Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2019, 6(9):92-102

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

The Thermal Parameters on the Semiconductor Performance N^+P

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Abstract In the field of electronics, semiconductors occupy an important spot. In this context, the study of the effects of thermal parameters on the distribution of minority carriers, in particular on the photocurrent density is essential for improving the performance of semiconductors. The generation minority carriers depend on these thermal parameters. Indeed, the aim of this work is to mount the thermal parameters can increase the current density transient.

Furthermore, we are before a nonlinear problem for the diffusion coefficient depends on the temperature. The algebraic equations obtained after spatial discretization (by a scheme of control volume) and temporal (thanks to the implicit method of alternating directions) is solved using the dual scan method.

Keywords Semiconductor, Temperature, thermal parameters

1. Introduction

With the arrival of the new millennium, the debate on the future of the planet's electronics has intensified in view of the ever-increasing needs and the consequences that this may have in the medium term. Indeed, the demographic evolution and the development of certain geographical areas, suggest a considerable increase in the use of electronic devices based on semiconductors.

At this rate, researchers are constantly developing analytical [1-3] or numerical [4-8] possibly into account the temperature, excitons models to meet the needs of the population. Some of these models are made at room temperature and in steady state. It should also be remembered that the majority of these researchers used semi-analytical methods such as Fourier series developments which are very heavy.

However, when we are dealing with nonlinear transport equations, we can no longer use Fourier series developments because the superposition theorem is no longer applicable. Indeed, we orient our research towards numerical models in transient state, which hold temperature and thermal parameters.

2. Modeling of physical problem

The semiconductor devices are based on control of transport of electrons and holes.

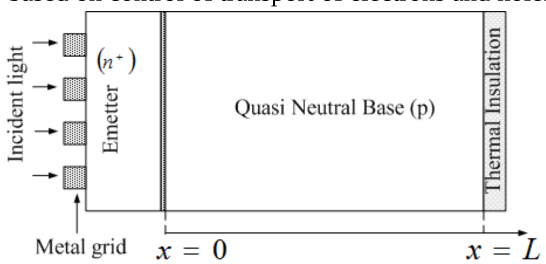

Figure 1: Schematics of a semiconductor to silicon N^+P -junction

To model the distribution of the charge carriers, we start from the general equation of following transportation

$$\frac{\partial G_i}{\partial t}+\vec{\nabla}\left[J_i(G_i)\right]=\Phi(G_i) \quad (1)$$

With

$J_i(G_i)$ the broadcast stream of G_i defined by $J_i(G_i)=\vec{J}_i\otimes\vec{G}_i$.

The field $\Phi(G_i)$ represents the existence of a source of G_i.

To solve equation (1), knowledge of the generation mechanisms, of recombination and currents is fundamental.

To maintain balance (no electric field), the electron flux induced by this concentration gradient is balanced by establishing an electric field space charge given by the standard formula :

$$E=-\frac{D}{\mu}\frac{1}{n}\frac{\partial n}{\partial x} \quad (2)$$

The sign $(-)$ of equation (2) simply reflects the fact that the distribution occurs in areas of high concentrations to low concentration areas, which is natural for the normalization of concentrations.

Here, we are interested in the distribution of minority carriers type (n).

$$\frac{\partial n}{\partial t}=G_n-\frac{n-n_0}{\tau_n}+\vec{\nabla}\left(\mu_n\times n\times\vec{E}\right)+\vec{\nabla}\left(D_n\times\vec{\nabla}n\right) \quad (3)$$

2.1. Simplifying assumptions

- The regions of the semiconductor are neutral ;
- They are homogeneous doping and monodimensional character ;
- They are conductive so that the voltage at these terminals is negligible ;
- The electric field in these areas is negligible ;
- The current carrier is essentially a diffusion current ;
- The majority carriers are not affected ;
- The faces $x=0$ and $x=L$ are the site of surface recombination phenomena.

Given the simplifying assumptions above the general equation of minority carriers diffusion is :

$$\frac{\partial n}{\partial t}=\frac{\partial}{\partial x}\left\{D\frac{\partial n}{\partial x}\right\}-\frac{n-n_0}{\tau_n}+G(x,t) \quad (4)$$

The diffusion coefficient D, of the minority carriers, is a function of the temperature of material. Recall that under certain assumptions, the diffusion coefficient is given by the following Einstein relation [9].

$$D=\mu_n\frac{K\times T}{q} \quad (5)$$

It is obvious that to know the distribution of carriers must first determine the temperature field which is solution of the following heat the equation:

$$\frac{\partial T}{\partial t}=\alpha\frac{\partial^2 T}{\partial x^2} \quad (6)$$

with α is the thermal diffusivity defined by: $\alpha=\frac{\lambda}{\rho\times C_p}$

ρ and C_p respectively represent the average density and the average heat capacity of the semiconductor.

