Internal Electric Field In The Space Charge Layer Of A Solar Cell Based On Silicon In The Presence Of Excitons

Modou Faye, Cheikh Mbow, Bassirou Ba

Abstract: The author, faced with the impossibility of assessing the relative importance of the different contributions of physical quantities appearing in the equations of transport, he appealed to the dimensional analysis. Thus by grouping the physical parameters, the dependent and independent variables, it generates dimensionless numbers. The latter, having a physical significance, make it possible to characterize the various contributions. To solve the dimensionless equations obtained, strongly coupled reduced scale, the author opts for a numerical method. The spatial discretization variable pitch and tight at the interfaces of different zones of the field because of the strong gradients in these regions is adopted. The equations are then integrated in the numerical domain using the finite volume method and the coefficients are approached by the schema of the power Patankar law. The resulting system of algebraic equations is solved by the method of double course combined with an iterative relaxation line by line type Gauss-Seidel. Furthermore, with a volumetric coefficient of coupling which depends on the dissociation of the excitons and the average temperature field, the author has studied the influence of some physical parameters on the total density of photocurrent such that: the heating factor , the conversion velocity and the volume coupling coefficient of charge carriers.

Keywords: Electric field, Excitons, Conversion, Electron-hole pairs.

1 INTRODUCTION

We present the study of a solar cell based on silicon, in static conditions under monochromatic illumination in the presence of excitons. Some writers, like Mr. Burgelman Minnaer and B. [2], consider that the base is the area that generates the majority of the photocurrent density. Thus, Zh. Karazhanov, made his study of the space charge layer under dark, while neglecting both the electric field that prevails in this area. However most of this work is limited to an analytical treatment of virtually neutral zone in the region p assuming dissociation and recombination of excitons are uniform in the volume of this region. In these models, the effects of coupling between the electrons and the excitons are considered either neglected or linear and the phenomenological constant coefficients taken. In this study we numerically analyze the role of the electric field in the space charge layer. This study is important, above all, that we have taken into account the non-uniformity of the dissociation, recombination of excitons in this area. Thus, we consider the variability of the coefficients as a function of temperature. To model the complex and tightly coupled transfers that govern the operation of the photovoltaic cell, the author has established the transport equations of electrons and excitons based on certain simplifying assumptions deemed reasonable. These equations are not only coupled but contain phenomenological coefficients that depend on the temperature field whose knowledge goes through the resolution of the thermal diffusion equation. The resulting system is finally closed by conditions of mixed type boundary. The simultaneous consideration of the variability of the coefficients as a function of temperature and the presence of the electric field in the space charge layer is a first in this type of study.

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2 POSITION OF THE PROBLEM, ASSUMPTION AND MATHEMATICAL FORMULATION

We will consider a semiconductor length L (Figure 1), one-dimensional character of inhomogeneous doping regions. They are conductive. The n^+-type region, called emitter is heavily doped $10^{+19}\,cm^{-3}$. This area ensures the existence of an intense internal electric field in the space charge layer. We recognize that this electric field in this zone is a linear function of the abscissa z that can be put in the form

$$E(z) = \frac{E_m}{w}(w - z) \text{ and } b(z) = b[E(z)] \text{ in } (0 \le z \le w)$$

Under illumination, the incident photons will generate electron-hole pairs. They may be bound or free. These electron-hole pairs are separated in the space charge layer (SCL) by the electric field.

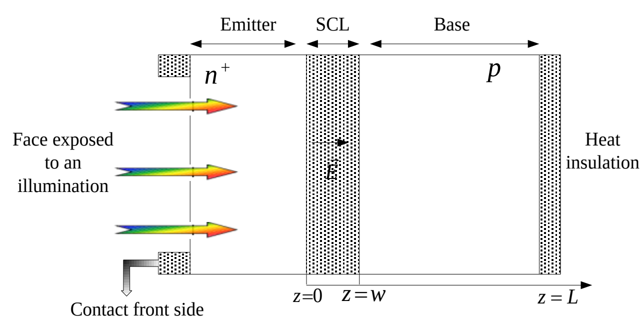

Figure 1: *Structure of a solar semiconductor silicon n^+p*

When this cell is subjected to illumination, there are the generation- recombination and diffusion mechanisms. These mechanisms control the diffusion equations of the minority carriers and excitons neglecting the inertia terms. They write:

