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Effects of the Nature of Boundaries Conditions and Their Truncation Errors on the Distribution of Minority Carriers in Silicon Solar Cell

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Abstract

In this work, the effects of boundaries conditions and truncation errors in the distribution of minority carriers in the semiconductor are studied. It is a one-dimensional digital study of a polycrystalline silicon solar cell under polychromatic illumination in a dynamic state. Starting from the Boltzmann equation of semiconductors, the author establishes the general equation of particle transport. Assumptions made on the latter allow it to give the equation of distribution of minority carriers in a general way in its case to be studied. This dimensioned distribution equation reveals the parameters of influences on the distribution of carriers. It obtains a partial derivative equation for the carrier distribution function. The boundary conditions are then discretized to order one and then to order two. By considering boundary conditions and the nature of the carriers, the author numerically resolves the discretized general equation by assessing the influence of the nature of the boundary conditions and truncation errors and the influence of the discretization step on the density of the charge carriers by setting certain parameters and varying others. The work ends with a conclusion and logical follow-up to this work.

Keywords

Transport Equation, Load Carrier Densities, Implicit Scheme, Semiconductor, Discretization

1. Introduction

Our daily energy needs have shown that it is impossible to live without energy.

Today, we are constantly witnessing problems linked to insufficient energy production in developed and underdeveloped countries, as well as those linked to the control of the natural energy resources of our universe, linked to many parameters.

These constraints, which can be summed up in its words "socio-economic and ecological constraints", lead to the development of research on renewable energies, which constitute a lasting solution to global energy problems. The latter, in particular photovoltaic energy is a source of hope in the face of the oil crisis, especially for non-oil producing countries. Although global photovoltaic energy production has increased significantly in recent years, its development is still limited by its high cost compared to fossil and nuclear energy.

An accessible way: numerical computation is reserved for mathematicians who are far from the realities of physical phenomena. The physicist must now be able to develop calculation codes to simulate the studied problems. He must have knowledge in numerical analysis in order to rigorously interpret the results of the numerical simulations [1]. It is with this in mind that we have chosen digital analysis as a tool to assess the results of our work. In particular, the effects of the nature of boundary conditions and their truncation errors on the distribution of minority charge carriers in a semiconductor to optimize the yields of photopiles [2]-[7] have been briefly studied.

Thus, to make our contribution in this approach, we propose a modeling of the equation of the distribution of minority carriers in a semiconductor.

2. Mathematical Problem Formulation, Model, Assumptions and Theory

2.1. Mathematical Formulation of the Problem

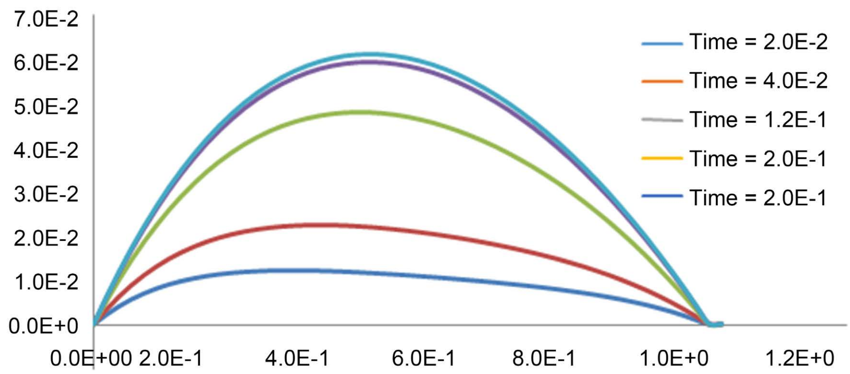
The modeling of the phenomenon studied consists in taking into account the fundamental principles, such as, for example, the conservation of mass, energy, and in determining the parameters essential to its description both simple and realistic. At each point of the object in question, several physical variables (position, speed, temperature, etc.) describe its state and its evolution and make it possible to fully characterize its movement. These quantities are not independent but are interrelated by equations, which are the mathematical translation of the laws of physics governing the behavior of the object [8] [9].