Equations (4) and (6) will be closed by initial and boundary conditions that will govern the behavior of the carriers in the semiconductor. We will ask the geometrical limitations of our semiconductor, quite generally, conditions in the third species limits. We write:

2.3. Conditions on carriers

$$\begin{cases} t = 0 \Rightarrow n(x,0) = n_i \\ x = 0 \Rightarrow A_0 \dfrac{\partial n}{\partial x} = B_0(n - n_0) \\ x = L \Rightarrow A_L \dfrac{\partial n}{\partial x} = B_L(n - n_0) \end{cases} \quad (7)$$

A_0 and A_L if the coefficients are the diffusion coefficients on the faces $x = 0$ and $x = L$, then B_0 and B_L are the recombination rates on these surfaces.

2.4. Conditions on the temperature

At $t = 0$, the semiconductor is in thermodynamic equilibrium at the temperature T_a. If we assume that the face that is under illumination, that is, $x = 0$, is subjected to a constant flux density q and that the other face is thermally insulated, then it comes:

$$\begin{cases} t = 0 \Rightarrow T(x,0) = T_a \\ x = 0 \Rightarrow q = -\lambda \dfrac{\partial T}{\partial x} \\ x = L \Rightarrow \dfrac{\partial T}{\partial x} = 0 \end{cases} \quad (8)$$

Assuming that the generation rate of carriers is independent of time, then we can write:

$$n(x,t) = n_{eq}(x) + C(x,t) \quad (9)$$

Where $n_{eq}(x)$ is the distribution of carriers in continuous and $C(x,t)$ the scope of the holders transient. In these conditions our problem reduces to

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x}\left\{D\frac{\partial C}{\partial x}\right\} - \frac{C}{\tau_n} \quad (10)$$

$$\begin{cases} t = 0 \Rightarrow C(x,0) = C_i \\ x = 0 \Rightarrow A_0 \dfrac{\partial C}{\partial x} = B_0 C(0,t) \\ x = L \Rightarrow A_L \dfrac{\partial n}{\partial x} = B_L C(L,t) \end{cases} \quad (11)$$

Our goal now is to use the one-dimensional model for defining and solving the number of parameters in the equations (6) and (10). To do this we associate the following reference values: C_i (for the minority carriers),

ΔT_r (for temperature difference), τ (for the time variable) and L (for the space variable x) and ask : $x^* = \frac{x}{L}$; $t^* = \frac{t}{\tau}$; $C^* = \frac{C}{C_i}$; $T^* = \frac{T - T_a}{\Delta T_r}$

The reference temperature difference $\Delta T_r = \frac{q \times L}{\lambda}$ is calculated from the heat flux density imposed on the face $x^* = 0$.

Under these conditions the general equation of the minority carriers and the warmth become :

$$\frac{\partial C^*}{\partial t^*} = \frac{1}{F_0} \frac{\partial}{\partial x^*}\left\{ D^* \frac{\partial C^*}{\partial x^*} \right\} - C^* \quad (12)$$

$$\frac{\partial T^*}{\partial t^*} = \frac{1}{F_0'} \frac{\partial^2 T^*}{\partial x^{*2}} \quad (13)$$

The equations (12) and (13) show two very important parameters groups and to characterize F_0 and F_0' transfers and defined $F_0 = \frac{L^2}{\tau \times D^0}$ and $F_0' = \frac{L^2}{\tau \times \alpha}$.

With D^0 is the diffusion coefficient of carriers calculated from the ambient temperature T_a considered constant.

Of the kinematic point of view these quantities compare the duration of the phenomenon of diffusion and the life of carriers. In terms of energy F_0' measures the ratio of the heat stored and transmitted heat.

The diffusion coefficient dimensionless D^* expression for :

$$D^* = 1 + \frac{\Delta T_r}{T_a} \times T^* \quad (14)$$

It is therefore a function of dimensionless temperature T^*. The amount is called heating factor $\frac{\Delta T_r}{T_a}$.