$$\frac{\partial}{\partial z}\left\{D_e\frac{\partial n_e}{\partial z}\right\}+\frac{E_m\mu_e}{w}\cdot\frac{\partial}{\partial z}\{n_e(w-z)\}=$$

$$\frac{1}{\tau_e}\cdot\frac{n_e n_h-n_{in}^2}{n_e+n_h+2n_{in}}+b\left(n_e n_h-n_x n^\circ\right)-f_e G_{eh} \qquad (1a)$$

$$\frac{\partial}{\partial z}\left\{D_x\frac{\partial n_x}{\partial z}\right\}=\frac{n_x-n_{x0}}{\tau_x}-b\left(n_e n_h-n_x n^\circ\right)-f_x G_x \qquad (1b)$$

In these equations, the electrons and excitons are coupled by a physical parameter, called volume coupling coefficient. Its expression is given by:

$$bv\{E(z)\}=bv\_low\times\exp\left[\left(1-\frac{z}{w}\right)\times\ln\left(\frac{bv\_\max}{bv\_low}\right)\right]$$

With $bv\_low=10^{-16}\,cm^3\,s^{-1}$,

$$10^{-16}\,cm^3\,s^{-1}\le bv\_\max\le 10^{-7}\,cm^3\,s^{-1}$$

It depends on the dissociation of excitons field and temperature of the material. Other parameters such as diffusion coefficients of electrons and excitons are also functions the material temperature. They are given by the Einstein relation [12]. These equations are not only coupled but contain phenomenological coefficients that depend on the temperature field whose knowledge goes through the resolution of the thermal diffusion equation.

$$\frac{\partial T}{\partial t}=a\frac{\partial^2 T}{\partial z^2} \qquad (3)$$

The resulting system is finally closed by boundary conditions following of mixed type.

For the electrons

$$\begin{cases} z=0 \Rightarrow n_e(0)=N_D \\ Z=L \Rightarrow \dfrac{\partial}{\partial z}\{D_e n_e\}=-S_e\left[n_e(L)-n_{e0}\right]+b_s\left[n_x(L)-n_{x1}\right] \end{cases} \quad (4a)$$

For the excitons

$$\begin{cases} z=0 \Rightarrow \dfrac{\partial}{\partial z}\{D_x n_x\}=S_{x0}\left[n_x(0)-n_{x0}\right]-b_s\left[n_x(0)-n_{x1}\right] \\ z=L \Rightarrow \dfrac{\partial}{\partial z}\{D_x n_x\}=-S_x\left[n_x(L)-n_{x0}\right]-b_s\left[n_x(L)-n_{x1}\right] \end{cases} \quad (4b)$$

For the temperature

$$\begin{cases} t=0 \Rightarrow T(z,0)=0 \\ z=0 \Rightarrow q=-\lambda\dfrac{\partial T}{\partial z}=q_m g(t) \quad (4c) \\ z=L \Rightarrow \dfrac{\partial T}{\partial z}=0 \end{cases}$$

The mixed boundary conditions show a very important physical parameter, called excitons conversion velocity in free electrons. It varies between $10^{-2}\,cm\,s^{-1}$ and $10^{+7}\,cm\,s^{-1}$.

3 Numerical Procedure

The mathematical formulation of our physical problem involves three differential equations with the derivative partial. They must be solved to find a solution to the problem in question. To generalize the physical problem, to reduce the number of parameters and to facilitate the numerical procedure, it is necessary to adimensionnalize the equations and their boundary conditions. In this case, the only way that we can provide an appropriate solution consists of the numerical approach. Before the numerical procedure, the mathematical formulation must be transformed by means of a discretization process to achieve an easy format. It is space with variable and tight steps at the interfaces of different zones of the field because of the strong gradients in these regions. The equations are then integrated in the numerical domain using the finite volume method and the coefficients are approached by the schema of the power Patankar law. The resulting system of algebraic equations is solved by the method of double course combined with an iterative relaxation line by line type Gauss-Seidel.

