

# ANALYSIS OF MANUFACTURING OF VOLTAGE RESTORE TO INCREASE DENSITY OF ELEMENTS OF THE CIRCUIT

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## ABSTRACT

*We introduce an approach for increasing density of voltage restore elements. The approach based on manufacturing of a heterostructure, which consist of a substrate and an epitaxial layer with special configuration. Several required sections of the layer should be doped by diffusion or ion implantation. After that dopants and/or radiation defects should be annealed.*

## KEYWORDS

*Voltage restore; optimization of manufacturing; increasing of density of elements*

## 1. INTRODUCTION

Now several actual questions of solid state electronics could be formulated. One of them is increasing of density of elements of integrated circuits. The increasing of density leads to necessity of decreasing of dimensions of these elements. Recently are have been elaborated several approaches for the above decreasing. One of them is manufacturing of solid state electronic devices in thin film heterostructures [1-4]. Other approach based on doping of required areas of a semiconductor sample or a heterostructure. After the doping one should consider laser or microwave annealing of dopant and/or radiation defects [5-7]. Due to these types of annealing one can find inhomogenous distribution of temperature in doped area. In this situation one can find inhomogeneity of doped structure and consequently to decreasing of dimensions of the considered elements. An alternative approach of changing of properties of materials before or during doping is radiation processing [8,9].

In this paper we consider an approach to manufacture of a voltage restore. We illustrate the approach by considering a heterostructure. The heterostructure consist of a substrate and an epitaxial layer. We consider that several sections take a place framework the epitaxial layer. We consider doping these sections by diffusion or ion implantation. The doping gives a possibility to obtain  $p$  or  $n$  type of conductivity during process of manufacture of diodes and bipolar transistors so as it is shown on Fig. 1. After finishing the doping we consider annealing of dopant and/or radiation defects. Our main aim is analysis of redistribution of dopant and/or radiation defects during annealing.

## 2. METHOD OF SOLUTION

We calculate distribution of concentration of dopant in space and time by solving the following boundary problem [10-12]

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

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

$$\frac{\partial C(x, y, z, t)}{\partial z} \Big|_{z=0} = 0, \frac{\partial C(x, y, z, t)}{\partial z} \Big|_{z=L_z} = 0, C(x, y, z, 0) = f_C(x, y, z).$$

The function  $C(x, y, z, t)$  describes distribution of concentration of dopant in space and time;  $T$

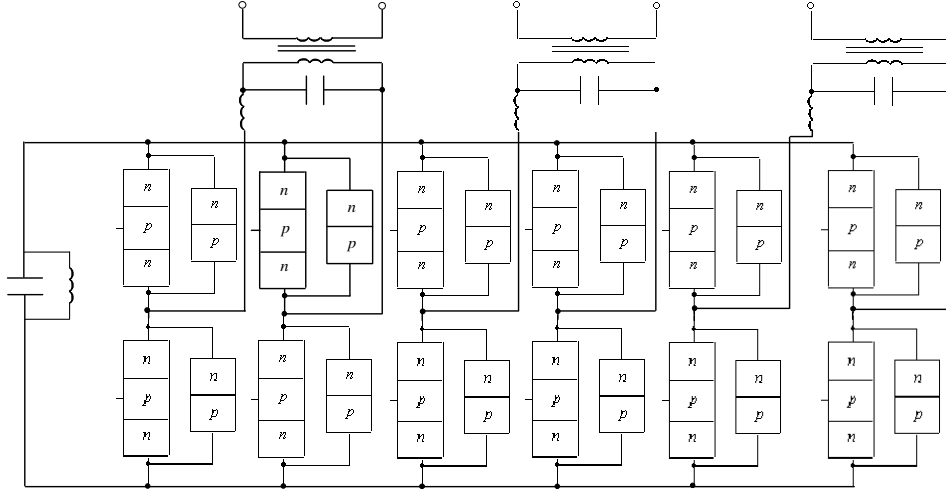


Fig. 1. Structure of voltage restorer.

View from top describes the temperature of annealing;  $D_C$  describes the dopant diffusion coefficient. Dopant diffusion coefficient is different in different materials of heterostructure. The diffusion coefficient will be also changed with changing of temperature. We approximate dopant diffusion coefficient by the following function based on Refs. [13-15]

$$D_C = D_L(x, y, z, T) \left[ 1 + \xi \frac{C^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \right] \left[ 1 + \zeta_1 \frac{V(x, y, z, t)}{V^*} + \zeta_2 \frac{V^2(x, y, z, t)}{(V^*)^2} \right] \quad (3)$$

Function  $D_L(x, y, z, T)$  describes spatial and temperature dependences of diffusion coefficient; function  $P(x, y, z, T)$  describes limit of solubility of dopant; parameter  $\gamma$  is differ in different materials and assume integer values; function  $V(x, y, z, t)$  describes distribution of concentration of vacancies with equilibrium distribution  $V^*$ . One can find detailed concentrational dependence of dopant diffusion coefficient in Ref. [13]. It should be noted, that using diffusive type of doping did not leads to radiation damage. In this situation  $\zeta_1 = \zeta_2 = 0$ . We determine spatio-temporal distributions of concentrations of point radiation defects by solution the following system of equations [14,15]

$$\begin{aligned} \frac{\partial I(x, y, z, t)}{\partial t} &= \frac{\partial}{\partial x} \left[ D_I(x, y, z, T) \frac{\partial I(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ D_I(x, y, z, T) \frac{\partial I(x, y, z, t)}{\partial y} \right] - k_{I,I}(x, y, z, T) \times \\ &\times I^2(x, y, z, t) + \frac{\partial}{\partial z} \left[ D_I(x, y, z, T) \frac{\partial I(x, y, z, t)}{\partial z} \right] - k_{I,V}(x, y, z, T) I(x, y, z, t) V(x, y, z, t) \quad (4) \\ \frac{\partial V(x, y, z, t)}{\partial t} &= \frac{\partial}{\partial x} \left[ D_V(x, y, z, T) \frac{\partial V(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ D_V(x, y, z, T) \frac{\partial V(x, y, z, t)}{\partial y} \right] - k_{V,V}(x, y, z, T) \times \\ &\times V^2(x, y, z, t) + \frac{\partial}{\partial z} \left[ D_V(x, y, z, T) \frac{\partial V(x, y, z, t)}{\partial z} \right] - k_{I,V}(x, y, z, T) I(x, y, z, t) V(x, y, z, t) \end{aligned}$$

with boundary and initial conditions

$$\begin{aligned} \left. \frac{\partial \rho(x, y, z, t)}{\partial x} \right|_{x=0} = 0, \quad \left. \frac{\partial \rho(x, y, z, t)}{\partial x} \right|_{x=L_x} = 0, \quad \left. \frac{\partial \rho(x, y, z, t)}{\partial y} \right|_{y=0} = 0, \quad \left. \frac{\partial \rho(x, y, z, t)}{\partial y} \right|_{y=L_y} = 0, \\ \left. \frac{\partial \rho(x, y, z, t)}{\partial z} \right|_{z=0} = 0, \quad \left. \frac{\partial \rho(x, y, z, t)}{\partial z} \right|_{z=L_z} = 0, \quad \rho(x, y, z, 0) = f_p(x, y, z). \end{aligned} \quad (5)$$

Here  $\rho=I, V$ ; function  $I(x, y, z, t)$  describes distribution of concentration of radiation interstitials in space and time; functions  $D_{\rho}(x, y, z, T)$  describe spatio-temperature dependences of the diffusion coefficients of point radiation defects; terms  $V^2(x, y, z, t)$  and  $I^2(x, y, z, t)$  describe generation divacancies and diinterstitials, respectively; function  $k_{I,V}(x, y, z, T)$  describes spatio-temperature dependence of recombination parameter of point radiation defects; functions  $k_{I,I}(x, y, z, T)$  and  $k_{V,V}(x, y, z, T)$  describe spatio-temperature dependence of parameters of generation of simplest complexes of point radiation defects.

We calculate distributions of concentrations of divacancies  $\Phi_V(x, y, z, t)$  and dinterstitials  $\Phi_I(x, y, z, t)$  in space and time by solving the following system of equations [14,15]

$$\begin{aligned} \frac{\partial \Phi_I(x, y, z, t)}{\partial t} &= \frac{\partial}{\partial x} \left[ D_{\Phi_I}(x, y, z, T) \frac{\partial \Phi_I(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ D_{\Phi_I}(x, y, z, T) \frac{\partial \Phi_I(x, y, z, t)}{\partial y} \right] + \\ &+ \frac{\partial}{\partial z} \left[ D_{\Phi_I}(x, y, z, T) \frac{\partial \Phi_I(x, y, z, t)}{\partial z} \right] + k_{I,I}(x, y, z, T) I^2(x, y, z, t) - k_I(x, y, z, T) I(x, y, z, t) \quad (6) \\ \frac{\partial \Phi_V(x, y, z, t)}{\partial t} &= \frac{\partial}{\partial x} \left[ D_{\Phi_V}(x, y, z, T) \frac{\partial \Phi_V(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ D_{\Phi_V}(x, y, z, T) \frac{\partial \Phi_V(x, y, z, t)}{\partial y} \right] + \\ &+ \frac{\partial}{\partial z} \left[ D_{\Phi_V}(x, y, z, T) \frac{\partial \Phi_V(x, y, z, t)}{\partial z} \right] + k_{V,V}(x, y, z, T) V^2(x, y, z, t) - k_V(x, y, z, T) V(x, y, z, t) \end{aligned}$$

with boundary and initial conditions

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

$$\left. \frac{\partial \Phi_\rho(x, y, z, t)}{\partial z} \right|_{z=0} = 0, \quad \left. \frac{\partial \Phi_\rho(x, y, z, t)}{\partial z} \right|_{z=L_z} = 0, \quad \Phi_I(x, y, z, 0) = f_{\Phi_I}(x, y, z), \quad \Phi_V(x, y, z, 0) = f_{\Phi_V}(x, y, z). \quad (7)$$

Function  $D_{\Phi\rho}(x, y, z, T)$  describes spatio-temperature dependences of diffusion coefficients of the considered complexes of radiation defects; function  $k_I(x, y, z, T)$  and  $k_V(x, y, z, T)$  describes spatio-temperature dependences of parameters of decay of these complexes.

