Journal of Materials Science & Surface Engineering Vol. 4 (7), 2016, pp 467-471

Contents lists available at http://www.jmsse.org/

Journal of Materials Science & Surface Engineering

Effects of Variability of The Average Temperature on The Distribution of Electrons and of Excitons in A Semiconductor

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Article history

Received: 22-Sep-2016
Revised: 28-Oct-2016
Available online: 02-Dec-2016

Keywords:
Semiconductor,
Average Temperature,
Fourier Number,
Heat Factor

Abstract

In this study, the effects of the average temperature on the distribution of minority carrier density, in particular on the density of the photocurrent have been shown. The generation of this minority carrier density (electrons and excitons) depends on the average temperature. In fact the aim of this work is obtained, a variation of the total density of photocurrent according to the depth of the space charge layer (SCL) and the base, which depends on that of the average temperature. Such a physical problem is a first of its kind. Furthermore we are before a nonlinear problem because many parameters depend on the average temperature. For the numerical solution of such a problem, we chose the finite volume method.

Introduction

The increase in temperature, known as the thermal agitation, plays a very important role on the distribution of minority carrier density in a semiconductor. It also leads to the generation of a bonded electron-hole pair and the related of free electron-hole pairs. This bounded electron-hole pairs by a Coulomb interaction is called exciton. Excitons as the electrons are moving. They are electrically neutral and highly localized. Their participation in the total density of the photocurrent in the semiconductor is the difference between the number of electron-hole pairs and the number of generation recombinations. This difference increases with increasing the average temperature.

Despite the large number of researchers' work in the field of solar cells, we always desire to bring their participation. We oriented inorganic semiconductor based silicon. Some authors like, Zh. Karazhanov [1] developed an analytical model of the dependence of temperature and doping level on the performance of solar cells in the presence of excitons.

The aim of our study is to show that the evolution of the photocurrent density for each of the depth in the base may depend on the average temperature of the cell. This solar cell is subjected to a monochromatic illumination through the front side and thermal insulation from the back side by taking into account inclusion of the space charge layer. There is a simultaneous consideration of the variability of the coefficients according to the average temperature and the presence of the electric field in the space charge layer. This electric field also depends on the average temperature.

Formulation of the problem

We considered a semiconductor of length L (Figure 1). It is characterized by regions with non-homogeneous doping.

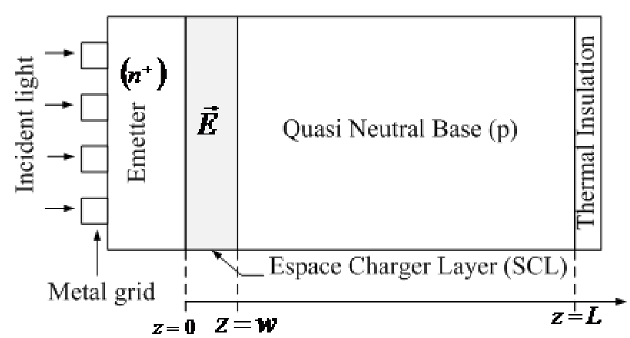

Figure 1: Schematic diagram of thermal insulation. The space charge layer (SCL) extends from $z = 0$ to $z = w$. The quasi-neutral base extends from $z = w$ to $z = L$.

The minority carriers (electrons and excitons) in excess in the base of a subjected semiconductor an illumination obey the equations of following continuities:

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

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

With $G_{eh}=G_{eho}\exp(-\alpha z)$; $G_x=G_{xo}\exp(-\alpha z)$ [2].