2.2. Model

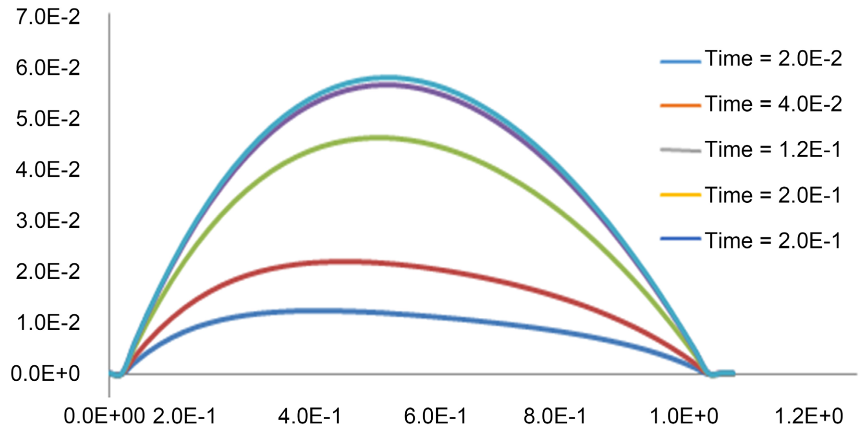
A uniformly doped L-length semiconductor was considered. The ionizing radiation is absorbed and generates electron-hole pairs, and $G(x, t)$ is set at the rate of generation of these pairs. The diagram of a particle of the photopile will be shown in **Figure 1**.

2.3. Assumptions

To model carrier transport, we accept that the experiment is carried out in a low



(a)



(b)

Figure 1. (a) The variation of the number of charge carriers as a function of the discretization step. Change in load carriers according to position x: bil = 0; $a = 1$; $R = 1$; dx = 0.02; (b) The variation of the number of charge carriers as a function of the discretization step. Change in load carriers according to position x: bi0 = 0; $a = 1$; $R = 1$; dx = 0.05.

injection regime in the absence of applied field and assuming that the transport is dominated by diffusion currents. For the resolution we consider the problem to a space dimension.

2.4. Theory

In a type semiconductor, we will high light an electron flow expressed by

$$F = -D\frac{\mathrm{d}\delta}{\mathrm{d}x} \quad [10]\ [11] \tag{1}$$

If we now accept that there is a rate G of generation of electron-hole pairs, a lifetime of which is approximately, that is to say, a recombination rate $[\ \delta - \delta_0\ ]\ \ \tau$ or n is the concentration of the instantaneous holes and n_0 is the concentration of the holes which would have at the thermal equilibrium in the absence of any disturbance; therefore the overall balance is obtained in the case of a one-dimensional model [2] [3] [5] [6] [7].

$$\frac{\partial\delta}{\partial t} = D\frac{\partial^2\delta}{\partial x^2} - \frac{\delta - \delta_0}{\tau} + G(x,t) \quad [10]\ [11]\ [12] \tag{2}$$

with:

- δ The density of excess minority charge carriers in the base.
- $G(x, t)$ The rate of generation of charge carriers under illumination.
- D The diffusion coefficient.
- τ The lifetime of excess minority charge carriers.

This equation will be closed by initial conditions and limits that will govern the behavior of the carriers in the semiconductor. In order to generalize our study, we will apply to the geometric limits of our semiconductor conditions to the limits of third type or mixed conditions [8] [9] [10] [11].

The initial conditions:

$$\text{A } t = 0 \text{ on a } \quad \delta = \delta_i(x,0) \tag{3}$$

Limit conditions

$$D\left[\frac{\partial\delta(x,t)}{\partial x}\right]_{x=0} = S_f \cdot \delta(0,t) \tag{4}$$

$$D\left[\frac{\partial\delta(x,t)}{\partial x}\right]_{x=L} = -S_b \cdot \delta(L,t) \quad \text{[12] [13] [14]} \tag{5}$$

- S_f The recombination speed at the junction of the excess minority charge carriers of the front-side illuminated photopile.
- S_b The recombination speed of excess minority charge carriers at the rear face when the front face is illuminated.
- L is the length of the photocell.

3. Results and Discussions

In this section, we will present the results of the numerical simulations and discuss the influence of the nature of the boundary conditions and their discretization errors on the behavior of the charge carriers.

The results discussed here are relative

3.1. Sensitivity of Results with Respect to Discretization Steps

To choose the "optimum", we tested the sensitivity of the results with respect to the calculation steps. The analysis of the curves of **Figure 1** shows that the results obtained for spacing steps of 0.05 and 0.02 are substantially the same. Therefore, it is useless to work with space pitches greater than 0.02 because we will have a greater volume of calculations and a longer execution time and finally have the same results as those of **Figure 1(b)**.

3.2. Overall Analysis of the Behavior of the Charge Carriers

Figure 2 and **Figure 3** show that the steady state begins to be reached when the adimensional time is greater than or equal to 0.2. When Dirichlet conditions are imposed on the limits of our semiconductor, the increase in the power of the incident radiation simply results in an increase in the maximum of the load carriers but the curves remain the same as we can see on the curves of **Figure 3**. On

