T4. Generalized theory of scaling

The physics of a semiconductor device in steady state largely reduces to the description of the electric field and charge carrier fluxes.

Let us introduce the following notation: electron concentration n, hole concentration p. Donor concentration N_D, acceptor concentration N_A.

A1	Express the charge density ρ at some point using n, p, N_A, N_D and the elementary charge $e = 1.602 \cdot 10^{-19}$ C.

For the potential of the electric field ϕ (it follows $\vec{E} = -\operatorname{grad}\phi$) the 1st Maxwell's equaetion could be written:

$$-\Delta\phi = \frac{\rho}{\varepsilon_0\varepsilon}, \tag{1}$$

where ε is the relative permitivity of medium. Therefore, we have the first equation which connects the potential of electric field ϕ and concentrations of carriers n and p.

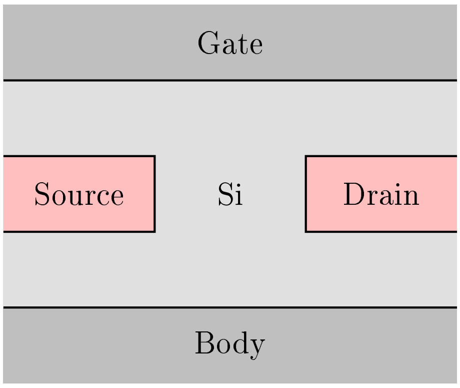
The second equation is connected with the mechanics of carriers.

A2	Express the electric current produced by the electrons J_n using their concentration n, mobility μ_n, the coefficient of diffusion D_n and $\operatorname{grad}\phi$, $\operatorname{grad} n$ and the elementary charge e.

From the stationairy condition of currents we obtain the second equation:

$$\operatorname{div} J_n = \operatorname{div} J_p = 0. \tag{2}$$

The solution of those two equations for given boundary conditions describe any semiconductor device in general, if other processes are suppressed, e.g. tunneling of electrons and holes.



Simplified geometry of the n-MOSFET transistor. Gate and Body are metallic electrodes, Source and Drain are field of N_D doping

Let's consider a scaling of coordinates into λ times and scaling of the potential ϕ into κ times

$$x' = x/\lambda, \quad y' = y/\lambda, \quad z' = z/\lambda, \quad \phi'(x', y', z') = \phi(x, y, z)/\kappa$$

To keep the form of electrostatic equation (1) the concentrations should also be changed:

$$n' = n \cdot \xi, \quad p' = p \cdot \xi, \quad N_A' = N_A \cdot \xi, \quad N_D' = N_D \cdot \xi$$

A3	Express ξ using λ and κ

If we apply proposed scaling to the transistor the important problem connected with the equation (2) arises. The electric field $-\phi$ also scales and mobility μ weakly depends on the value of this field.

A4	Which condition for λ and κ should be satisfied to keep electrostatic fields the same in the transistor?