4 Results And Discussion

To validate our code, we compared our results with those of Mr. Burgelman and B. Minnaer [2]. The results from the mathematical and numerical modeling of various phenomena are summarized by considering the representation below. We present essentially influences the conversion velocity excitons in free electrons, volume coupling coefficient and the heating factor on the total density of photocurrent of electrons and excitons in the junction. The tests we conducted showed that the time step, the index that tracks the position of the load interface space charge layer and base, the number of nodes, the relative error and allowed the relaxation parameter; $\delta t^*=10^{-3}$; $i_w=81$; $i_m=201$; $\varepsilon=10^{-3}$ and $w=0.15$ are a good compromise between an acceptable calculation volume and a reasonable calculation time. We used the low density coupling coefficient $bv\_low=10^{-16}\,cm^3\,s^{-1}$ in the base. This part is devoted to the study of total density of photocurrent at the junction depending on the electric field. The terms of the photocurrent density of electrons, of the excitons and of the electrons and excitons, were specified in [6]. We reproduce the figure (2) the volume coupling coefficient and the conversion velocity according to the internal electric field that exists in the space charge layer. Considering a curve to the other, we see strong volume couplings and high conversion velocities correspond to the internal field values $E\ge 2.95.10^{+6}\,V\,cm^{-1}$. Changes in the volume coupling coefficient and the conversion velocity according to the electric field, will allow us to draw a conclusion from the effect of the field on the total density of photocurrent, we set each parameter

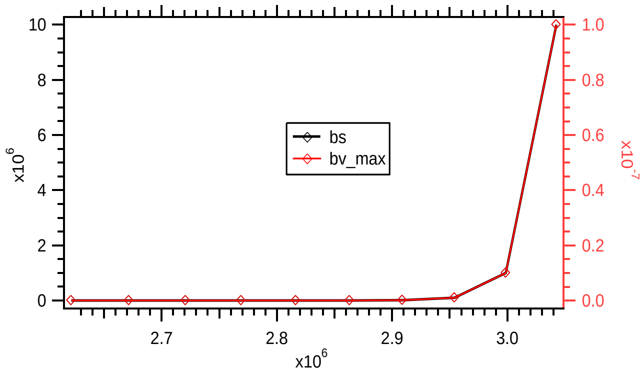

Figure 2: *Variation of the excitons conversion velocity and volumetric coupling coefficient as a function of the electric field $N_A=10^{16}\ cm^{-3}$; $N_D=10^{19}\ cm^{-3}$; $n_i=1.45\ 10^{10}\ cm^{-3}$; n_mott=$1.0310^{18}\ cm^{-3}$; Se= Sx =10 cm s^{-1} ; Fo=10 ; bv_low=$10^{-16}\ cm^3\ s^{-1}$; L_e=f (average temperature)*

4.1 First case:

$$10^{-16}\,cm^3\,s^{-1} \le bv\_\max \le 10^{-7}\,cm^3\,s^{-1}$$

The figures (3 and 4), are produced the measure of the total density of photocurrent versus electric field for various values of the coupling coefficient to the volume level of space charge layer. We noted, for low values of the coupling coefficient and the values of the field $E \le 2.91.10^{+6}\,V\,cm^{-1}$, a decrease in the total density of photocurrent. However, the heating factor (Figure 3) and the conversion velocity of excitons in free electrons (Figure 4) have effects on the variation of the photocurrent density. Figure (3) shows that we have two cases of the effect of heat factor on the total density of photocurrent: For $10^{-16}\,cm^3\,s^{-1} \le bv\_\max \le 10^{-10}\,cm^3\,s^{-1}$ and $E \le 2.91.10^{+6}\,V\,cm^{-1}$ we should not heat the material. Like, in the strong coupling volume still in the space charge layer and $E \ge 2.91.10^{+6}\,V\,cm^{-1}$ the positive effect of the heating factor is observed by heating the material. Furthermore, in Figure (4), in both cases of figures, one obtains a high photocurrent density by increasing the exciton conversion velocity in free electrons.

