ON DECREASING OF QUANTITY OF RADIATION DEFECTS IN WORKING AREA OF AN INTEGRATED CIRCUIT

E.L. Pankratov

Nizhny Novgorod State University, 23 Gagarin avenue, Nizhny Novgorod, 603950, Russia
Nizhny Novgorod State Agrotechnical University, 97 Gagarin avenue, Nizhny Novgorod, 603950, Russia

ABSTRACT

In this paper we introduce a approach to organize a drain of radiation defects, which were generated during ion doping and other types of radiation processing of the working area of an integrated circuits, manufactured in the framework of a multilayer structure. The approach based on the difference of properties of materials of the layers of the considered multilayer structure. An analytical approach for analysis of mass and heat transfer in a multilayer structures was introduced with account the spatial and temporal variations of their parameters, as well as the nonlinearity of the processes under consideration.

KEYWORDS

drain of radiation defects; integrated circuits; multilayer structures; analytical approach for prognosis.

1. INTRODUCTION

Currently one of the intensively solving problems is increasing of performance of solid-state electronics devices (diodes, field-effect and bipolar transistors, ...) [1-6]. Also the influence of various types of radiation processing on semiconductor materials is currently being investigated [7-9]. Different approaches to reduce influence of the radiation processing on the considered materials are revealeding [10-12]. In this paper we consider a multilayer structure, which is presented on Fig. 1. Next, the ion doping of the epitaxial layer is considered in order to manufacture several elements of integrated circuit. With time annealing of radiation defects was considered. Main aim of this paper is to analyze the redistribution and interaction of point radiation defects, as well as their simplest complexes in the materials of the considered multilayer structure after radiation exposure.

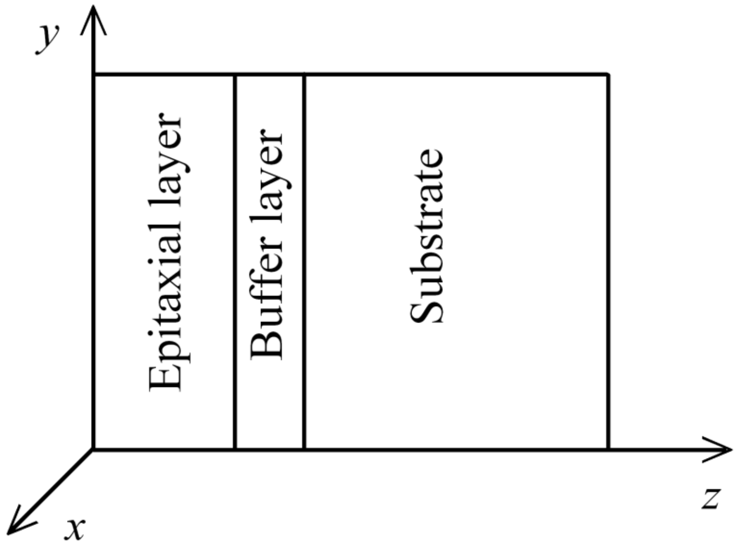

Fig. 1*b*. Three layer structure, which includes into itself a substrate, epitaxial layers and buffer layer (view from side)

2. METHOD OF SOLUTION

To solve our aim we calculate and analyzed distribution of concentration of point radiation defects in space and time in the considered multilayer structure. We calculate the distribution by solving the second Fick's law in the following form [13-17]

$$\frac{\partial I(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial y}\right]+$$
$$+\frac{\partial}{\partial z}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial z}\right]-k_{I,I}(x,y,z,T)\,I^2(x,y,z,t)-k_{I,V}(x,y,z,T)\times$$
$$\times I(x,y,z,t)V(x,y,z,t)+\Omega\frac{\partial}{\partial x}\left[\frac{D_{IS}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}I(x,y,W,t)dW\right]+$$
$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{IS}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}I(x,y,W,t)dW\right] \tag{1}$$
$$\frac{\partial V(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial y}\right]+$$
$$+\frac{\partial}{\partial z}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial z}\right]-k_{V,V}(x,y,z,T)\,V^2(x,y,z,t)-k_{I,V}(x,y,z,T)\times$$
$$\times I(x,y,z,t)V(x,y,z,t)+\Omega\frac{\partial}{\partial x}\left[\frac{D_{VS}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}V(x,y,W,t)\,dW\right]+$$

$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{VS}}{kT}\nabla_S\mu\left(x,y,z,t\right)\int_0^{L_z}V\left(x,y,W,t\right)dW\right]$$

with boundary and initial conditions

$$\left.\frac{\partial I\left(x,y,z,t\right)}{\partial x}\right|_{x=0}=0,\ \left.\frac{\partial I\left(x,y,z,t\right)}{\partial x}\right|_{x=L_x}=0,\ \left.\frac{\partial I\left(x,y,z,t\right)}{\partial y}\right|_{y=0}=0,\ I\left(x,y,z,0\right)=$$

$$=f_I\left(x,y,z\right),\ \left.\frac{\partial I\left(x,y,z,t\right)}{\partial y}\right|_{y=L_y}=0,\ \left.\frac{\partial I\left(x,y,z,t\right)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial I\left(x,y,z,t\right)}{\partial z}\right|_{z=L_z}=0,$$

$$\left.\frac{\partial V\left(x,y,z,t\right)}{\partial x}\right|_{x=0}=0,\ \left.\frac{\partial V\left(x,y,z,t\right)}{\partial x}\right|_{x=L_x}=0,\ \left.\frac{\partial V\left(x,y,z,t\right)}{\partial y}\right|_{y=0}=0,\ V\left(x,y,z,0\right)=$$

(2)

$$=f_V\left(x,y,z\right),\ \left.\frac{\partial V\left(x,y,z,t\right)}{\partial y}\right|_{y=L_y}=0,\ \left.\frac{\partial V\left(x,y,z,t\right)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial V\left(x,y,z,t\right)}{\partial z}\right|_{z=L_z}=0.$$

Here are $I\,(x,y,z,t)$ is the spatio-temporal distribution of concentration of radiation interstitials with the equilibrium distribution I^*; $V\,(x,y,z,t)$ is the spatio-temporal distribution of concentration of radiation vacancies with the equilibrium distribution V^*; $D_I(x,y,z,T)$, $D_V(x,y,z,T)$, $D_{IS}(x,y,z,T)$, $D_{VS}(x,y,z,T)$ are the coefficients of volumetric and surficial diffusions of interstitials and vacancies, respectively; terms $V^2(x,y,z,t)$ and $I^2(x,y,z,t)$ correspond to generation of divacancies and diinterstitials, respectively (see, for example, [17] and appropriate references in this book); $k_{I,V}(x,y,z,T)$, $k_{I,I}(x,y,z,\ T)$ and $k_{V,V}(x,y,z,T)$ are the parameters of recombination of point radiation defects and generation of their complexes; Ω is the atomic volume of dopant; ∇_s is the symbol of surficial gradient; $\int_0^{L_z}I\left(x,y,z,t\right)d\,z$ and $\int_0^{L_z}V\left(x,y,z,t\right)d\,z$ are the surficial concentrations of interstitials and vacancies on interface between layers of heterostructure (in this situation we assume, that Z-axis is perpendicular to interface between layers of heterostructure); $\mu\,(x,y,z,t)$ is the chemical potential due to the presence of mismatch-induced stress in the considered multilayer structure. Distributions of divacancies $\Phi_V\,(x,y,z,t)$ and diinterstitials $\Phi_I\,(x,y,z,t)$ in space and time could be calculated by solving the following system of equations [16,17]

$$\frac{\partial\Phi_I\left(x,y,z,t\right)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_I}\left(x,y,z,T\right)\frac{\partial\Phi_I\left(x,y,z,t\right)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_I}\left(x,y,z,T\right)\frac{\partial\Phi_I\left(x,y,z,t\right)}{\partial y}\right]+$$

$$+\frac{\partial}{\partial z}\left[D_{\Phi_I}\left(x,y,z,T\right)\frac{\partial\Phi_I\left(x,y,z,t\right)}{\partial z}\right]+\Omega\frac{\partial}{\partial x}\left[\frac{D_{\Phi_I S}}{kT}\nabla_S\mu\left(x,y,z,t\right)\int_0^{L_z}\Phi_I\left(x,y,W,t\right)dW\right]+$$

$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{\Phi_I S}}{kT}\nabla_S\mu\left(x,y,z,t\right)\int_0^{L_z}\Phi_I\left(x,y,W,t\right)dW\right]+k_{I,I}\left(x,y,z,T\right)I^2\left(x,y,z,t\right)+$$

$$+k_I\left(x,y,z,T\right)I\left(x,y,z,t\right) \qquad (3)$$

$$\frac{\partial \Phi_V(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_V(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_V(x,y,z,t)}{\partial y}\right]+$$

$$+\frac{\partial}{\partial z}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_V(x,y,z,t)}{\partial z}\right]+\Omega\frac{\partial}{\partial x}\left[\frac{D_{\Phi_V S}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}\Phi_V(x,y,W,t)dW\right]+$$