We used recently elaborated approach [16,17] to calculate distributions of concentrations of point radiation defects in space and time. To use the approach we shall transform spatio-temperature dependences of diffusion coefficients to the following form:  $D_\rho(x, y, z, T) = D_{0\rho} [1 + \varepsilon_\rho g_\rho(x, y, z, T)]$ . Here  $D_{0\rho}$  are the average values of diffusion coefficients,  $0 \leq \varepsilon_\rho < 1$ ,  $|g_\rho(x, y, z, T)| \leq 1$ ,  $\rho = I, V$ . We used the same transformation of approximations of recombination parameters of point defects and generation parameters of their complexes:  $k_{I,V}(x, y, z, T) = k_{0I,V} [1 + \varepsilon_{I,V} g_{I,V}(x, y, z, T)]$ ,  $k_{I,I}(x, y, z, T) = k_{0I,I} [1 + \varepsilon_{I,I} g_{I,I}(x, y, z, T)]$  and  $k_{V,V}(x, y, z, T) = k_{0V,V} [1 + \varepsilon_{V,V} g_{V,V}(x, y, z, T)]$ , where  $k_{0\rho 1, \rho 2}$  are their average values,  $0 \leq \varepsilon_{I,V} < 1$ ,  $0 \leq \varepsilon_{I,I} < 1$ ,  $0 \leq \varepsilon_{V,V} < 1$ ,  $|g_{I,V}(x, y, z, T)| \leq 1$ ,  $|g_{I,I}(x, y, z, T)| \leq 1$ ,  $|g_{V,V}(x, y, z, T)| \leq 1$ . Let us introduce the following dimensionless variables:  $\chi = x/L_x$ ,  $\eta = y/L_y$ ,  $\phi = z/L_z$ ,  $\tilde{I}(x, y, z, t) = I(x, y, z, t)/I^*$ ,  $\tilde{V}(x, y, z, t) = V(x, y, z, t)/V^*$ ,  $\Omega_\rho = L^2 k_{0\rho, \rho} / \sqrt{D_{0I} D_{0V}}$ ,  $\omega = L^2 k_{0I,V} / \sqrt{D_{0I} D_{0V}}$ ,  $\vartheta = \sqrt{D_{0I} D_{0V}} t / L^2$ . Now we can transform boundary problem Eqs.(4) and (5) to the following form

$$\begin{aligned} \frac{\partial \tilde{I}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \frac{D_{0I}}{\sqrt{D_{0I} D_{0V}}} \frac{\partial}{\partial \chi} \left\{ [1 + \varepsilon_I g_I(\chi, \eta, \phi, T)] \frac{\partial \tilde{I}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right\} + \frac{D_{0I}}{\sqrt{D_{0I} D_{0V}}} \frac{\partial}{\partial \eta} \left\{ \frac{\partial \tilde{I}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right\} \times \\ &\times [1 + \varepsilon_I g_I(\chi, \eta, \phi, T)] + \frac{D_{0I}}{\sqrt{D_{0I} D_{0V}}} \frac{\partial}{\partial \phi} \left\{ [1 + \varepsilon_I g_I(\chi, \eta, \phi, T)] \frac{\partial \tilde{I}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right\} - \tilde{I}(\chi, \eta, \phi, \vartheta) \times \\ &\times \omega [1 + \varepsilon_{I,V} g_{I,V}(\chi, \eta, \phi, T)] \tilde{V}(\chi, \eta, \phi, \vartheta) - \Omega_I [1 + \varepsilon_{I,I} g_{I,I}(\chi, \eta, \phi, T)] \tilde{I}^2(\chi, \eta, \phi, \vartheta) \quad (8) \end{aligned}$$

$$\begin{aligned} \frac{\partial \tilde{V}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \frac{D_{0V}}{\sqrt{D_{0I} D_{0V}}} \frac{\partial}{\partial \chi} \left\{ [1 + \varepsilon_V g_V(\chi, \eta, \phi, T)] \frac{\partial \tilde{V}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right\} + \frac{D_{0V}}{\sqrt{D_{0I} D_{0V}}} \frac{\partial}{\partial \eta} \left\{ \frac{\partial \tilde{V}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right\} \times \\ &\times [1 + \varepsilon_V g_V(\chi, \eta, \phi, T)] + \frac{D_{0V}}{\sqrt{D_{0I} D_{0V}}} \frac{\partial}{\partial \phi} \left\{ [1 + \varepsilon_V g_V(\chi, \eta, \phi, T)] \frac{\partial \tilde{V}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right\} - \tilde{V}(\chi, \eta, \phi, \vartheta) \times \\ &\times \omega [1 + \varepsilon_{I,V} g_{I,V}(\chi, \eta, \phi, T)] \tilde{I}(\chi, \eta, \phi, \vartheta) - \Omega_V [1 + \varepsilon_{V,V} g_{V,V}(\chi, \eta, \phi, T)] \tilde{V}^2(\chi, \eta, \phi, \vartheta) \\ \frac{\partial \tilde{\rho}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \Big|_{\chi=0} &= 0, \quad \frac{\partial \tilde{\rho}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \Big|_{\chi=1} = 0, \quad \frac{\partial \tilde{\rho}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \Big|_{\eta=0} = 0, \quad \frac{\partial \tilde{\rho}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \Big|_{\eta=1} = 0, \\ \frac{\partial \tilde{\rho}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \Big|_{\phi=0} &= 0, \quad \frac{\partial \tilde{\rho}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \Big|_{\phi=1} = 0, \quad \tilde{\rho}(\chi, \eta, \phi, \vartheta) = \frac{f_\rho(\chi, \eta, \phi, \vartheta)}{\rho^*}. \quad (9) \end{aligned}$$

We calculate solutions of boundary problem Eqs.(8) and (9) by using recently introduced approach [16,17]. In this situation we used the following power series

$$\tilde{\rho}(\chi, \eta, \phi, \vartheta) = \sum_{i=0}^{\infty} \varepsilon_{\rho}^i \sum_{j=0}^{\infty} \omega^j \sum_{k=0}^{\infty} \Omega_{\rho}^k \tilde{\rho}_{ijk}(\chi, \eta, \phi, \vartheta). \quad (10)$$

We substitute the series (10) into the boundary problem Eqs.(8) and (9). After that we obtain equations for initial-order approximations of point defects concentration  $\tilde{I}_{000}(\chi, \eta, \phi, \vartheta)$  and  $\tilde{V}_{000}(\chi, \eta, \phi, \vartheta)$  and corrections for them  $\tilde{I}_{ijk}(\chi, \eta, \phi, \vartheta)$  and  $\tilde{V}_{ijk}(\chi, \eta, \phi, \vartheta)$ ,  $i \geq 1, j \geq 1, k \geq 1$ . The equations are presented in the Appendix. We obtain solution of the above equations by the standard Fourier approach [18,19]. The solutions are presented in the Appendix.