Level of these equations, we have some coefficients that depend on the temperature:

The coefficients of diffusion of electrons and of excitons generated in the base. They are given by the Einstein relation [3];

The volumique coupling coefficient, given by:

$$bv(T_{moy})=\left(10^{-3}\times T_{moy}^{-2}+2.5\times10^{-6}\times T_{moy}^{-0.5}+1.5\times10^{-7}\right)en\ cm^3s^{-1}$$

[2];

- The thickness of the space charge layer;
- The electrical field which reigns in the space charge layer:

$$E(z)=\frac{E_m}{w(T_{moy})}\left[w(T_{moy})-z\right]$$

Indeed, if we want to know the distribution of the minority carriers and the total density of photocurrent, it will be beforehand necessary to determine the field of the temperatures which is solution of the equation of the following heat:

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

The dimensionless equations of coupled system with the equation of the heat become:

$$F_{e0}\frac{\partial}{\partial z^*}\left\{D_T^*\frac{\partial n_e^*}{\partial z^*}\right\}+A\frac{\partial}{\partial z^*}\left\{n_e^*\left(w^*-z^*\right)\right\}=\frac{n_e^*n_h^*-n_{in}^{*\,2}}{n_e^*+n_h^*+2n_{in}^*}+$$
$$B_e\left(n_e^*n_h^*-n_x^*n_1^*\right)-C_e f_e G^* \quad (3a)$$

$$F_{x0}\frac{\partial}{\partial z^*}\left\{R_\mu D_T^*\frac{\partial n_x^*}{\partial z^*}\right\}=\left(n_x^*-n_{x0}^*\right)-B_x\left(n_e^*n_h^*-n_x^*n_1^*\right)-C_x(1-f_e)G^* \quad (3b)$$

$$\frac{\partial T^*}{\partial z^*}=\frac{\partial^2 T^*}{\partial z^{*2}} \quad (4)$$

These dimensionless equations were obtained from the hypotheses of modelling and physical quantities of reference [4].

Dimensionless numbers and characteristics are:

$F_0=\frac{\tau\times D^0}{L^2}$ Relationship between the time of diffusion time and the lifetime (fourier number).

The quantity D^0 is the diffusion of the electrons coefficient calculated from the ambient temperature T_a considered constant.

The quantity $Fact-ch=\frac{\Delta T_r^*}{T_a}$ is called heat factor. This is the ratio of heat flow imposed and conduction.

It is therefore according to the dimensionless temperature. The quantityt is called heat factor. To complete the system of equations (3) and (4) in the interval [0,1], we associate the initial conditions and boundary conditions dimensionless following:

For the electrons

$$\begin{cases} z^*=0 \Rightarrow n_e^*(0)=N_D^* \\ z^*=1 \Rightarrow A_{Le}\frac{\partial}{\partial z^*}\left\{D_T^*n_e^*\right\}_{z=1}=-\left[n_e^*(1)-n_{e0}^*\right]+B_{Le}\left[n_x^*(1)-n_{x1}^*\right] \end{cases} \quad (5a)$$

For the excitons

$$\begin{cases} z^*=0 \Rightarrow A_{0x}\frac{\partial}{\partial z^*}\left\{R_\mu D_T^*n_x^*\right\}_{z=0}=\left[n_x^*(0)-n_{x0}^*\right]-B_{0x}\left[n_x^*(0)-n_{x1}^*\right] \\ z^*=1 \Rightarrow A_{Lx}\frac{\partial}{\partial z^*}\left\{R_\mu D_T^*n_x^*\right\}_{z=1}=-\left[n_x^*(1)-n_{x0}^*\right]-B_{Lx}\left[n_x^*(1)-n_{x1}^*\right] \end{cases} \quad (5b)$$

For the temperature

$$\begin{cases} t^*=0 \Rightarrow T^*\left(z^*,0\right)=0 \\ z^*=0 \Rightarrow \frac{\partial T^*}{\partial z^*}=-g\left(t^*\right) \\ z^*=1 \Rightarrow \frac{\partial T^*}{\partial z^*}=0 \end{cases} \quad (5c)$$

These dimensionless equations are very complicated, that is to say non-linear one hand and coupled on the other. In this case, the use of numerical solution is necessary and prompts us to choose the appropriate numerical method to get the best approximations. In fact, we chose the finite volume method [4]. As different parts of our area of study (the space charge layer and the base) are not the same size and are the site of physical phenomena of very different natures, it is appropriate to use a variable mesh [4].