$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{\Phi_V S}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}\Phi_V(x,y,W,t)dW\right]+k_{V,V}(x,y,z,T)V^2(x,y,z,t)+$$

$$+k_V(x,y,z,T)V(x,y,z,t)$$

with boundary and initial conditions

$$\left.\frac{\partial \Phi_I(x,y,z,t)}{\partial x}\right|_{x=0}=0,\ \left.\frac{\partial \Phi_I(x,y,z,t)}{\partial x}\right|_{x=L_x}=0,\ \left.\frac{\partial \Phi_I(x,y,z,t)}{\partial y}\right|_{y=0}=0,$$

$$\left.\frac{\partial \Phi_I(x,y,z,t)}{\partial y}\right|_{y=L_y}=0,\ \left.\frac{\partial \Phi_I(x,y,z,t)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial \Phi_I(x,y,z,t)}{\partial z}\right|_{z=L_z}=0,$$

$$\left.\frac{\partial \Phi_V(x,y,z,t)}{\partial x}\right|_{x=0}=0,\ \left.\frac{\partial \Phi_V(x,y,z,t)}{\partial x}\right|_{x=L_x}=0,\ \left.\frac{\partial \Phi_V(x,y,z,t)}{\partial y}\right|_{y=0}=0, \quad (4)$$

$$\left.\frac{\partial \Phi_V(x,y,z,t)}{\partial y}\right|_{y=L_y}=0,\ \left.\frac{\partial \Phi_V(x,y,z,t)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial \Phi_V(x,y,z,t)}{\partial z}\right|_{z=L_z}=0,$$

$$\Phi_I(x,y,z,0)=f_{\Phi I}(x,y,z),\ \Phi_V(x,y,z,0)=f_{\Phi V}(x,y,z).$$

Here $D_{\Phi I}(x,y,z,T)$, $D_{\Phi V}(x,y,z,T)$, $D_{\Phi IS}(x,y,z,T)$ and $D_{\Phi VS}(x,y,z,T)$ are the coefficients of volumetric and surficial diffusions of complexes of radiation defects; $k_I(x,y,z,T)$ and $k_V(x,y,z,T)$ are the parameters of decay of complexes of radiation defects. Chemical potential μ_1 in Eq.(1) could be determine by the following relation [13]

$$\mu_1=E(z)\Omega\sigma_{ij}\,[u_{ij}(x,y,z,t)+u_{ji}(x,y,z,t)]/2, \quad (5)$$

where $E(z)$ is the Young modulus, σ_{ij} is the stress tensor; $u_{ij}=\frac{1}{2}\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)$ is the deformation tensor; u_i, u_j are the components $u_x(x,y,z,t)$, $u_y(x,y,z,t)$ and $u_z(x,y,z,t)$ of the displacement vector $\vec{u}(x,y,z,t)$; x_i, x_j are the coordinate x, y, z. The Eq. (5) could be transform to the following form

$$\mu\left(x,y,z,t\right)=\left[\frac{\partial u_i\left(x,y,z,t\right)}{\partial x_j}+\frac{\partial u_j\left(x,y,z,t\right)}{\partial x_i}\right]\left\{\frac{1}{2}\left[\frac{\partial u_i\left(x,y,z,t\right)}{\partial x_j}+\frac{\partial u_j\left(x,y,z,t\right)}{\partial x_i}\right]-\right.$$

$$\left.-\varepsilon_0\delta_{ij}+\frac{\sigma\left(z\right)\delta_{ij}}{1-2\sigma\left(z\right)}\left[\frac{\partial u_k\left(x,y,z,t\right)}{\partial x_k}-3\varepsilon_0\right]-K\left(z\right)\beta\left(z\right)\left[T\left(x,y,z,t\right)-T_0\right]\delta_{ij}\right\}\frac{\Omega}{2}E\left(z\right),$$

where σ is Poisson coefficient; $\varepsilon_0 = (a_s-a_{EL})/a_{EL}$ is the mismatch parameter; a_s, a_{EL} are lattice distances of the substrate and the epitaxial layer; K is the modulus of uniform compression; β is the coefficient of thermal expansion; T_r is the equilibrium temperature, which coincide (for our case) with room temperature. Components of displacement vector could be obtained by solution of the following equations [14]

$$\rho\left(z\right)\frac{\partial^2 u_x\left(x,y,z,t\right)}{\partial t^2}=\frac{\partial\sigma_{xx}\left(x,y,z,t\right)}{\partial x}+\frac{\partial\sigma_{xy}\left(x,y,z,t\right)}{\partial y}+\frac{\partial\sigma_{xz}\left(x,y,z,t\right)}{\partial z}$$

$$\rho\left(z\right)\frac{\partial^2 u_y\left(x,y,z,t\right)}{\partial t^2}=\frac{\partial\sigma_{yx}\left(x,y,z,t\right)}{\partial x}+\frac{\partial\sigma_{yy}\left(x,y,z,t\right)}{\partial y}+\frac{\partial\sigma_{yz}\left(x,y,z,t\right)}{\partial z}$$

$$\rho\left(z\right)\frac{\partial^2 u_z\left(x,y,z,t\right)}{\partial t^2}=\frac{\partial\sigma_{zx}\left(x,y,z,t\right)}{\partial x}+\frac{\partial\sigma_{zy}\left(x,y,z,t\right)}{\partial y}+\frac{\partial\sigma_{zz}\left(x,y,z,t\right)}{\partial z},$$

where

$$\sigma_{ij}=\frac{E\left(z\right)}{2\left[1+\sigma\left(z\right)\right]}\left[\frac{\partial u_i\left(x,y,z,t\right)}{\partial x_j}+\frac{\partial u_j\left(x,y,z,t\right)}{\partial x_i}-\frac{\delta_{ij}}{3}\frac{\partial u_k\left(x,y,z,t\right)}{\partial x_k}\right]+K\left(z\right)\delta_{ij}\times$$

$\times\frac{\partial u_k\left(x,y,z,t\right)}{\partial x_k}-\beta\left(z\right)K\left(z\right)\left[T\left(x,y,z,t\right)-T_r\right]$, $\rho(z)$ is the density of materials of heterostructure, δ_{ij} Is the Kronecker symbol. With account the relation for σ_{ij} last system of equation could be written as

$$\rho(z)\frac{\partial^2 u_x\left(x,y,z,t\right)}{\partial t^2}=\left\{K\left(z\right)+\frac{5E\left(z\right)}{6\left[1+\sigma\left(z\right)\right]}\right\}\frac{\partial^2 u_x\left(x,y,z,t\right)}{\partial x^2}+\left\{K\left(z\right)-\frac{E\left(z\right)}{3\left[1+\sigma\left(z\right)\right]}\right\}\times$$

$$\times\frac{\partial^2 u_y\left(x,y,z,t\right)}{\partial x\partial y}+\frac{E\left(z\right)}{2\left[1+\sigma\left(z\right)\right]}\left[\frac{\partial^2 u_y\left(x,y,z,t\right)}{\partial y^2}+\frac{\partial^2 u_z\left(x,y,z,t\right)}{\partial z^2}\right]+\left[K\left(z\right)+\frac{E\left(z\right)}{3\left[1+\sigma\left(z\right)\right]}\right]\times$$

$$\times\frac{\partial^2 u_z\left(x,y,z,t\right)}{\partial x\partial z}-K\left(z\right)\beta\left(z\right)\frac{\partial T\left(x,y,z,t\right)}{\partial x}$$

$$\rho(z)\frac{\partial^2 u_y\left(x,y,z,t\right)}{\partial t^2}=\frac{E\left(z\right)}{2\left[1+\sigma\left(z\right)\right]}\left[\frac{\partial^2 u_y\left(x,y,z,t\right)}{\partial x^2}+\frac{\partial^2 u_x\left(x,y,z,t\right)}{\partial x\partial y}\right]-\frac{\partial T\left(x,y,z,t\right)}{\partial y}\times$$

$$\times K\left(z\right)\beta\left(z\right)+\frac{\partial}{\partial z}\left\{\frac{E\left(z\right)}{2\left[1+\sigma\left(z\right)\right]}\left[\frac{\partial u_y\left(x,y,z,t\right)}{\partial z}+\frac{\partial u_z\left(x,y,z,t\right)}{\partial y}\right]\right\}+\frac{\partial^2 u_y\left(x,y,z,t\right)}{\partial y^2}\times \quad (6)$$

$$\times\left\{\frac{5E(z)}{12[1+\sigma(z)]}+K(z)\right\}+\left\{K(z)-\frac{E(z)}{6[1+\sigma(z)]}\right\}\frac{\partial^2 u_y(x,y,z,t)}{\partial y\partial z}+K(z)\frac{\partial^2 u_y(x,y,z,t)}{\partial x\partial y}$$

