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On optimization of manufacturing of field-effect heterotransistors with several channels

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ABSTRACT

In this paper we introduce an approach to manufacture field-effect heterotransistors with several channel. The approach based on manufacturing of a heterostructure with required configuration, doping by diffusion or ion implantation of required areas of the heterostructure and optimization of annealing of dopant and/or radiation defects. We consider the optimization framework recently introduced approach. At the same time we introduce an analytical approach for analysis of redistribution of dopant and radiation defects. The approach gives us possibility to formulate recommendations for optimization of annealing of dopant and/or radiation defects.

INTRODUCTION

Intensive development of solid state electronic devices leads to necessity to increase integration rate of elements of integrated circuits (p-n-junctions, their systems et al)[1-7]. Increasing of integration rate of elements of integrated circuits leads to necessity to decrease dimensions of the elements. To decrease dimensions of integrated circuits it have been elaborated and systematically using several approaches[8-17].

Framework the paper we consider a heterostructure, which consist of a substrate and seven epitaxial layers (see Figure 1). After manufacturing the second, the forth and the sixth epitaxial layers the layers have been doped by diffusion or ion implantation. The layers will take a role of channels after finishing of manufacturing of the transistor. It should be taken into account necessity of presents of contacts during the manufacturing. Two sections have been manufacturing by using another materials framework the heterostructure (see Figure 1). The sections will take a role of source and drain after finishing of manufacturing of the transistor. After finishing of manufacturing and doping of the heterostructure the considered dopants and/or generated radiation defects have been annealed. Main aim of the present paper is analysis of dynamics of dopant and radiation defects during annealing of them.

Method of solution

To solve our aim we determine spatio-temporal

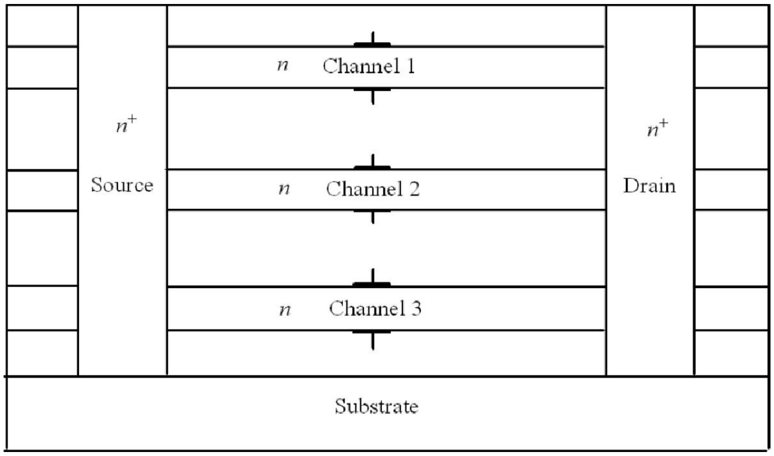

Figure 1 : Heterostructure, which consist of a substrate, seven epitaxial layers and sections framework the layers

distributions of concentrations of dopants. We calculate the required distributions by solving the second Fick's law in the following form[1,3,17]

$$\frac{\partial C(x,y,z,t)}{\partial t}=\frac{\partial}{\partial x}\left[D_C\frac{\partial C(x,y,z,t)}{\partial x}\right]+$$

$$+\frac{\partial}{\partial y}\left[D_C\frac{\partial C(x,y,z,t)}{\partial y}\right]+\frac{\partial}{\partial z}\left[D_C\frac{\partial C(x,y,z,t)}{\partial z}\right] \tag{1}$$

with boundary and initial conditions

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

$$\left.\frac{\partial C(x,y,z,t)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial C(x,y,z,t)}{\partial z}\right|_{x=L_z}=0,\ C(x,y,z,0)=f(x,y,z). \tag{2}$$

Here C(x,y,z,t) is the spatio-temporal distribution of concentration of dopant; T is the temperature of annealing; D_C is the dopant diffusion coefficient. Value of dopant diffusion coefficient depends on properties of materials of heterostructure, speed of heating and cooling of heterostructure (with account Arrhenius law). Dependences of dopant diffusion coefficient on parameters could be approximated by the following relation[22-24]

$$D_C=D_L(x,y,z,T)\left[1+\xi\frac{C^\gamma(x,y,z,t)}{P^\gamma(x,y,z,T)}\right]\left[1+\varsigma_1\frac{V(x,y,z,t)}{V^*}+\varsigma_2\frac{V^2(x,y,z,t)}{(V^*)^2}\right], \tag{3}$$

where D_L (x,y,z,T) is the spatial (due to presents several layers in heterostructure) and temperature (due to Arrhenius law) dependences of dopant diffusion coefficient; P (x, y,z,T) is the limit of solubility of dopant; parameter γ depends on properties of materials and could be integer in the following interval $\gamma \in [1,3]$[22]; V (x,y,z,t) is the spatio-temporal distribution of concentration of radiation vacancies; V^* is the equilibrium distribution of concentration of vacancies. Concentrational dependence of dopant diffusion coefficient has been described in details in[22]. It should be noted, that using diffusion type of doping did not generation radiation defects. In this situation $\zeta_1= \zeta_2= 0$. We determine spatio-temporal distributions of concentrations of radiation defects by solving the following system of equations[23,24]

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

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

$$-k_{I,I}(x,y,z,T)I^2(x,y,z,t) \quad (4)$$

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

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

$$-k_{V,V}(x,y,z,T)V^2(x,y,z,t)$$

with boundary and initial conditions

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

$$\left.\frac{\partial\rho(x,y,z,t)}{\partial z}\right|_{z=0}=0,\ \left.\frac{\partial\rho(x,y,z,t)}{\partial z}\right|_{z=L_z}=0,\ \rho(x,y,z,0)=f_\rho(x,y,z). \quad (5)$$

Here ρ =I,V; I (x,y,z,t) is the spatio-temporal distribution of concentration of radiation interstitials; D_ρ(x,y,z,T) are the diffusion coefficients of point radiation defects; terms V^2(x,y,z,t) and I^2(x,y,z,t) correspond to generation divacancies and diinterstitials; $k_{I,V}$(x,y,z,T) is the parameter of recombination of point radiation defects; $k_{I,I}$(x,y,z,T) and $k_{V,V}$(x,y,z,T) are the parameters of generation of simplest complexes of point radiation defects.

We determine spatio-temporal distributions of concentrations of divacancies Φ_V (x, y,z,t) and dinterstitials Φ_I (x,y,z,t) by solving the following system of equations[23, 24]

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

$$+\frac{\partial}{\partial z}\left[D_{\Phi I}(x,y,z,T)\frac{\partial\Phi_I(x,y,z,t)}{\partial z}\right]+k_{I,I}(x,y,z,T)I^2(x,y,z,t)-k_I(x,y,z,T)I(x,y,z,t) \quad (6)$$

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

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$$+\frac{\partial}{\partial z}\left[D_{\Phi V}(x,y,z,T)\frac{\partial \Phi_V(x,y,z,t)}{\partial z}\right]+k_{V,V}(x,y,z,T)V^2(x,y,z,t)-k_V(x,y,z,T)V(x,y,z,t)$$

with boundary and initial conditions

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

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

$\Phi_I(x,y,z,0)=f_{\Phi I}(x,y,z)$, $\Phi_V(x,y,z,0)=f_{\Phi V}(x,y,z)$. (7)

Here $D_{\Phi\rho}(x,y,z,T)$ are the diffusion coefficients of the above complexes of radiation defects; $k_I(x,y,z,T)$ and $k_V(x,y,z,T)$ are the parameters of decay of these complexes.

