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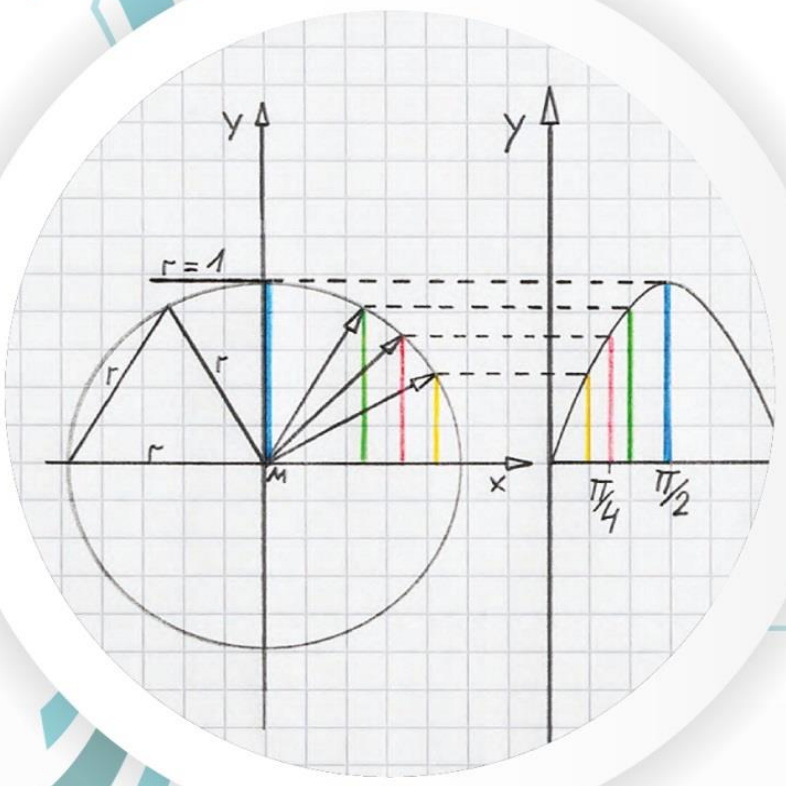

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SIMULATION OF POTENTIAL DISTRIBUTIONS IN THE SPACE CHARGE REGION OF SEMICONDUCTOR STRUCTURES

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Abstract. The methods of description of semiconductor-insulator interface characteristics based on process change of MIS type structure was considered. By using Maple Software, the calculations of quantities of inversion layer charge, total charge of semiconductor, inversion layer width and SCR semiconductor total width were made. Also, dependence theses quantities from doping level, temperature and surface potential were obtained.

Keywords: MIS structure, space charge region, inversion layer, maple software

The metal-insulator-semiconductor (MIS) capacitor is the most useful device in the study of semiconductor surfaces. Since most practical problems in the reliability and stability of all semiconductor devices are intimately related to their surface conditions, an understanding of the surface physics with the help of MIS capacitors is of great importance to device operations [1].

The properties description of the semiconductor-insulator interface carries out by comparing the theoretically calculated characteristics of an ideal MIS structure with the experimentally obtained dependences of real structures. For example, capacitive methods assume comparisons of volt-farad characteristics, and methods based on conductivity measurements assume comparisons of the theoretically calculated conductance of the channel of an ideal MIS transistor with the experimentally obtained conductivity of the channel of the real MIS transistor.

It is obvious that both the conductivity and capacity of the MIS structure are determined by the space charge region (SCR) parameters of the semiconductor, such as the concentration of the charge carrier in the near-surface region of the semiconductor, the thickness of the space-charge region and in the case of studying nonequilibrium characteristics, and the rate of generation-recombination processes. Thus, the accuracy of determining the characteristics of the interface and the unambiguous interpretation of the obtained results is determined not only by the

accuracy of obtaining the experimental data, but also by the accuracy of calculating the theoretical SCR parameters of the semiconductor [2].

In this work we present the simulation of the *p*-type semiconductor SCR characteristics performed by Maple software package on the basis of theoretical assumptions and models.

First, we define the potential $\phi(x)$by the equation

$$q\phi(x) = E_F - E_i(x) \tag{1}$$

whereE_F is the extrinsic Fermi level. The intrinsic energy level $E_i(x)$is parallel to both bands everywhere in the silicon and coincides in the bulk with the intrinsic Fermi level whose exact position in the deep in the bulk silicon $(x \to \infty)$, $\phi(x)$ is called the *bulk potential*ϕ_B, and at the silicon surface $(x = 0)$,$\phi(x)$ is called the surface potential ϕ_S (Fig.1).