Farther we calculate distributions of concentrations of simplest complexes of point radiation defects in space and time. To determine the distributions we transform approximations of diffusion coefficients in the following form:  $D_{\phi\rho}(x, y, z, T) = D_{0\phi\rho}[1 + \varepsilon_{\phi\rho} g_{\phi\rho}(x, y, z, T)]$ . Here  $D_{0\phi\rho}$  describe average values of diffusion coefficients. In this situation the Eqs.(6) could be written as

$$\begin{aligned} \frac{\partial \Phi_I(x, y, z, t)}{\partial t} &= D_{0\phi I} \frac{\partial}{\partial x} \left\{ [1 + \varepsilon_{\phi I} g_{\phi I}(x, y, z, T)] \frac{\partial \Phi_I(x, y, z, t)}{\partial x} \right\} + D_{0\phi I} \frac{\partial}{\partial y} \left\{ \frac{\partial \Phi_I(x, y, z, t)}{\partial y} \times \right. \\ &\quad \left. \times [1 + \varepsilon_{\phi I} g_{\phi I}(x, y, z, T)] \right\} + D_{0\phi I} \frac{\partial}{\partial z} \left\{ [1 + \varepsilon_{\phi I} g_{\phi I}(x, y, z, T)] \frac{\partial \Phi_I(x, y, z, t)}{\partial z} \right\} - k_I(x, y, z, T) \times \\ &\quad \times I(x, y, z, t) + k_{I,I}(x, y, z, T) I^2(x, y, z, t) \\ \frac{\partial \Phi_V(x, y, z, t)}{\partial t} &= D_{0\phi V} \frac{\partial}{\partial x} \left\{ [1 + \varepsilon_{\phi V} g_{\phi V}(x, y, z, T)] \frac{\partial \Phi_V(x, y, z, t)}{\partial x} \right\} + D_{0\phi V} \frac{\partial}{\partial y} \left\{ \frac{\partial \Phi_V(x, y, z, t)}{\partial y} \times \right. \\ &\quad \left. \times [1 + \varepsilon_{\phi V} g_{\phi V}(x, y, z, T)] \right\} + D_{0\phi V} \frac{\partial}{\partial z} \left\{ [1 + \varepsilon_{\phi V} g_{\phi V}(x, y, z, T)] \frac{\partial \Phi_V(x, y, z, t)}{\partial z} \right\} + k_{I,I}(x, y, z, T) \times \\ &\quad \times I^2(x, y, z, t) - k_I(x, y, z, T) I(x, y, z, t). \end{aligned}$$

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

$$\Phi_{\rho}(x, y, z, t) = \sum_{i=0}^{\infty} \varepsilon_{\phi\rho}^i \Phi_{\rho i}(x, y, z, t). \quad (11)$$

Now we substitute series (11) into Eqs.(6) and conditions for them. The substitution gives a obtain equations for initial-order approximations of concentrations of complexes of defects  $\Phi_{\rho 0}(x, y, z, t)$  and corrections for them  $\Phi_{\rho i}(x, y, z, t)$ ,  $i \geq 1$  and boundary and initial conditions for them. We present the equations and conditions in Appendix. We obtain solutions of the obtain equations by using standard Fourier approaches [18,19] and presented in the Appendix.

We calculate distribution of concentration of dopant in space and time by using the same approach, which was used for calculation distributions of concentrations of radiation defects in

space and time. To use the approach we transform approximation of dopant diffusion coefficient to the following form:  $D_L(x,y,z,T)=D_{0L}[1+\varepsilon_L g_L(x,y,z,T)]$ . Here  $D_{0L}$  is the average value of diffusion coefficient of dopant,  $0 \leq \varepsilon_L < 1$ ,  $|g_L(x,y,z,T)| \leq 1$ . Now we calculate solution of Eq.(1) as the following power series

$$C(x,y,z,t) = \sum_{i=0}^{\infty} \varepsilon_L^i \sum_{j=1}^{\infty} \xi^j C_{ij}(x,y,z,t).$$

Now we substitute the above series into boundary problem Eqs.(1) and (2) leads to equations for the initial-order approximation of concentration of dopant  $C_{00}(x,y,z,t)$ , corrections for them  $C_{ij}(x,y,z,t)$  ( $i \geq 1, j \geq 1$ ) and conditions for the above equations. The equations are presented in the Appendix. Solutions of the equations have been calculated by standard Fourier approaches [18,19]. The solutions are presented in the Appendix.

We analyze distributions of concentrations of dopant and radiation defects in space and time analytically by using the second-order approximations of considered series. Usually we obtain enough good qualitative analysis and quantitative results. We check all analytical results by comparison with results of numerical simulation.

### 3. DISCUSSION

Now we analyzed distributions of concentrations of dopants in space and time by using calculated in previous section relations. Figs. 2 show typical distributions of concentrations of dopants on coordinate near interface between materials of heterostructures in direction, which is perpendicular to the interface. We calculate these distributions for larger value of dopant diffusion coefficient in doped area in comparison of value of dopant diffusion coefficient in nearest areas. These distributions show that in the case sharpness of  $p$ - $n$ -junctions increases. At the same time one can find increasing of homogeneity of distribution of dopant concentration. One can find both effects for single  $p$ - $n$ -junctions and  $p$ - $n$ -junctions framework their systems (transistors, thyristors).

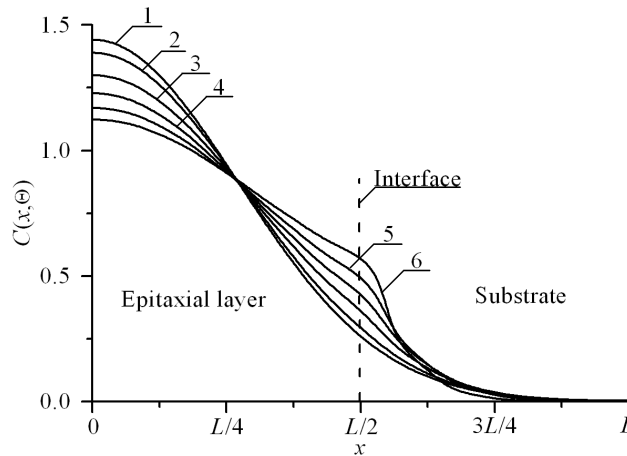


Fig.2a. Spatial distributions of infused dopant concentration in the considered heterostructure. The considered direction perpendicular to the interface between epitaxial layer substrate. Difference between values of dopant diffusion coefficient in layers of heterostructure increases with increasing of number of curves

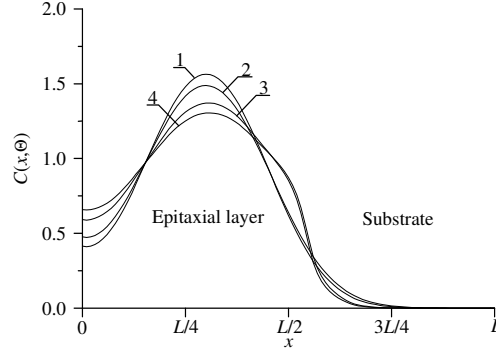


Fig.2b. Spatial distributions of infused dopant concentration in the considered heterostructure. Curves 1 and 3 corresponds to annealing time  $\Theta = 0.0048(L_x^2 + L_y^2 + L_z^2)/D_0$ . Curves 2 and 4 corresponds to annealing time  $\Theta = 0.0057(L_x^2 + L_y^2 + L_z^2)/D_0$ . Curves 1 and 2 corresponds to homogenous sample. Curves 3 and 4 corresponds to the considered heterostructure. Difference between values of dopant diffusion coefficient in layers of heterostructure increases with increasing of number of curves

Now we consider optimization of annealing of dopant and/or radiation defects. To do the optimization we used recently introduced criterion [16,17,20,21]. Framework the criterion we approximate real distribution by step-wise function  $\psi(x,y,z)$ . We calculate optimal annealing time by minimization the following mean-squared error

$$U = \frac{1}{L_x L_y L_z} \int_0^{L_x} \int_0^{L_y} \int_0^{L_z} [C(x, y, z, \Theta) - \psi(x, y, z)]^2 dz dy dx. \quad (12)$$

Optimal annealing time as functions of parameters are presented on Figs. 3. It should be noted, that in the ideal case after finishing of annealing of radiation defects dopant achieves interface between layers of heterostructure. If the dopant do not achieves the interface, it is practically to use additional annealing of the dopant. The Fig. 3b shows just the dependences of optimal values of additional annealing time. In this situation optimal annealing of implanted dopant is smaller in comparison with optimal annealing time of infused dopant.

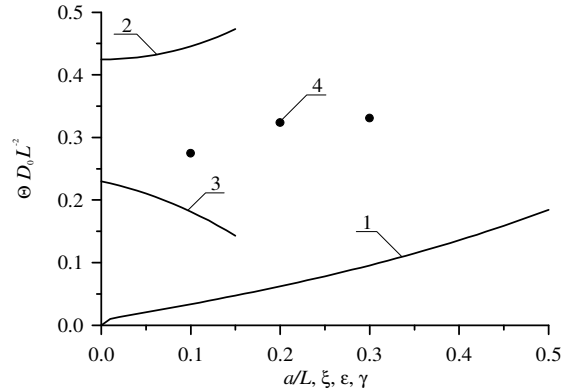


Fig.3a. Optimal annealing time of infused dopant as dependences of several parameters. Curve 1 is the dependence of the considered annealing time on dimensionless thickness of epitaxial layer  $a/L$  and  $\xi = \gamma = 0$  for equal to each other values of dopant diffusion coefficient in all parts of heterostructure. Curve 2 is the dependence of the considered annealing time on the parameter  $\varepsilon$  for  $a/L = 1/2$  and  $\xi = \gamma = 0$ . Curve 3 is the dependence of the considered annealing time on the parameter  $\xi$  for  $a/L = 1/2$  and  $\varepsilon = \gamma = 0$ . Curve 4 is the dependence of the considered annealing time on parameter  $\gamma$  for  $a/L = 1/2$  and  $\varepsilon = \xi = 0$