To determine spatio-temporal distribution of concentration of dopant we transform the Eq.(1) to the following integro-differential form

$$\frac{xyz}{L_xL_yL_z}\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}C(u,v,w,t)\,dw\,dv\,du=\frac{yz}{L_yL_z}\int_0^t\int_{L_y}^{y}\int_{L_z}^{z}\left[1+\varsigma_1\frac{V(x,v,w,\tau)}{V^*}+\varsigma_2\frac{V^2(x,v,w,\tau)}{(V^*)^2}\right]\times$$

$$\times D_L(x,v,w,T)\left[1+\xi\frac{C^\gamma(x,v,w,\tau)}{P^\gamma(x,v,w,T)}\right]\frac{\partial C(x,v,w,\tau)}{\partial x}\,d\tau+\frac{xz}{L_xL_z}\int_0^t\int_{L_x}^{x}\int_{L_z}^{z}D_L(u,y,w,T)\times$$

$$\times\left[1+\varsigma_1\frac{V(u,y,w,\tau)}{V^*}+\varsigma_2\frac{V^2(u,y,w,\tau)}{(V^*)^2}\right]\left[1+\xi\frac{C^\gamma(u,y,w,\tau)}{P^\gamma(x,y,z,T)}\right]\frac{\partial C(u,y,w,\tau)}{\partial y}\,d\tau+$$

$$+\frac{xy}{L_xL_y}\int_0^t\int_{L_x}^{x}\int_{L_y}^{y}D_L(u,v,z,T)\left[1+\varsigma_1\frac{V(u,v,z,\tau)}{V^*}+\varsigma_2\frac{V^2(u,v,z,\tau)}{(V^*)^2}\right]\left[1+\xi\frac{C^\gamma(u,v,z,\tau)}{P^\gamma(x,y,z,T)}\right]\times$$

$$\times\frac{\partial C(u,v,z,\tau)}{\partial z}\,d\tau+\frac{xyz}{L_xL_yL_z}\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}f(u,v,w)\,dw\,dv\,du. \quad (1a)$$

We determine solution of the above equation by using Bubnov-Galerkin approach[25]. Framework the approach we determine solution of the Eq.(1a) as the following series

$$C_0(x,y,z,t)=\sum_{n=1}^{N}a_{nC}\,c_n(x)\,c_n(y)\,c_n(z)\,e_{nC}(t),$$

where $e_{nC}(t)=\exp\left[-\pi^2n^2D_{0C}t\left(L_x^{-2}+L_y^{-2}+L_z^{-2}\right)\right]$, $c_n(\chi)=\cos(\pi n\chi/L_\chi)$. The above series includes into itself finite number of terms N. The considered series is similar with solution of linear Eq.(1) (i.e. with $\xi=0$) and averaged dopant diffusion coefficient D_0. Substitution of the series into Eq.(1a) leads to the following result

$$\frac{x\,y\,z}{\pi^2}\sum_{n=1}^{N}\frac{a_C}{n^3}\,s_n(x)\,s_n(y)\,s_n(z)\,e_{nC}(t)=-\frac{y\,z}{L_yL_z}\int_0^t\int_{L_y}^{y}\int_{L_z}^{z}\left\{1+\left[\sum_{n=1}^{N}a_{nC}\,c_n(x)\,c_n(v)\,c_n(w)\,e_{nC}(\tau)\right]^{\gamma}\times\right.$$

$$\left.\times\frac{\xi}{P^{\gamma}(x,v,w,T)}\right\}\left[1+\varsigma_1\frac{V(x,v,w,\tau)}{V^*}+\varsigma_2\frac{V^2(x,v,w,\tau)}{(V^*)^2}\right]D_L(x,v,w,T)\sum_{n=1}^{N}a_{nC}\,s_n(x)\,c_n(v)\times$$

$$\times\,n\,c_n(w)\,e_{nC}(\tau)\,d\tau-\frac{x\,z}{L_xL_z}\int_0^t\int_{L_x}^{x}\int_{L_z}^{z}\left\{1+\left[\sum_{m=1}^{N}a_{mC}\,c_m(u)\,c_m(y)\,c_m(w)\,e_{mC}(\tau)\right]^{\gamma}\frac{\xi}{P^{\gamma}(u,y,w,T)}\right\}\times$$

$$\times D_L(u,y,w,T)\left[1+\varsigma_1\frac{V(u,y,w,\tau)}{V^*}+\varsigma_2\frac{V^2(u,y,w,\tau)}{(V^*)^2}\right]\sum_{n=1}^{N}n\,c_n(u)\,s_n(y)\,c_n(w)\,e_{nC}(\tau)\,d\tau\,\times$$

$$\times\,a_{nC}-\frac{x\,y}{L_xL_y}\int_0^t\int_{L_x}^{x}\int_{L_y}^{y}D_L(u,v,z,T)\left\{1+\frac{\xi}{P^{\gamma}(u,v,z,T)}\left[\sum_{n=1}^{N}a_{nC}\,c_n(u)\,c_n(v)\,c_n(z)\,e_{nC}(\tau)\right]^{\gamma}\right\}\times$$

$$\times\left[1+\varsigma_1\frac{V(u,v,z,\tau)}{V^*}+\varsigma_2\frac{V^2(u,v,z,\tau)}{(V^*)^2}\right]\sum_{n=1}^{N}n\,a_{nC}c_n(u)\,c_n(v)\,s_n(z)\,e_{nC}(\tau)\,d\tau+\frac{x\,y\,z}{L_xL_yL_z}\times$$

$$\times\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}f(u,v,w)\,d\,w\,d\,v\,d\,u,$$

where $s_n(\chi) = \sin(\pi\, n\, \chi/L_\chi)$. We determine coefficients a_n by using orthogonality condition of terms of the considered series framework scale of heterostructure. The condition gives us possibility to obtain relations for calculation of parameters a_n for any quantity of terms N. In the common case the relations could be written as

$$-\frac{L_x^2L_y^2L_z^2}{\pi^5}\sum_{n=1}^{N}\frac{a_{nC}}{n^6}\,e_{nC}(t)=-\frac{L_yL_z}{2\pi^2}\int_0^t\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}D_L(x,y,z,T)\left\{1+\left[\sum_{n=1}^{N}a_{nC}\,c_n(x)\,c_n(y)\,c_n(z)\,e_{nC}(\tau)\right]^{\gamma}\times\right.$$

$$\left.\times\frac{\xi}{P^{\gamma}(x,y,z,T)}\right\}\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\right]\sum_{n=1}^{N}\frac{a_{nC}}{n}\,s_n(2x)\,c_n(y)\,c_n(z)\,e_{nC}(\tau)\times$$

$$\times\left\{y\,s_n(y)+\frac{L_y}{\pi\,n}[c_n(y)-1]\right\}\left\{z\,s_n(z)+\frac{L_z}{\pi\,n}[c_n(z)-1]\right\}d\,z\,d\,y\,d\,x\,d\,\tau-\int_0^t\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}D_L(x,y,z,T)\times$$

$$\times D_L(x,y,z,T)\left\{1+\left[\sum_{n=1}^{N}a_{nC}\,c_n(x)\,c_n(y)\,c_n(z)\,e_{nC}(\tau)\right]^{\gamma}\frac{\xi}{P^{\gamma}(x,y,z,T)}\right\}\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\right.$$

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$$+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\Bigg]\Bigg[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\Bigg]\sum_{n=1}^{N}\left\{x\,s_n(x)+\frac{L_x}{\pi n}[c_n(x)-1]\right\}\frac{a_{nC}}{n}\times$$

$$\times\frac{L_xL_z}{2\pi^2}c_n(x)s_n(2y)\,c_n(z)\,e_{nC}(\tau)\left\{z\,s_n(z)+\frac{L_z}{\pi n}[c_n(z)-1]\right\}d\,z\,d\,y\,d\,x\,d\,\tau-\frac{L_xL_y}{2\pi^2}\times$$

$$\times\int_0^t\int_0^{L_x}\int_0^{L_y}\int_0^{L_z}\left\{1+\left[\sum_{n=1}^{N}a_{nC}\,c_n(x)\,c_n(y)\,c_n(z)\,e_{nC}(\tau)\right]^{\gamma}\frac{\xi}{P^{\gamma}(x,y,z,T)}\right\}\Bigg[1+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}+$$

$$+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}\Bigg]D_L(x,y,z,T)\sum_{n=1}^{N}\frac{a_{nC}}{n}c_n(x)\,c_n(y)\,s_n(z)\left\{x\,s_n(x)+\frac{L_x}{\pi n}[c_n(x)-1]\right\}\times$$

$$\times\left\{y\,s_n(y)+\frac{L_y}{\pi n}[c_n(y)-1]\right\}e_{nC}(\tau)d\,z\,d\,y\,d\,x\,d\,\tau+\sum_{n=1}^{N}\int_0^{L_x}\left\{x\,s_n(x)+\frac{L_x}{\pi n}[c_n(x)-1]\right\}\times$$

$$\times\int_0^{L_y}\left\{y\,s_n(y)+\frac{L_y}{\pi n}[c_n(y)-1]\right\}\int_0^{L_z}\left\{z\,s_n(z)+\frac{L_z}{\pi n}[c_n(z)-1]\right\}f(x,y,z)d\,z\,d\,y\,d\,x\;.$$