$$\rho(z)\frac{\partial^2 u_z(x,y,z,t)}{\partial t^2}=\frac{E(z)}{2[1+\sigma(z)]}\left[\frac{\partial^2 u_z(x,y,z,t)}{\partial x^2}+\frac{\partial^2 u_z(x,y,z,t)}{\partial y^2}+\frac{\partial^2 u_x(x,y,z,t)}{\partial x\partial z}+\right.$$

$$\left.+\frac{\partial^2 u_y(x,y,z,t)}{\partial y\partial z}\right]+\frac{\partial}{\partial z}\left\{K(z)\left[\frac{\partial u_x(x,y,z,t)}{\partial x}+\frac{\partial u_y(x,y,z,t)}{\partial y}+\frac{\partial u_x(x,y,z,t)}{\partial z}\right]\right\}+$$

$$+\frac{1}{6}\frac{\partial}{\partial z}\left\{\frac{E(z)}{1+\sigma(z)}\left[6\frac{\partial u_z(x,y,z,t)}{\partial z}-\frac{\partial u_x(x,y,z,t)}{\partial x}-\frac{\partial u_y(x,y,z,t)}{\partial y}-\frac{\partial u_z(x,y,z,t)}{\partial z}\right]\right\}-$$

$$-K(z)\beta(z)\frac{\partial T(x,y,z,t)}{\partial z}.$$

Conditions for the system of Eq. (6) could be written in the form

$$\frac{\partial \vec{u}(0,y,z,t)}{\partial x}=0;\ \frac{\partial \vec{u}(L_x,y,z,t)}{\partial x}=0;\ \frac{\partial \vec{u}(x,0,z,t)}{\partial y}=0;\ \frac{\partial \vec{u}(x,L_y,z,t)}{\partial y}=0;$$

$$\frac{\partial \vec{u}(x,y,0,t)}{\partial z}=0;\ \frac{\partial \vec{u}(x,y,L_z,t)}{\partial z}=0;\ \vec{u}(x,y,z,0)=\vec{u}_0;\ \vec{u}(x,y,z,\infty)=\vec{u}_0.$$

We calculate distributions of concentrations of radiation defects in space and time by solving of the Eqs.(1) and (3) framework standard algorithm of method of averaging of function corrections [18-21]. Previously we transform the Eqs. (1) and (3) to the following form with account initial distributions of the considered concentrations

$$\frac{\partial I(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial y}\right]+$$

$$+\frac{\partial}{\partial z}\left[D_I(x,y,z,T)\frac{\partial I(x,y,z,t)}{\partial z}\right]+\Omega\frac{\partial}{\partial x}\left[\frac{D_{IS}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}I(x,y,W,t)dW\right]+$$

$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{IS}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}I(x,y,W,t)dW\right]-k_{I,I}(x,y,z,T)I^2(x,y,z,t)-$$

$$-k_{I,V}(x,y,z,T)I(x,y,z,t)V(x,y,z,t)+f_I(x,y,z)\delta(t) \qquad (1a)$$

$$\frac{\partial V(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial y}\right]+$$

$$+\frac{\partial}{\partial z}\left[D_V(x,y,z,T)\frac{\partial V(x,y,z,t)}{\partial z}\right]+\Omega\frac{\partial}{\partial x}\left[\frac{D_{VS}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}V(x,y,W,t)dW\right]+$$

$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{IS}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}I(x,y,W,t)dW\right]-k_{I,I}(x,y,z,T)I^2(x,y,z,t)-$$
$$-k_{I,V}(x,y,z,T)I(x,y,z,t)V(x,y,z,t)+f_V(x,y,z)\delta(t)$$

$$\frac{\partial\Phi_I(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial\Phi_I(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial\Phi_I(x,y,z,t)}{\partial y}\right]+$$
$$+\frac{\partial}{\partial z}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial\Phi_I(x,y,z,t)}{\partial z}\right]+\Omega\frac{\partial}{\partial x}\left[\frac{D_{\Phi_I S}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}\Phi_I(x,y,W,t)dW\right]+$$
$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{\Phi_I S}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}\Phi_I(x,y,W,t)dW\right]+k_I(x,y,z,T)I(x,y,z,t)+$$
$$+k_{I,I}(x,y,z,T)I^2(x,y,z,t)+f_{\Phi_I}(x,y,z)\delta(t) \qquad (3a)$$

$$\frac{\partial\Phi_V(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial\Phi_V(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial\Phi_V(x,y,z,t)}{\partial y}\right]+$$
$$+\frac{\partial}{\partial z}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial\Phi_V(x,y,z,t)}{\partial z}\right]+\Omega\frac{\partial}{\partial x}\left[\frac{D_{\Phi_V S}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}\Phi_V(x,y,W,t)dW\right]+$$
$$+\Omega\frac{\partial}{\partial y}\left[\frac{D_{\Phi_I S}}{kT}\nabla_S\mu(x,y,z,t)\int_0^{L_z}\Phi_I(x,y,W,t)dW\right]+k_I(x,y,z,T)I(x,y,z,t)+$$
$$+k_{V,V}(x,y,z,T)V^2(x,y,z,t)+f_{\Phi_V}(x,y,z)\delta(t).$$

Farther we replace concentrations of radiation defects in right sides of Eqs. (1*a*) and (3*a*) on their not yet known average values $\alpha_{1\rho}$. In this situation we obtain equations for the first-order approximations of the required concentrations in the following form

$$\frac{\partial I_1(x,y,z,t)}{\partial t}=\alpha_{1I}z\Omega\frac{\partial}{\partial x}\left[\frac{D_{IS}}{kT}\nabla_S\mu(x,y,z,t)\right]+\alpha_{1I}\Omega\frac{\partial}{\partial y}\left[z\frac{D_{IS}}{kT}\nabla_S\mu(x,y,z,t)\right]+$$
$$+f_I(x,y,z)\delta(t)-\alpha_{1I}^2k_{I,I}(x,y,z,T)-\alpha_{1I}\alpha_{1V}k_{I,V}(x,y,z,T) \qquad (1b)$$

$$\frac{\partial V_1(x,y,z,t)}{\partial t}=\alpha_{1V}z\Omega\frac{\partial}{\partial x}\left[\frac{D_{VS}}{kT}\nabla_S\mu(x,y,z,t)\right]+\alpha_{1V}\Omega\frac{\partial}{\partial y}\left[z\frac{D_{VS}}{kT}\nabla_S\mu(x,y,z,t)\right]+$$
$$+f_V(x,y,z)\delta(t)-\alpha_{1V}^2k_{V,V}(x,y,z,T)-\alpha_{1I}\alpha_{1V}k_{I,V}(x,y,z,T)$$

$$\frac{\partial\Phi_{1I}(x,y,z,t)}{\partial t}=\alpha_{1\Phi_I}z\Omega\frac{\partial}{\partial x}\left[\frac{D_{\Phi_I S}}{kT}\nabla_S\mu(x,y,z,t)\right]+\alpha_{1\Phi_I}z\Omega\frac{\partial}{\partial y}\left[\frac{D_{\Phi_I S}}{kT}\nabla_S\mu(x,y,z,t)\right]+$$
$$+f_{\Phi_I}(x,y,z)\delta(t)+k_I(x,y,z,T)I(x,y,z,t)+k_{I,I}(x,y,z,T)I^2(x,y,z,t) \qquad (3b)$$

$$\frac{\partial \Phi_{1V}(x,y,z,t)}{\partial t} = \alpha_{1\Phi_V} z\Omega \frac{\partial}{\partial x}\left[\frac{D_{\Phi_V S}}{kT}\nabla_S \mu(x,y,z,t)\right] + \alpha_{1\Phi_V} z\Omega \frac{\partial}{\partial y}\left[\frac{D_{\Phi_V S}}{kT}\nabla_S \mu(x,y,z,t)\right] +$$
$$+ f_{\Phi_V}(x,y,z)\delta(t) + k_V(x,y,z,T)V(x,y,z,t) + k_{V,V}(x,y,z,T)V^2(x,y,z,t).$$