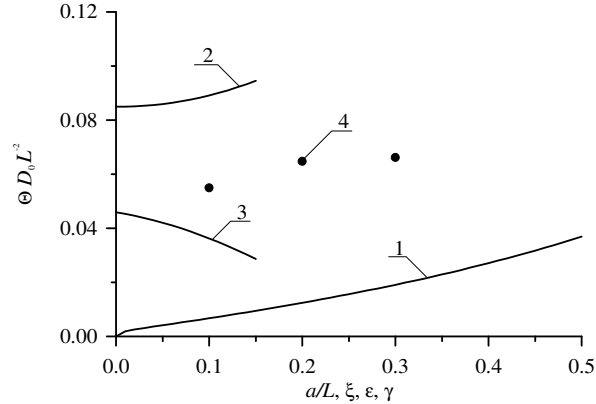


Fig.3b. Optimal annealing time of implanted dopant as dependences of several parameters. Curve 1 is the dependence of the considered annealing time on dimensionless thickness of epitaxial layer  $a/L$  and  $\xi=\gamma=0$  for equal to each other values of dopant diffusion coefficient in all parts of heterostructure. Curve 2 is the dependence of the considered annealing time on the parameter  $\varepsilon$  for  $a/L=1/2$  and  $\xi=\gamma=0$ . Curve 3 is the dependence of the considered annealing time on the parameter  $\xi$  for  $a/L=1/2$  and  $\varepsilon=\gamma=0$ . Curve 4 is the dependence of the considered annealing time on parameter  $\gamma$  for  $a/L=1/2$  and  $\varepsilon=\xi=0$

#### 4. CONCLUSIONS

We introduce an approach to increase density of elements of an voltage restore. Several recommendations for optimization technological processes were formulated.

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## Appendix

Equations for the functions  $\tilde{I}_{ijk}(\chi, \eta, \phi, \vartheta)$  and  $\tilde{V}_{ijk}(\chi, \eta, \phi, \vartheta)$ ,  $i \geq 0, j \geq 0, k \geq 0$  and conditions for them

$$\begin{aligned} \frac{\partial \tilde{I}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{0i}}{D_{0v}}} \frac{\partial^2 \tilde{I}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \sqrt{\frac{D_{0i}}{D_{0v}}} \frac{\partial^2 \tilde{I}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \sqrt{\frac{D_{0i}}{D_{0v}}} \frac{\partial^2 \tilde{I}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \\ \frac{\partial \tilde{V}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{0v}}{D_{0i}}} \frac{\partial^2 \tilde{V}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \sqrt{\frac{D_{0v}}{D_{0i}}} \frac{\partial^2 \tilde{V}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \sqrt{\frac{D_{0v}}{D_{0i}}} \frac{\partial^2 \tilde{V}_{000}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \\ \frac{\partial \tilde{I}_{i00}(\chi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{0i}}{D_{0v}}} \left[ \frac{\partial^2 \tilde{I}_{i00}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{i00}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{i00}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] + \\ &+ \sqrt{\frac{D_{0i}}{D_{0v}}} \frac{\partial}{\partial \chi} \left[ g_i(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{i-100}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right] + \sqrt{\frac{D_{0i}}{D_{0v}}} \frac{\partial}{\partial \eta} \left[ g_i(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{i-100}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right] + \\ &+ \sqrt{\frac{D_{0i}}{D_{0v}}} \frac{\partial}{\partial \phi} \left[ g_i(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{i-100}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right], \quad i \geq 1, \\ \frac{\partial \tilde{V}_{i00}(\chi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{0v}}{D_{0i}}} \left[ \frac{\partial^2 \tilde{V}_{i00}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{V}_{i00}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{V}_{i00}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] + \\ &+ \sqrt{\frac{D_{0v}}{D_{0i}}} \frac{\partial}{\partial \chi} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{i-100}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right] + \sqrt{\frac{D_{0v}}{D_{0i}}} \frac{\partial}{\partial \eta} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{i-100}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right] + \end{aligned}$$

$$\begin{aligned}
& + \sqrt{\frac{D_{ov}}{D_{oi}}} \frac{\partial}{\partial \phi} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{i-100}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right], i \geq 1; \\
\frac{\partial \tilde{I}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{oi}}{D_{ov}}} \left[ \frac{\partial^2 \tilde{I}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
& - [1 + \varepsilon_{i,v} g_{i,v}(\chi, \eta, \phi, T)] \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta) \\
\frac{\partial \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{ov}}{D_{oi}}} \left[ \frac{\partial^2 \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
& - [1 + \varepsilon_{i,v} g_{i,v}(\chi, \eta, \phi, T)] \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta); \\
\frac{\partial \tilde{I}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{oi}}{D_{ov}}} \left[ \frac{\partial^2 \tilde{I}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
& - [1 + \varepsilon_{i,v} g_{i,v}(\chi, \eta, \phi, T)] [\tilde{I}_{010}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta) + \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)] \\
\frac{\partial \tilde{V}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{oi}}{D_{ov}}} \left[ \frac{\partial^2 \tilde{V}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{V}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{V}_{020}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
& - [1 + \varepsilon_{i,v} g_{i,v}(\chi, \eta, \phi, T)] [\tilde{I}_{010}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta) + \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)]; \\
\frac{\partial \tilde{I}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{oi}}{D_{ov}}} \left[ \frac{\partial^2 \tilde{I}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
& - [1 + \varepsilon_{i,l} g_{i,l}(\chi, \eta, \phi, T)] \tilde{I}_{000}^2(\chi, \eta, \phi, \vartheta) \\
\frac{\partial \tilde{V}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{ov}}{D_{oi}}} \left[ \frac{\partial^2 \tilde{V}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{V}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{V}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
& - [1 + \varepsilon_{i,l} g_{i,l}(\chi, \eta, \phi, T)] \tilde{V}_{000}^2(\chi, \eta, \phi, \vartheta); \\
\frac{\partial \tilde{I}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{oi}}{D_{ov}}} \left[ \frac{\partial^2 \tilde{I}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] + \\
& + \sqrt{\frac{D_{oi}}{D_{ov}}} \left\{ \frac{\partial}{\partial \chi} \left[ g_l(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right] + \frac{\partial}{\partial \eta} \left[ g_l(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right] \right\} + \\
& + \frac{\partial}{\partial \phi} \left[ g_l(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right] \left\{ - [1 + \varepsilon_{i,l} g_{i,l}(\chi, \eta, \phi, T)] [\tilde{I}_{100}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta) + \right. \\
& \quad \left. + \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \tilde{V}_{100}(\chi, \eta, \phi, \vartheta)] \right\} \\
\frac{\partial \tilde{V}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} &= \sqrt{\frac{D_{ov}}{D_{oi}}} \left[ \frac{\partial^2 \tilde{V}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{V}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{V}_{110}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] + \\
& + \sqrt{\frac{D_{ov}}{D_{oi}}} \left\{ \frac{\partial}{\partial \chi} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right] + \frac{\partial}{\partial \eta} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right] \right\} +
\end{aligned}$$

$$\begin{aligned}
 & + \frac{\partial}{\partial \phi} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{010}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right] \Bigg\} - [1 + \varepsilon_{v,v} g_{v,v}(\chi, \eta, \phi, T)] [\tilde{V}_{100}(\chi, \eta, \phi, \vartheta) \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) + \\
 & \quad + \tilde{V}_{000}(\chi, \eta, \phi, \vartheta) \tilde{I}_{100}(\chi, \eta, \phi, \vartheta)]; \\
 \frac{\partial \tilde{I}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} & = \sqrt{\frac{D_{0l}}{D_{0v}}} \left[ \frac{\partial^2 \tilde{I}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
 & \quad - [1 + \varepsilon_{l,l} g_{l,l}(\chi, \eta, \phi, T)] \tilde{I}_{001}(\chi, \eta, \phi, \vartheta) \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \\
 \frac{\partial \tilde{V}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} & = \sqrt{\frac{D_{0v}}{D_{0l}}} \left[ \frac{\partial^2 \tilde{V}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{V}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{V}_{002}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
 & \quad - [1 + \varepsilon_{v,v} g_{v,v}(\chi, \eta, \phi, E)] \tilde{V}_{001}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta); \\
 \frac{\partial \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} & = \sqrt{\frac{D_{0l}}{D_{0v}}} \left[ \frac{\partial^2 \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] + \\
 & \quad + \sqrt{\frac{D_{0l}}{D_{0v}}} \left\{ \frac{\partial}{\partial \chi} \left[ g_l(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right] + \frac{\partial}{\partial \eta} \left[ g_l(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right] + \right. \\
 & \quad \left. + \frac{\partial}{\partial \phi} \left[ g_l(\chi, \eta, \phi, T) \frac{\partial \tilde{I}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right] \right\} - [1 + \varepsilon_l g_l(\chi, \eta, \phi, T)] \tilde{I}_{100}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta) \\
 \frac{\partial \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} & = \sqrt{\frac{D_{0v}}{D_{0l}}} \left[ \frac{\partial^2 \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{101}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] + \\
 & \quad + \sqrt{\frac{D_{0v}}{D_{0l}}} \left\{ \frac{\partial}{\partial \chi} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \chi} \right] + \frac{\partial}{\partial \eta} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \eta} \right] + \right. \\
 & \quad \left. + \frac{\partial}{\partial \phi} \left[ g_v(\chi, \eta, \phi, T) \frac{\partial \tilde{V}_{001}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right] \right\} - [1 + \varepsilon_v g_v(\chi, \eta, \phi, T)] \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \tilde{V}_{100}(\chi, \eta, \phi, \vartheta); \\
 \frac{\partial \tilde{I}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} & = \sqrt{\frac{D_{0l}}{D_{0v}}} \left[ \frac{\partial^2 \tilde{I}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{I}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{I}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
 & \quad - [1 + \varepsilon_{l,l} g_{l,l}(\chi, \eta, \phi, T)] \tilde{I}_{000}(\chi, \eta, \phi, \vartheta) \tilde{I}_{010}(\chi, \eta, \phi, \vartheta) - [1 + \varepsilon_{l,v} g_{l,v}(\chi, \eta, \phi, T)] \times \\
 & \quad \times \tilde{I}_{001}(\chi, \eta, \phi, \vartheta) \tilde{V}_{000}(\chi, \eta, \phi, \vartheta) \\
 \frac{\partial \tilde{V}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \vartheta} & = \sqrt{\frac{D_{0v}}{D_{0l}}} \left[ \frac{\partial^2 \tilde{V}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \chi^2} + \frac{\partial^2 \tilde{V}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \eta^2} + \frac{\partial^2 \tilde{V}_{011}(\chi, \eta, \phi, \vartheta)}{\partial \phi^2} \right] - \\
 & \quad [ \quad \quad \quad ( \quad \quad ) ] \quad ( \quad \quad ) \quad ( \quad \quad ) [ \quad \quad \quad ( \quad \quad ) ]
 \end{aligned}$$