As an example for γ = 0 we obtain

$$a_{nC}=\int_0^{L_x}\int_0^{L_y}\left\{y\,s_n(y)+\frac{L_y}{\pi n}[c_n(y)-1]\right\}\int_0^{L_z}\left\{z\,s_n(z)+\frac{L_y}{\pi n}[c_n(z)-1]\right\}f(x,y,z)d\,z\,d\,y\,\{\,x\,s_n(x)+$$

$$\times[c_n(x)-1]\frac{L_x}{\pi n}\Bigg\}d\,x\Bigg(\frac{n}{2}\Bigg\{\int_0^t\int_0^{L_x}s_n(2x)\int_0^{L_y}c_n(y)\left\{y\,s_n(y)+\frac{L_y}{\pi n}[c_n(y)-1]\right\}\int_0^{L_z}D_L(x,y,z,T)\times$$

$$\times\left\{z\,s_n(z)+\frac{L_y}{\pi n}[c_n(z)-1]\right\}\Bigg[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\Bigg]\Bigg[1+\frac{\xi}{P^{\gamma}(x,y,z,T)}\Bigg]\times$$

$$\times\,c_n(z)d\,z\,d\,y\,d\,x\,e_{nC}(\tau)d\,\tau+\int_0^t e_{nC}(\tau)\int_0^{L_x}c_n(x)\left\{x\,s_n(x)+\frac{L_y}{\pi n}[c_n(x)-1]\right\}\int_0^{L_y}s_n(2y)\int_0^{L_z}c_n(z)\times$$

$$\times\left\{z\,s_n(z)+\frac{L_y}{\pi n}[c_n(z)-1]\right\}\Bigg[1+\frac{\xi}{P^{\gamma}(x,y,z,T)}\Bigg]\Bigg[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\Bigg]\times$$

$$\times\,D_L(x,y,z,T)\,d\,z\,d\,y\,d\,x\,d\,\tau+\int_0^t e_{nC}(\tau)\int_0^{L_x}c_n(x)\left\{x\,s_n(x)+\frac{L_x}{\pi n}[c_n(x)-1]\right\}\int_0^{L_y}c_n(y)\,\{\,s_n(y)\times$$

$$\times y+\frac{L_y}{\pi n}\left[c_n(y)-1\right]\Bigg\}\int_0^{L_z} s_n(2z)\,D_L(x,y,z,T)\left[1+\frac{\xi}{P^{\gamma}(x,y,z,T)}\right]\left[1+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}+\right.$$

$$\left.+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}\right]d\,z\,d\,y\,d\,x\,d\,\tau\Bigg\}-\frac{L_z^2L_z^2L_z^2}{\pi^5 n^6}e_{nC}(t)\Bigg)^{-1}.$$

For γ = 1 one can obtain the following relation to determine required parameters

$$a_{nC}=-\frac{\beta_n}{2\alpha_n}\pm\sqrt{\beta_n^2+4\alpha_n\int_0^{L_x}c_n(x)\int_0^{L_y}c_n(y)\int_0^{L_z}c_n(z)\,f(x,y,z)\,d\,z\,d\,y\,d\,x},$$

where $\alpha_n=\frac{\xi L_yL_z}{2\pi^2 n}\int_0^t e_{nC}(\tau)\int_0^{L_x}s_n(2x)\int_0^{L_y}c_n(y)\int_0^{L_z}\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\right]\times$

$$\times c_n(z)\frac{D_L(x,y,z,T)}{P(x,y,z,T)}\left\{y\,s_n(y)+\frac{L_y}{\pi n}\left[c_n(y)-1\right]\right\}\left\{z\,s_n(z)+\frac{L_z}{\pi n}\left[c_n(z)-1\right]\right\}d\,z\,d\,y\,d\,x\,d\,\tau+$$

$$+\frac{\xi L_xL_z}{2\pi^2 n}\int_0^t e_{nC}(\tau)\int_0^{L_x}c_n(x)\left\{x\,s_n(x)+\frac{L_x}{\pi n}\left[c_n(x)-1\right]\right\}\int_0^{L_y}s_n(2y)\int_0^{L_z}\left\{z\,s_n(z)-\frac{L_z}{\pi n}\left[c_n(z)-1\right]\right\}\times$$

$$\times c_n(z)\frac{D_L(x,y,z,T)}{P(x,y,z,T)}\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\right]d\,z\,d\,y\,d\,x\,d\,\tau+\frac{\xi L_xL_y}{2\pi^2 n}\times$$

$$\times\int_0^t e_{nC}(\tau)\int_0^{L_x}c_n(x)\int_0^{L_y}c_n(y)\int_0^{L_z}s_n(2z)\frac{D_L(x,y,z,T)}{P(x,y,z,T)}\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\right]\times$$

$$\times\left\{x\,s_n(x)+\frac{L_x}{\pi n}\left[c_n(x)-1\right]\right\}\left\{y\,s_n(y)+\frac{L_y}{\pi n}\left[c_n(y)-1\right]\right\}d\,z\,d\,y\,d\,x\,d\,\tau,\ \beta_n=\frac{L_yL_z}{2n\pi^2}\times$$

$$\times\int_0^t e_{nC}(\tau)\int_0^{L_x}s_n(2x)\int_0^{L_y}c_n(y)\int_0^{L_z}c_n(z)D_L(x,y,z,T)\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\right]\times$$

$$\times\left\{z\,s_n(z)+\frac{L_z}{\pi n}\left[c_n(z)-1\right]\right\}d\,z\left\{y\,s_n(y)+\frac{L_y}{\pi n}\left[c_n(y)-1\right]\right\}d\,y\,d\,x\,d\,\tau+\frac{L_xL_z}{2n\pi^2}\int_0^t e_{nC}(\tau)\times$$

$$\times\int_0^{L_x}c_n(x)\left\{x\,s_n(x)+\frac{L_x}{\pi n}\left[c_n(x)-1\right]\right\}\int_0^{L_y}s_n(2y)\int_0^{L_z}\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{(V^*)^2}\right]\times$$

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$$\times c_n(z) D_L(x,y,z,T)\left\{z\, s_n(z)+\frac{L_z}{\pi n}\left[c_n(z)-1\right]\right\} d\,z\,d\,y\,d\,x\,d\,\tau+\frac{L_x L_y}{2n\pi^2}\int_0^t e_{nC}(\tau)\int_0^{L_x}\left\{x\, s_n(x)+\right.$$

$$\left.+\frac{L_x}{\pi n}\left[c_n(x)-1\right]\right\}\int_0^{L_y}\left\{y\, s_n(y)+\frac{L_y}{\pi n}\left[c_n(y)-1\right]\right\}\int_0^{L_z}\left[1+\varsigma_1\frac{V(x,y,z,\tau)}{V^*}+\varsigma_2\frac{V^2(x,y,z,\tau)}{\left(V^*\right)^2}\right]\times$$

$$\times\, s_n(2z) D_L(x,y,z,T)\; d\,z\, c_n(y) d\,y\, c_n(x) d\,x\,d\,\tau - L_x^2 L_y^2 L_z^2 e_{nC}(t)\big/\pi^5 n^6\,.$$

Analogous way could be used to calculate values of parameters a_n for larger values of parameter γ. However the relations will not be present in the paper because the relations are bulky. Advantage of the approach is absent of necessity to join dopant concentration on interfaces of heterostructure.

Equations of the system (4) have been also solved by using Bubnov-Galerkin approach. Previously we transform the differential equations to the following integro- differential form

$$\begin{cases}\dfrac{xyz}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} I(u,v,w,t)\,d w\,d v\,d u=\int\limits_0^t\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} D_I(x,v,w,T)\dfrac{\partial I(x,v,w,\tau)}{\partial x}d w\,d v\,d\tau\times\\ \times\dfrac{yz}{L_yL_z}+\dfrac{xz}{L_xL_z}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_z}^{z} D_I(u,y,w,T)\dfrac{\partial I(u,y,w,\tau)}{\partial x}d w\,d u\,d\tau-\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} k_{I,V}(u,v,w,T)\times\\ \times I(u,v,w,t)V(u,v,w,t)\,d w\,d v\,d u\dfrac{xyz}{L_xL_yL_z}+\dfrac{xy}{L_xL_y}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\dfrac{\partial I(u,v,z,\tau)}{\partial z}\times\\ \times D_I(u,v,z,T)\,d v\,d u\,d\tau-\dfrac{xyz}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} k_{I,I}(u,v,w,T)I^2(u,v,w,t)\,d w\,d v\,d u+\\ +\dfrac{xyz}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} f_I(u,v,w)\,d w\,d v\,d u\\ \dfrac{xyz}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} V(u,v,w,t)\,d w\,d v\,d u=\int\limits_0^t\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} D_V(x,v,w,T)\dfrac{\partial V(x,v,w,\tau)}{\partial x}d w\,d v\,d\tau\times\\ \times\dfrac{yz}{L_yL_z}+\dfrac{xz}{L_xL_z}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_z}^{z} D_V(u,y,w,T)\dfrac{\partial V(u,y,w,\tau)}{\partial x}d w\,d u\,d\tau+\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_y}^{y} D_V(u,v,z,T)\times\\ \times\dfrac{\partial V(u,v,z,\tau)}{\partial z}d v\,d u\,d\tau\dfrac{xy}{L_xL_y}-\dfrac{xyz}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} k_{I,V}(u,v,w,T)I(u,v,w,t)\times\\ \times V(u,v,w,t)\,d w\,d v\,d u-\dfrac{xyz}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} k_{V,V}(u,v,w,T)\,V^2(u,v,w,t)\,d w\,d v\,d u+\\ +\dfrac{xyz}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z} f_V(u,v,w)\,d w\,d v\,d u\end{cases}\qquad(4a)$$