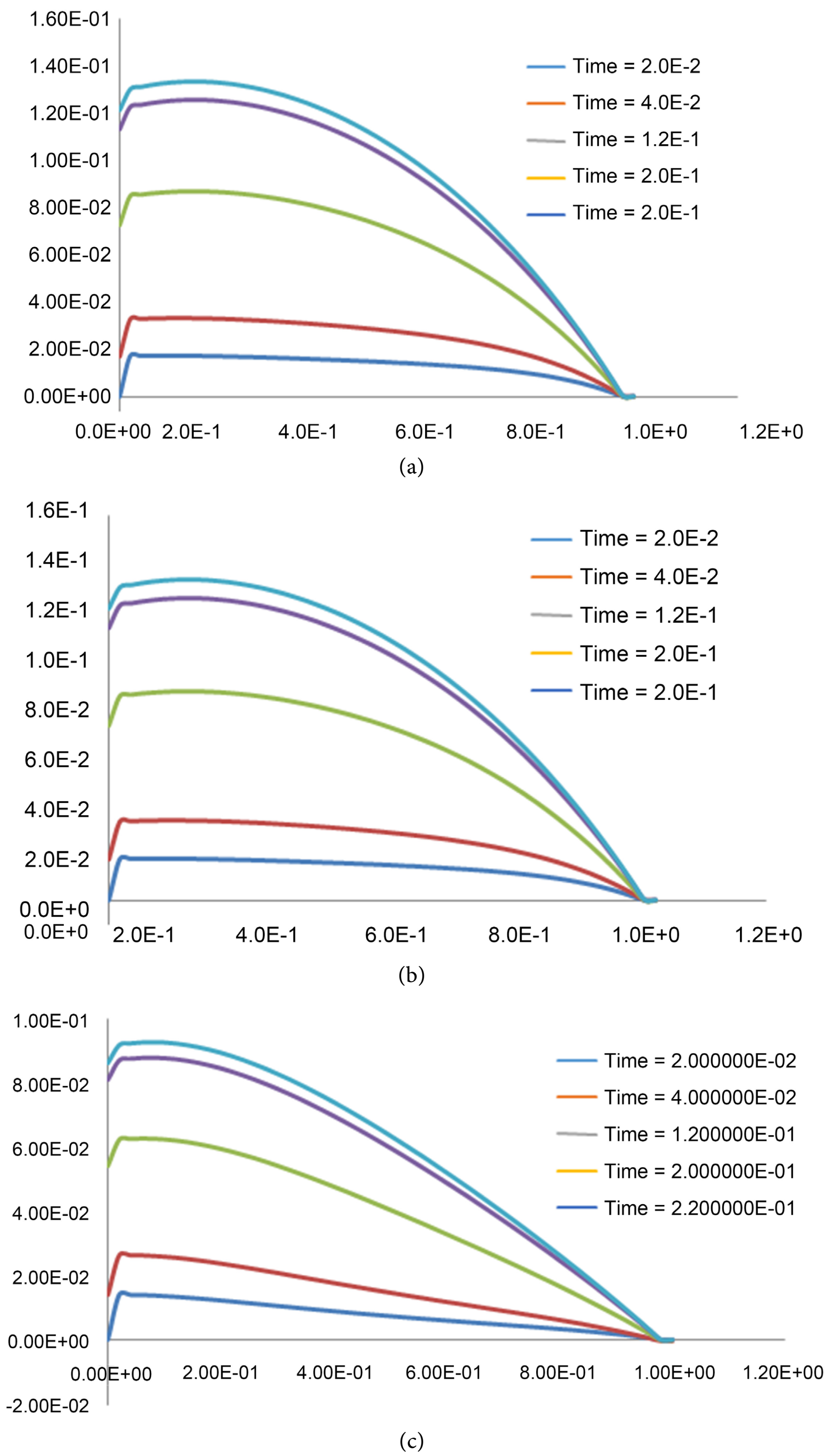
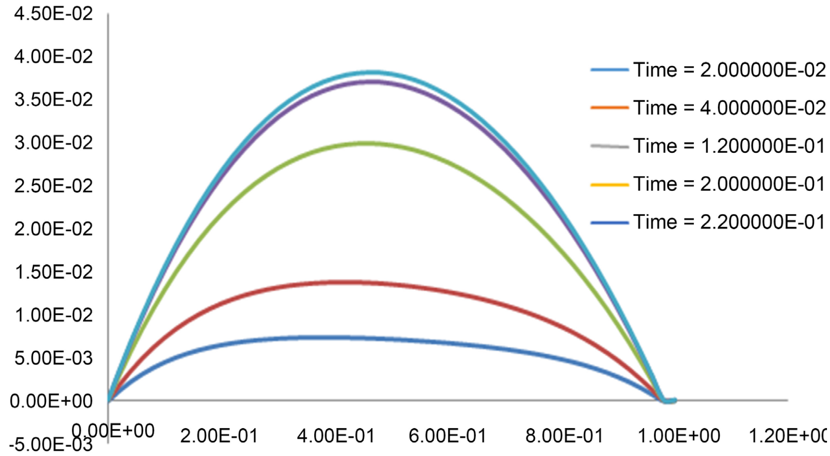
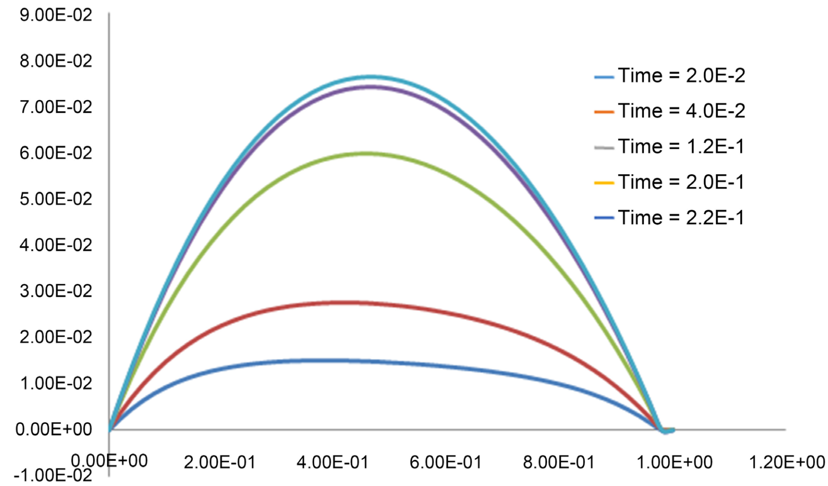


