International Journal of Materials Science

E-ISSN: 2707-823X
P-ISSN: 2707-8221
IJMS 2023; 4(1): 40-42
Received: 12-02-2023
Accepted: 06-04-2023

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On the method of prognosis of the effect of self-heating of a p-n-heterojunction on its properties

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Abstract
In this paper we consider a model for predicting the effect of self-heating of a *p*-*n*-heterojunction on its properties. An analytical approach for analyzing of the processes framework the model is also introduced.

Keywords: self-heating of *p*-*n*-junction, analytical approach for prognosis

Introduction

Currently one is actual questions is development of new and improvement of traditional devices for solid-state electronics (increasing the switching frequency of *p*-*n*-junctions, reliability of diodes and other devices,...) [1-3]. During solving of these problems both the technological processes used for the manufacture of these devices and the characteristics of already manufactured devices are attracted an interest. In this paper using as the example of a diffusion *p*-*n*-junction a model has been introduced for predicting of the effect of self-heating of a *p*-*n*-heterojunction during its operation on a change of its properties. Framework this paper we consider a *p*-*n*-junction, which was manufactured as follows [4]: a dopant has been infused through epitaxial layer with thickness *a* into two-layer system with thickness *L* (epitaxial layer and substrate with known type of conductivity). Presence of interface between the layers of the two-layer structure makes it possible to increase sharpness of the considered *p*-*n*-junction. In this paper we also introduced an analytical approach for analysis of the considered processes within the framework of this model.

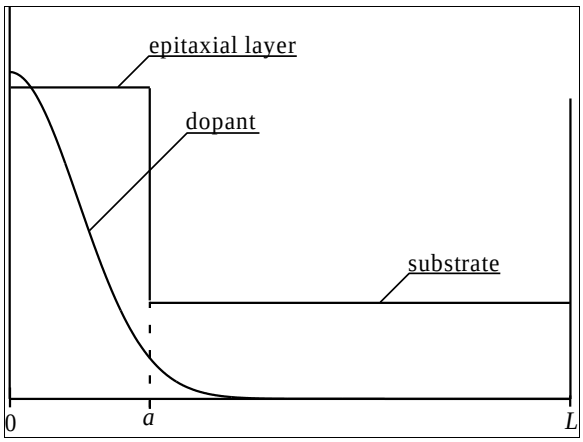

Fig 1: The considered two-layer structure

Method of solution

To analyze the self-heating of heterostructure materials we use the Joule-Lenz law: $w = \vec{j} \cdot \vec{E}$, where *w* is the density of the power released in the materials, $\vec{j}$ is the density of the current flowing through the *p*-*n*-junction, $\vec{E}$ is the electric current. The spatio-temporal distribution of temperature was determine as solution of the second Fourier law in the following form

$$C(T)\frac{\partial T(x,t)}{\partial t}=\frac{\partial}{\partial x}\left[\lambda(x,T)\frac{\partial T(x,t)}{\partial x}\right]+w(x,t) \quad (1)$$

where $C(T)=C_{ass}[1-\vartheta\, exp(-T\,(x,\,t)/T_d)]$ is the heat capacity of the considered heterostructure; T_d is the Debye temperature [5] (in the most interest case for us the temperature is comparable with the Debye temperature or larger and we can assume: $C(T)\approx C_{ass}$); $\lambda(x,\,T)$ is the heat transfer coefficient; temperature dependence of the heat transfer coefficient in the most interest area of values of temperatures could be approximated by the following relation: $\lambda(x,\,T)=\lambda_{ass}(x)\{1+\mu\,[T_d/T(x,\,t)]^{\varphi}\}$ (see, for example, [5]); $\alpha\,(x,\,T)=\lambda(x,\,T)/C(T)$ is the thermal diffusivity. Accounting of the above temperature dependence of heat transfer coefficient leads the Eq. (1) to the following form

$$C_{ass}\frac{\partial T(x,t)}{\partial t}=\frac{\partial}{\partial x}\left\{\lambda_{ass}(x)\left[1+\frac{\mu T_d^{\varphi}}{T^{\varphi}(x,t)}\right]\frac{\partial T(x,t)}{\partial x}\right\}+w(x,t) \quad (1a)$$

Boundary and initial conditions could be written in the following form

$$\left.\frac{\partial T(x,t)}{\partial x}\right|_{x=0}=0,\quad \left.\frac{\partial T(x,t)}{\partial x}\right|_{x=L}=0,\quad T(x,\,0)=f(x). \quad (2)$$