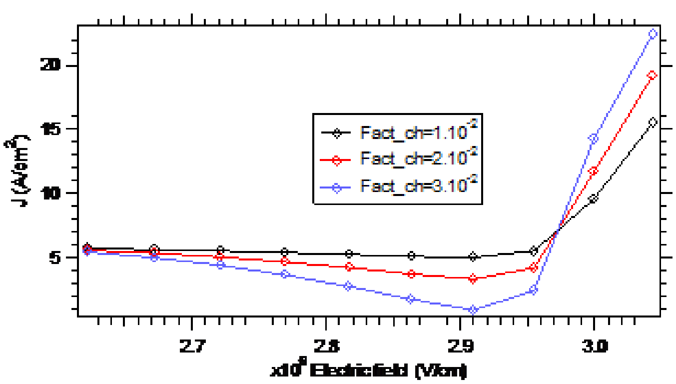

Figure 3: *Influence of the heating factor of the variation in the total density of photocurrent of the charge carriers as a function of the electric field*
$N_A=10^{16}$ cm^{-3} ; $N_D=10^{19}$ cm^{-3} ; $n_i=1.45\ 10^{10}$ cm^{-3} ; n_mott=1.0310^{18} cm^{-3} ; Se= Sx =10 cm s^{-1} ; Fo=10 ; bs=10^{+1} cm s^{-1} ; bv_low=10^{-16} cm^3 s^{-1} ; bv_max=10^{-7} cm^3 s^{-1} ; L_e=f (average temperature)

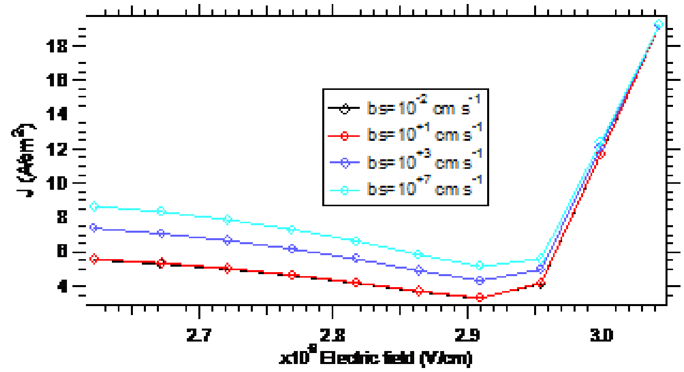

Figure 4: *Influenc of the conversion velocity of the variation in the total density of photocurrent of the charge carriers as a function of the electric field*
$N_A=10^{16}$ cm^{-3} ; $N_D=10^{19}$ cm^{-3} ; $n_i=1.45\ 10^{10}$ cm^{-3} ; n_mott=1.0310^{18} cm^{-3} ; Se= Sx =10 cm s^{-1} ; Fo=10 ; Fact_ch=2.10^{-2} ; bv_low=10^{-16} cm^3 s^{-1} ; L_e=f (average temperature)

4.2 Second case

$$10^{-2}\,cm\,s^{-1} \le bs \le 10^{+7}\,cm\,s^{-1}$$

Figures (5 and 6) show the evolution of the total density of photocurrent versus electric field for various values of the conversion velocity.On the one curve to the other in Figure (5), an analysis of the variation of the total density of photocurrent versus the internal electric field, show that the increase in electric field that causes the photocurrent. This increase in photocurrent density is much more interesting with that of the heating factor. Therefore, to have a high photocurrent density, for $10^{-2}\,cm\,s^{-1} \le bs \le 10^{+7}\,cm\,s^{-1}$ it can heat the solar material. The variation in the total density of photocurrent versus electric field reproduced in Figure (5) shows two ranges of volume coupling coefficient in the space charger layer. The first interval ($10^{-16}\,cm^3\,s^{-1} \le bv\_\max \le 10^{-9}\,cm^3\,s^{-1}$) which leads a decrease in the total density of photocurrent versus electric field is weak exciton dissociation. The second interval ($bv\_\max \ge 10^{-8}\,cm^3\,s^{-1}$) defines a solar cell strong field for exciton dissociation.