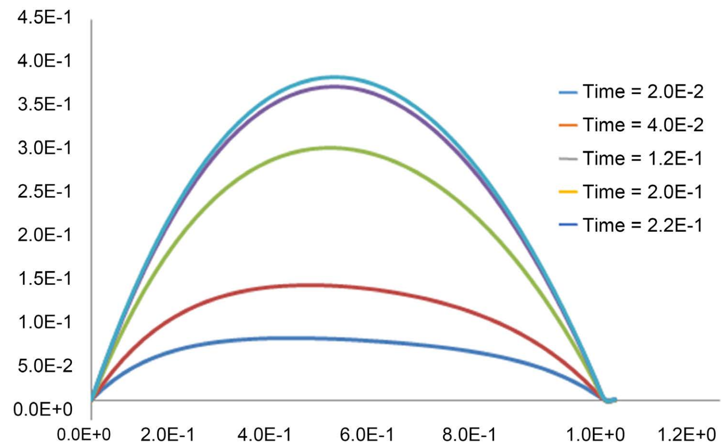
Figure 2. (a) The change in the number of charge carriers as a function of the absorption coefficient α. Change in load carriers according to position x: bi0 = 2; $\alpha = 0.1$; $R = 1$; $dx = 0.1$; (b) The change in the number of charge carriers as a function of the absorption coefficient α. Change in load carriers according to position x: bi0 = 2; $\alpha = 1$; $R = 1$; $dx = 0.1$; (c) The change in the number of charge carriers as a function of the absorption coefficient α. Change in load carriers according to position x: bi0 = 2; $\alpha = 2$; $R = 1$; $dx = 0.1$.



(a)



(b)



(c)

Figure 3. (a) The variation in the number of load carriers as a function of the incident Power R. Change in load carriers according to position x: bi0 = 2; $\alpha = 0.1$; $R = 0.5$; $\mathrm{d}x = 0.1$; (b) The variation in the number of load carriers as a function of the incident Power R. Change in load carriers according to position x: bi0 = 2; $\alpha = 0.1$; $R = 1$; $\mathrm{d}x = 0.1$; (c) The variation in the number of load carriers as a function of the incident Power R. Change in load carriers according to position x: bi0 = 2; $\alpha = 0.1$; $R = 0.5$; $\mathrm{d}x = 5$.

the other hand, an increase in the absorption coefficient of the material causes a reduction in the values of the maximum carriers as shown by the curves of **Figure 2**.

Thereafter, the following results will relate to a space step of 0.02, that is to say of 1/50.

- dx the discretization step;
- α the absorption coefficient;
- R the incident power.

4. Conclusions

This work is a modeling study of the effects of the natures of boundary conditions and their truncation errors on the distribution of minority carriers in a semiconductor.

A mathematical study of the load carrier distribution equation and boundary conditions was used to model the distribution of minority carriers in a semiconductor. This model is based on Thomas' method and the scheme used is the implicit scheme. However, we studied the influence on load carrier distribution, discretization of boundary conditions, and semiconductor characteristics.

It should be noted that the method used is rapid and allowed us to appreciate the influence of the discretization of boundary conditions and the nature of boundary conditions. In this work, we have punctuated the influence or not on the number of diffused carriers of the characteristics of the material. Here, a simple case was considered; there are parameters that are not considered. Thus, it is conceivable to make a complete study of the photopile while taking into account the real values of its characteristics, taking into account the speeds of recombination, currents, etc.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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