To complete the system $(12)-(13)$ in the meantime $[0;1]$ it is necessary to associate its original terms and conditions dimensionless limits. Taking into account the reference quantities, conditions (8) and (11) become again:

Then we get:

$$\begin{cases} t^* = 0 \Rightarrow C^*(x^*, 0) = 1 \\ x^* = 0 \Rightarrow \frac{\partial C^*}{\partial x^*} = Ai_0 \times C^*(0, t) \\ x^* = 1 \Rightarrow \frac{\partial C^*}{\partial x^*} = Ai_L \times C^*(L, t) \end{cases} \quad (15)$$

$Ai_0 = \frac{B_0 \times L}{A_0}$ and $Ai_L = \frac{B_L \times L}{A_L}$

$$\begin{cases} t^* = 0 \Rightarrow T^*(x^*,0) = 0 \\ x^* = 0 \Rightarrow \dfrac{\partial T^*}{\partial x^*} = -1 \\ x^* = 1 \Rightarrow \dfrac{\partial T^*}{\partial x^*} = 0 \end{cases} \quad (16)$$

3. Numerical Procedure of the Physical Problem

From a qualitative description of the problem, we wrote a mathematical model based on simplifying assumptions deemed reasonable. In doing so we get a system of partial differential equations of parabolic type.

To solve these equations, it took the development of solving techniques involving discretization, that is to say an approximation of the continuous problem.

Below, we give the example of a control volume mesh that can be adopted for the discretization of the equation of the minority carriers and that the heat.

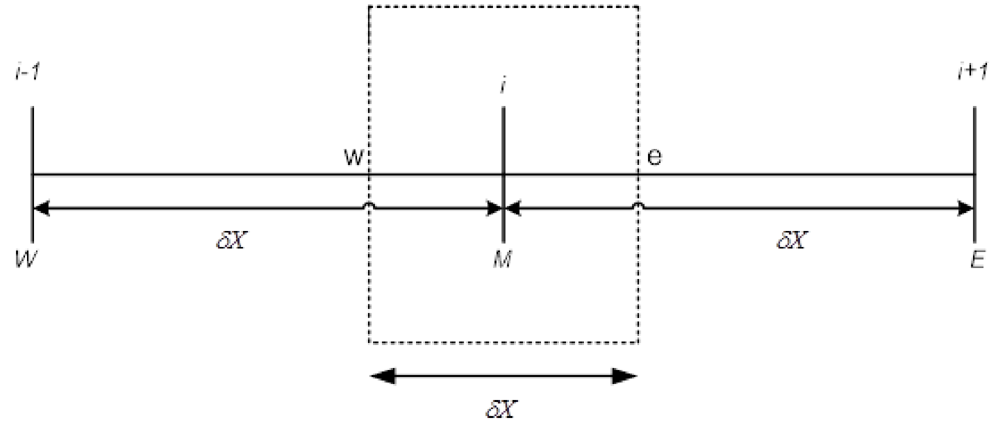

Figure 2: Control volume in the one-dimensional case

The continuous domain $[0;1]$ is reduced in a discrete area in the form of $i_m - 1$ regular length δx discretization said. The x^*-direction is approximated by continuous dimensionless $x^* = \delta x(i-1)$.

With $\delta x = \dfrac{1}{i_m - 1} \times i_m$ (i_m the number of nodes)

Nodes W, M and E are then respectively identified by the indices $(i-1)$, (i) and $(i+1)$.

Are focusing M to develop a volume V_c called volume control, dimension δx whose faces are denoted by w and e. We equations (12) and (13) in the general form:

$$\frac{\partial \phi}{\partial t^*} = a \times \frac{\partial}{\partial x^*}\left\{\Gamma \frac{\partial \phi}{\partial x^*}\right\} + b \times \phi \quad (17)$$

By integrating this equation in the control volume V_c we get:

$$\frac{\delta x \times \partial \phi_M}{\partial t^*} = a \times \int_w^e \frac{\partial}{\partial x^*}\left\{\Gamma \frac{\partial \phi}{\partial x^*}\right\} dx + b \times \delta x \times \phi_M \quad (18)$$

Which give :

$$\frac{\partial \phi_M}{\partial t^*} = a_w \times \phi_w - (a_w + a_E - b) \times \phi_M + a_E \times \phi_E \quad (19)$$

With $a_w = \Gamma_w \times \frac{a}{\delta x^2}$ and $a_E = \Gamma_e \times \frac{a}{\delta x^2}$

By discretizing time through $t^* = (n-1) \times \delta t$, we can then approach the temporal term $\frac{\partial \phi_M}{\partial t^*}$, with an error on the order of δt , for $\frac{\partial \phi_M}{\partial t^*} = \frac{\phi_M^{n+1} - \phi_M^n}{\delta t}$.