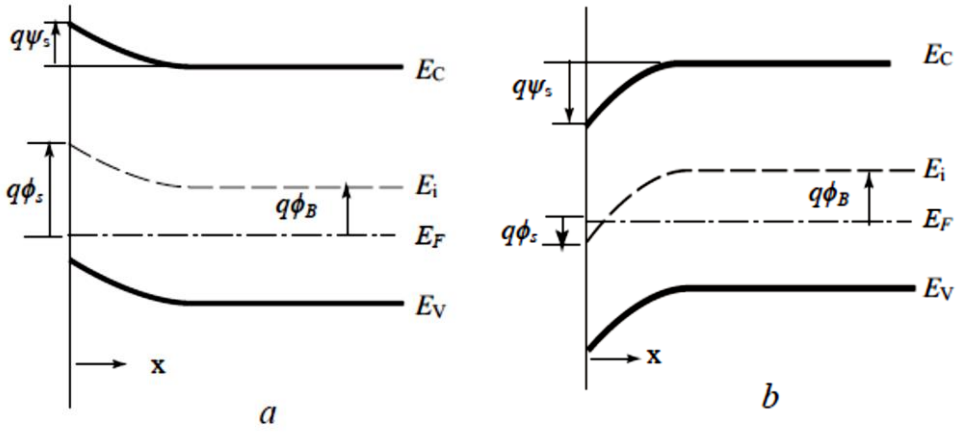

Fig.1. *Potential energy diagram of SCR for p-type silicon*

It is convenient to define dimensionless potentials $u(x)$ and $v(x)$ by the equations

$$u(x) = \frac{q\phi(x)}{kT} \qquad \text{and} \qquad v(x) = \frac{q\psi(x)}{kT} \tag{2}$$

At the silicon surface, $u(0) = u_s$and $v(0) = v_s$.

To determine the change in hole density, Δp, and electron density, Δn, per unit area when the u at the surface is shifted from u_B to a final value u_s, it is necessary to evaluate the following expressions and these equations do not solve in analytic view because of difficult function under integral (3) and (4) [3]

$$\Delta p = p_i \cdot L_D \cdot \int_{u_s}^{u_B} \frac{\left(e^{-u} - e^{u_B}\right)}{F\left(u_s, u_B\right)}\,du \text{ and} \Delta n = n_i \cdot L_D \cdot \int_{u_s}^{u_B} \frac{\left(e^{u} - e^{u_B}\right)}{F\left(u_s, u_B\right)}\,du \tag{3}$$

$$F(u_s, u_B) = 2^{1/2}[(u_B - u_s)\sinh u_s - (\cosh u_B - \cosh u_s)]^{1/2} \tag{4}$$

$$G(u_s, u_B) = \int_{u_s}^{u_B} \frac{\left(e^{-u} - e^{u_B}\right)}{F(u_s, u_B)} \, du \tag{5}$$

L_D, called the intrinsic Debye length, is defined as [4]

$$L_D = \left(\frac{\varepsilon_s kT}{2q^2 n_i}\right)^{1/2} \quad (\text{см}) \tag{6}$$

In our previous work [5], we tried to solve these equations by the mathematical tool. To get the total charge per unit area, we use Gauss's law

$$Q_s = \varepsilon_s F_s = Sgn(u_B - u_s) C_o \frac{kT}{q\lambda_i} F(u_s, u_B) \tag{7}$$

where$C_o = \varepsilon_s / \lambda_i$ is an effective semiconductor capacitance per unit area.
The excess charge calculated by the formula

$$Q_{sc} = \varepsilon_0 \varepsilon_s E_s = \frac{\varepsilon_0 \varepsilon_s kT}{q\lambda_i} F(u_s, u_B) \text{-} \tag{8}$$

Fig.2 shows surface charge as a function surface potential for p-type conductivity with specific concentration of dopant $4 \cdot 10^{15} cm^{-3}$ at the temperature $T = 300K$.

