POLUVODIČI

$n_i = (N_c \cdot N_v)^{1/2} \cdot \exp\left(-\frac{E_G}{2E_T}\right)$ [cm^{-3}]. Za Si na T=300 K izmjereno je $n_i = 10^{10}$ cm^{-3}. Za Si:

$N_c = 6{,}2 \cdot 10^{15} \cdot T^{3/2}$ [cm^{-3}]; $N_v = 3{,}5 \cdot 10^{15} \cdot T^{3/2}$ [cm^{-3}]; $E_G(T) = 1{,}17 - 4{,}73 \cdot 10^{-4} \cdot \frac{T^2}{T + 636}$ [eV]

$E_T = k \cdot T = \frac{T}{11605}$ [eV]

Električna provodnost: $\sigma = \sigma_n + \sigma_p = q \cdot n \cdot \mu_n + q \cdot p \cdot \mu_p = q \cdot (n \cdot \mu_n + p \cdot \mu_p)$

Pokretljivost nosilaca

Za Si na *T*=300 K:

$$\mu = \mu_{\min} + \frac{\mu_{\max} - \mu_{\min}}{1 + \left(\frac{N}{N_{ref}}\right)^{\alpha}}$$

	N_{ref} [cm^{-3}]	μ_{max} [cm^{2}V^{-1}s^{-1}]	μ_{min} [cm^{2}V^{-1}s^{-1}]	α
elektron	$1{,}12 \cdot 10^{17}$	1430	80	0,72
šupljina	$2{,}23 \cdot 10^{17}$	460	45	0,72

Vrijeme života i poništavanje (rekombinacija) nosilaca;

Za Si na *T*=300K:

$\tau_p = \frac{\tau_{p0}}{1 + \frac{N_D}{N_{0D}}}$; τ_{p0}=3,52·10^{-5}s, N_{0D}=7,1·10^{15}cm^{-3} $\qquad$ $\tau_n = \frac{\tau_{n0}}{1 + \frac{N_A}{N_{0A}}}$; τ_{n0}=1,7·10^{-5}s, N_{0A}=7,1·10^{15}cm^{-3}.

PN SPOJ

$U_k = U_T \ln\left(\frac{n_{0n} \cdot p_{op}}{n_i^2}\right) = U_T \ln\left(\frac{N_D \cdot N_A}{n_i^2}\right)$; $x_p = \frac{N_D}{N_A + N_D} d_B$; $x_n = \frac{N_A}{N_A + N_D} d_B$; $U_{TOT} = U_k - U$;

$d_B = \sqrt{\frac{2\varepsilon}{q} \frac{N_A + N_D}{N_A \cdot N_D} \cdot U_{TOT}}$

$E_{\max} = -\frac{2 \cdot U_{TOT}}{d_B}$; $C_T = \varepsilon \frac{S}{d_B}$

Široka n-strana:

$Q_p = q \cdot S \cdot (p_{n0} - p_{0n}) \cdot L_p$

$I_p = \frac{Q_p}{\tau_p}$

Uska n-strana:

$Q_p = q \cdot S \cdot (p_{n0} - p_{0n}) \cdot \frac{w_n}{2}$

$I_p = \frac{Q_p}{t_{pr}}$

$t_{pr} = \frac{(w_n)^2}{2D_p}$

$I_S = q \cdot n_i^2 \cdot S \cdot \left(\frac{D_n}{L_n \cdot N_A} + \frac{D_p}{L_p \cdot N_D}\right)$ (dioda sa širokim stranama)

BIPOLARNI TRANZISTOR

pnp tranzistor

$$\gamma = \left[1 + \frac{D_{nE} \cdot N_{DB} \cdot w_B}{D_{pB} \cdot N_{AE} \cdot L_{nE}}\right]^{-1}$$

$$\beta^* = \frac{1}{1 + \frac{w_B^2}{2L_{pB}^2}} \approx 1 - \frac{1}{2} \cdot \left(\frac{w_B}{L_{pB}}\right)^2$$

npn tranzistor

$$\gamma = \left[1 + \frac{D_{pE} \cdot N_{AB} \cdot w_B}{D_{nB} \cdot N_{DE} \cdot L_{pE}}\right]^{-1}$$

$$\beta^* = \frac{1}{1 + \frac{w_B^2}{2L_{nB}^2}} \approx 1 - \frac{1}{2} \cdot \left(\frac{w_B}{L_{nB}}\right)^2$$