The problem that arises is: at what moment he wills approximating the terms of the second member of the equation (19).

It shows that if we approach the second member of the equation (19) in $t^* - \delta t$. The discrete problem now reduces to an equation with one unknown. However, no time and space must check a very demanding relationship to ensure the stability of the scheme. By against approaching the second member by implication that is to say at the moment t^* the stability of the numerical scheme is unconditional guarantee which allows to choose δt independently δx. But against part we shall have to solve every moment a system of i_m equations i_m with unknowns.

To close this system, we set the boundary conditions under the following general forms.

$$\begin{cases} x^* = 0 \Rightarrow A_0 \times \frac{\partial \phi}{\partial x^*} + B_0 \times \phi(0) + D_0 = 0 \\ x^* = 1 \Rightarrow A_m \times \frac{\partial \phi}{\partial x^*} + B_m \times \phi(0) + D_m = 0 \end{cases} \quad (20)$$

We opted for an implicit scheme because after discretization so we will have a sparse matrix easy to reverse. [5].
The full matrix system which continuously approach the problem is:

$$\begin{cases} b_1' \times \phi_1 + c_1' \times \phi_2 = d_1' & i = 1 \\ a_i \times \phi_{i-1}^{n+1} + b_i \times \phi_i^{n+1} + c_i \times \phi_{i+1}^{n+1} = d_i & 1 \prec i \prec i_m \\ a_m' \times \phi_{i_m - 1} + b_m' \times \phi_{i_m} = d_m' & i = i_m \end{cases} \quad (21)$$

With

$a_i = -\delta t \times a_w$; $c_i = -\delta t \times a_E$; $b_i = 1 - a_i - c_i - \delta t \times b$; $d_i = \phi_i^n$

$\phi_W^{n+1} = \phi_{i-1}^{n+1}$; $\phi_M^{n+1} = \phi_i^{n+1}$; $\phi_E^{n+1} = \phi_{i+1}^{n+1}$

$b_1' = -(B_0 \times \delta x - A_0)$; $c_1' = -A_0$; $d_1' = -D_0 \times \delta x$

$a_m' = A_m$; $b_m' = -(B_m \times \delta x - A_m)$; $d_m' = -D_m \times \delta x$

In order for the scheme to be structurally stable, the matrix must have a dominant main diagonal [4], in other words it must be:

$$|b_i| \succ |a_i| + |c_i| \quad (22)$$

4. Calculation conditions

Results from numerical simulations will allow us to discuss the influence of temperature and the nature of boundary conditions

The tests we conducted showed that no time and space and are good compromise between an acceptable calculation volume $\delta t = 10^{-2}$ and $\delta x = 10^{-2}$ a reasonable calculation time. We assumed that the recombination velocity on the face $x = L$ is zero. The reference carrier diffusion coefficient is fixed D^0 to $2.6 \times 10^{-3} m^2 s^{-1}$.

5. Results and Discussion

The results are related to the dimensionless parameters. Our comments will focus on the influences of the heating factor, number Fourier F_0 coefficients and the report of the distributions of the density of minority carriers, temperature and current density.

5.1. Influence of the heating factor

The curves of Figures 3, 4 and 5 show the variations of the density of minority carriers and the temperature according da depth in the base and the time for three factors heated $\frac{\Delta T_r}{T_a} = 00.10$, $\frac{\Delta T_r}{T_a} = 05.00$ and $\frac{\Delta T_r}{T_a} = 10.00$ ..

We note that the heating factor has a negligible effect on the temporal distributions (Figure 5) and space (Figure 3) the temperature. It has a positive effect on temporal distributions (Figure 5) and space (Figure 4) of the minority carriers. Thermal agitation thus leads to an increase of minority carriers in a semiconductor. However we must not forget that the continuous rise in temperature is avoided in a semiconductor because, from a certain threshold, it can lead to thermal breakdown of the semiconductor.