Integration of the left and right sides of the Eqs. (1*b*) and (3*b*) on time gives us possibility to obtain relations for above approximation in the final form

$$I_1(x,y,z,t) = \alpha_{1I} z\Omega \frac{\partial}{\partial x}\int_0^t \frac{D_{IS}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau + \alpha_{1I} z\Omega \frac{\partial}{\partial y}\int_0^t \frac{D_{IS}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau +$$
$$+ f_I(x,y,z) - \alpha_{1I}^2 \int_0^t k_{I,I}(x,y,z,T)d\tau - \alpha_{1I}\alpha_{1V}\int_0^t k_{I,V}(x,y,z,T)d\tau \qquad (3c)$$
$$V_1(x,y,z,t) = \alpha_{1V} z\Omega \frac{\partial}{\partial x}\int_0^t \frac{D_{IS}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau + \alpha_{1V} z\Omega \frac{\partial}{\partial y}\int_0^t \frac{D_{IS}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau +$$
$$+ f_V(x,y,z) - \alpha_{1V}^2 \int_0^t k_{V,V}(x,y,z,T)d\tau - \alpha_{1I}\alpha_{1V}\int_0^t k_{I,V}(x,y,z,T)d\tau$$
$$\Phi_{1I}(x,y,z,t) = \alpha_{1\Phi_I} z\Omega \frac{\partial}{\partial x}\int_0^t \frac{D_{\Phi_I S}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau + \Omega \frac{\partial}{\partial x}\int_0^t \frac{D_{\Phi_I S}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau \times$$
$$\times \alpha_{1\Phi_I} z + f_{\Phi_I}(x,y,z) + \int_0^t k_I(x,y,z,T)I(x,y,z,\tau)d\tau + \int_0^t k_{I,I}(x,y,z,T)I^2(x,y,z,\tau)d\tau \qquad (3c)$$
$$\Phi_{1V}(x,y,z,t) = \alpha_{1\Phi_V} z\Omega \frac{\partial}{\partial x}\int_0^t \frac{D_{\Phi_V S}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau + \Omega \frac{\partial}{\partial x}\int_0^t \frac{D_{\Phi_V S}}{kT}\nabla_S \mu(x,y,z,\tau)d\tau \times$$
$$\times \alpha_{1\Phi_V} z + f_{\Phi_V}(x,y,z) + \int_0^t k_V(x,y,z,T)V(x,y,z,\tau)d\tau + \int_0^t k_{V,V}(x,y,z,T)V^2(x,y,z,\tau)d\tau.$$

We determine average values of the first-order approximations of concentrations of radiation defects by the following standard relation [18-21]

$$\alpha_{1\rho} = \frac{1}{\Theta L_x L_y L_z}\int_0^\Theta \int_0^{L_x}\int_0^{L_y}\int_0^{L_z} \rho_1(x,y,z,t)\,d z\,d y\,d x\,d t. \qquad (7)$$

Substitution of the relations (1*c*) and (3*c*) into relation (7) gives us possibility to obtain required average values in the following form

$$\alpha_{1C} = \frac{1}{L_x L_y L_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} f_C(x,y,z)\,d z\,d y\,d x,$$
$$\alpha_{1I} = \sqrt{\frac{(a_3 + A)^2}{4a_4^2} - 4\left(B + \frac{\Theta a_3 B + \Theta^2 L_x L_y L_z a_1}{a_4}\right)} -$$

$$-\frac{a_3+A}{4a_4},\ \alpha_{1V}=\frac{1}{S_{IV00}}\left[\frac{\Theta}{\alpha_{1I}}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_I(x,y,z)\,d\,z\,d\,y\,d\,x-\alpha_{1I}S_{II00}-\Theta L_xL_yL_z\right],$$

where $S_{\rho\rho ij}=\int_0^{\Theta}(\Theta-t)\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}k_{\rho,\rho}(x,y,z,T)I_1^i(x,y,z,t)V_1^j(x,y,z,t)d\,z\,d\,y\,d\,x\,d\,t$,

$$a_4=S_{II00}\times$$

$$\times\left(S_{IV00}^2-S_{II00}S_{VV00}\right),\qquad a_3=S_{IV00}S_{II00}+S_{IV00}^2-S_{II00}S_{VV00},$$

$$a_2=\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_V(x,y,z)d\,z\,d\,y\,d\,x\times$$

$$\times S_{IV00}S_{IV00}^2+S_{IV00}\Theta L_x^2L_y^2L_z^2+2S_{VV00}S_{II00}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_I(x,y,z)d\,z\,d\,y\,d\,x-\Theta L_x^2L_y^2L_z^2S_{VV00}-$$

$$-S_{IV00}^2\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_I(x,y,z)d\,z\,d\,y\,d\,x,\qquad a_1=S_{IV00}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_I(x,y,z)d\,z\,d\,y\,d\,x,$$

$$a_0=S_{VV00}\times$$

$$\times\left[\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_I(x,y,z)d\,z\,d\,y\,d\,x\right]^2,\qquad A=\sqrt{8y+\Theta^2\frac{a_3^2}{a_4^2}-4\Theta\frac{a_2}{a_4}},$$

$$B=\frac{\Theta a_2}{6a_4}+\sqrt[3]{\sqrt{q^2+p^3}-q}-$$

$$-\sqrt[3]{\sqrt{q^2+p^3}+q},$$

$$q=\frac{\Theta^3a_2}{24a_4^2}\left(4a_0-\Theta L_xL_yL_z\frac{a_1a_3}{a_4}\right)-\Theta^2\frac{a_0}{8a_4^2}\left(4\Theta a_2-\Theta^2\frac{a_3^2}{a_4}\right)-$$

$$-\frac{\Theta^3a_2^3}{54a_4^3}-L_x^2L_y^2L_z^2\frac{\Theta^4a_1^2}{8a_4^2},\ p=\Theta^2\frac{4a_0a_4-\Theta L_xL_yL_za_1a_3}{12a_4^2}-\frac{\Theta a_2}{18a_4},$$

$$\alpha_{1\Phi_I}=\frac{R_{I1}}{\Theta L_xL_yL_z}+\frac{S_{II20}}{\Theta L_xL_yL_z}+\frac{1}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_{\Phi_I}(x,y,z)\,d\,z\,d\,y\,d\,x$$

$$\alpha_{1\Phi_V}=\frac{R_{V1}}{\Theta L_xL_yL_z}+\frac{S_{VV20}}{\Theta L_xL_yL_z}+\frac{1}{L_xL_yL_z}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}f_{\Phi_V}(x,y,z)\,d\,z\,d\,y\,d\,x,$$

where $R_{\rho i}=\int_0^{\Theta}(\Theta-t)\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}k_I(x,y,z,T)I_1^i(x,y,z,t)\,d\,z\,d\,y\,d\,x\,d\,t$.

We determine approximations of the second and higher orders of concentrations of dopant and radiation defects framework standard iterative procedure of method of averaging of function corrections [18-21]. In the framework of this procedure to determine approximations of the *n*-th order of concentrations of radiation defects we replace the required concentrations in the Eqs. (1*c*), (3*c*) on the following sum $\alpha_{n\rho}+\rho_{n-1}(x,y,z,t)$. The replacement leads to the following transformation of the appropriate equations

$$\frac{\partial I_2(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_I(x,y,z,T)\frac{\partial I_1(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_I(x,y,z,T)\frac{\partial I_1(x,y,z,t)}{\partial y}\right]+$$
$$+\frac{\partial}{\partial z}\left[D_I(x,y,z,T)\frac{\partial I_1(x,y,z,t)}{\partial z}\right]-k_{I,I}(x,y,z,T)[\alpha_{1I}+I_1(x,y,z,t)]^2-k_{I,V}(x,y,z,T)\times$$
$$\times[\alpha_{1I}+I_1(x,y,z,t)][\alpha_{1V}+V_1(x,y,z,t)]+\Omega\frac{\partial}{\partial x}\left\{\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2I}+I_1(x,y,W,t)]\,dW\times\right.$$
$$\left.\times\frac{D_{IS}}{kT}\right\}+\Omega\frac{\partial}{\partial y}\left\{\frac{D_{IS}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2I}+I_1(x,y,W,t)]\,dW\right\} \quad (1d)$$

$$\frac{\partial V_2(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_V(x,y,z,T)\frac{\partial V_1(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_V(x,y,z,T)\frac{\partial V_1(x,y,z,t)}{\partial y}\right]+$$
$$+\frac{\partial}{\partial z}\left[D_V(x,y,z,T)\frac{\partial V_1(x,y,z,t)}{\partial z}\right]-k_{V,V}(x,y,z,T)[\alpha_{1V}+V_1(x,y,z,t)]^2-k_{I,V}(x,y,z,T)\times$$
$$\times[\alpha_{1I}+I_1(x,y,z,t)][\alpha_{1V}+V_1(x,y,z,t)]+\Omega\frac{\partial}{\partial x}\left\{\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2V}+V_1(x,y,W,t)]\,dW\times\right.$$
$$\left.\times\frac{D_{VS}}{kT}\right\}+\Omega\frac{\partial}{\partial y}\left\{\frac{D_{VS}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2V}+V_1(x,y,W,t)]\,dW\right\}$$