Farther we determine solutions of the above equations as the following series

$$\rho_0(x,y,z,t)=\sum_{n=1}^{N} a_{n\rho}\, c_n(x)\, c_n(y)\, c_n(z)\, e_{n\rho}(t),$$

where $a_{n\rho}$ are not yet known coefficients. Substitution of the series into Eqs.(4a) leads to the following results

$$\frac{xyz}{\pi^3}\sum_{n=1}^{N}\frac{a_{nI}}{n^3}\, s_n(x)\, s_n(y)\, s_n(z)\, e_{nI}(t)=-\frac{yz\pi}{L_xL_yL_z}\sum_{n=1}^{N} a_{nI}\int_0^t\int_{L_y}^{y} c_n(y)\int_{L_z}^{z} c_n(z) D_I(x,v,w,T)\; d\,w\,d\,v\;\times$$

$$\times e_{nI}(\tau)\,d\tau\; s_n(x)-\frac{x\,z\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}a_{nI}\,s_n(y)\int_0^t e_{nI}(\tau)\int_{L_x}^{x}c_n(x)\int_{L_z}^{z}c_n(z)D_I(u,y,w,T)\,d\,w\,d\,u\,d\,\tau-$$

$$-\frac{x\,y\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}a_{nI}s_n(z)\int_0^t e_{nI}(\tau)\int_{L_x}^{x}c_n(x)\int_{L_y}^{y}c_n(y)D_I(u,v,z,T)d\,v\,d\,u\,d\,\tau-\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}k_{I,I}(u,v,v,T)\times$$

$$\times\left[\sum_{n=1}^{N}a_{nI}\,c_n(u)\,c_n(v)\,c_n(w)\,e_{nI}(t)\right]^2 d\,w\,d\,v\,d\,u\,\frac{x\,y\,z}{L_xL_yL_z}-\frac{x\,y\,z}{L_xL_yL_z}\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}\sum_{n=1}^{N}a_{nI}\,c_n(u)\,c_n(v)\,c_n(w)\times$$

$$\times e_{nI}(t)\sum_{n=1}^{N}a_{nV}\,c_n(u)\,c_n(v)\,c_n(w)\,e_{nV}(t)k_{I,V}(u,v,v,T)\,d\,w\,d\,v\,d\,u+\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}f_I(u,v,w)\,d\,w\,d\,v\,d\,u\times$$

$$\times\,x\,y\,z/L_xL_yL_z$$

$$\frac{x\,y\,z}{\pi^3}\sum_{n=1}^{N}\frac{a_{nV}}{n^3}s_n(x)\,s_n(y)\,s_n(z)\,e_{nV}(t)=-\frac{y\,z\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}a_{nV}\int_0^t\int_{L_y}^{y}c_n(y)\int_{L_z}^{z}c_n(z)D_V(x,v,w,T)\,d\,w\,d\,v\times$$

$$\times e_{nV}(\tau)\,d\,\tau\; s_n(x)-\frac{x\,z\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}a_{nV}\,s_n(y)\int_0^t e_{nV}(\tau)\int_{L_x}^{x}c_n(x)\int_{L_z}^{z}c_n(z)D_V(u,y,w,T)\,d\,w\,d\,u\,d\,\tau-$$

$$-\frac{x\,y\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}a_{nV}s_n(z)\int_0^t e_{nV}(\tau)\int_{L_x}^{x}c_n(x)\int_{L_y}^{y}c_n(y)D_V(u,v,z,T)d\,v\,d\,u\,d\,\tau-\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}k_{V,V}(u,v,v,T)\times$$

$$\times\left[\sum_{n=1}^{N}a_{nV}\,c_n(u)\,c_n(v)\,c_n(w)\,e_{nI}(t)\right]^2 d\,w\,d\,v\,d\,u\,\frac{x\,y\,z}{L_xL_yL_z}-\frac{x\,y\,z}{L_xL_yL_z}\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}\sum_{n=1}^{N}a_{nI}c_n(u)\,c_n(v)\,c_n(w)\times$$

$$\times e_{nI}(t)\sum_{n=1}^{N}a_{nV}\,c_n(u)\,c_n(v)\,c_n(w)\,e_{nV}(t)k_{I,V}(u,v,v,T)\,d\,w\,d\,v\,d\,u+\int_{L_x}^{x}\int_{L_y}^{y}\int_{L_z}^{z}f_V(u,v,w)\,d\,w\,d\,v\,d\,u\times$$

$$\times\,x\,y\,z/L_xL_yL_z\,.$$

We determine coefficients $a_{n\rho}$ by using orthogonality condition on the scale of heterostructure. The condition gives us possibility to obtain relations to calculate $a_{n\rho}$ for any quantity N of terms of considered series. In the common case equations for the required coefficients could be written as

$$-\frac{L_x^2L_y^2L_z^2}{\pi^5}\sum_{n=1}^{N}\frac{a_{nI}}{n^6}e_{nI}(t)=-\frac{1}{2\pi\,L_x}\sum_{n=1}^{N}\frac{a_{nI}}{n^2}\int_0^t\int_0^{L_x}[1-c_n(2x)]\int_0^{L_y}\left\{L_y+y\,s_n(2y)+\frac{L_y}{2\pi\,n}[c_n(2y)-1]\right\}\times$$

$$\times\int_0^{L_z}D_I(x,y,z,T)\left\{z\,s_n(z)+\frac{L_z}{2\pi\,n}[c_n(z)-1]\right\}d\,z\,d\,y\,d\,x\,e_{nI}(\tau)\,d\,\tau-\frac{1}{2\pi\,L_y}\sum_{n=1}^{N}\frac{a_{nI}}{n^2}\int_0^t\int_0^{L_x}\{x\,s_n(2x)+$$

$$+L_x+\frac{L_x}{\pi\,n}[c_n(2x)-1]\Bigg\}\int_0^{L_y}\int_0^{L_z}D_I(x,y,z,T)\left\{L_z+z\,s_n(2z)+\frac{L_z}{2\pi\,n}[c_n(2z)-1]\right\}d\,z[1-c_n(2y)]\times$$

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$$\times d\,y\,d\,x\,e_{nI}(\tau)\,d\,\tau\int_0^{L_z}D_I(x,y,z,T)\left\{L_z+z\,s_n(2z)+\frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\}d\,z\,d\,y\,d\,x\,e_{nI}(\tau)\,d\,\tau-$$

$$-\frac{1}{2\pi L_z}\sum_{n=1}^{N}\frac{a_{nI}}{n^2}\int_0^t\int_0^{L_x}\left\{L_x+x\,s_n(2x)+\frac{L_x}{2\pi n}\left[c_n(2x)-1\right]\right\}\int_0^{L_y}\left\{L_y+y\,s_n(2y)+\frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\}\times$$

$$\times\int_0^{L_z}\left[1-c_n(2z)\right]D_I(x,y,z,T)\,d\,z\,d\,y\,d\,x\,e_{nI}(\tau)\,d\,\tau-\sum_{n=1}^{N}a_{nI}^2e_{nI}(2t)\int_0^{L_x}\left\{L_x+\frac{L_x}{2\pi n}\left[c_n(2x)-1\right]+\right.$$

$$\left.+x\,s_n(2x)\right\}\int_0^{L_y}\left\{L_y+y\,s_n(2y)+\frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\}\int_0^{L_z}k_{I,I}(x,y,z,T)\left\{L_z+\frac{L_z}{2\pi n}\left[c_n(2z)-1\right]+\right.$$

$$\left.+z\,s_n(2z)\right\}d\,z\,d\,y\,d\,x-\sum_{n=1}^{N}a_{nI}a_{nV}e_{nI}(t)e_{nV}(t)\int_0^{L_x}\left\{L_x+x\,s_n(2x)+\frac{L_x}{2\pi n}\left[c_n(2x)-1\right]\right\}\int_0^{L_y}\left\{L_y+\right.$$

$$\left.+y\,s_n(2y)+\frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\}\int_0^{L_z}k_{I,V}(x,y,z,T)\left\{L_z+z\,s_n(2z)+\frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\}d\,z\times$$

$$\times d\,y\,d\,x+\sum_{n=1}^{N}\int_0^{L_x}\left\{x\,s_n(x)+\frac{L_x}{\pi n}\left[c_n(x)-1\right]\right\}\int_0^{L_y}\left\{y\,s_n(y)+\frac{L_y}{\pi n}\left[c_n(y)-1\right]\right\}\int_0^{L_z}f_I(x,y,z,T)\times$$

$$\times\left\{L_z+z\,s_n(2z)+\frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\}d\,z\,d\,y\,d\,x$$

$$-\frac{L_x^2L_y^2L_z^2}{\pi^5}\sum_{n=1}^{N}\frac{a_{nV}}{n^6}e_{nV}(t)=-\frac{1}{2\pi L_x}\sum_{n=1}^{N}\frac{a_{nV}}{n^2}\int_0^t\int_0^{L_x}\left[1-c_n(2x)\right]\int_0^{L_y}\left\{L_y+y\,s_n(2y)+\frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\}\times$$