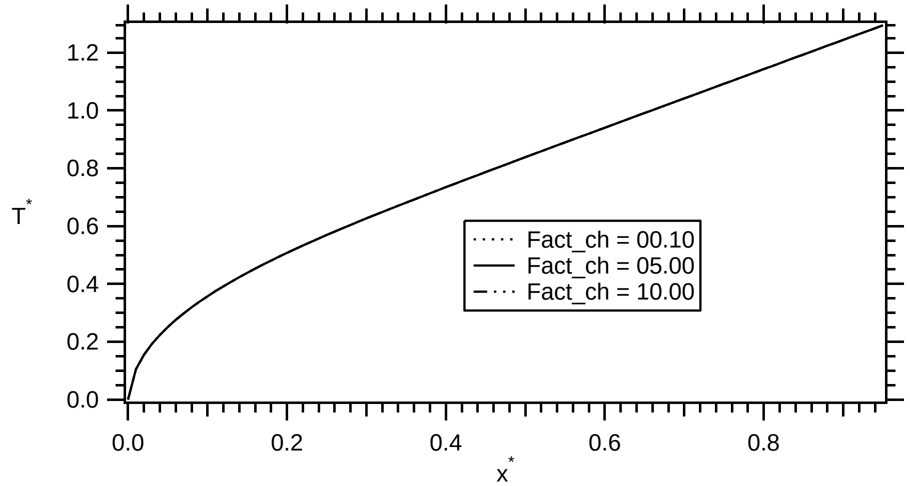

Figure 3: Influence of the heating factor of the temperature variation
V_0 = 10.00; Fo = 01.00; Rd = 10.00 ; t^* = 00.10

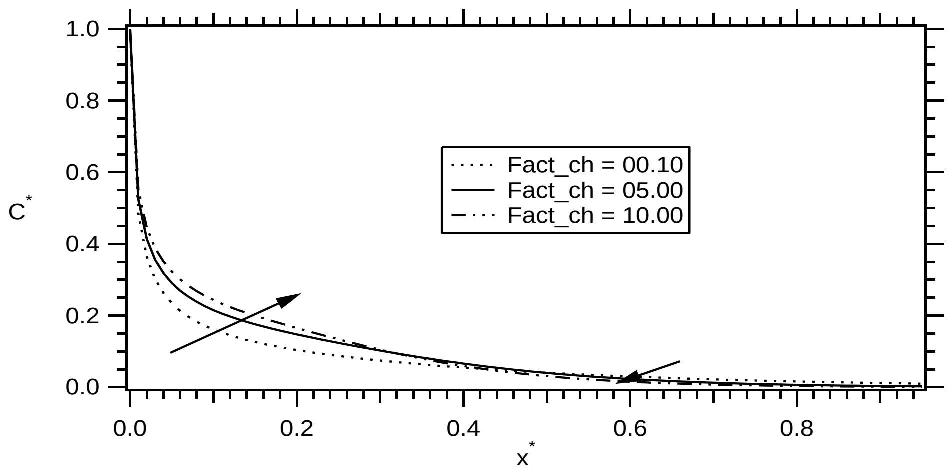

Figure 4: Influence of the heating factor on the variation of the density of minority carriers
V_0 = 10.00; Fo = 01.00; Rd = 10.00; t^* = 00.10

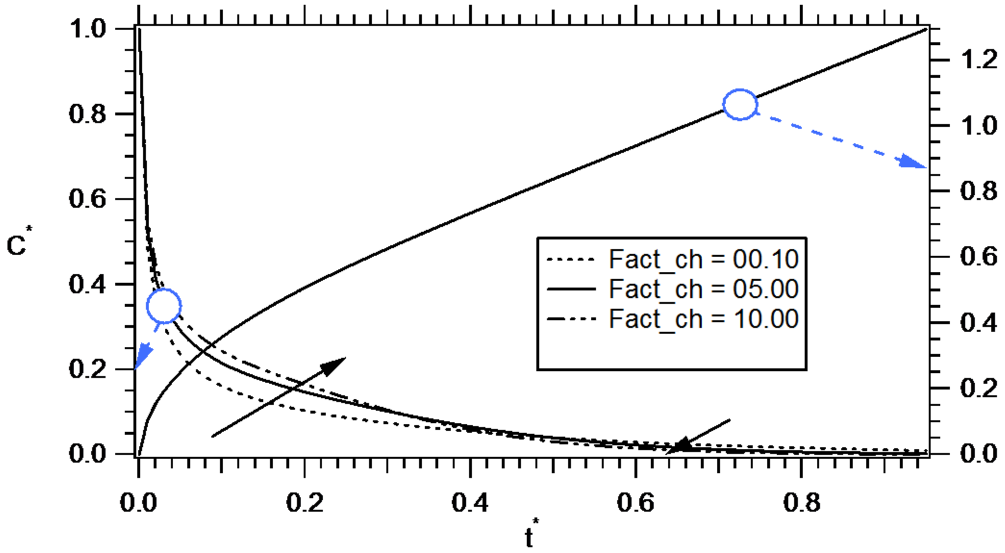

Figure 5: Influence of the heating factor on the variation of the density of minority carriers and temperature
$V_0 = 10.00$; $Fo = 01.00$; $Rd = 10.00$; $x^* = 00.00$