$$\frac{\partial \Phi_{2I}(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{1I}(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{1I}(x,y,z,t)}{\partial y}\right]+$$
$$+\Omega\frac{\partial}{\partial x}\left\{\frac{D_{\Phi_I S}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2\Phi_I}+\Phi_{1I}(x,y,W,t)]\,dW\right\}+k_{I,I}(x,y,z,T)I^2(x,y,z,t)+$$
$$+\Omega\frac{\partial}{\partial y}\left\{\frac{D_{\Phi_I S}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2\Phi_I}+\Phi_{1I}(x,y,W,t)]\,dW\right\}+k_I(x,y,z,T)I(x,y,z,t)+$$
$$+\frac{\partial}{\partial z}\left[D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{1I}(x,y,z,t)}{\partial z}\right]+f_{\Phi_I}(x,y,z)\delta(t) \quad (3d)$$

$$\frac{\partial \Phi_{2V}(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{1V}(x,y,z,t)}{\partial x}\right]+\frac{\partial}{\partial y}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{1V}(x,y,z,t)}{\partial y}\right]+$$
$$+\Omega\frac{\partial}{\partial x}\left\{\frac{D_{\Phi_V S}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2\Phi_V}+\Phi_{1V}(x,y,W,t)]\,dW\right\}+k_{V,V}(x,y,z,T)V^2(x,y,z,t)+$$
$$+\Omega\frac{\partial}{\partial y}\left\{\frac{D_{\Phi_V S}}{kT}\nabla_S\mu\,(x,y,z,t)\int_0^{L_z}[\alpha_{2\Phi_V}+\Phi_{1V}(x,y,W,t)]\,dW\right\}+k_V(x,y,z,T)V(x,y,z,t)+$$

$$+\frac{\partial}{\partial z}\left[D_{\Phi_V}(x,y,z,T)\frac{\partial \Phi_{1V}(x,y,z,t)}{\partial z}\right]+f_{\Phi_V}(x,y,z)\delta(t).$$

Integration of the left and the right sides of Eqs. (1*d*) and (3*d*) gives us possibility to obtain relations for the required concentrations in the final form

$$I_2(x,y,z,t)=\frac{\partial}{\partial x}\int_0^t D_I(x,y,z,T)\frac{\partial I_1(x,y,z,\tau)}{\partial x}d\tau+\frac{\partial}{\partial y}\int_0^t D_I(x,y,z,T)\frac{\partial I_1(x,y,z,\tau)}{\partial y}d\tau+$$

$$+\frac{\partial}{\partial z}\int_0^t D_I(x,y,z,T)\frac{\partial I_1(x,y,z,\tau)}{\partial z}d\tau-\int_0^t k_{I,I}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,\tau)\right]^2 d\tau-$$

$$-\int_0^t k_{I,V}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,\tau)\right]\left[\alpha_{2V}+V_1(x,y,z,\tau)\right]d\tau+\frac{\partial}{\partial x}\int_0^t \nabla_S\mu(x,y,z,\tau)\times$$

$$\times\Omega\frac{D_{IS}}{kT}\int_0^{L_z}\left[\alpha_{2I}+I_1(x,y,W,\tau)\right]dW\,d\tau+\frac{\partial}{\partial y}\int_0^t \nabla_S\mu(x,y,z,\tau)\int_0^{L_z}\left[\alpha_{2I}+I_1(x,y,W,\tau)\right]\times$$

$$\times\Omega\frac{D_{IS}}{kT}d\,W\,d\tau+f_I(x,y,z) \tag{1e}$$

$$V_2(x,y,z,t)=\frac{\partial}{\partial x}\int_0^t D_V(x,y,z,T)\frac{\partial V_1(x,y,z,\tau)}{\partial x}d\tau+\frac{\partial}{\partial y}\int_0^t D_V(x,y,z,T)\frac{\partial V_1(x,y,z,\tau)}{\partial y}d\tau+$$

$$+\frac{\partial}{\partial z}\int_0^t D_V(x,y,z,T)\frac{\partial V_1(x,y,z,\tau)}{\partial z}d\tau-\int_0^t k_{V,V}(x,y,z,T)\left[\alpha_{2V}+V_1(x,y,z,\tau)\right]^2 d\tau-$$

$$-\int_0^t k_{I,V}(x,y,z,T)\left[\alpha_{2I}+I_1(x,y,z,\tau)\right]\left[\alpha_{2V}+V_1(x,y,z,\tau)\right]d\tau+\frac{\partial}{\partial x}\int_0^t \nabla_S\mu(x,y,z,\tau)\times$$

$$\times\Omega\frac{D_{VS}}{kT}\int_0^{L_z}\left[\alpha_{2V}+V_1(x,y,W,\tau)\right]dW\,d\tau+\frac{\partial}{\partial y}\int_0^t \nabla_S\mu(x,y,z,\tau)\int_0^{L_z}\left[\alpha_{2V}+V_1(x,y,W,\tau)\right]\times$$

$$\times\Omega\frac{D_{VS}}{kT}d\,W\,d\tau+f_V(x,y,z)$$

$$\Phi_{2I}(x,y,z,t)=\frac{\partial}{\partial x}\int_0^t D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{1I}(x,y,z,\tau)}{\partial x}d\tau+\frac{\partial}{\partial y}\int_0^t\frac{\partial \Phi_{1I}(x,y,z,\tau)}{\partial y}\times$$

$$\times D_{\Phi_I}(x,y,z,T)d\tau+\frac{\partial}{\partial z}\int_0^t D_{\Phi_I}(x,y,z,T)\frac{\partial \Phi_{1I}(x,y,z,\tau)}{\partial z}d\tau+\Omega\frac{\partial}{\partial x}\int_0^t \nabla_S\mu(x,y,z,\tau)\times$$

$$\times\frac{D_{\Phi_I S}}{kT}\int_0^{L_z}\left[\alpha_{2\Phi_I}+\Phi_{1I}(x,y,W,\tau)\right]dW\,d\tau+\Omega\frac{\partial}{\partial y}\int_0^t\frac{D_{\Phi_I S}}{kT}\int_0^{L_z}\left[\alpha_{2\Phi_I}+\Phi_{1I}(x,y,W,\tau)\right]dW\times$$

$$\times \nabla_S \mu (x,y,z,\tau) d\tau + \int_0^t k_{I,I}(x,y,z,T) I^2(x,y,z,\tau)\, d\tau + \int_0^t k_I(x,y,z,T) I(x,y,z,\tau)\, d\tau + + f_{\Phi_I}(x,y,z) \qquad (3e)$$

$$\Phi_{2V}(x,y,z,t) = \frac{\partial}{\partial x}\int_0^t D_{\Phi_V}(x,y,z,T) \frac{\partial \Phi_{1V}(x,y,z,\tau)}{\partial x} d\tau + \frac{\partial}{\partial y}\int_0^t \frac{\partial \Phi_{1V}(x,y,z,\tau)}{\partial y} \times$$

$$\times D_{\Phi_V}(x,y,z,T) d\tau + \frac{\partial}{\partial z}\int_0^t D_{\Phi_V}(x,y,z,T) \frac{\partial \Phi_{1V}(x,y,z,\tau)}{\partial z} d\tau + \Omega \frac{\partial}{\partial x}\int_0^t \nabla_S \mu (x,y,z,\tau) \times$$

$$\times \frac{D_{\Phi_V S}}{kT}\int_0^{L_z} \left[\alpha_{2\Phi_V} + \Phi_{1V}(x,y,W,\tau)\right] dW\, d\tau + \Omega \frac{\partial}{\partial y}\int_0^t \frac{D_{\Phi_V S}}{kT}\int_0^{L_z} \left[\alpha_{2\Phi_V} + \Phi_{1V}(x,y,W,\tau)\right] dW \times$$

$$\times \nabla_S \mu (x,y,z,\tau)\, d\tau + \int_0^t k_{V,V}(x,y,z,T) V^2(x,y,z,\tau)\, d\tau + \int_0^t k_V(x,y,z,T) V(x,y,z,\tau)\, d\tau + + f_{\Phi_V}(x,y,z).$$

Average values of the second-order approximations of required approximations by using the following standard relation [18-20]

$$\alpha_{2\rho} = \frac{1}{\Theta L_x L_y L_z}\int_0^{\Theta}\int_0^{L_x}\int_0^{L_y}\int_0^{L_z} \left[\rho_2(x,y,z,t) - \rho_1(x,y,z,t)\right] dz\, dy\, dx\, dt. \qquad (8)$$

Substitution of the relations (1*e*), (3*e*) into relation (8) gives us possibility to obtain relations for required average values $\alpha_{2\rho}$

$$\alpha_{2C}=0,\ \alpha_{2\Phi I}=0,\ \alpha_{2\Phi V}=0,$$

$$\alpha_{2V} = \sqrt{\frac{(b_3+E)^2}{4b_4^2} - 4\left(F + \frac{\Theta a_3 F + \Theta^2 L_x L_y L_z b_1}{b_4}\right)} - \frac{b_3+E}{4b_4},$$

$$\alpha_{2I} = \frac{C_V - \alpha_{2V}^2 S_{VV00} - \alpha_{2V}\left(2 S_{VV01} + S_{IV10} + \Theta L_x L_y L_z\right) - S_{VV02} - S_{IV11}}{S_{IV01} + \alpha_{2V} S_{IV00}},$$