$$\times\int_0^{L_z}D_V(x,y,z,T)\left\{z\,s_n(z)+\frac{L_z}{2\pi n}\left[c_n(z)-1\right]\right\}d\,z\,d\,y\,d\,x\,e_{nV}(\tau)\,d\,\tau-\frac{1}{2\pi L_y}\sum_{n=1}^{N}\frac{a_{nV}}{n^2}\int_0^t\int_0^{L_x}\left\{x\,s_n(2x)+\right.$$

$$\left.+L_x+\frac{L_x}{\pi n}\left[c_n(2x)-1\right]\right\}\int_0^{L_y}\int_0^{L_z}D_V(x,y,z,T)\left\{L_z+z\,s_n(2z)+\frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\}d\,z\left[1-c_n(2y)\right]\times$$

$$\times d\,y\,d\,x\,e_{nV}(\tau)\,d\,\tau\int_0^{L_z}D_V(x,y,z,T)\left\{L_z+z\,s_n(2z)+\frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\}d\,z\,d\,y\,d\,x\,e_{nV}(\tau)\,d\,\tau-$$

$$-\frac{1}{2\pi L_z}\sum_{n=1}^{N}\frac{a_{nV}}{n^2}\int_0^t\int_0^{L_x}\left\{L_x+x\,s_n(2x)+\frac{L_x}{2\pi n}\left[c_n(2x)-1\right]\right\}\int_0^{L_y}\left\{L_y+y\,s_n(2y)+\frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\}\times$$

$$\times \int_0^{L_z} \left[1-c_n(2z)\right] D_V(x,y,z,T)\, d\,z\,d\,y\,d\,x\, e_{nV}(\tau)\, d\,\tau - \sum_{n=1}^{N} a_{nV}^2 e_{nV}(2t) \int_0^{L_x} \left\{ L_x + \frac{L_x}{2\pi n}\left[c_n(2x)-1\right] + \right.$$

$$\left. + x\,s_n(2x)\right\} \int_0^{L_y} \left\{ L_y + y\,s_n(2y) + \frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\} \int_0^{L_z} k_{V,V}(x,y,z,T) \left\{ L_z + \frac{L_z}{2\pi n}\left[c_n(2z)-1\right] + \right.$$

$$\left. + z\,s_n(2z)\right\} d\,z\,d\,y\,d\,x - \sum_{n=1}^{N} a_{nI} a_{nV} e_{nI}(t) e_{nV}(t) \int_0^{L_x} \left\{ L_x + x\,s_n(2x) + \frac{L_x}{2\pi n}\left[c_n(2x)-1\right]\right\} \int_0^{L_y} \left\{ L_y + \right.$$

$$\left. + y\,s_n(2y) + \frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\} \int_0^{L_z} k_{I,V}(x,y,z,T) \left\{ L_z + z\,s_n(2z) + \frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\} d\,z \times$$

$$\times d\,y\,d\,x + \sum_{n=1}^{N} \int_0^{L_x} \left\{ x\,s_n(x) + \frac{L_x}{\pi n}\left[c_n(x)-1\right]\right\} \int_0^{L_y} \left\{ y\,s_n(y) + \frac{L_y}{\pi n}\left[c_n(y)-1\right]\right\} \int_0^{L_z} f_V(x,y,z,T) \times$$

$$\times \left\{ L_z + z\,s_n(2z) + \frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\} d\,z\,d\,y\,d\,x\,.$$

In the final form relations for required parameters could be written as

$$a_{nI} = -\frac{b_3 + A}{4\,b_4} \pm \sqrt{\frac{(b_3 + A)^2}{4} - 4\,b_4\left(y + \frac{b_3 y - \gamma_{nV}\lambda_{nI}^2}{A}\right)},\quad a_{nV} = -\frac{\gamma_{nI}\,a_{nI}^2 + \delta_{nI}\,a_{nI} + \lambda_{nI}}{\chi_{nI}\,a_{nI}},$$

where $\gamma_{n\rho} = e_{n\rho}(2t) \int_0^{L_x}\int_0^{L_y}\int_0^{L_z} k_{\rho,\rho}(x,y,z,T) \left\{ L_x + x\,s_n(2x) + \frac{L_x}{2\pi n}\left[c_n(2x)-1\right]\right\} \left\{ y\,s_n(2y) + L_y + \right.$

$$\left. + \frac{L_y}{2\pi n}\left[c_n(2y)-1\right]\right\} \left\{ L_z + z\,s_n(2z) + \frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\} d\,z\,d\,y\,d\,x\,,\quad \delta_{n\rho} = \frac{1}{2\pi\, L_x n^2} \int_0^t e_{n\rho}(\tau) \times$$

$$\times \int_0^{L_x}\int_0^{L_y} \left\{ y\,s_n(y) + \frac{L_y}{2\pi n}\left[c_n(y)-1\right]\right\} \int_0^{L_z} \left\{ z\,s_n(z) + \frac{L_z}{2\pi n}\left[c_n(z)-1\right]\right\} D_\rho(x,y,z,T)\, d\,z\,d\,y\,\left[1 - \right.$$

$$\left. - c_n(2x)\right] d\,x\,d\,\tau + \frac{1}{2\pi\, L_y n^2} \int_0^t e_{n\rho}(\tau) \int_0^{L_x} \left\{ L_x + x\,s_n(2x) + \frac{L_x}{\pi n}\left[c_n(2x)-1\right]\right\} \int_0^{L_y} \left[1-c_n(2y)\right] \int_0^{L_z} \left\{ L_z + \right.$$

$$\left. + z\,s_n(2z) + \frac{L_z}{2\pi n}\left[c_n(2z)-1\right]\right\} D_\rho(x,y,z,T)\, d\,z\,d\,y\,d\,x\,d\,\tau + \frac{1}{2\pi\, L_z n^2} \int_0^t e_{n\rho}(\tau) \int_0^{L_x} \left\{ x\,s_n(2x) + \right.$$

$$\left. + L_x + \frac{L_x}{\pi n}\left[c_n(2x)-1\right]\right\} \int_0^{L_y} \left\{ L_y + y\,s_n(y) + \frac{L_y}{2\pi n}\left[c_n(y)-1\right]\right\} \int_0^{L_z} \left[1 - c_n(2z)\right] D_\rho(x,y,z,T)\, d\,z\,\times$$

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$$\times d\,y\,d\,x\,d\,\tau-\frac{L_x^2L_y^2L_z^2}{\pi^5n^6}e_{n\rho}(t),\ \chi_{nIV}=\int\limits_0^{L_x}\left\{x\,s_n(x)+\frac{L_x}{\pi\,n}[c_n(x)-1]\right\}\int\limits_0^{L_y}\left\{L_y+\frac{L_y}{2\pi\,n}[c_n(2y)-1]+\right.$$

$$\left.+y\,s_n(2y)\right\}\int\limits_0^{L_z}k_{I,V}(x,y,z,T)\left\{L_z+z\,s_n(2z)+\frac{L_z}{2\pi\,n}[c_n(2z)-1]\right\}d\,z\,d\,y\,d\,x\,e_{nI}(t)\,e_{nV}(t),$$

$$\lambda_{n\rho}=\int\limits_0^{L_x}\left\{x\,s_n(x)+\frac{L_x}{\pi\,n}[c_n(x)-1]\right\}\int\limits_0^{L_y}\left\{y\,s_n(y)+\frac{L_y}{\pi\,n}[c_n(y)-1]\right\}\int\limits_0^{L_z}\left\{z\,s_n(z)+\frac{L_z}{\pi\,n}[c_n(z)-1]\right\}\times$$

$$\times f_\rho(x,y,z,T)d\,z\,d\,y\,d\,x,\ b_4=\gamma_{nV}\gamma_{nI}^2-\gamma_{nI}\chi_{nI}^2,\ b_3=2\gamma_{nV}\gamma_{nI}\delta_{nI}-\delta_{nI}\chi_{nI}^2-\delta_{nV}\chi_{nI}\gamma_{nI},$$

$$A=\sqrt{8y+b_3^2-4b_2},\ b_2=\gamma_{nV}\delta_{nI}^2+2\lambda_{nI}\gamma_{nV}\gamma_{nI}-\delta_{nV}\chi_{nI}\delta_{nI}+(\lambda_{nV}-\lambda_{nI})\chi_{nI}^2,\ b_1=2\lambda_{nI}\times$$

$$\times\gamma_{nV}\delta_{nI}-\delta_{nV}\chi_{nI}\lambda_{nI},\ y=\sqrt[3]{\sqrt{q^2+p^3}-q}-\sqrt[3]{\sqrt{q^2+p^3}+q}-\frac{b_3}{3b_4},\ p=\frac{3b_2b_4-b_3^2}{9b_4^2},$$