In each region of study area we will first evaluate the average temperature by the Thomas algorithm. In this section we explain the different steps of the calculation process we adopted using the Thomas algorithm. Given that the coupled equations of transporting electrons and excitons are coupled to that of the heat, the resolution must be sequential:

- We set $\phi_{e,i}^m$ the density of the electrons and $\phi_{x,i}^m$ the the density the excitons ;
- We fix all the physical, geometrical and numerical constants which fall within the discretized equation systems. It must also impose another stop criterion when the number of iterations becomes prohibitive. We will ask $m_{\max}$ the maximum number of iterations imposed ;
- We initialize the iteration count $m=1$ and given arbitrary profiles of electrons and excitons $\left(\phi_{e,i}^m \text{ and } \phi_{x,i}^m\right)$;
- It solves the heat equation to find an average temperature that we will use to calculate the various coefficients ;
- We calculate the coefficients of the equations expressing the initial and boundary conditions for electrons ;
- The distribution of electrons is determined with the Thomas algorithm ;
- For the determination of the density of excitons, we use the density of electrons to calculate the coefficients into the equation of excitons ;
- We determine the distribution of excitons thanks to Thomas's algorithm ;
- If the test is satisfactory, we do the annexes calculations and we arrest the program. Otherwise we first check if $m=m_{\max}$; if that is the case one stops the calculations to find the sources of non-convergence. Otherwise the

increment is increased m by one unit, $\phi_{e,i}^{m}$ and $\phi_{x,i}^{m}$ is replaced by $\phi_{e,i}^{m+1}$ and $\phi_{x,i}^{m+1}$ and returns to calculate another average temperature.

Results and Discussion

Our comments will concern essentially the importance of the average temperature on the distribution and the total density of the photocurrent of electrons and of excitons.

Thus, we address the simulation study of the influence of the average temperature on the distribution of minority carrier density. This study shows the importance of the average temperature in our work.

Profiles of the excess minority carrier density depending on the average temperature

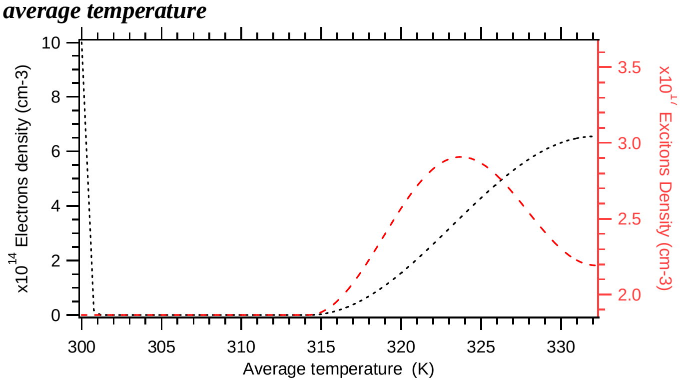


Figure 2: Profiles of the excess minority carrier density depending on the average temperature $N_A=10^{15}$ cm^{-3} ; $N_D=10^{19}$ cm^{-3} ; $n_i=1{,}45\ 10^{10}$ cm^{-3} ; n_mott=1,0310^{18} cm^{-3} ; bs=10^{+1} cm s^{-1} ; Fact_ch=5×10^{-2}; Se= Sx =3×10^{+3} cm s^{-1} ; F_0=10