5.2. Influence of the Fourier number

Remember that the size F_0 we defined $F_0 = \frac{L^2}{\tau \times D^0}$ is actually the inverse Fourier number. The curves of Figures 6 and 7 show that the Fourier number plays a very important role in the distribution of minority carriers and temperatures. When Fo increases the density of minority carriers are increasing but also the carriers hardly diffuse into the material (Figure 7) and the steady state is established slowly. Furthermore, increasing the Fourier number causes a reduction in temperature. Indeed an increase of F_0, for a given material, is équilavent to decreased D^0 or / and τ . So the combination of these two effects simultaneously results in increased density of minority carriers in depth and with low minority carriers diffusion. This increase in the density of minority carriers is due to the increase of the term containing the volume generation.

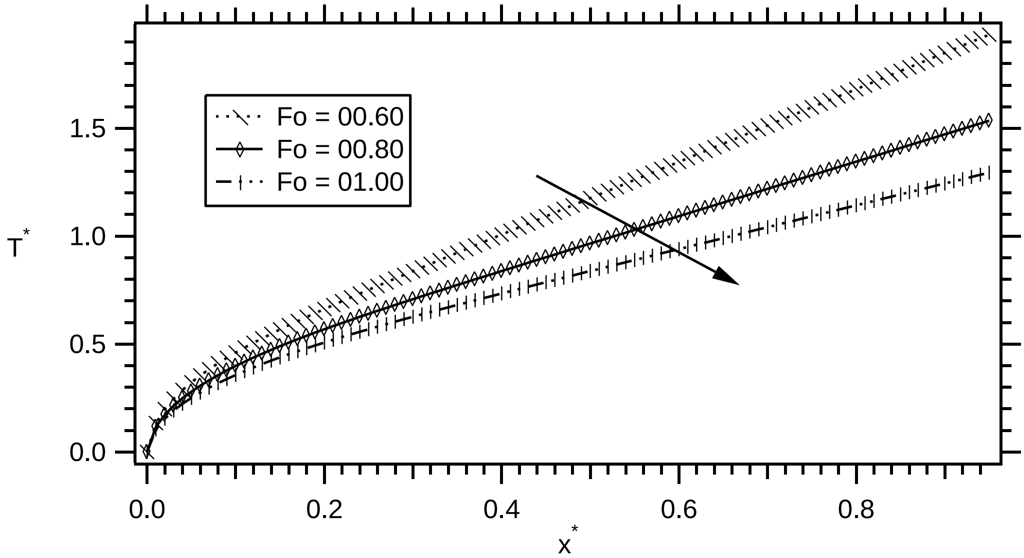

Figure 6: Influence of the Fourier number on the temperature variation
$V_0 = 10.00$; $Fact\_ch = 00.10$; $Rd = 10.00$; $t^* = 00.10$

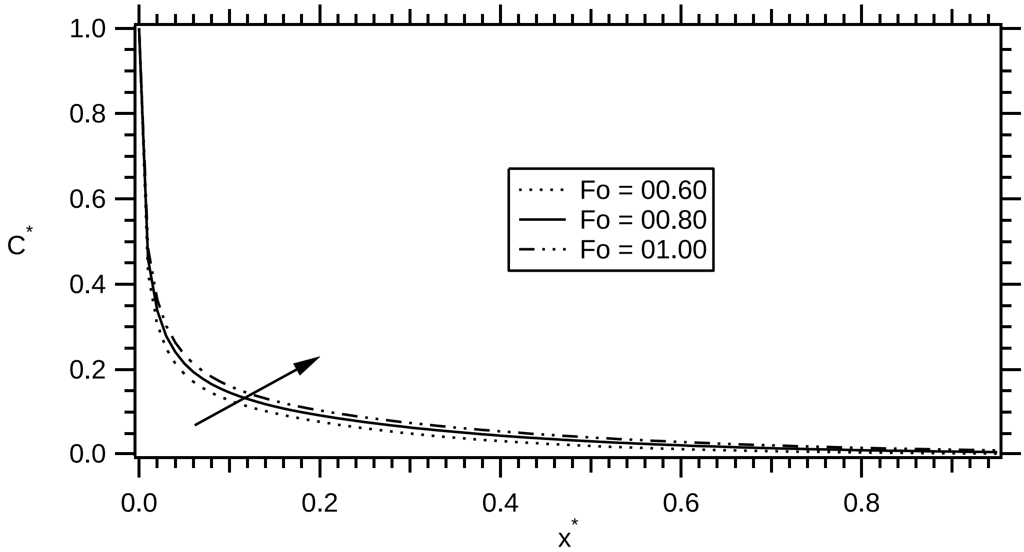

Figure 7: Influence of the Fourier number on the variation of the density of minority carriers
V_0 = 10.00; Fact_ch = 00.10; Rd = 10.00; t^* = 00.10