$$q=\left(2b_3^3-9b_2b_3+27b_1b_4^2\right)/54b_4^3.$$

We determine spatio-temporal distributions of concentrations of complexes of radiation defects in the following form

$$\Phi_{\rho 0}(x,y,z,t)=\sum_{n=1}^{N}a_{n\Phi\rho}\,c_n(x)\,c_n(y)\,c_n(z)\,e_{n\rho}(t),$$

where $a_{n\Phi\rho}$ are not yet known coefficients. Let us previously transform the Eqs.(6) to the following integro-differential form

$$\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}\Phi_I(u,v,w,t)d\,w\,d\,v\,d\,u=\int\limits_0^t\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}D_{\Phi I}(x,v,w,T)\frac{\partial\Phi_I(x,v,w,\tau)}{\partial x}d\,w\,d\,v\,d\,\tau\times$$

$$\times\frac{y\,z}{L_yL_z}+\frac{x\,z}{L_xL_z}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_z}^{z}D_{\Phi I}(u,y,w,T)\frac{\partial\Phi_I(u,y,w,\tau)}{\partial y}d\,w\,d\,u\,d\,\tau+\frac{x\,y}{L_xL_y}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}D_{\Phi I}(u,v,z,T)\times$$

$$\times\frac{\partial\Phi_I(u,v,z,\tau)}{\partial z}d\,v\,d\,u\,d\,\tau+\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_{I,I}(u,v,w,T)I^2(u,v,w,\tau)d\,w\,d\,v\,d\,u-\quad(6a)$$

$$-\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_I(u,v,w,T)\,I(u,v,w,\tau)d\,w\,d\,v\,d\,u+\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}f_{\Phi I}(u,v,w)d\,w\,d\,v\,d\,u$$

$$\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}\Phi_V(u,v,w,t)d\,w\,d\,v\,d\,u=\int\limits_0^t\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}D_{\Phi V}(x,v,w,T)\frac{\partial\Phi_V(x,v,w,\tau)}{\partial x}d\,w\,d\,v\,d\,\tau\times$$

$$\times\frac{y\,z}{L_yL_z}+\frac{x\,z}{L_xL_z}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_z}^{z}D_{\Phi V}(u,y,w,T)\frac{\partial\Phi_V(u,y,w,\tau)}{\partial y}d\,w\,d\,u\,d\,\tau+\frac{x\,y}{L_xL_y}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}D_{\Phi V}(u,v,z,T)\times$$

$$\times\frac{\partial\Phi_V(u,v,z,\tau)}{\partial z}d\,v\,d\,u\,d\,\tau+\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_{V,V}(u,v,w,T)V^2(u,v,w,\tau)d\,w\,d\,v\,d\,u-$$

$$-\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_V(u,v,w,T)\,V(u,v,w,\tau)d\,w\,d\,v\,d\,u+\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}f_{\Phi V}(u,v,w)d\,w\,d\,v\,d\,u\,.$$

Substitution of the previously considered series in the Eqs.(6a) leads to the following form

$$-x\,y\,z\sum_{n=1}^{N}\frac{a_{n\Phi I}}{\pi^3n^3}s_n(x)\,s_n(y)\,s_n(z)\,e_{nI}(t)=-\frac{y\,z\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}n\,a_{n\Phi I}s_n(x)e_{nI}(t)\int\limits_0^t\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}c_n(v)c_n(w)\times$$

$$\times D_{\Phi I}(x,v,w,T)d\,w\,d\,v\,d\,\tau-\frac{x\,z\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}a_{n\Phi I}\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_z}^{z}c_n(u)c_n(w)\,D_{\Phi I}(u,v,w,T)\,d\,w\,d\,u\,d\,\tau\times$$

$$\times n\,s_n(y)e_{n\Phi I}(t)-\frac{x\,y\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}n\,a_{n\Phi I}\,s_n(z)e_{n\Phi I}(t)\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}c_n(u)c_n(v)\,D_{\Phi I}(u,v,z,T)\,d\,v\,d\,u\,d\,\tau+$$

$$+\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_{I,I}(u,v,w,T)I^2(u,v,w,\tau)d\,w\,d\,v\,d\,u+\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}f_{\Phi I}(u,v,w)d\,w\,d\,v\,d\,u\times$$

$$\times\frac{x\,y\,z}{L_xL_yL_z}-\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_I(u,v,w,T)\,I(u,v,w,\tau)d\,w\,d\,v\,d\,u$$

$$-x\,y\,z\sum_{n=1}^{N}\frac{a_{n\Phi V}}{\pi^3n^3}s_n(x)\,s_n(y)\,s_n(z)\,e_{nV}(t)=-\frac{y\,z\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}n\,a_{n\Phi V}s_n(x)e_{nV}(t)\int\limits_0^t\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}c_n(v)c_n(w)\times$$

$$\times D_{\Phi V}(x,v,w,T)\,d\,w\,d\,v\,d\,\tau-\frac{x\,z\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}n\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_z}^{z}c_n(u)c_n(w)\,D_{\Phi V}(u,v,w,T)\,d\,w\,d\,u\,d\,\tau\times$$

$$\times a_{n\Phi V}s_n(y)e_{n\Phi V}(t)-\frac{x\,y\,\pi}{L_xL_yL_z}\sum_{n=1}^{N}n\,s_n(z)e_{n\Phi V}(t)\int\limits_0^t\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}c_n(u)c_n(v)\,D_{\Phi V}(u,v,z,T)\,d\,v\,d\,u\,d\,\tau\times$$

$$\times a_{n\Phi V}+\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_{V,V}(u,v,w,T)V^2(u,v,w,\tau)d\,w\,d\,v\,d\,u+\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}f_{\Phi V}(u,v,w)d\,w\,d\,v\,d\,u\times$$

$$\times\frac{x\,y\,z}{L_xL_yL_z}-\frac{x\,y\,z}{L_xL_yL_z}\int\limits_{L_x}^{x}\int\limits_{L_y}^{y}\int\limits_{L_z}^{z}k_V(u,v,w,T)\,V(u,v,w,\tau)d\,w\,d\,v\,d\,u\,.$$

We determine coefficients $a_{n\Phi\rho}$ by using orthogonality condition on the scale of heterostructure. The condition gives us possibility to obtain relations to calculate $a_{n\Phi\rho}$ for any quantity N of terms of considered series. In the common case equations for the required coefficients could be written as

$$-\frac{L_x^2L_y^2L_z^2}{\pi^5}\sum_{n=1}^{N}\frac{a_{n\Phi I}}{n^6}e_{n\Phi I}(t)=-\frac{1}{2\pi\,L_x}\sum_{n=1}^{N}\int\limits_0^t\int\limits_0^{L_x}[1-c_n(2x)]\int\limits_0^{L_y}\left\{L_y+y\,s_n(2y)+\frac{L_y}{2\pi\,n}[c_n(2y)-1]\right\}\times$$

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$$\times \frac{a_{n\Phi I}}{n^2} \int_0^{L_z} D_{\Phi I}(x,y,z,T) \left\{ z\, s_n(z) + \frac{L_z}{2\pi n}[c_n(z)-1] \right\} d\,z\,d\,y\,d\,x\, e_{n\Phi I}(\tau)\, d\,\tau - \frac{1}{2\pi} \sum_{n=1}^{N} \int_0^t \int_0^{L_x} \{x\, s_n(2x) +$$

$$+ L_x + \frac{L_x}{2\pi n}[c_n(2x)-1]\} \int_0^{L_y} [1-c_n(2y)] \int_0^{L_z} D_{\Phi I}(x,y,z,T) \left\{ z\, s_n(z) + \frac{L_z}{2\pi n}[c_n(z)-1] \right\} d\,z\,d\,y\,d\,x \times$$

$$\times a_{n\Phi I} \frac{e_{n\Phi I}(\tau)}{n^2 L_y} d\,\tau - \frac{1}{2\pi L_x} \sum_{n=1}^{N} \frac{a_{n\Phi I}}{n^2} \int_0^t \int_0^{L_x} \left\{ x\, s_n(x) + \frac{L_x}{2\pi n}[c_n(x)-1] \right\} \int_0^{L_y} \left\{ y\, s_n(2y) + \frac{L_y}{2\pi n}[c_n(2y)-1] + \right.$$

$$\left. + L_y \right\} \int_0^{L_z} [1-c_n(2y)] D_{\Phi I}(x,y,z,T)\, d\,z\,d\,y\,d\,x\; e_{n\Phi I}(\tau) d\,\tau + \frac{1}{\pi^3} \sum_{n=1}^{N} \frac{a_{n\Phi I}}{n^3} \int_0^t e_{n\Phi I}(\tau) \int_0^{L_x} \left\{ \frac{L_x}{2\pi n}[c_n(x)-1] + \right.$$

$$\left. + x\, s_n(x) \right\} \int_0^{L_y} \left\{ y\, s_n(y) + \frac{L_y}{2\pi n}[c_n(y)-1] \right\} \int_0^{L_z} I^2(x,y,z,t) k_{I,I}(x,y,z,T) \left\{ \frac{L_z}{2\pi n}[c_n(z)-1] + \right.$$