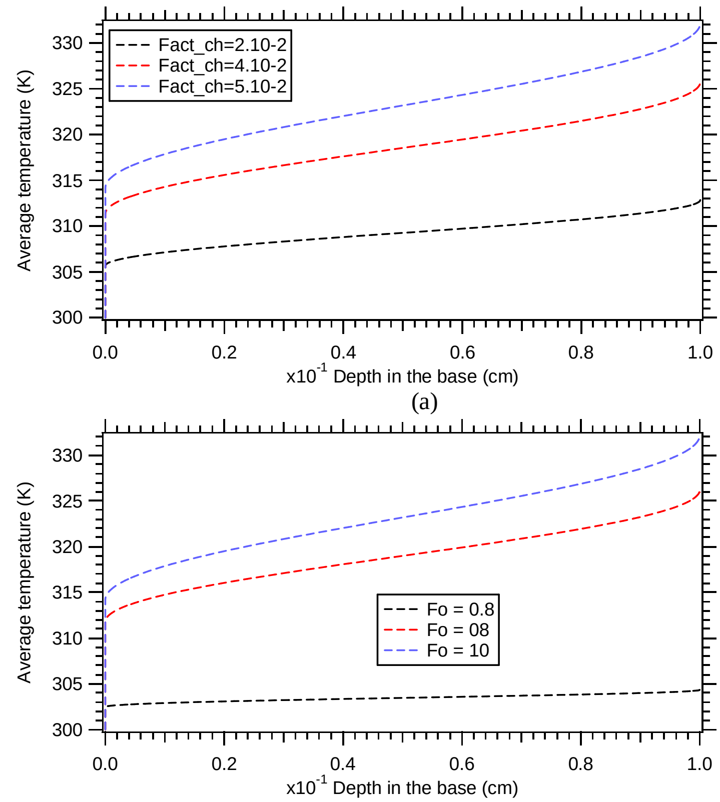
We will better to encircle from Figure 2, with fixed physical parameters, changes in the the excess minority carrier density according to the average temperature. At ambient temperature, we note a significant presence of the electrons. At this temperature there is no generation of excitons. Then we notice that the density of electrons decreases while that of excitons is constant. Also from 301K to 315K densities of electrons and the excitons are constant and almost zero. In this range of the average temperature, we see that the photocurrent will vary slightly. While from 315K, there is an increase of the electron density and the excitons, which peaked respectively at 324 and 332 according to the excitons and electrons.

In summary, we can remember that each range of the average temperature is a variation in the excess minority carrier density. The decrease in the density of excitons with large values of the average temperature is due to their dissociation and their participation in the total density of the phocourant.

Average temperature according to the depth in the base by including the space charge layer (SCL).

In Figure 3 we reproduce the average temperature versus depth in the base including the space charge layer for different parameters given.

Figures 3a and 3b edify us on the influence of various physical and kinematic parameters on the average temperature of the solar cell. Among these parameters, the heat factor and the Fourier number have considerable impact on the profile of the average temperature. The increase of the latter causes the average temperature. There is a special case of small values of the Fourier number, the latter a little appreciable influence on changes in the average temperature. The findings of these figures will help the comments of the different profiles of the total density of the photocurrent.



(b)

Figure 3: (a) Influence of the heat factor on the average temperature $N_A = 10^{16}$ cm^{-3} ; $N_D = 10^{19}$ cm^{-3} ; $n_i = 1.45\ 10^{10}$ cm^{-3} ; n_mott = 1.0310^{18} cm^{-3} ; bs = 10^{-2} cm s^{-1} ; Se = Sx = 10 cm s^{-1} ; F_0 = 10; (b) Influence of the Fourier number on the average temperature $N_A = 10^{16}$ cm^{-3} ; $N_D = 10^{19}$ cm^{-3} ; $n_i = 1.45\ 10^{10}$ cm^{-3} ; n_mott = 1.0310^{18} cm^{-3} ; bs = 10^{-2} cm s^{-1} ; Se = Sx = 10 cm s^{-1} ; Fact_ch = 5×10^{-2}

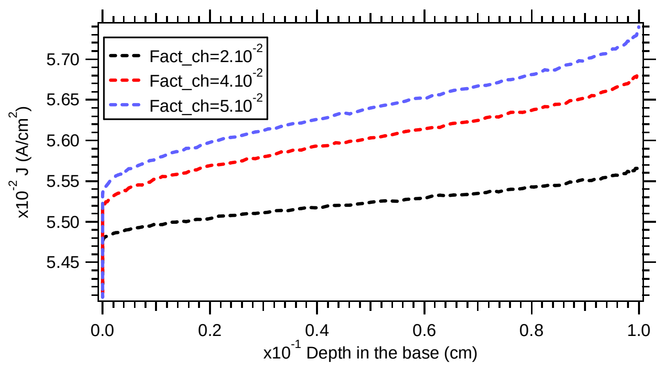
Study of the total density of the photocurrent

In this part, we will study the effects of kinematic and intrinsic parameters of the total density of the photocurrent based on the average temperature and the depth of the base including the space charge layer (SCL).