5.3. Influence of coefficients report Rd

Greatness $Rd = \dfrac{D^0}{\alpha}$ is the ratio between the thermal diffusion coefficients and porters.

When the ratio between the thermal diffusion coefficients and carriers increases, the temperature decreases (Figure 8), but the values of the minority carriers remain constant (Figure 9).
We also note that increasing the ratio between the thermal diffusion coefficients and porters very more negative than that of the Fourier number on the temperature distribution.
The decrease in thermal diffusivity does not promote the distribution of minority carriers, so the relationship between the thermal diffusion coefficients and the holders will not affect the density of minority carriers.

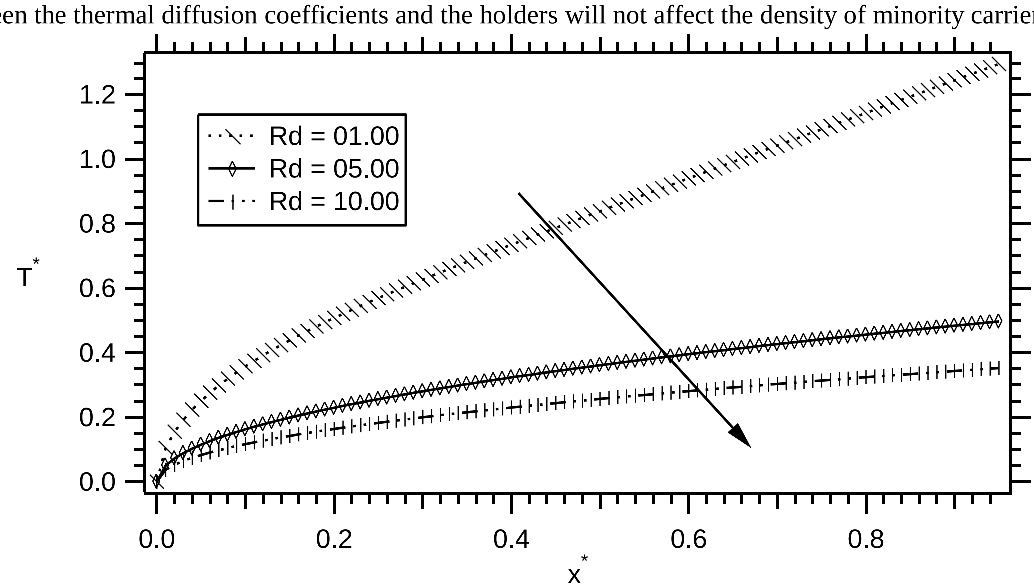

Figure 8: Influence of the ratio of the coefficients on the temperature variation
V_0 = 10.00; Fact_ch = 00.10; Fo = 01.00; t^* = 00.10