$$\left. \frac{\partial \tilde{\rho}_{ijk}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right|_{\phi=0} = 0, \quad \left. \frac{\partial \tilde{\rho}_{ijk}(\chi, \eta, \phi, \vartheta)}{\partial \phi} \right|_{\phi=1} = 0 \quad (i \geq 0, j \geq 0, k \geq 0);$$

$$\tilde{\rho}_{000}(\chi, \eta, \phi, 0) = f_{\rho}(\chi, \eta, \phi) / \rho^*, \quad \tilde{\rho}_{ijk}(\chi, \eta, \phi, 0) = 0 \quad (i \geq 1, j \geq 1, k \geq 1).$$

Solutions of these equations with account boundary and initial conditions could be written as

$$\tilde{\rho}_{000}(\chi, \eta, \phi, \vartheta) = \frac{1}{L} + \frac{2}{L} \sum_{n=1}^{\infty} F_{np} c(\chi) c(\eta) c(\phi) e_{np}(\vartheta),$$

where  $F_{np} = \frac{1}{\rho^*} \int_0^1 \cos(\pi n u) \int_0^1 \cos(\pi n v) \int_0^1 \cos(\pi n w) f_{np}(u, v, w) d w d v d u$ ,  $e_{ni}(\vartheta) = \exp(-\pi^2 n^2 \vartheta \sqrt{D_{0i}/D_{0i}})$ ,  
 $e_{nv}(\vartheta) = \exp(-\pi^2 n^2 \vartheta \sqrt{D_{0i}/D_{0v}})$ ,  $c_n(\chi) = \cos(\pi n \chi)$ ;

$$\begin{aligned} \tilde{I}_{i00}(\chi, \eta, \phi, \vartheta) &= -2\pi \sqrt{\frac{D_{0i}}{D_{0v}}} \sum_{n=1}^{\infty} n c_n(\chi) c(\eta) c(\phi) e_{ni}(\vartheta) \int_0^{\vartheta} e_{ni}(-\tau) \int_0^1 s_n(u) \int_0^1 c_n(v) \int_0^1 g_i(u, v, w, T) \times \\ &\times c_n(w) \frac{\partial \tilde{I}_{i-100}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - 2 \sqrt{\frac{D_{0i}}{D_{0v}}} \sum_{n=1}^{\infty} n c_n(\chi) c(\eta) c(\phi) e_{ni}(\vartheta) \int_0^{\vartheta} e_{ni}(-\tau) \int_0^1 c_n(u) \times \\ &\times \pi \int_0^1 s_n(v) \int_0^1 c_n(w) g_i(u, v, w, T) \frac{\partial \tilde{I}_{i-100}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0i}}{D_{0v}}} \sum_{n=1}^{\infty} n c_n(\chi) c(\eta) c(\phi) \times \\ &\times e_{ni}(\vartheta) \int_0^{\vartheta} e_{ni}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 s_n(w) g_i(u, v, w, T) \frac{\partial \tilde{I}_{i-100}(u, v, w, \tau)}{\partial w} d w d v d u d \tau, \quad i \geq 1, \\ \tilde{V}_{i00}(\chi, \eta, \phi, \vartheta) &= -2\pi \sqrt{\frac{D_{0v}}{D_{0i}}} \sum_{n=1}^{\infty} n c_n(\chi) c(\eta) c(\phi) e_{nv}(\vartheta) \int_0^{\vartheta} e_{nv}(-\tau) \int_0^1 s_n(u) \int_0^1 c_n(v) \int_0^1 g_v(u, v, w, T) \times \\ &\times c_n(w) \frac{\partial \tilde{V}_{i-100}(u, \tau)}{\partial u} d w d v d u d \tau - \sqrt{\frac{D_{0v}}{D_{0i}}} \sum_{n=1}^{\infty} n c_n(\chi) c(\eta) c(\phi) e_{nv}(\vartheta) \int_0^{\vartheta} e_{nv}(-\tau) \int_0^1 c_n(u) \int_0^1 s_n(v) \times \\ &\times 2\pi \int_0^1 c_n(w) g_v(u, v, w, T) \frac{\partial \tilde{V}_{i-100}(u, \tau)}{\partial v} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0v}}{D_{0i}}} \sum_{n=1}^{\infty} n c_n(\chi) c(\eta) c(\phi) e_{nv}(\vartheta) \times \\ &\times \int_0^{\vartheta} e_{nv}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 s_n(w) g_v(u, v, w, T) \frac{\partial \tilde{V}_{i-100}(u, \tau)}{\partial w} d w d v d u d \tau, \quad i \geq 1, \end{aligned}$$

where  $s_n(\chi) = \sin(\pi n \chi)$ ;

$$\begin{aligned} \tilde{\rho}_{010}(\chi, \eta, \phi, \vartheta) &= -2 \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) c_n(\phi) e_{np}(\vartheta) \int_0^{\vartheta} e_{np}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 c_n(w) \times \\ &\times [1 + \varepsilon_{i,v} g_{i,v}(u, v, w, T)] \tilde{I}_{000}(u, v, w, \tau) \tilde{V}_{000}(u, v, w, \tau) d w d v d u d \tau; \\ \tilde{\rho}_{020}(\chi, \eta, \phi, \vartheta) &= -2 \sqrt{\frac{D_{0i}}{D_{0v}}} \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) c_n(\phi) e_{np}(\vartheta) \int_0^{\vartheta} e_{np}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 c_n(w) [\tilde{I}_{010}(u, v, w, \tau) \times \\ &\times \tilde{V}_{000}(u, v, w, \tau) + \tilde{I}_{000}(u, v, w, \tau) \tilde{V}_{010}(u, v, w, \tau)] [1 + \varepsilon_{i,v} g_{i,v}(u, v, w, T)] d w d v d u d \tau; \\ \tilde{\rho}_{001}(\chi, \eta, \phi, \vartheta) &= -2 \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) c_n(\phi) e_{np}(\vartheta) \int_0^{\vartheta} e_{np}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 \tilde{\rho}_{000}^2(u, v, w, \tau) \times \end{aligned}$$