Ebbers-Mollove jednadžbe

$$I_{ES} = \frac{I_{EB0}}{1 - \alpha_N \cdot \alpha_I};\ I_{CS} = \frac{I_{CB0}}{1 - \alpha_N \cdot \alpha_I};\ \alpha_I \cdot I_{CS} = \alpha_N \cdot I_{ES}$$

pnp:

$$I_E = I_{ES} \cdot \left[\exp\left(\frac{U_{EB}}{U_T}\right) - 1\right] - \alpha_I \cdot I_{CS} \cdot \left[\exp\left(\frac{U_{CB}}{U_T}\right) - 1\right]$$

$$I_C = -\alpha_N \cdot I_{ES} \cdot \left[\exp\left(\frac{U_{EB}}{U_T}\right) - 1\right] + I_{CS} \cdot \left[\exp\left(\frac{U_{CB}}{U_T}\right) - 1\right]$$

npn:

$$I_E = -I_{ES} \cdot \left[\exp\left(\frac{U_{BE}}{U_T}\right) - 1\right] + \alpha_I \cdot I_{CS} \cdot \left[\exp\left(\frac{U_{BC}}{U_T}\right) - 1\right]$$

$$I_C = \alpha_N \cdot I_{ES} \cdot \left[\exp\left(\frac{U_{BE}}{U_T}\right) - 1\right] - I_{CS} \cdot \left[\exp\left(\frac{U_{BC}}{U_T}\right) - 1\right]$$

UNIPOLARNI TRANZISTOR - JFET

n-kanalni

$$U_{GS0} = U_k - \frac{a^2 \cdot q \cdot N_D}{2 \cdot \varepsilon},\ b = a \cdot \left(1 - \sqrt{\frac{U_k - U_{GS}}{U_k - U_{GS0}}}\right),\ G_0 = \frac{2a \cdot w \cdot q \cdot N_D \cdot \mu_n}{L},\ \mu = \frac{\partial U_{DS}}{\partial U_{GS}} = r_d \cdot g_m$$

Triodno područje:

$$I_D = G_0 \cdot \left[U_{DS} - \frac{2}{3} \cdot \frac{(U_k - U_{GS} + U_{DS})^{\frac{3}{2}} - (U_k - U_{GS})^{\frac{3}{2}}}{\sqrt{U_k - U_{GS0}}}\right]$$

$$g_m = G_0 \cdot \frac{\sqrt{U_k - U_{GS} + U_{DS}} - \sqrt{U_k - U_{GS}}}{\sqrt{U_k - U_{GS0}}}$$

$$g_d = G_0 \cdot \left[1 - \sqrt{\frac{U_k - U_{GS} + U_{DS}}{U_k - U_{GS0}}}\right]$$

Područje zasićenja:

$$I_{Dzas} = G_0 \cdot \left[U_{GS} - U_{GS0} - \frac{2}{3} \cdot \frac{(U_k - U_{GS0})^{\frac{3}{2}} - (U_k - U_{GS})^{\frac{3}{2}}}{\sqrt{U_k - U_{GS0}}}\right]$$

$$I_{Dzas} = I_{DSS} \cdot \left(1 - \frac{U_{GS}}{U_{GS0}}\right)^2$$

$$g_m = G_0 \cdot \left(1 - \frac{\sqrt{U_k - U_{GS}}}{\sqrt{U_k - U_{GS0}}}\right)$$

$$g_d = \lambda \cdot I_{Dzas}$$

MOSFET

n-kanalni

$$K = \frac{\mu_{nk} \cdot \varepsilon_0 \cdot \varepsilon_{0x}' \cdot w}{t_{0x} \cdot L}$$

Triodno područje:

$$I_D = K\left[(U_{GS} - U_{GS0}) \cdot U_{DS} - \frac{1}{2} \cdot U_{DS}^2\right]$$

$$g_m = K \cdot U_{DS}$$

$$g_d = K \cdot (U_{GS} - U_{GS0} - U_{DS})$$

$$\mu = g_m \cdot r_d$$

Područje zasićenja:

$$I_{Dzas} = \frac{K}{2} \cdot (U_{GS} - U_{GS0})^2$$

$$g_m = K \cdot (U_{GS} - U_{GS0})$$

$$\frac{1}{r_d} = g_d = I_{Dzas} \cdot \lambda$$

$$\mu = g_m \cdot r_d$$

Kod p-kanalnog unipolarnog tranzistora naponi su suprotnog polariteta, a struja odvoda teče u suprotnom smjeru.