 1999.

A. Ben Arab, "Analytical solutions for the photocurrent and dark diffusion current of preferentially doped polysilicon solar cells," Sol. Energy Mater. Sol. Cells, vol. 37, no. 3–4, pp. 239–258, 1995, doi: 10.1016/0927-0248(95)00018-6.

Zoungrana Martial, Zerbo Issa, Soro Boubacar, Savadogo Mahamadi, Tiedrebeogo Sanna, and Bathiebo Dieudonné Joseph, "the Effect of Magnetic Field on the Efficiency of a Silicon Solar Cell Under an Intense Light Concentration," Adv. Sci. Technol. Res. J., vol. 11, no. 2, pp. 133–138, 2017, doi: 10.12913/22998624/69699.

M. Savadogo, M. Zoungrana, I. Zerbo, B. Soro, and D. J. Bathiebo, "3-D modeling of grains sizes effects on polycrystalline silicon solar cell under intense light illumination," Smart Grid Renew. Energy, vol. 08, no. 09, pp. 291–304, 2017, doi: 10.4236/sgre.2017.89019.

M. Imaizumi, T. Ito, M. Yamaguchi, and K. Kaneko, "Effect of grain size and dislocation density on the performance of thin film polycrystalline silicon solar cells," J. Appl. Phys., vol. 81, no. 11, pp. 7635–7640, 1997, doi: 10.1063/1.365341.

A. K. Ghosh, C. Fishman, and T. Feng, "Theory of the electrical and photovoltaic properties of polycrystalline silicon," J. Appl. Phys., vol. 51, no. 1, pp. 446–454, 1980, doi: 10.1063/1.327342.

S. N. Leye, A. Diouf, S. Mbodji, and G. G. Sissoko, "A method to determine the transient capacitance of the bifacial solar cell considering the cylindrical grain and the dynamic junction velocity (Sf)," EAI Endorsed Trans. Collab. Comput., vol. 3, no. 11, p. 153166, 2017, doi: 10.4108/eai.30-6-2017.153166.

A.Trabelsi, A. Zouari, and A. Arab, "Modeling of polycrystalline N/P junction solar cell with columnar cylindrical grain," Revue des Energies Renouvelables Vol. 12 N°2 (2009) 279 – 297

J. Dugas, "3D modelling of a reverse cell made with improved multicrystalline silicon wafers," Sol. Energy Mater. Sol. Cells, vol. 32, no. 1, pp. 71–88, 1994, doi: 10.1016/0927-0248(94)90257-7.

Furlan, J and S. Amon,. "Approximation of the carrier generation rate in illuminated silicon", Solid-State Electronics, 12(28): 241-1243, 1985.

H. El Ghitani, S. Martinuzzi, J. Appl. Phys. 66, 4, 1989.

M. Sané and F.I. Barro, "Effect of both magnetic field and doping density on series and shunt resistances under frequency modulation", Indian Journal of Pure and Applied Physics Vol. 53, September 2015, pp. 590-595.

H.L. Diallo,A.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, 203–211, 2008.