$$\begin{aligned}
 & \times [1 + \varepsilon_{\rho,\rho} g_{\rho,\rho}(u, v, w, T)] c_n(w) d w d v d u d \tau ; \\
 \tilde{\rho}_{002}(\chi, \eta, \phi, \vartheta) = & -2 \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) c_n(\phi) e_{n\rho}(\vartheta) \int_0^\vartheta e_{n\rho}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 c_n(w) \tilde{\rho}_{000}(u, v, w, \tau) \times \\
 & \times [1 + \varepsilon_{\rho,\rho} g_{\rho,\rho}(u, v, w, T)] \tilde{\rho}_{001}(u, v, w, \tau) d w d v d u d \tau ; \\
 \tilde{I}_{110}(\chi, \eta, \phi, \vartheta) = & -2\pi \sqrt{\frac{D_{0I}}{D_{0V}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nI}(\vartheta) \int_0^\vartheta e_{nI}(-\tau) \int_0^1 s_n(u) \int_0^1 c_n(v) \int_0^1 c_n(u) \times \\
 & \times g_I(u, v, w, T) \frac{\partial \tilde{I}_{i-100}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0I}}{D_{0V}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nI}(\vartheta) \times \\
 & \times \int_0^\vartheta e_{nI}(-\tau) \int_0^1 c_n(u) \int_0^1 s_n(v) \int_0^1 c_n(u) g_I(u, v, w, T) \frac{\partial \tilde{I}_{i-100}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0I}}{D_{0V}}} \times \\
 & \times \sum_{n=1}^{\infty} n e_{nI}(\vartheta) \int_0^\vartheta e_{nI}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 s_n(u) g_I(u, v, w, T) \frac{\partial \tilde{I}_{i-100}(u, v, w, \tau)}{\partial w} d w d v d u d \tau \times \\
 & \times c_n(\chi) c_n(\eta) c_n(\phi) - 2 \sum_{n=1}^{\infty} c_n(\chi) e_{nI}(\vartheta) c_n(\eta) c_n(\phi) \int_0^\vartheta e_{nI}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 c_n(v) [1 + \varepsilon_{I,V} \times \\
 & \times g_{I,V}(u, v, w, T)] [\tilde{I}_{100}(u, v, w, \tau) \tilde{V}_{000}(u, v, w, \tau) + \tilde{I}_{000}(u, v, w, \tau) \tilde{V}_{100}(u, v, w, \tau)] d w d v d u d \tau \\
 \tilde{V}_{110}(\chi, \eta, \phi, \vartheta) = & -2\pi \sqrt{\frac{D_{0V}}{D_{0I}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nV}(\vartheta) \int_0^\vartheta e_{nV}(-\tau) \int_0^1 s_n(u) \int_0^1 c_n(v) \int_0^1 c_n(u) \times \\
 & \times g_V(u, v, w, T) \frac{\partial \tilde{V}_{i-100}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0V}}{D_{0I}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nV}(\vartheta) \times \\
 & \times \int_0^\vartheta e_{nV}(-\tau) \int_0^1 c_n(u) \int_0^1 s_n(v) \int_0^1 c_n(u) g_V(u, v, w, T) \frac{\partial \tilde{V}_{i-100}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0V}}{D_{0I}}} \times \\
 & \times \sum_{n=1}^{\infty} n e_{nV}(\vartheta) \int_0^\vartheta e_{nV}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 s_n(u) g_V(u, v, w, T) \frac{\partial \tilde{V}_{i-100}(u, v, w, \tau)}{\partial w} d w d v d u d \tau \times \\
 & \times c_n(\chi) c_n(\eta) c_n(\phi) - 2 \sum_{n=1}^{\infty} c_n(\chi) e_{nV}(\vartheta) c_n(\eta) c_n(\phi) \int_0^\vartheta e_{nV}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 c_n(v) [1 + \varepsilon_{I,V} \times \\
 & \times g_{I,V}(u, v, w, T)] [\tilde{I}_{100}(u, v, w, \tau) \tilde{V}_{000}(u, v, w, \tau) + \tilde{I}_{000}(u, v, w, \tau) \tilde{V}_{100}(u, v, w, \tau)] d w d v d u d \tau ; \\
 \tilde{I}_{101}(\chi, \eta, \phi, \vartheta) = & -2\pi \sqrt{\frac{D_{0I}}{D_{0V}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nI}(\vartheta) \int_0^\vartheta e_{nI}(-\tau) \int_0^1 s_n(u) \int_0^1 c_n(v) \int_0^1 g_I(u, v, w, T) \times \\
 & \times c_n(w) \frac{\partial \tilde{I}_{001}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0I}}{D_{0V}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nI}(\vartheta) \int_0^\vartheta e_{nI}(-\tau) \int_0^1 c_n(u) \times \\
 & \times \int_0^1 s_n(v) \int_0^1 c_n(w) g_I(u, v, w, T) \frac{\partial \tilde{I}_{001}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0I}}{D_{0V}}} \sum_{n=1}^{\infty} c_n(\chi) e_{nI}(\vartheta) \int_0^\vartheta e_{nI}(-\tau) \times \\
 & \times n \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 s_n(w) g_I(u, v, w, T) \frac{\partial \tilde{I}_{001}(u, v, w, \tau)}{\partial w} d w d v d u d \tau c_n(\eta) c_n(\phi) - 2 \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) \times
 \end{aligned}$$

$$\begin{aligned}
 & \times c_n(\phi) e_{nI}(\vartheta) \int_0^\vartheta e_{nI}(-\tau) \int_0^1 c_n(u) [1 + \varepsilon_{I,V} g_{I,V}(u, v, w, T)] \tilde{I}_{100}(u, v, w, \tau) \tilde{V}_{000}(u, v, w, \tau) d w d v d u d \tau \\
 & \tilde{V}_{101}(\chi, \eta, \phi, \vartheta) = -2\pi \sqrt{\frac{D_{0V}}{D_{0I}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nV}(\vartheta) \int_0^\vartheta e_{nV}(-\tau) \int_0^1 s_n(u) \int_0^1 c_n(v) \int_0^1 g_V(u, v, w, T) \times \\
 & \times c_n(w) \frac{\partial \tilde{V}_{001}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0V}}{D_{0I}}} \sum_{n=1}^{\infty} n c_n(\chi) c_n(\eta) c_n(\phi) e_{nV}(\vartheta) \int_0^\vartheta e_{nV}(-\tau) \int_0^1 c_n(u) \times \\
 & \times \int_0^1 s_n(v) \int_0^1 c_n(w) g_V(u, v, w, T) \frac{\partial \tilde{V}_{001}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - 2\pi \sqrt{\frac{D_{0V}}{D_{0I}}} \sum_{n=1}^{\infty} c_n(\chi) e_{nV}(\vartheta) \int_0^\vartheta e_{nV}(-\tau) \times \\
 & \times n \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 s_n(w) g_V(u, v, w, T) \frac{\partial \tilde{V}_{001}(u, v, w, \tau)}{\partial w} d w d v d u d \tau c_n(\eta) c_n(\phi) - 2 \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) \times \\
 & \times c_n(\phi) e_{nV}(\vartheta) \int_0^\vartheta e_{nV}(-\tau) \int_0^1 c_n(u) [1 + \varepsilon_{I,V} g_{I,V}(u, v, w, T)] \tilde{I}_{000}(u, v, w, \tau) \tilde{V}_{100}(u, v, w, \tau) d w d v d u d \tau \\
 & \tilde{I}_{011}(\chi, \eta, \phi, \vartheta) = -2 \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) c_n(\phi) e_{nI}(\vartheta) \int_0^\vartheta e_{nI}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 c_n(w) \{ [1 + \varepsilon_{I,I} g_{I,I}(u, v, w, T)] \times \\
 & \times \tilde{I}_{000}(u, v, w, \tau) \tilde{I}_{010}(u, v, w, \tau) + [1 + \varepsilon_{I,V} g_{I,V}(u, v, w, T)] \tilde{I}_{001}(u, v, w, \tau) \tilde{V}_{000}(u, v, w, \tau) \} d w d v d u d \tau \\
 & \tilde{V}_{011}(\chi, \eta, \phi, \vartheta) = -2 \sum_{n=1}^{\infty} c_n(\chi) c_n(\eta) c_n(\phi) e_{nV}(\vartheta) \int_0^\vartheta e_{nV}(-\tau) \int_0^1 c_n(u) \int_0^1 c_n(v) \int_0^1 c_n(w) \{ [1 + \varepsilon_{V,V} g_{V,V}(u, v, w, T)] \times \\
 & \times \tilde{V}_{000}(u, v, w, \tau) \tilde{V}_{010}(u, v, w, \tau) + [1 + \varepsilon_{I,V} g_{I,V}(u, v, w, T)] \tilde{I}_{000}(u, v, w, \tau) \tilde{V}_{001}(u, v, w, \tau) \} d w d v d u d \tau .
 \end{aligned}$$

Equations for initial-order approximations of distributions of concentrations of simplest complexes of radiation defects  $\Phi_{\rho 0}(x, y, z, t)$  and corrections for them  $\Phi_{\rho i}(x, y, z, t)$ ,  $i \geq 1$  and boundary and initial conditions for them takes the form

$$\begin{aligned}
 \frac{\partial \Phi_{I0}(x, y, z, t)}{\partial t} &= D_{0\Phi I} \left[ \frac{\partial^2 \Phi_{I0}(x, y, z, t)}{\partial x^2} + \frac{\partial^2 \Phi_{I0}(x, y, z, t)}{\partial y^2} + \frac{\partial^2 \Phi_{I0}(x, y, z, t)}{\partial z^2} \right] + \\
 &+ k_{I,I}(x, y, z, T) I^2(x, y, z, t) - k_I(x, y, z, T) I(x, y, z, t) \\
 \frac{\partial \Phi_{V0}(x, y, z, t)}{\partial t} &= D_{0\Phi V} \left[ \frac{\partial^2 \Phi_{V0}(x, y, z, t)}{\partial x^2} + \frac{\partial^2 \Phi_{V0}(x, y, z, t)}{\partial y^2} + \frac{\partial^2 \Phi_{V0}(x, y, z, t)}{\partial z^2} \right] + \\
 &+ k_{V,V}(x, y, z, T) V^2(x, y, z, t) - k_V(x, y, z, T) V(x, y, z, t); \\
 \frac{\partial \Phi_{Ii}(x, y, z, t)}{\partial t} &= D_{0\Phi I} \left[ \frac{\partial^2 \Phi_{Ii}(x, y, z, t)}{\partial x^2} + \frac{\partial^2 \Phi_{Ii}(x, y, z, t)}{\partial y^2} + \frac{\partial^2 \Phi_{Ii}(x, y, z, t)}{\partial z^2} \right] + \\
 &+ D_{0\Phi I} \left\{ \frac{\partial}{\partial x} \left[ g_{\Phi I}(x, y, z, T) \frac{\partial \Phi_{Ii-1}(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ g_{\Phi I}(x, y, z, T) \frac{\partial \Phi_{Ii-1}(x, y, z, t)}{\partial y} \right] + \right. \\
 &\left. + \frac{\partial}{\partial z} \left[ g_{\Phi I}(x, y, z, T) \frac{\partial \Phi_{Ii-1}(x, y, z, t)}{\partial z} \right] \right\}, i \geq 1,
 \end{aligned}$$