Where $b_4 = \frac{1}{\Theta L_x L_y L_z} S_{IV00}^2 S_{VV00} - \frac{1}{\Theta L_x L_y L_z} S_{VV00}^2 S_{II00}$,

$$b_3 = -\frac{S_{II00} S_{VV00}}{\Theta L_x L_y L_z}\left(2S_{VV01} + S_{IV10} + \right.$$

$$\left. + \Theta L_x L_y L_z\right) + \frac{S_{IV00} S_{VV00}}{\Theta L_x L_y L_z}\left(S_{IV01} + 2S_{II10} + S_{IV01} + \Theta L_x L_y L_z\right) + \frac{S_{IV00}^2}{\Theta L_x L_y L_z}\left(2S_{VV01} + S_{IV10} + \right.$$

$$+\Theta L_x L_y L_z\Big)-\frac{S_{IV00}^2 S_{IV10}}{\Theta^3 L_x^3 L_y^3 L_z^3},$$

$$b_2=\frac{S_{II00}S_{VV00}}{\Theta L_x L_y L_z}\left(S_{VV02}+S_{IV11}+C_V\right)-\Big(S_{IV10}-2S_{VV01}+\Theta L_x L_y\times$$

$$\times L_z\Big)^2+\frac{S_{IV01}S_{VV00}}{\Theta L_x L_y L_z}\left(\Theta L_x L_y L_z+2S_{II10}+S_{IV01}\right)+\frac{S_{IV00}}{\Theta L_x L_y L_z}\Big(S_{IV01}+2S_{II10}+2S_{IV01}+\Theta L_x L_y\times$$

$$\times L_z\Big)\left(2S_{VV01}+\Theta L_x L_y L_z+S_{IV10}\right)-\frac{S_{IV00}^2}{\Theta L_x L_y L_z}\left(C_V-S_{VV02}-S_{IV11}\right)+\frac{C_I S_{IV00}^2}{\Theta^2 L_x^2 L_y^2 L_z^2}-\frac{2S_{IV10}}{\Theta L_x L_y L_z}\times$$

$$\times S_{IV00}S_{IV01},$$

$$b_1=S_{II00}\frac{S_{IV11}+S_{VV02}+C_V}{\Theta L_x L_y L_z}\left(2S_{VV01}+S_{IV10}+\Theta L_x L_y L_z\right)+\frac{S_{IV01}}{\Theta L_x L_y L_z}\Big(\Theta L_x L_y\times$$

$$\times L_z+2S_{II10}+S_{IV01}\Big)\left(2S_{VV01}+S_{IV10}+\Theta L L_y L_z\right)-\frac{S_{IV10}S_{IV01}^2}{\Theta L_x L_y L_z}-\frac{S_{IV00}}{\Theta L_x L_y L_z}\Big(3S_{IV01}+2S_{II10}+$$

$$+\Theta L_x L_y L_z\Big)\left(C_V-S_{VV02}-S_{IV11}\right)+2C_I S_{IV00}S_{IV01},$$

$$b_0=\frac{S_{II00}}{\Theta L_x L_y L_z}\left(S_{IV00}+S_{VV02}\right)^2-\frac{S_{IV01}}{L_x L_y L_z}\times$$

$$\times\frac{1}{\Theta}\left(\Theta L_x L_y L_z+2S_{II10}+S_{IV01}\right)\left(C_V-S_{VV02}-S_{IV11}\right)+2C_I S_{IV01}^2-S_{IV01}\frac{C_V-S_{VV02}-S_{IV11}}{\Theta L_x L_y L_z}\times$$

$$\times\left(\Theta L_x L_y L_z+2S_{II10}+S_{IV01}\right),$$

$$C_I=\frac{\alpha_{1I}\alpha_{1V}}{\Theta L_x L_y L_z}S_{IV00}+\frac{\alpha_{1I}^2 S_{II00}}{\Theta L_x L_y L_z}-\frac{S_{II20}S_{II20}}{\Theta L_x L_y L_z}-\frac{S_{IV11}}{\Theta L_x L_y L_z},$$

$$C_V=\alpha_{1I}\alpha_{1V}S_{IV00}+\alpha_{1V}^2 S_{VV00}-S_{VV02}-S_{IV11},\ E=\sqrt{8y+\Theta^2\frac{a_3^2}{a_4^2}-4\Theta\frac{a_2}{a_4}},\ F=\frac{\Theta a_2}{6a_4}+$$

$$+\sqrt[3]{\sqrt{r^2+s^3}-r}-\sqrt[3]{\sqrt{r^2+s^3}+r},$$

$$r=\frac{\Theta^3 b_2}{24b_4^2}\left(4b_0-\Theta L_x L_y L_z\frac{b_1 b_3}{b_4}\right)-\frac{\Theta^3 b_2^3}{54b_4^3}-b_0\frac{\Theta^2}{8b_4^2}\times$$

$$\times\left(4\Theta b_2-\Theta^2\frac{b_3^2}{b_4}\right)-L_x^2L_y^2L_z^2\frac{\Theta^4 b_1^2}{8b_4^2},\ s=\Theta^2\frac{4b_0b_4-\Theta L_x L_y L_z b_1 b_3}{12b_4^2}-\frac{\Theta b_2}{18b_4}.$$

Farther we determine solutions of Eqs.(6), i.e. components of displacement vector. To determine the first-order approximations of the considered components framework method of averaging of function corrections we replace the required functions in the right sides of the equations by their not yet known average values α_i. The substitution leads to the following result

$$\rho(z)\frac{\partial^2 u_{1x}(x,y,z,t)}{\partial t^2}=-K(z)\beta(z)\frac{\partial T(x,y,z,t)}{\partial x},\ \rho(z)\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial t^2}=$$

$$=-K(z)\beta(z)\frac{\partial T(x,y,z,t)}{\partial y},\ \rho(z)\frac{\partial^2 u_{1z}(x,y,z,t)}{\partial t^2}=-K(z)\beta(z)\frac{\partial T(x,y,z,t)}{\partial z}.$$

Integration of the left and the right sides of the above relations on time t leads to the following result

$$u_{1x}(x,y,z,t)=u_{0x}+K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial x}\int_0^t\int_0^{\vartheta} T(x,y,z,\tau)\,d\tau\,d\vartheta-$$
$$-K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial x}\int_0^{\infty}\int_0^{\vartheta} T(x,y,z,\tau)\,d\tau\,d\vartheta,$$

$$u_{1y}(x,y,z,t)=u_{0y}+K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial y}\int_0^t\int_0^{\vartheta} T(x,y,z,\tau)\,d\tau\,d\vartheta-$$
$$-K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial y}\int_0^{\infty}\int_0^{\vartheta} T(x,y,z,\tau)\,d\tau\,d\vartheta,$$

$$u_{1z}(x,y,z,t)=u_{0z}+K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial z}\int_0^t\int_0^{\vartheta} T(x,y,z,\tau)\,d\tau\,d\vartheta-$$
$$-K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial z}\int_0^{\infty}\int_0^{\vartheta} T(x,y,z,\tau)\,d\tau\,d\vartheta.$$

Approximations of the second and higher orders of components of displacement vector could be determined by using standard replacement of the required components on the following sums $\alpha_i+u_i(x,y,z,t)$ [18-20]. The replacement leads to the following result

$$\rho(z)\frac{\partial^2 u_{2x}(x,y,z,t)}{\partial t^2}=\left\{K(z)+\frac{5E(z)}{6[1+\sigma(z)]}\right\}\frac{\partial^2 u_{1x}(x,y,z,t)}{\partial x^2}+\left\{K(z)-\frac{E(z)}{3[1+\sigma(z)]}\right\}\times$$

$$\times\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial x\partial y}+\frac{E(z)}{2[1+\sigma(z)]}\left[\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial y^2}+\frac{\partial^2 u_{1z}(x,y,z,t)}{\partial z^2}\right]-\frac{\partial T(x,y,z,t)}{\partial x}\times$$

$$\times K(z)\beta(z)+\left\{K(z)+\frac{E(z)}{3[1+\sigma(z)]}\right\}\frac{\partial^2 u_{1z}(x,y,z,t)}{\partial x\partial z}$$

$$\rho(z)\frac{\partial^2 u_{2y}(x,y,z,t)}{\partial t^2}=\frac{E(z)}{2[1+\sigma(z)]}\left[\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial x^2}+\frac{\partial^2 u_{1x}(x,y,z,t)}{\partial x\partial y}\right]-\frac{\partial T(x,y,z,t)}{\partial y}\times$$