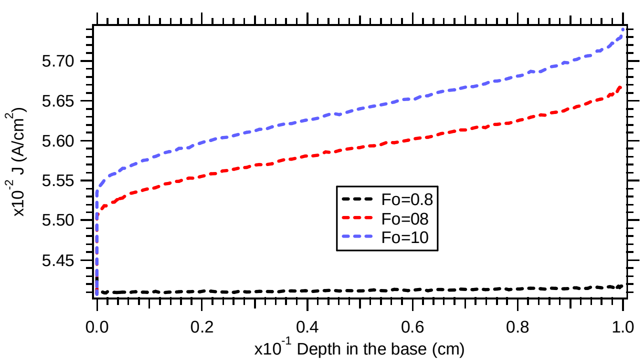
To further examine the influence of these parameters on the total density of phtocourant we begin our study with the profile of the average temperature in function of depth in the base including the space charge layer (SCL). The remarks and the conclusions will be selected we will build on those that will be drawn from the study of the total density of the photocurrent.

In the hypothesis of an electric field of unimportant polarization in the base, the photocurrent of electrons and of excitons is given by the gradient of the excess minority carriers to the junction [5]. Total density of the photocurrent at the junction according to the depth in the space charge layer (SCL) and the base: front side

The total density of the photocurrent is a function of the depth in the space charge layer (SCL) and the base and its profiles for different parameters are represented by figure 4.



(a)



(b)

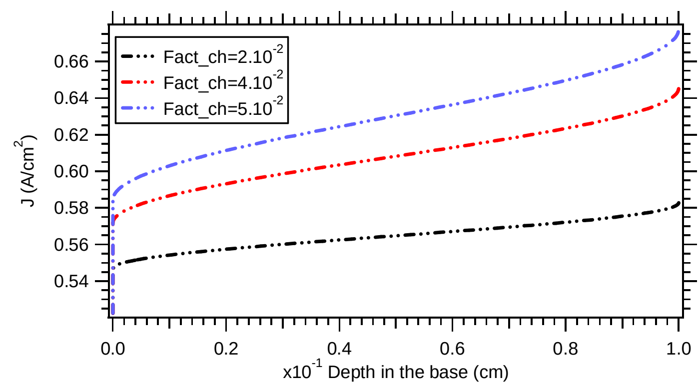
Figure 4: (a) Influence of the heat factor on the variation of the total density of the photocurrent as a function of depth in the SCL and the base $N_A = 10^{16}$ cm^{-3} ; $N_D = 10^{19}$ cm^{-3} ; $n_i = 1.45\ 10^{10}$ cm^{-3} ; n_mott = 1.0310^{18} cm^{-3} ; bs = 10^{-2} cm s^{-1} ; Se = Sx = 10 cm s^{-1} ; Fo = 10; (b) Influence of the Fourier number on the variation of the total density of photocurrent as a function of depth in the SCL and the base $N_A = 10^{16}$ cm^{-3} ; $N_D = 10^{19}$ cm^{-3} ; $n_i = 1.45\ 10^{10}$ cm^{-3} ; n_mott = 1.0310^{18} cm^{-3} ; bs = 10^{-2} cm s^{-1} ; Se = Sx = 10 cm s^{-1} ; Fact_ch = 5×10^{-2}

Considering any curve in Figure 4a, there is an increase of the total density of photocurrent of the solar cell according to the depth in the base. This increase is more significant with larger values of the heat factor. We saw earlier, increasing the heat factor is synonymous with that of the average temperature. Therefore the variation of the heat factor that leads to the total density of the photocurrent.