$$\begin{aligned} \frac{\partial \Phi_{\nu_i}(x, y, z, t)}{\partial t} &= D_{0\Phi\nu} \left[ \frac{\partial^2 \Phi_{\nu_i}(x, y, z, t)}{\partial x^2} + \frac{\partial^2 \Phi_{\nu_i}(x, y, z, t)}{\partial y^2} + \frac{\partial^2 \Phi_{\nu_i}(x, y, z, t)}{\partial z^2} \right] + \\ &+ D_{0\Phi\nu} \left\{ \frac{\partial}{\partial x} \left[ g_{\Phi\nu}(x, y, z, T) \frac{\partial \Phi_{\nu_{i-1}}(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ g_{\Phi\nu}(x, y, z, T) \frac{\partial \Phi_{\nu_{i-1}}(x, y, z, t)}{\partial y} \right] + \right. \\ &\quad \left. + \frac{\partial}{\partial z} \left[ g_{\Phi\nu}(x, y, z, T) \frac{\partial \Phi_{\nu_{i-1}}(x, y, z, t)}{\partial z} \right] \right\}, i \geq 1; \\ \frac{\partial \Phi_{\rho_i}(x, y, z, t)}{\partial x} \Big|_{x=0} &= 0, \quad \frac{\partial \Phi_{\rho_i}(x, y, z, t)}{\partial x} \Big|_{x=L_x} = 0, \quad \frac{\partial \Phi_{\rho_i}(x, y, z, t)}{\partial y} \Big|_{y=0} = 0, \quad \frac{\partial \Phi_{\rho_i}(x, y, z, t)}{\partial y} \Big|_{y=L_y} = 0, \\ \frac{\partial \Phi_{\rho_i}(x, y, z, t)}{\partial z} \Big|_{z=0} &= 0, \quad \frac{\partial \Phi_{\rho_i}(x, y, z, t)}{\partial z} \Big|_{z=L_z} = 0, \quad i \geq 0; \quad \Phi_{\rho_0}(x, y, z, 0) = f_{\Phi\rho}(x, y, z), \quad \Phi_{\rho_i}(x, y, z, 0) = 0, \quad i \geq 1. \end{aligned}$$

Solutions of the above equations could be written as

$$\begin{aligned} \Phi_{\rho_0}(x, y, z, t) &= \frac{1}{L_x L_y L_z} + \frac{2}{L_x L_y L_z} \sum_{n=1}^{\infty} F_{n\Phi\rho} c_n(x) c_n(y) c_n(z) e_{n\Phi\rho}(t) + \frac{2}{L_x L_y L_z} \sum_{n=1}^{\infty} n c_n(x) c_n(y) c_n(z) \times \\ &\times e_{\Phi\rho n}(t) \int_0^t e_{\Phi\rho n}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} [k_{l,i}(u, v, w, T) I^2(u, v, w, \tau) - k_l(u, v, w, T) I(u, v, w, \tau)] \\ &\quad \times c_n(w) d w d v d u d \tau, \end{aligned}$$

where  $F_{n\Phi\rho} = \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(w) f_{\Phi\rho}(u, v, w) d w d v d u$ ,  $e_{n\Phi\rho}(t) = \exp[-\pi^2 n^2 D_{0\Phi\rho} t (L_x^2 + L_y^2 + L_z^2)]$ ,  $c_n(x) = \cos(\pi n x / L_x)$ ;

$$\begin{aligned} \Phi_{\rho_i}(x, y, z, t) &= -\frac{2\pi}{L_x^2 L_y L_z} \sum_{n=1}^{\infty} n c_n(x) c_n(y) c_n(z) e_{\Phi\rho n}(t) \int_0^t e_{\Phi\rho n}(-\tau) \int_0^{L_x} s_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} g_{\Phi\rho}(u, v, w, T) \times \\ &\times c_n(w) \frac{\partial \Phi_{l\rho i-1}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z^2} \sum_{n=1}^{\infty} n c_n(x) c_n(y) c_n(z) e_{\Phi\rho n}(t) \int_0^t e_{\Phi\rho n}(-\tau) \int_0^{L_x} c_n(u) \times \\ &\times \int_0^{L_y} s_n(v) \int_0^{L_z} c_n(w) g_{\Phi\rho}(u, v, w, T) \frac{\partial \Phi_{l\rho i-1}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z^2} \sum_{n=1}^{\infty} n c_n(x) c_n(y) c_n(z) \times \\ &\times e_{\Phi\rho n}(t) \int_0^t e_{\Phi\rho n}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} s_n(w) \frac{\partial \Phi_{l\rho i-1}(u, v, w, \tau)}{\partial w} g_{\Phi\rho}(u, v, w, T) d w d v d u d \tau, \quad i \geq 1, \end{aligned}$$

where  $s_n(x) = \sin(\pi n x / L_x)$ . Equations for calculation functions  $C_{ij}(x, y, z, t)$  ( $i \geq 0, j \geq 0$ ), boundary and initial conditions take the form

$$\begin{aligned} \frac{\partial C_{00}(x, y, z, t)}{\partial t} &= D_{0L} \frac{\partial^2 C_{00}(x, y, z, t)}{\partial x^2} + D_{0L} \frac{\partial^2 C_{00}(x, y, z, t)}{\partial y^2} + D_{0L} \frac{\partial^2 C_{00}(x, y, z, t)}{\partial z^2}; \\ \frac{\partial C_{i0}(x, y, z, t)}{\partial t} &= D_{0L} \frac{\partial^2 C_{i0}(x, y, z, t)}{\partial x^2} + D_{0L} \frac{\partial^2 C_{i0}(x, y, z, t)}{\partial y^2} + D_{0L} \frac{\partial^2 C_{i0}(x, y, z, t)}{\partial z^2} + \end{aligned}$$

$$\begin{aligned}
& + D_{0L} \frac{\partial}{\partial x} \left[ g_L(x, y, z, T) \frac{\partial C_{i-10}(x, y, z, t)}{\partial x} \right] + D_{0L} \frac{\partial}{\partial y} \left[ g_L(x, y, z, T) \frac{\partial C_{i-10}(x, y, z, t)}{\partial y} \right] + \\
& \quad + D_{0L} \frac{\partial}{\partial z} \left[ g_L(x, y, z, T) \frac{\partial C_{i-10}(x, y, z, t)}{\partial z} \right], i \geq 1; \\
\frac{\partial C_{01}(x, y, z, t)}{\partial t} & = D_{0L} \frac{\partial^2 C_{01}(x, y, z, t)}{\partial x^2} + D_{0L} \frac{\partial^2 C_{01}(x, y, z, t)}{\partial y^2} + D_{0L} \frac{\partial^2 C_{01}(x, y, z, t)}{\partial z^2} + \\
& + D_{0L} \frac{\partial}{\partial x} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{00}(x, y, z, t)}{\partial x} \right] + D_{0L} \frac{\partial}{\partial y} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{00}(x, y, z, t)}{\partial y} \right] + \\
& \quad + D_{0L} \frac{\partial}{\partial z} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{00}(x, y, z, t)}{\partial z} \right]; \\
\frac{\partial C_{02}(x, y, z, t)}{\partial t} & = D_{0L} \frac{\partial^2 C_{02}(x, y, z, t)}{\partial x^2} + D_{0L} \frac{\partial^2 C_{02}(x, y, z, t)}{\partial y^2} + D_{0L} \frac{\partial^2 C_{02}(x, y, z, t)}{\partial z^2} + \\
& + D_{0L} \left\{ \frac{\partial}{\partial x} \left[ C_{01}(x, y, z, t) \frac{C_{00}^{\gamma-1}(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{00}(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ C_{01}(x, y, z, t) \frac{C_{00}^{\gamma-1}(x, y, z, t)}{P^\gamma(x, y, z, T)} \times \right. \right. \\
& \times \left. \frac{\partial C_{00}(x, y, z, t)}{\partial y} \right] + \frac{\partial}{\partial z} \left[ C_{01}(x, y, z, t) \frac{C_{00}^{\gamma-1}(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{00}(x, y, z, t)}{\partial z} \right] \left. \right\} + D_{0L} \left\{ \frac{\partial}{\partial x} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \times \right. \right. \\
& \times \left. \frac{\partial C_{01}(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{01}(x, y, z, t)}{\partial y} \right] + \frac{\partial}{\partial z} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{01}(x, y, z, t)}{\partial z} \right] \left. \right\}; \\
\frac{\partial C_{11}(x, y, z, t)}{\partial t} & = D_{0L} \frac{\partial^2 C_{11}(x, y, z, t)}{\partial x^2} + D_{0L} \frac{\partial^2 C_{11}(x, y, z, t)}{\partial y^2} + D_{0L} \frac{\partial^2 C_{11}(x, y, z, t)}{\partial z^2} + \\
& + \left\{ \frac{\partial}{\partial x} \left[ C_{10}(x, y, z, t) \frac{C_{00}^{\gamma-1}(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{00}(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ C_{10}(x, y, z, t) \frac{C_{00}^{\gamma-1}(x, y, z, t)}{P^\gamma(x, y, z, T)} \times \right. \right. \\
& \times \left. \frac{\partial C_{00}(x, y, z, t)}{\partial y} \right] + \frac{\partial}{\partial z} \left[ C_{10}(x, y, z, t) \frac{C_{00}^{\gamma-1}(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{00}(x, y, z, t)}{\partial z} \right] \left. \right\} D_{0L} + \\
& + D_{0L} \left\{ \frac{\partial}{\partial x} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{10}(x, y, z, t)}{\partial x} \right] + \frac{\partial}{\partial y} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{10}(x, y, z, t)}{\partial y} \right] + \right. \\
& + \left. \frac{\partial}{\partial z} \left[ \frac{C_{00}^\gamma(x, y, z, t)}{P^\gamma(x, y, z, T)} \frac{\partial C_{10}(x, y, z, t)}{\partial z} \right] \right\} + D_{0L} \left\{ \frac{\partial}{\partial x} \left[ g_L(x, y, z, T) \frac{\partial C_{01}(x, y, z, t)}{\partial x} \right] + \right. \\
& + \frac{\partial}{\partial y} \left[ g_L(x, y, z, T) \frac{\partial C_{01}(x, y, z, t)}{\partial y} \right] + \left. \frac{\partial}{\partial z} \left[ g_L(x, y, z, T) \frac{\partial C_{01}(x, y, z, t)}{\partial z} \right] \right\}; \\
\frac{\partial C_{ij}(x, y, z, t)}{\partial x} \Big|_{x=0} & = 0, \quad \frac{\partial C_{ij}(x, y, z, t)}{\partial x} \Big|_{x=L_x} = 0, \quad \frac{\partial C_{ij}(x, y, z, t)}{\partial y} \Big|_{y=0} = 0, \quad \frac{\partial C_{ij}(x, y, z, t)}{\partial y} \Big|_{y=L_y} = 0,
\end{aligned}$$