$$\times K(z)\beta(z)+\frac{\partial}{\partial z}\left\{\frac{E(z)}{2[1+\sigma(z)]}\left[\frac{\partial u_{1y}(x,y,z,t)}{\partial z}+\frac{\partial u_{1z}(x,y,z,t)}{\partial y}\right]\right\}+\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial y^2}\times$$

$$\times\left\{\frac{5E(z)}{12[1+\sigma(z)]}+K(z)\right\}+\left\{K(z)-\frac{E(z)}{6[1+\sigma(z)]}\right\}\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial y\partial z}+K(z)\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial x\partial y}$$

$$\rho(z)\frac{\partial^2 u_{2z}(x,y,z,t)}{\partial t^2}=\frac{E(z)}{2\,[1+\sigma(z)]}\left[\frac{\partial^2 u_{1z}(x,y,z,t)}{\partial x^2}+\frac{\partial^2 u_{1z}(x,y,z,t)}{\partial y^2}+\frac{\partial^2 u_{1x}(x,y,z,t)}{\partial x\partial z}+\right.$$

$$\left.+\frac{\partial^2 u_{1y}(x,y,z,t)}{\partial y\partial z}\right]+\frac{\partial}{\partial z}\left\{K(z)\left[\frac{\partial u_{1x}(x,y,z,t)}{\partial x}+\frac{\partial u_{1y}(x,y,z,t)}{\partial y}+\frac{\partial u_{1x}(x,y,z,t)}{\partial z}\right]\right\}+$$

$$+\frac{E(z)}{6[1+\sigma(z)]}\frac{\partial}{\partial z}\left[6\frac{\partial u_{1z}(x,y,z,t)}{\partial z}-\frac{\partial u_{1x}(x,y,z,t)}{\partial x}-\frac{\partial u_{1y}(x,y,z,t)}{\partial y}-\frac{\partial u_{1z}(x,y,z,t)}{\partial z}\right]-$$

$$\left.\left.-\frac{\partial u_{1x}(x,y,z,t)}{\partial x}-\frac{\partial u_{1y}(x,y,z,t)}{\partial y}-\frac{\partial u_{1z}(x,y,z,t)}{\partial z}\right]\right\}\frac{E(z)}{1+\sigma(z)}-K(z)\beta(z)\frac{\partial T(x,y,z,t)}{\partial z}.$$

Integration of the left and right sides of the above relations on time t leads to the following result

$$u_{2x}(x,y,z,t)=\frac{1}{\rho(z)}\left\{K(z)+\frac{5E(z)}{6[1+\sigma(z)]}\right\}\frac{\partial^2}{\partial x^2}\int_0^t\int_0^{\vartheta}u_{1x}(x,y,z,\tau)\,d\tau\,d\vartheta+\frac{1}{\rho(z)}\left\{K(z)-\right.$$

$$\left.-\frac{E(z)}{3\,[1+\sigma(z)]}\right\}\frac{\partial^2}{\partial x\partial y}\int_0^t\int_0^{\vartheta}u_{1y}(x,y,z,\tau)\,d\tau\,d\vartheta+\frac{E(z)}{2\rho(z)}\left[\frac{\partial^2}{\partial y^2}\int_0^t\int_0^{\vartheta}u_{1y}(x,y,z,\tau)\,d\tau\,d\vartheta+\right.$$

$$\left.+\frac{\partial^2}{\partial z^2}\int_0^t\int_0^{\vartheta}u_{1z}(x,y,z,\tau)\,d\tau\,d\vartheta\right]\frac{1}{1+\sigma(z)}+\frac{1}{\rho(z)}\frac{\partial^2}{\partial x\partial z}\int_0^t\int_0^{\vartheta}u_{1z}(x,y,z,\tau)d\tau\,d\vartheta\left\{K(z)+\right.$$

$$\left.+\frac{E(z)}{3\,[1+\sigma(z)]}\right\}-K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial x}\int_0^t\int_0^{\vartheta}T(x,y,z,\tau)\,d\tau\,d\vartheta-\frac{\partial^2}{\partial x^2}\int_0^{\infty}\int_0^{\vartheta}u_{1x}(x,y,z,\tau)d\tau\,d\vartheta\times$$

$$\times\frac{1}{\rho(z)}\left\{K(z)+\frac{5E(z)}{6\,[1+\sigma(z)]}\right\}-\left\{K(z)-\frac{E(z)}{3[1+\sigma(z)]}\right\}\frac{\partial^2}{\partial x\partial y}\int_0^{\infty}\int_0^{\vartheta}u_{1y}(x,y,z,\tau)d\tau\,d\vartheta\times$$

$$\times\frac{1}{\rho(z)}-\frac{E(z)}{2\rho(z)[1+\sigma(z)]}\left[\frac{\partial^2}{\partial y^2}\int_0^{\infty}\int_0^{\vartheta}u_{1y}(x,y,z,\tau)d\tau\,d\vartheta+\frac{\partial^2}{\partial z^2}\int_0^{\infty}\int_0^{\vartheta}u_{1z}(x,y,z,\tau)d\tau\,d\vartheta\right]-$$

$$-\frac{1}{\rho(z)}\left\{K(z)+\frac{E(z)}{3\,[1+\sigma(z)]}\right\}\frac{\partial^2}{\partial x\partial z}\int_0^{\infty}\int_0^{\vartheta}u_{1z}(x,y,z,\tau)d\tau\,d\vartheta+u_{0x}+K(z)\frac{\beta(z)}{\rho(z)}\times$$

$$\times \frac{\partial}{\partial x}\int_0^\infty\int_0^\vartheta T\left(x,y,z,\tau\right) d\tau\, d\vartheta$$

$$u_{2y}(x,y,z,t) = \frac{E(z)}{2\rho(z)}\left[\frac{\partial^2}{\partial x^2}\int_0^t\int_0^\vartheta u_{1x}(x,y,z,\tau)d\tau\, d\vartheta + \frac{\partial^2}{\partial x\partial y}\int_0^t\int_0^\vartheta u_{1x}(x,y,z,\tau)d\tau\, d\vartheta\right]\times$$

$$\times\frac{1}{1+\sigma(z)} + \frac{K(z)}{\rho(z)}\frac{\partial^2}{\partial x\partial y}\int_0^t\int_0^\vartheta u_{1y}(x,y,z,\tau)d\tau\, d\vartheta + \frac{1}{\rho(z)}\left\{\frac{5E(z)}{12[1+\sigma(z)]}+K(z)\right\}\times$$

$$\times\frac{\partial^2}{\partial y^2}\int_0^t\int_0^\vartheta u_{1x}(x,y,z,\tau)\, d\tau\, d\vartheta + \frac{1}{2\rho(z)}\frac{\partial}{\partial z}\left\{\frac{E(z)}{1+\sigma(z)}\left[\frac{\partial}{\partial z}\int_0^t\int_0^\vartheta u_{1y}(x,y,z,\tau)\, d\tau\, d\vartheta +\right.\right.$$

$$\left.\left.+\frac{\partial}{\partial y}\int_0^t\int_0^\vartheta u_{1z}(x,y,z,\tau)d\tau\, d\vartheta\right]\right\} - K(z)\frac{\beta(z)}{\rho(z)}\int_0^t\int_0^\vartheta T\,(x,y,z,\tau)d\tau\, d\vartheta - \left\{\frac{E(z)}{6[1+\sigma(z)]}-\right.$$

$$\left.-K(z)\right\}\frac{1}{\rho(z)}\frac{\partial^2}{\partial y\partial z}\int_0^t\int_0^\vartheta u_{1y}(x,y,z,\tau)d\tau\, d\vartheta - \frac{E(z)}{2\rho(z)}\left[\frac{\partial^2}{\partial x^2}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)d\tau\, d\vartheta+\right.$$

$$\left.+\frac{\partial^2}{\partial x\partial y}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)d\tau\, d\vartheta\right]\frac{1}{1+\sigma(z)} - K(z)\frac{\beta(z)}{\rho(z)}\int_0^\infty\int_0^\vartheta T\,(x,y,z,\tau)\, d\tau\, d\vartheta - \frac{K(z)}{\rho(z)}\times$$

$$\times\frac{\partial^2}{\partial x\partial y}\int_0^\infty\int_0^\vartheta u_{1y}(x,y,z,\tau)d\tau\, d\vartheta - \frac{1}{\rho(z)}\frac{\partial^2}{\partial y^2}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)\, d\tau\, d\vartheta\left\{\frac{5E(z)}{12[1+\sigma(z)]}+\right.$$

$$\left.+K(z)\right\} - \frac{\partial}{\partial z}\left\{\frac{E(z)}{1+\sigma(z)}\left[\frac{\partial}{\partial z}\int_0^\infty\int_0^\vartheta u_{1y}(x,y,z,\tau)\, d\tau\, d\vartheta + \frac{\partial}{\partial y}\int_0^\infty\int_0^\vartheta u_{1z}(x,y,z,\tau)\, d\tau\, d\vartheta\right]\right\}\times$$