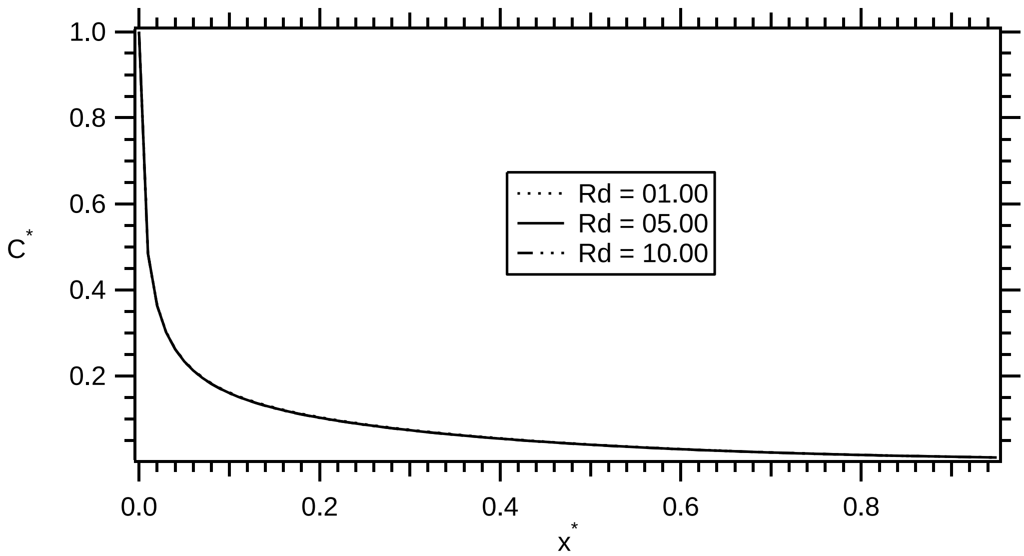

Figure 9: Influence coefficients report on the change in the density of minority carriers
V_0 = 10.00; Fact_ch = 00.10; Fo = 01.00; t^* = 00.10

5.4. Density of photocurrent in the junction

The simplifying assumptions state that the electric field in regions of the semiconductor is negligible. Therefore the current of minority carriers is essentially a diffusion current. It is defined by the following relationship:

$$J = q \times \frac{D_o \times C_i}{L} \times D_T^* \left. \frac{\partial C^*}{\partial z^*} \right|_{z=0}$$

Figure 10 shows the evolution of the current density as a function of the temperature.
The curves in Figure 10 show that the heating factor has positive effects on the variation of the current density. The heating factor therefore increases the number of generated minority carriers. Moreover, we can say that the heating factor reduces losses by surface recombination. From the large temperature effect fades.
Other thermal parameters have similar effects to those of the heating factor [7].

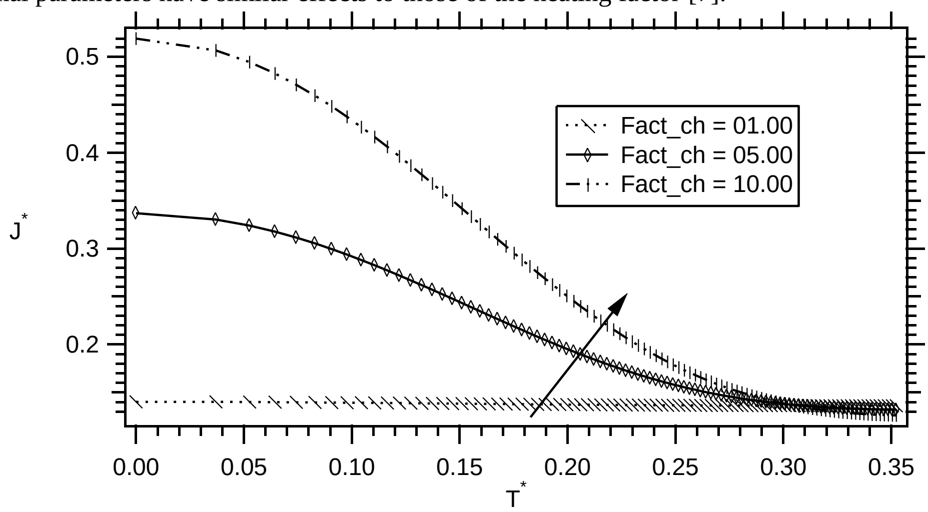

Figure 10: Influence of the heating factor on the variation of the current density
V_0 = 10.00; Fo = 01.00; Rd = 10.00; x^* = 00.00

6. Conclusion

The aim of this work involved a study of numerical modeling of the effects of thermal parameters on the distribution of minority carriers in a semiconductor.

For this, we are interested in numerical study of the distribution equation of the charge carriers and the boundary conditions. This numerical study is due to the strong coupling between the transport equation of the minority carriers and the warmth and strong coupling boundary conditions. These equations were discretized by the method of Patankar control volume and an inexpensive implicit scheme in time and volume calculation was used. Algebraic equations are then solved by the double scanning method.

It appears from our study that tested the most influential variables on the distribution of minority carriers is the heating factor and the Fourier number. What is remarkable about the Fourier number coefficients and the report is that they have a negative effect on the temperature distribution. It also appears from our study that the temperature variation in the semiconductor has a negligible effect on the temperature explicit so the ratio of the coefficients of the minority carriers. In the end, these thermal parameters have positive effects on the current density

Therefore, to improve the performance of semiconductor without the presence of excitons, it is necessary to modeling small values of the temperature and the large values of the thermal parameters.

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