Further, equation (1*a*) will be solved by the method of averaging functional corrections [6]. Framework of the method to calculate the first-order approximation of the considered temperature distribution we replace it on the right-hand side of Eq. (1a) by its not yet known mean value α_1. After the replacement we obtain the following equation to calculate the first-order approximation of the considered function

$$C_{ass}\frac{\partial T_1(x,t)}{\partial t}=w(x,t) \quad (3)$$

The Eq. (3) has been solved framework standard theory of ordinary differential equations [7]

$$T_1(x,t)=\frac{1}{C_{ass}}\int_0^t w(x,\tau)d\tau+f(x) \quad (4)$$

The second-order approximation of the considered temperature was calculated framework standard iterative procedure, i.e. by replacement of the required function on sum of it's average value and approximation with the previous order: $T\,(x,\,t)\rightarrow\alpha_2+T_1(x,\,t)$. Substitution of the replacement into Eq. (1*a*) leads to the following result

$$C_{ass}\frac{\partial T_2(x,t)}{\partial t}=\frac{\partial}{\partial x}\left(\lambda_{ass}(x)\left\{1+\frac{\mu T_d^{\varphi}}{[\alpha_2+T_1(x,t)]^{\varphi}}\right\}\frac{\partial T_1(x,t)}{\partial x}\right)+w(x,t) \quad (5)$$

We solved Eq. (5) framework standard theory of ordinary differential equations. The solution could be written in the following form

$$T_2(x,t)=\frac{1}{C_{ass}}\frac{\partial}{\partial x}\lambda_{ass}(x)\int_0^t\left\{1+\frac{\mu T_d^{\varphi}}{[\alpha_2+T_1(x,\tau)]^{\varphi}}\right\}\frac{\partial T_1(x,\tau)}{\partial x}d\tau+\frac{1}{C_{ass}}\int_0^t w(x,\tau)d\tau+f(x) \quad (6)$$

Average value α_2 of the considered the second-order approximation of temperature has been determined by using standard procedure of method of averaging of averaging corrections [7]

$$\alpha_2=\frac{1}{\Theta L}\int_0^{\Theta}\int_0^{L}[T_2(x,t)-T_1(x,t)]dx\,dt, \quad (7)$$

Where Θ is the continuance of observation on heat transport. Approximation of the third-, the fourth-order and other approximations could be calculated by using the same algorithm as for calculation of the second-order approximation.

Discussion

Now based on results obtained in the previous section of this paper we analyzed temperature dependence of charge carrier mobility μ in the considered *p-n*-junction. The dependence could be determined by the following empirical relation [5]

$$\mu^{-1}=a\cdot T^{\alpha}+b\cdot T^{\beta}, \quad (8)$$

Where a, b, $\alpha>0$, $\beta>0$ are the parameters, which were obtained from experimental data. The dependence is illustrated by Fig. 2. From this dependence it follows that increasing of density of the current flowing through the p-n-junction and the applied voltage with time leads to a decrease in the value of the mobility of charge carriers. The dependence shows that increasing density of flowing current through the *p-n*-junction and increasing of applied voltage with time leads to decreasing value of the charge carriers mobility.

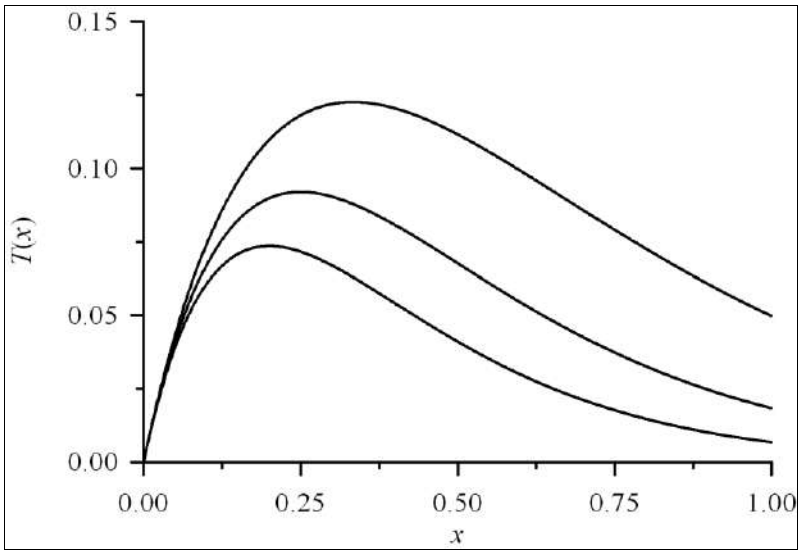

Fig 2: Typical dependences of normalized temperature on coordinate

Conclusion

In this paper we introduced a model for predicting of self-heating of a *p-n*-junction during its functioning. An analytical approach for analysis of heat transfer is introduced. The approach makes it possible to more fully take into account various factors. Also the approach makes it possible to analyze heat transfer in multilayer structures without crosslinking of solutions at their interfaces of its layers.

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