$$\times\frac{1}{2\rho(z)} - \frac{1}{\rho(z)}\left\{K(z) - \frac{E(z)}{6[1+\sigma(z)]}\right\}\frac{\partial^2}{\partial y\partial z}\int_0^\infty\int_0^\vartheta u_{1y}(x,y,z,\tau)\, d\tau\, d\vartheta + u_{0y}$$

$$u_z(x,y,z,t) = \frac{E(z)}{2[1+\sigma(z)]}\left[\frac{\partial^2}{\partial x^2}\int_0^\infty\int_0^\vartheta u_{1z}(x,y,z,\tau)\, d\tau\, d\vartheta + \frac{\partial^2}{\partial y^2}\int_0^\infty\int_0^\vartheta u_{1z}(x,y,z,\tau)\, d\tau\, d\vartheta +\right.$$

$$\left.+\frac{\partial^2}{\partial x\partial z}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)\, d\tau\, d\vartheta + \frac{\partial^2}{\partial y\partial z}\int_0^\infty\int_0^\vartheta u_{1y}(x,y,z,\tau)\, d\tau\, d\vartheta\right]\frac{1}{\rho(z)} + \frac{1}{\rho(z)}\times$$

$$\times\frac{\partial}{\partial z}\left\{K(z)\left[\frac{\partial}{\partial x}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)\, d\tau\, d\vartheta + \frac{\partial}{\partial y}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)\, d\tau\, d\vartheta +\right.\right.$$

$$\left.\left.+\frac{\partial}{\partial z}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)\, d\tau\, d\vartheta\right]\right\} + \frac{1}{6\rho(z)}\frac{\partial}{\partial z}\left\{\frac{E(z)}{1+\sigma(z)}\left[6\frac{\partial}{\partial z}\int_0^\infty\int_0^\vartheta u_{1z}(x,y,z,\tau)\, d\tau\, d\vartheta -\right.\right.$$

$$\left.\left.-\frac{\partial}{\partial x}\int_0^\infty\int_0^\vartheta u_{1x}(x,y,z,\tau)\, d\tau\, d\vartheta - \frac{\partial}{\partial y}\int_0^\infty\int_0^\vartheta u_{1y}(x,y,z,\tau)\, d\tau\, d\vartheta - \frac{\partial}{\partial z}\int_0^\infty\int_0^\vartheta u_{1z}(x,y,z,\tau)\, d\tau\, d\vartheta\right]\right\} -$$

$$-K(z)\frac{\beta(z)}{\rho(z)}\frac{\partial}{\partial z}\int_0^{\infty}\int_0^{\vartheta}T(x,y,z,\tau)\,d\tau\,d\vartheta+u_{0z}.$$

In the framework of this paper we determine concentration of radiation defects and components of displacement vector by using the second-order approximation framework method of averaging of function corrections. The approximation is usually enough good approximation to make qualitative analysis and to obtain some quantitative results. All obtained results have been checked by comparison with results of numerical simulations.

3. Discussion

In this section, we will analyze the redistribution of radiation defects during annealing of them with into account relaxation of missmatch-induced stresses. Typical distributions of concentrations of point radiation defects (for both types of radiation defects, the distribution of concentrations will be similar to each other) in the considered multilayer structures are shown on Fig. 2 for the case, when the diffusion coefficient of defects in the buffer layer is larger, than the same coefficient in the epitaxial layer. One can find qualitatively similar distributions of concentration for point defect complexes. It follows from these figure, that the inhomogeneity of properties of the multilayer structure could decrease quantity of radiation defects in the working region of integrated circuits of the multilayer structure.

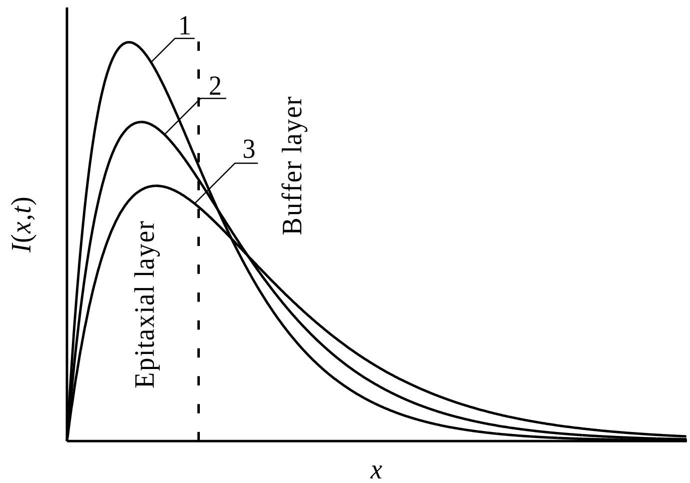

Fig. 2. Typical distributions of concentration of interstitial atoms (distributions of concentrations of other types of defects are similar to distributions of concentration of interstitial atoms). Increasing of number of curves corresponds to increasing of annealing time

4. Conclusion

In this paper we introduce an approach for organization of a drain of radiation defects, which were generated during ion doping or other types of radiation processing of the working area of integrated circuits, manufactured framework a multilayer structure. The approach based on the difference of properties of materials of the layers of the considered multilayer structure. An analytical approach for analysis of mass and heat transfer in a multilayer structures was introduced with account the spatial and temporal variations of their parameters, as well as the nonlinearity of the processes under consideration.

REFERENCES

[1] V.I. Lachin, N.S. Savelov. Electronics. Rostov-on-Don: Phoenix, 2001.

[2] A. Polishscuk. Modern Electronics. Issue 12. P. 8-11 (2004).

[3] G. Volovich. Modern Electronics. Issue 2. P. 10-17 (2006).

[4] A. Kerentsev, V. Lanin, Power Electronics. Issue 1. P. 34 (2008).

[5] A.O. Ageev, A.E. Belyaev, N.S. Boltovets, V.N. Ivanov, R.V. Konakova, Ya.Ya. Kudrik, P.M. Litvin, V.V. Milenin, A.V. Sachenko. Semiconductors. Vol. 43 (7). P. 897-903 (2009).

[6] Jung-Hui Tsai, Shao-Yen Chiu, Wen-Shiung Lour, Der-Feng Guo. Semiconductors. Vol. 43 (7). C. 971-974 (2009).

[7] G.A. Tarnavsky, E.V. Vorozhtsov. Energy and Power Engineering. Vol. 2 (2). P. 73-77 (2010).

[8] V.A. Ivchenko. Technical physics letters. Vol. 39 (4). P. 357-359 (2013).

[9] V.M. Barbashov, O.A. Kalashnikov. Russian Microelectronics. Vol. 46 (3). P. 155-161 (2017).

[10] A.A. Lebedev, A.M. Ivanov, N.B. Strokan. Semiconductors. Vol. 38 (2). P. 124-145 (2004).

[11] E.V. Kalinina, V.G. Kossov, R.R. Yafaev, A.M. Strel'chuk, G.N. Violina. Semi-conductors. Vol. 44 (6). P. 778-788 (2010).

[12] A.A. Lebedev, S.V. Belov, M.G. Mynbaeva, A.M. Strel'chuk, E.V. Bogdanova, Yu.N. Makarov, A.S. Usikov, S.Yu. Kurin, I.S. Barash, A.D. Roenkov, V.V. Kozlovski. Semiconductors. Vol. 49 (10). P. 1341-1343 (2015).

[13] Y.W. Zhang, A.F. Bower. Journal of the Mechanics and Physics of Solids. Vol. 47 (11). P. 2273-2297 (1999).

[14] L.D. Landau, E.M. Lefshits. Theoretical physics. 7 (Theory of elasticity) (Physmatlit, Moscow, 2001).

[15] M. Kitayama, T. Narushima, W.C. Carter, R.M. Cannon, A.M. Glaeser. J. Am. Ceram. Soc. Vol. 83. P. 2561 (2000); M. Kitayama, T. Narushima, A.M. Glaeser. J. Am. Ceram. Soc. Vol. 83. P. 2572 (2000).

[16] P.M. Fahey, P.B. Griffin, J.D. Plummer. Rev. Mod. Phys. Vol. 61 (2). P. 289-388 (1989).

[17] V.L. Vinetskiy, G.A. Kholodar', Radiative physics of semiconductors. ("Naukova Dumka", Kiev, 1979).

[18] Yu.D. Sokolov. Applied Mechanics. Vol. 1 (1). P. 23-35 (1955).

[19] E.L. Pankratov, E.A. Bulaeva. Reviews in Theoretical Science. Vol. 1 (1). P. 58-82 (2013).

[20] E.L. Pankratov, E.A. Bulaeva. Materials science in semiconductor processing. Vol. 34. P. 260-268 (2015).

[21] E.L. Pankratov. International journal of modeling, simulation and applications. Vol. 4 (1). P. 11-25 (2023).