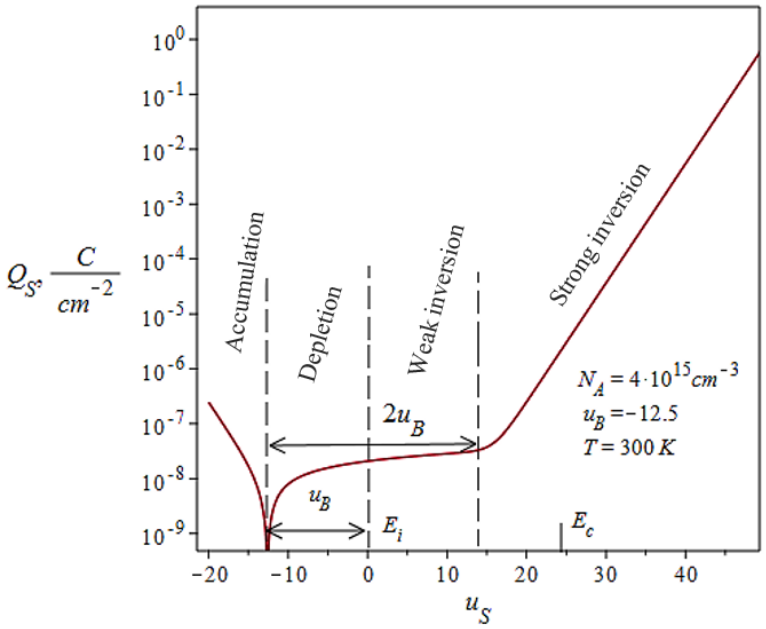

Fig.2. *Surface charge as a function surface potential for p-type semiconductor*

These data were also obtained in one calculation cycle, which made it easy to significantly simplify the processing of the results and avoid the process of stitching the Qs values obtained for different regions, without a significant loss of accuracy of the results obtained. All results were in agreement with experimental data [6].

Fig. 3 shows the calculated dependence of the value of u_B on T obtained in the temperature range from 100K to 300K for different values of impurity concentration. The values of u_B can be used to calculate the corresponding functions $F(u_s, u_B)$ and $G(u_s, u_B)$.

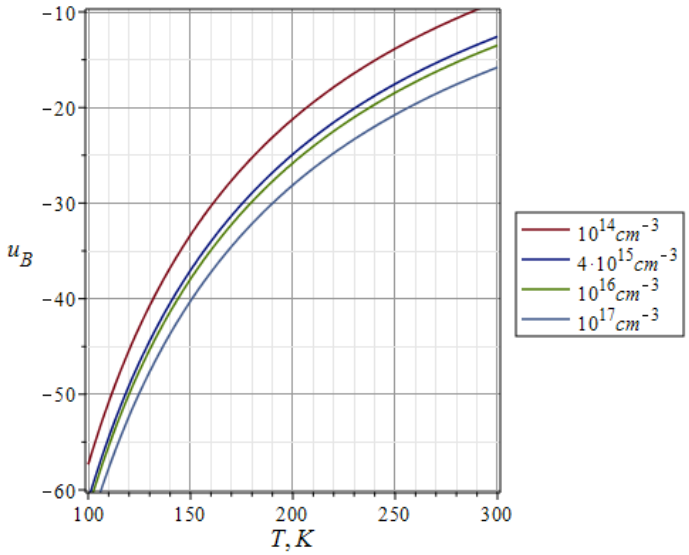

Fig.3. *Plot of bulk potential as a function temperature for p-type semiconductor*

Fig. 4 shows a three-dimensional view of the dependence of the u_B value on the impurity concentration and temperature (calculated as functions of N_A and T). This graph is more intuitive and makes it possible to easily determine u_B in a semiconductor substrate for different N_A and T values.

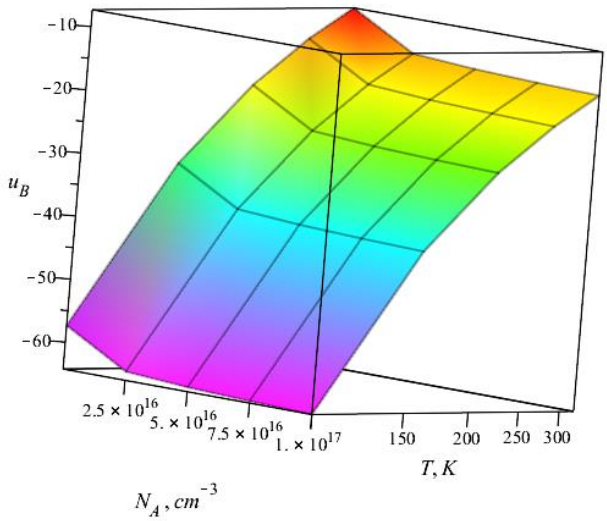

Fig.4. *3D plot of bulk potential as a function doping concentration and temperature for p-type silicon*

To calculate the shape of the surface potential and the inversion layer width at the silicon surface, we write

$$w_{inv} = L_D \int_{u_s}^{u} \frac{du}{F(u_s,u_B)} \tag{9}$$

The following Fig. 5 shows the calculation data for the thickness of the inversion layer determined from the condition u_s = -2u_B, carried out using approximate formulas and by numerical integration. It can be seen that the use of the Maple package makes it possible to perform the calculation without resorting to simplification of the original formulas, which makes it possible to increase the accuracy of determining w_{inv} by 10-13%.