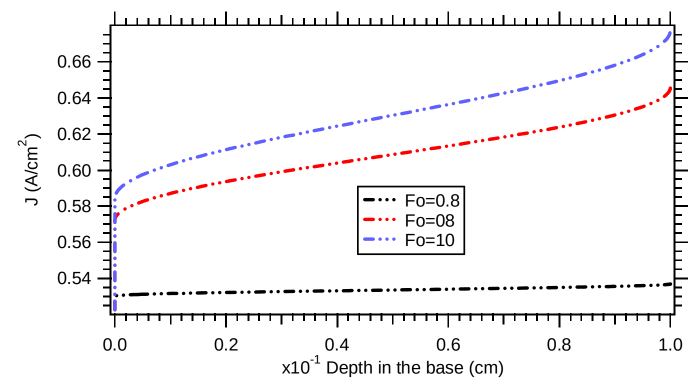
The figure 4b shows the evolution of total density of the photocurrent, depending on the depth in the base and the space charge layer (SCL) for different values of the Fourier number. There are slight variations of the total density of the photocurrent for small values of the Fourier number. We then note a significant increase in the total density of the photocurrent Fo = 08. The small values of the Fourier number correspond to constant values of the average temperature in the space charge layer to the depth in the base. The density of electrons and excitons in this temperature range is constant; this is what explains the small variation in the total density of the photocurrent. In addition, the substantial increase of the total density of the photocurrent is due to that of the average temperature, since the latter not only cause's variation of the excess minority carrier density but it promotes their participation in the total density of the photocurrent.

Total density of the photocurrent at the junction according to the depth in the space charge layer (SCL) and the base: back side

With thermal insulation by the back side, the resulting values of the total density of the photocurrent are higher than the total density of the photocurrent that we have at the junction. Indeed, we can say that there is generation of electrons and excitons in the back side due to the increase in average temperature. The dissemination of these towards the junction is favored by the heat factor. However, it is these electrons and excitons that contribute to the photocurrent.



(a)



(b)

Figure 5: (a) Influence of the heat factor on the variation of the total density of photocurrent as a function of depth in the SCL and the base $N_A = 10^{16}$ cm^{-3} ; $N_D = 10^{19}$ cm^{-3} ; $n_i = 1.45\ 10^{10}$ cm^{-3} ; n_mott = 1.0310^{18} cm^{-3} ; bs= 10^{-2} cm s^{-1} ; Se = Sx = 10 cm s^{-1} ; $F_0 = 10$; (b) Influence of the Fourier number on the variation of the total density of photocurrent as a function of depth in the SCL and the base $N_A = 10^{16}$ cm^{-3} ; $N_D = 10^{19}$ cm^{-3} ; $n_i = 1.45\ 10^{10}$ cm^{-3} ; n_mott = 1.0310^{18} cm^{-3} ; bs = 10^{-2} cm s^{-1} ; Se = Sx = 10 cm s^{-1} ; Fact_ch = 5.10^{-2}

Figure 5a shows the same analysis we have at figure 4a. In figure 5a, we can always do a correlation of the various comments that have been made in figure 4a.

At the back side, figure 5b shows the same analyzes and interpretations that we performed at the front side figure 4b.

Conclusions

The numerical study of the effects of the variability of the average temperature in semiconductor silicon was presented. The geometric configuration of the physical model is a semiconductor junction n^+p by the model of the extension of the space charge layer, subjected to monochromatic illumination and thermal insulation from the back surface. The fundamental equations that govern the operation of the components of our semiconductor were resolved by the dual scanning method. The numerical study was a company to identify the influence of the average temperature on the distribution of electrons and of excitons and especially on the total density of the photocurrent.

It appears from our study that each range of the average temperature variation corresponds to an excess minority carrier density. The excess minority carrier density was calculated with a volumique coupling coefficient which depends on the average temperature. Increasing this average led to a dissociation of excitons and their participation in the total density of the phocourant. The heat factor and the Fourier number have positive effect on the total density of the photocurrent at the front side to the back side. The total density of the phocourant is much more meaningful to the isolated side.

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