$$\left. + z\, s_n(z) \right\} d\,z\,d\,y\,d\,x - \frac{1}{\pi^3} \sum_{n=1}^{N} \frac{a_{n\Phi I}}{n^3} \int_0^t e_{n\Phi I}(\tau) \int_0^{L_x} \left\{ x\, s_n(x) + \frac{L_x}{2\pi n}[c_n(x)-1] \right\} \int_0^{L_y} \left\{ \frac{L_y}{2\pi n}[c_n(y)-1] + \right.$$

$$\left. + y\, s_n(y) \right\} \int_0^{L_z} \left\{ z\, s_n(z) + \frac{L_z}{2\pi n}[c_n(z)-1] \right\} k_I(x,y,z,T) I\,(x,y,z,t) d\,z\,d\,y\,d\,x + \frac{1}{\pi^3} \sum_{n=1}^{N} \frac{a_{n\Phi I}}{n^3} \times$$

$$\times \int_0^t e_{n\Phi I}(\tau) \int_0^{L_x} \left\{ x\, s_n(x) + \frac{L_x}{2\pi n}[c_n(x)-1] \right\} \int_0^{L_y} \left\{ y\, s_n(y) + \frac{L_y}{2\pi n}[c_n(y)-1] \right\} \int_0^{L_z} \left\{ \frac{L_z}{2\pi n}[c_n(z)-1] + \right.$$

$$\left. + z\, s_n(z) \right\} f_{\Phi I}(x,y,z)\, d\,z\,d\,y\,d\,x$$

$$-\frac{L_x^2 L_y^2 L_z^2}{\pi^5} \sum_{n=1}^{N} \frac{a_{n\Phi V}}{n^6} e_{n\Phi V}(t) = -\frac{1}{2\pi L_x} \sum_{n=1}^{N} \int_0^t \int_0^{L_x} [1-c_n(2x)] \int_0^{L_y} \left\{ L_y + y\, s_n(2y) + \frac{L_y}{2\pi n}[c_n(2y)-1] \right\} \times$$

$$\times \frac{a_{n\Phi V}}{n^2} \int_0^{L_z} D_{\Phi V}(x,y,z,T) \left\{ z\, s_n(z) + \frac{L_z}{2\pi n}[c_n(z)-1] \right\} d\,z\,d\,y\,d\,x\, e_{n\Phi V}(\tau)\, d\,\tau - \frac{1}{2\pi} \sum_{n=1}^{N} \int_0^t \int_0^{L_x} \{x\, s_n(2x) +$$

$$+ L_x + \frac{L_x}{2\pi n}[c_n(2x)-1]\} \int_0^{L_y} [1-c_n(2y)] \int_0^{L_z} D_{\Phi V}(x,y,z,T) \left\{ z\, s_n(z) + \frac{L_z}{2\pi n}[c_n(z)-1] \right\} d\,z\,d\,y\,d\,x \times$$

$$\times a_{n\Phi V} \frac{e_{n\Phi V}(\tau)}{n^2 L_y} d\,\tau - \frac{1}{2\pi L_x} \sum_{n=1}^{N} \frac{a_{n\Phi V}}{n^2} \int_0^t \int_0^{L_x} \left\{ x\, s_n(x) + \frac{L_x}{2\pi n}[c_n(x)-1] \right\} \int_0^{L_y} \left\{ y\, s_n(2y) + \frac{L_y}{2\pi n}[c_n(2y)-1] + \right.$$

$$\left. + L_y \right\} \int_0^{L_z} [1-c_n(2y)] D_{\Phi V}(x,y,z,T)\, d\,z\,d\,y\,d\,x\; e_{n\Phi V}(\tau) d\,\tau + \frac{1}{\pi^3} \sum_{n=1}^{N} \frac{a_{n\Phi V}}{n^3} \int_0^t e_{n\Phi V}(\tau) \int_0^{L_x} \left\{ \frac{L_x}{2\pi n}[c_n(x)-1] + \right.$$

$$+x\,s_n(x)\}\int_0^{L_y}\left\{y\,s_n(y)+\frac{L_y}{2\pi n}[c_n(y)-1]\right\}\int_0^{L_z}V^2(x,y,z,t)\,k_{V,V}(x,y,z,T)\left\{\frac{L_z}{2\pi n}[c_n(z)-1]+\right.$$

$$\left.+z\,s_n(z)\right\}d\,z\,d\,y\,d\,x-\frac{1}{\pi^3}\sum_{n=1}^{N}\frac{a_{n\Phi V}}{n^3}\int_0^t e_{n\Phi V}(\tau)\int_0^{L_x}\left\{x\,s_n(x)+\frac{L_x}{2\pi n}[c_n(x)-1]\right\}\int_0^{L_y}\left\{\frac{L_y}{2\pi n}[c_n(y)-1]+\right.$$

$$\left.+y\,s_n(y)\right\}\int_0^{L_z}\left\{z\,s_n(z)+\frac{L_z}{2\pi n}[c_n(z)-1]\right\}k_V(x,y,z,T)V(x,y,z,t)d\,z\,d\,y\,d\,x+\frac{1}{\pi^3}\sum_{n=1}^{N}\frac{a_{n\Phi V}}{n^3}\times$$

$$\times\int_0^t e_{n\Phi V}(\tau)\int_0^{L_x}\left\{x\,s_n(x)+\frac{L_x}{2\pi n}[c_n(x)-1]\right\}\int_0^{L_y}\left\{y\,s_n(y)+\frac{L_y}{2\pi n}[c_n(y)-1]\right\}\int_0^{L_z}\left\{\frac{L_z}{2\pi n}[c_n(z)-1]+\right.$$

$$\left.+z\,s_n(z)\right\}f_{\Phi V}(x,y,z)\,d\,z\,d\,y\,d\,x\,.$$

DISCUSSION

In this section we used relations calculated in the previous section to analyze spatio -temporal distributions of concentrations of dopant and radiation defects. Typical spatial distributions of concentrations of infused and implanted dopants in doped and nearest layers are presented on Figures 2 and 3, respectively for different values of difference between values of dopant diffusion coefficients in the layers. The distributions have been calculated for the case, when value of dopant diffusion coefficient in doped layer is larger, than value of dopant diffusion coefficient in undoped layer. Typical spatial distributions of concentrations of

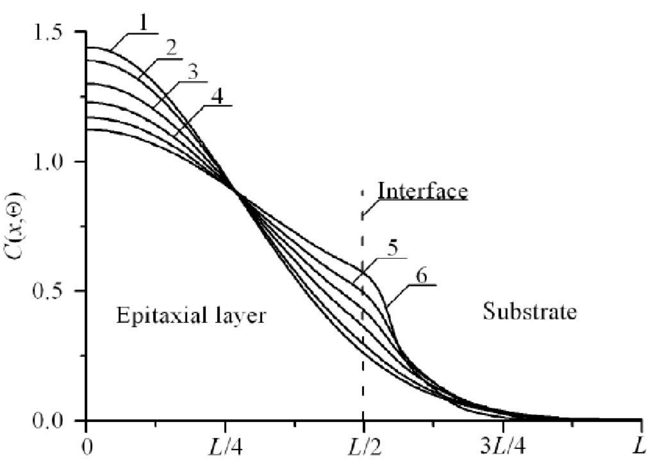

Figure 2 : Distributions of concentration of infused dopant in heterostructure from Figure 1 in direction, which is perpendicular to interface between epitaxial layer substrate. Increasing of number of curve corresponds to increasing of difference between values of dopant diffusion coefficient in layers of heterostructure under condition, when value of dopant diffusion coefficient in epitaxial layer is larger, than value of dopant diffusion coefficient in substrate

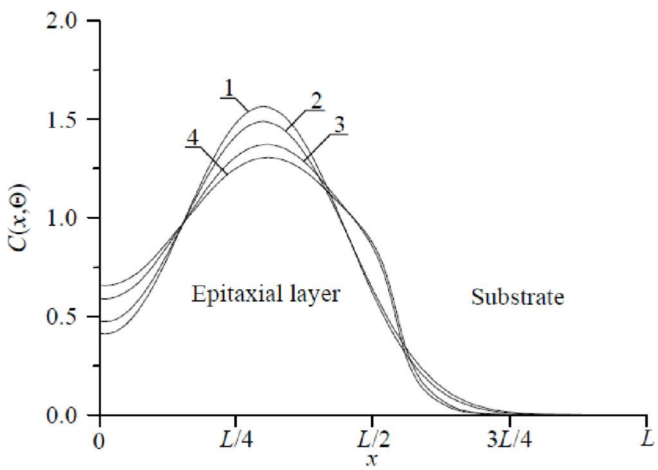

Figure 3 : Distributions of concentration of implanted dopant in heterostructure from Figure 1 in direction, which is perpendicular to interface between epitaxial layer substrate. Curves 1 and 3 corresponds to annealing time $\Theta = 0.0048(L_x^2+L_y^2+L_z^2)/D_0$. Curves 2 and 4 corresponds to annealing time $\Theta = 0.0057(L_x^2+L_y^2+L_z^2)/D_0$. Curves 1 and 2 corresponds to homogenous sample. Curves 3 and 4 corresponds to heterostructure under condition, when value of dopant diffusion coefficient in epitaxial layer is larger, than value of dopant diffusion coefficient in substrate

radiation defects are similar with spatial distributions of concentrations of dopant in Figure 3. The Figures 2 and 3 are illustrated possibility to manufacture more thin field-effect heterotransistors. At the same time homogeneity of distribution of concentration of dopant increases. In this case it is possible to decrease local overheat of doped materials during behavior of electric current. The decreasing gives us possibility