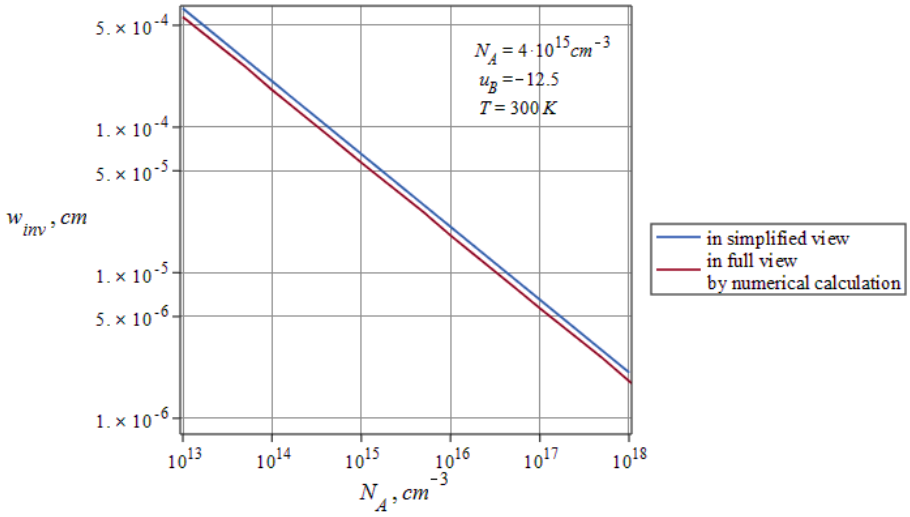

Fig.5. *Inversion layer width as a function of doping concentration with variety methods calculation for p-type silicon*

Fig. 6 shows the dependence of the inversion layer charge thickness of and the SCR thickness of the near-surface region of silicon on the levels of doping that draws attention to the fact that the ratio w_{inv} to w_{SCR} remains practically constant with a change in the doping levels of the semiconductor.

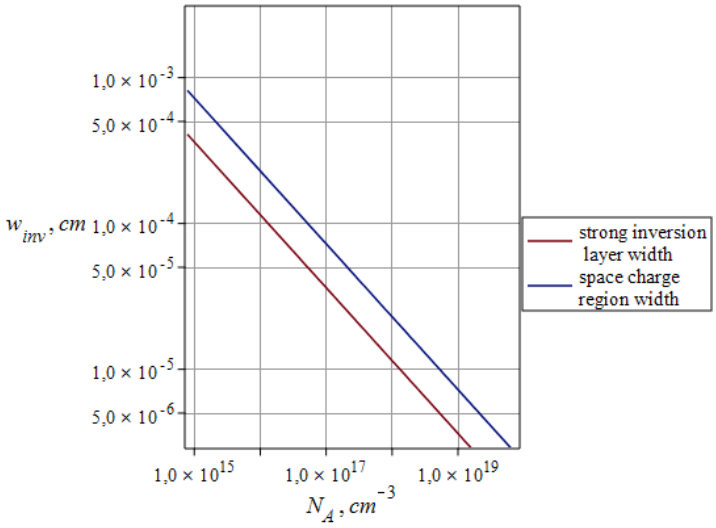

Fig.6. *Plot of inversion layer width for two regions*

In Fig. 7 shows the calculations of distribution of the dimensionless potential $u(x)$ in the inversion layer at the semiconductor-insulator interface. It is noteworthy that this dependence is close to linear. This indicates that the nonlinear dependence of $u(x)$ should be manifested outside the inversion region, and in the depletion region.

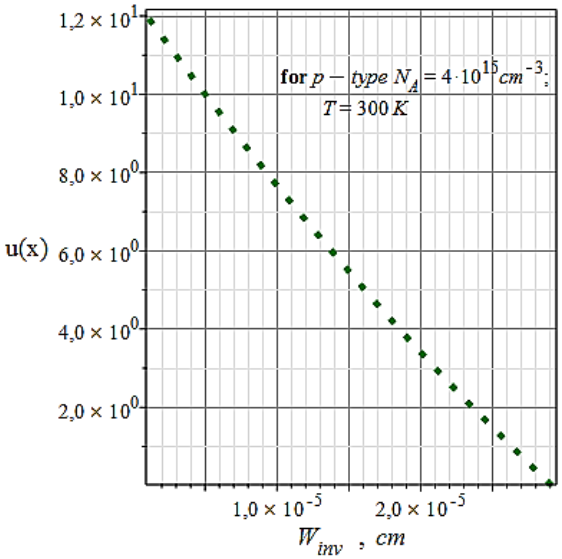

Fig.7. *Plot of distribution of the dimensionless potential u(x) versus inversion layer width*

Thus, MIS-structure can serve as an effective tool for researching of electrophysical characteristics of semiconductor-insulator interface. It was examined physical fundamentals of calculation methods of SCR semiconductor adjacenting to semiconductor-insulator interface. It was indicated that proprieties of SCR

semiconductor influences of interfaces lead to real deviation of SCR semiconductor from calculating.

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