$$\left. \frac{\partial C_{ij}(x, y, z, t)}{\partial z} \right|_{z=0} = 0, \left. \frac{\partial C_{ij}(x, y, z, t)}{\partial z} \right|_{z=L_z} = 0, i \geq 0, j \geq 0; C_{00}(x, y, z, 0) = f_C(x, y, z), C_{ij}(x, y, z, 0) = 0, \\ i \geq 1, j \geq 1.$$

Solutions of the above equations with account boundary and initial conditions could be written as

$$C_{00}(x, y, z, t) = \frac{1}{L_x L_y L_z} + \frac{2}{L_x L_y L_z} \sum_{n=1}^{\infty} F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t),$$

where  $e_{nC}(t) = \exp[-\pi^2 n^2 D_{0C} t (L_x^{-2} + L_y^{-2} + L_z^{-2})]$ ,  $F_{nC} = \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} f_C(u, v, w) c_n(w) dw dv du$ ;

$$C_{i0}(x, y, z, t) = -\frac{2\pi}{L_x^2 L_y L_z} \sum_{n=1}^{\infty} n F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t) \int_0^t e_{nC}(-\tau) \int_0^{L_x} s_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(v) g_L(u, v, w, T) \times \\ \times \frac{\partial C_{i-10}(u, v, w, \tau)}{\partial u} dw dv du d\tau - \frac{2\pi}{L_x L_y L_z^2} \sum_{n=1}^{\infty} n F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t) \int_0^t e_{nC}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \times \\ \times \int_0^{L_z} c_n(v) g_L(u, v, w, T) \frac{\partial C_{i-10}(u, v, w, \tau)}{\partial v} dw dv du d\tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t) \times \\ \times \int_0^t e_{nC}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} s_n(v) g_L(u, v, w, T) \frac{\partial C_{i-10}(u, v, w, \tau)}{\partial w} dw dv du d\tau, i \geq 1;$$

$$C_{01}(x, y, z, t) = -\frac{2\pi}{L_x^2 L_y L_z} \sum_{n=1}^{\infty} n F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t) \int_0^t e_{nC}(-\tau) \int_0^{L_x} s_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(w) \times \\ \times \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial u} dw dv du d\tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t) \int_0^t e_{nC}(-\tau) \times \\ \times \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \int_0^{L_z} c_n(w) \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial v} dw dv du d\tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n e_{nC}(t) \times \\ \times F_{nC} c_n(x) c_n(y) c_n(z) \int_0^t e_{nC}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} s_n(w) \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial w} dw dv du d\tau;$$

$$C_{02}(x, y, z, t) = -\frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t) \int_0^t e_{nC}(-\tau) \int_0^{L_x} s_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(w) \times \\ \times C_{01}(u, v, w, \tau) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial u} dw dv du d\tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} F_{nC} c_n(x) c_n(y) \times \\ \times n c_n(z) e_{nC}(t) \int_0^t e_{nC}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \int_0^{L_z} C_{01}(u, v, w, \tau) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial v} \times \\ \times c_n(w) dw dv du d\tau - \frac{2\pi}{L_x L_y L_z^2} \sum_{n=1}^{\infty} n F_{nC} c_n(x) c_n(y) c_n(z) e_{nC}(t) \int_0^t e_{nC}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \times \\ \times \int_0^{L_z} s_n(w) C_{01}(u, v, w, \tau) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial w} dw dv du d\tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n c_n(x) \times$$

$$\begin{aligned}
 & \times F_{nc} c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} s_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(w) C_{01}(u, v, w, \tau) \frac{\partial C_{00}(u, v, w, \tau)}{\partial u} \times \\
 & \times \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \times \\
 & \times \int_0^{L_y} s_n(v) \int_0^{L_z} c_n(w) C_{01}(u, v, w, \tau) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n \times \\
 & \times F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \int_0^{L_z} s_n(w) C_{01}(u, v, w, \tau) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \times \\
 & \times \frac{\partial C_{00}(u, v, w, \tau)}{\partial w} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} s_n(u) \times \\
 & \times n \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(w) \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{01}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} c_n(x) e_{nc}(t) \times \\
 & \times F_{nc} c_n(y) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \int_0^{L_z} c_n(w) \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{01}(u, v, w, \tau)}{\partial v} d w d v d u d \tau \times \\
 & \times n c_n(z) - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} s_n(w) \times \\
 & \times \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{01}(u, v, w, \tau)}{\partial w} d w d v d u d \tau; \\
 C_{11}(x, y, z, t) = & -\frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} s_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(w) \times \\
 & \times g_L(u, v, w, T) \frac{\partial C_{01}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \times \\
 & \times \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \int_0^{L_z} c_n(w) g_L(u, v, w, T) \frac{\partial C_{01}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \times \\
 & \times \sum_{n=1}^{\infty} n e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} s_n(w) g_L(u, v, w, T) \frac{\partial C_{01}(u, v, w, \tau)}{\partial w} d w d v d u d \tau \times \\
 & \times F_{nc} c_n(x) c_n(y) c_n(z) - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} s_n(u) \int_0^{L_y} c_n(v) \times \\
 & \times n \int_0^{L_z} c_n(w) \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{10}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) \times \\
 & \times c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \int_0^{L_z} c_n(w) \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{10}(u, v, w, \tau)}{\partial v} d w d v d u d \tau - \\
 & - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} c_n(v) \int_0^{L_z} s_n(w) \frac{C_{00}^\gamma(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \times \\
 & \times \frac{\partial C_{10}(u, v, w, \tau)}{\partial w} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} s_n(u) \times
 \end{aligned}$$

$$\begin{aligned}
& \times \int_0^{L_y} c_n(v) \int_0^{L_z} c_n(w) C_{10}(u, v, w, \tau) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial u} d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n \times \\
& \times F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \int_0^{L_y} s_n(v) \int_0^{L_z} c_n(w) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial v} \times \\
& \times C_{10}(u, v, w, \tau) d w d v d u d \tau - \frac{2\pi}{L_x L_y L_z} \sum_{n=1}^{\infty} n F_{nc} c_n(x) c_n(y) c_n(z) e_{nc}(t) \int_0^t e_{nc}(-\tau) \int_0^{L_x} c_n(u) \times \\
& \times \int_0^{L_y} c_n(v) \int_0^{L_z} s_n(w) C_{10}(u, v, w, \tau) \frac{C_{00}^{\gamma-1}(u, v, w, \tau)}{P^\gamma(u, v, w, T)} \frac{\partial C_{00}(u, v, w, \tau)}{\partial w} d w d v d u d \tau.
\end{aligned}$$

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