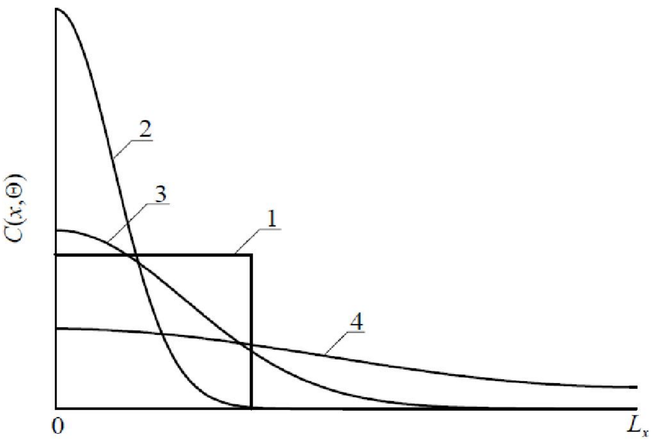

Figure 4 : Spatial distributions of dopant in heterostructure after dopant infusion. Curve 1 is idealized distribution of dopant. Curves 2-4 are real distributions of dopant for different values of annealing time. Increasing of number of curve corresponds to increasing of annealing time

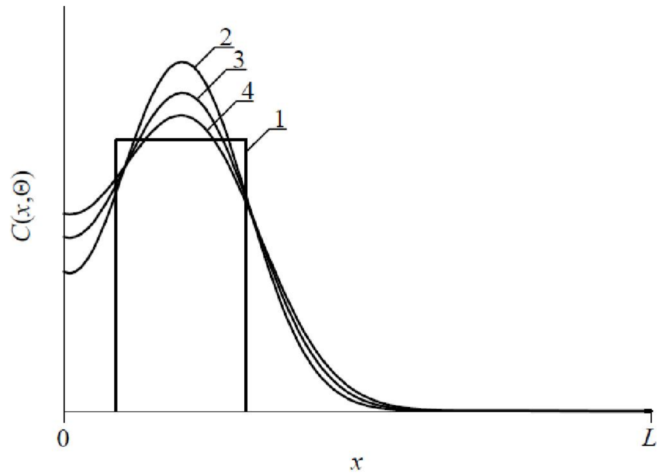

Figure 5 : Spatial distributions of dopant in heterostructure after ion implantation. Curve 1 is idealized distribution of dopant. Curves 2-4 are real distributions of dopant for different values of annealing time. Increasing of number of curve corresponds to increasing of annealing time

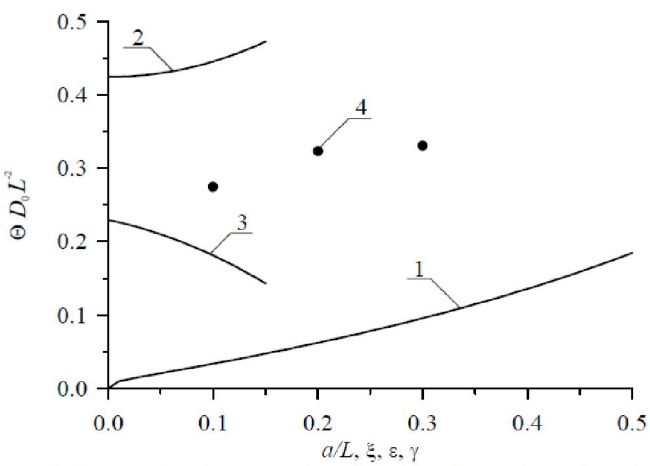

Figure 6 : Dependences of dimensionless optimal annealing time for doping by diffusion, which have been obtained by minimization of mean-squared error, on several parameters. Curve 1 is the dependence of dimensionless optimal annealing time on the relation a/L and ξ = γ = 0 for equal to each other values of dopant diffusion coefficient in all parts of heterostructure. Curve 2 is the dependence of dimensionless optimal annealing time on value of parameter ε for a/L=1/2 and ξ = γ = 0. Curve 3 is the dependence of dimensionless optimal annealing time on value of parameter ξ for a/L=1/2 and ε = γ = 0. Curve 4 is the dependence of dimensionless optimal annealing time on value of parameter γ for a/L=1/2 and ε = ξ = 0

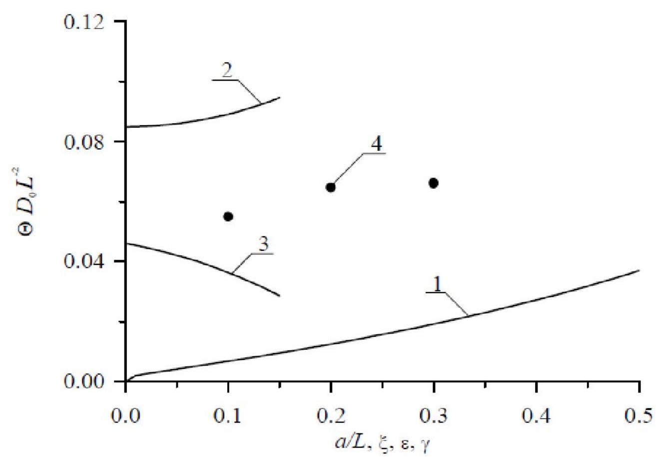

Figure 7 : Dependences of dimensionless optimal annealing time for doping by ion implantation, which have been obtained by minimization of mean-squared error, on several parameters. Curve 1 is the dependence of dimensionless optimal annealing time on the relation a/L and ξ = γ = 0 for equal to each other values of dopant diffusion coefficient in all parts of heterostructure. Curve 2 is the dependence of dimensionless optimal annealing time on value of parameter ε for a/L=1/2 and ξ = γ = 0. Curve 3 is the dependence of dimensionless optimal annealing time on value of parameter ξ for a/L=1/2 and ε = γ = 0. Curve 4 is the dependence of dimensionless optimal annealing time on value of parameter γ for a/L=1/2 and ε = ξ = 0

to increase density of electric current (if necessary) for fixed value tolerance for local overheats or to decrease dimensions of the considered transistor. It should be noted, that radiation damage of doped materials leads to additional increasing of homogeneity of distribution of concentration of dopant[29].

It should be also noted, that framework the approach it is necessary to optimize of annealing. Reason of the optimization is following. If annealing time is small dopant have not enough time to achieve nearest interface between layers of heterostructure. In this situation one have not possibility to obtain any changes of distribution of concentration of dopant in comparison with the distribution in homogenous sample. If annealing time is large, distribution of concentration of dopant became too large. We determine compromise annealing time framework recently introduced criterion[26-35]. Framework the criterion we approximate real distribution of concentration of dopant by step-wise function ψ (x,y,z) (see Figures 4 and 5). Farther we determine required optimal value of annealing time by minimization of mean-squared error

$$U = \frac{1}{L_x L_y L_z} \int_0^{L_x} \int_0^{L_y} \int_0^{L_z} \left[C\left(x, y, z, \Theta\right) - \psi\left(x, y, z\right)\right] d\,z\,d\,y\,d\,x . \quad (8)$$

Dependences of optimal annealing times are presented on Figures 6 and 7 for diffusion and ion types of doping, respectively. The figures show, that values of optimal annealing time for ion type of doping is smaller, than for diffusion one. Reason of this difference is necessity to anneal radiation defects. If dopant did not achieves the interface during the annealing, additional annealing of dopant attracted an interest. The Figure 7 shows dependences of the additional annealing time.

It should be noted, that using diffusion type of doping did not leads to so serous damage of materials as one can obtain during ion implantation. However ion implantation gives us possibility gives us possibility to decrease mismatch-induced stress in heterostructure[36].

CONCLUSION

In this paper we introduce an approach to manufacture field-effect heterotransistors with several channels. The approach based on manufacturing of a heterostructure with required configuration, doping by diffusion or ion implantation of required parts of the heterostructure and optimization of annealing of dopant and/or radiation defects. At the same time we consider an analytical approach to model technological processes. Framework the approach gives a possibility to manage without stitching decisions on the interfaces between layers heterostructures.

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