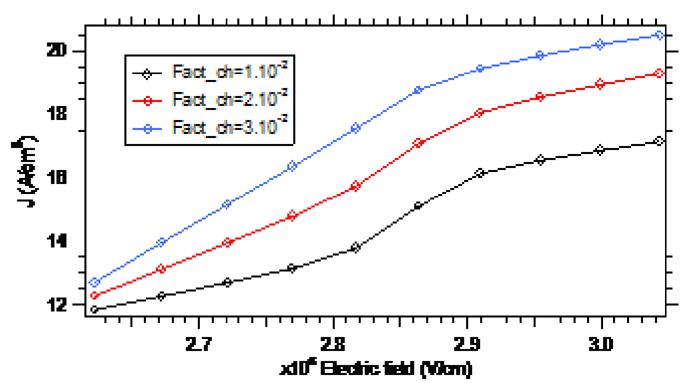

Figure 5: *Influence of the heating factor of the change in the total density of photocurrent of charge carriers as a function of the electric field*

N_A=10^{16} cm^{-3} ; N_D=10^{19} cm^{-3} ; n_i=1.45 10^{10} cm^{-3} ; n_mott=1.0310^{18} cm^{-3} ; Se= Sx =10 cm s^{-1} ; Fo=10 ; bv_max=10^{-7} cm^3 s^{-1} ; bv_low=10^{-16} cm^3 s^{-1} ; L_e=f (average temperature)

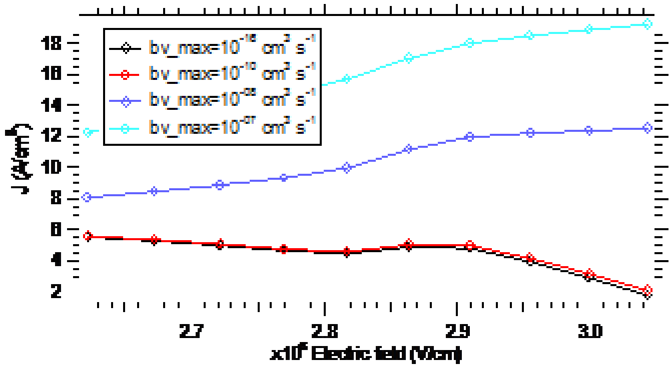

Figure 6: *Influence of the volume of the coupling coefficient of the variation of the total density of photocurrent of charge carriers as a function of the electric field*
N_A=10^{16} cm^{-3} ; N_D=10^{19} cm^{-3} ; n_i=1.45 10^{10} cm^{-3} ; n_mott=1.0310^{18} cm^{-3} ; Se= Sx =10 cm s^{-1} ; Fo=10 ; Fact_ch=2.10^{-2} ; bv_low=10^{-16} cm^3 s^{-1} ; L_e=f (average temperature)

5 CONCLUSION

The study of the role of the internal electric field in the space charge layer of a solar cell made of silicon was presented. The numerical study was undertaken to determine the appropriate parameters for the evaluation of different contributions. The computer code that we developed was validated by the results of work available in the literature. It appears from our study that the influence of the heating factor on total density of photocurrent is greater in the case $10^{-16}\, cm^3\, s^{-1} \le bv\_\max \le 10^{-9}\, cm^3\, s^{-1}$ for $E \ge 2.91.10^{+6}\, V\, cm^{-1}$. The positive influence of the volume coupling coefficient in the space charge layer on the total density of photocurrent in the event $10^{-2}\, cm\, s^{-1} \le bs \le 10^{+7}\, cm\, s^{-1}$ occurs for $bv\_\max \ge 10^{-8}\, cm^3\, s^{-1}$. To develop a numerical model to solar cells supporting heat, it is recommended to consider a volume coupling coefficient in the space charge layer regardless of the value of the conversion velocity.

APPENDIX

$$G_{eh} = G_{eho} \exp(-\alpha z) \;\; ; \; G_x = G_{xo} \exp(-\alpha z)$$
$$G_{eho} = f_e \alpha(\lambda) N(\lambda) \; ; \;\; G_{xo} = f_x \alpha(\lambda) N(\lambda)$$

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