Električna svojstva poluvodiča

Širina zabranjenog pojasa: $E_G(T) = E_c - E_v$

Intrinzično: $n = \dfrac{1}{2}\left[N_D + \sqrt{N_D^2 + 4n_i^2}\right]$

Specifična vodljivost[S/m]: $\sigma = q(n\mu_n + p\mu_p), \sigma_n = qn\mu_n, \sigma_p = qp\mu_p$

              Najveća: N1=Nd1, N2=nd2
              Najmanja:N1=Nd, N2=Na

Driftna struja: $I_p = qp\mu_p SF = \sigma SF$

$$U = Fd, R = \rho\frac{l}{S}\frac{1}{\sigma}\frac{l}{S}$$

Poluvodičke diode

Većinski nosioci: $n_{0n} = N_D, p_{op} = N_A$

Manjinski nosioci:
$$n_{0p} = \frac{n_i^2}{N_A} - p - strana$$
$$p_{on} = \frac{n_i^2}{N_D} - n - strana$$

Struja kroz diodu: $I = I_S(\exp\left(\dfrac{U}{mU_T}\right) - 1)$

$$r_d = \frac{U_T}{I + I_S}$$

Dinamički otpor i svojstva: $i_D(t) = I_D + i_d(t)$

$$u_D(t) = U_D + u_d(t), u_d = i_d(r_d + R_S)$$

Široka n: Wn>>Lp   Široka p: Wp>>Ln
Uska n: Wn<<Lp   Uska p: Wp<<Ln

MOSFET

Zasićenje:

$$I_D = \frac{1}{2}K(U_{GS} - U_{GS0})^2 [mA]$$

$$K = \frac{2I_D}{(U_{GS} - U_{GS0})^2}[mA/V^2]$$

Triodno:

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

$$|U_{DS}| > |U_{GS} - U_{GS0}| - zasićasić$$
$$|U_{DS}| < |U_{GS} - U_{GS0}| - triodno$$

Nmos   Ugs>0 obogaćeni
           Ugs<0 osiromašeni

Pmos   Ugs>0 osiromašeni
           Ugs<0 obogaćeni

$$U_{GS0} = \frac{U_{GSB}\sqrt{\dfrac{I_{DA}}{I_{DB}}} - U_{GSA}}{\sqrt{\dfrac{I_{DA}}{I_{DB}}} - 1}$$

Dinamički parametri :

Zasićenje

$$I_D = \frac{1}{2}K(U_{GS} - U_{GS0})^2(1 + \lambda U_{DS})$$

$$K = \frac{2I_D}{(U_{GS} - U_{GS0})^2(1 + \lambda U_{DS})}$$

$$g_m = K(U_{GS} - U_{GS0}) = \sqrt{2KI_D}[mA/V]$$

$$g_d = \lambda I_D, \; r_d = 1/g_d$$

$$\mu = g_m r_d$$

Triodno

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

$$K = \frac{I_D}{(U_{GS} - U_{GS0})U_{DS} - \dfrac{1}{2}U_{DS}^2}$$

$$g_m = KU_{DS}$$

$$g_d = K(U_{GS} - U_{GS0} - U_{DS}), r_d = 1/g_d, \mu = g_m r_d$$

Dinamički na izlaznim karakteristikama:

Zasićenje

$$K = \frac{g_m}{(U_{GS} - U_{GS0})\sqrt{1 + \lambda U_{DS}}}$$

$$\lambda = \frac{I_{DA} - I_{DB}}{I_{DB}U_{DSA} - I_{DA}U_{DSB}}$$

$$g_m = K(U_{GS} - U_{GS0}), g_d = \lambda I_D$$

Triodno

$$K = \frac{g_m}{U_{DS}}, g_d = K(U_{GS} - U_{GS0} - U_{DS})$$

Projektiranje MOSFET-a

$$K = \frac{g_m}{(U_{GS} - U_{GS0})\sqrt{1 + \lambda U_{DS}}} \, ili \, K = \frac{g_m}{(U_{GS} - U_{GS0})}$$

$$K = \frac{W}{L}\mu C_{0x}, C_{0x} = \frac{\varepsilon_{0x}}{t_{0x}}$$

$$C_G = C_{0x}WL, \frac{K}{C_G} = \mu / L^2$$

$$U_{p0'} \frac{r(U_{DD} + U_{GS0p}) + U_{GSon}}{1 + r}$$

$$r = \sqrt{\frac{-K_p}{K_n}}, \frac{K_p}{K_n} = -\frac{\mu_p}{\mu_n}\frac{w_p}{w_n} = \frac{-\mu_p C_{0xp}\frac{W_p}{L_p}}{\mu_n C_{0xn}\frac{W_n}{L_n}}$$

$$t_{dVN} = \frac{C_T U_{DD}}{K_n(U_{DD} - U_{GS0n})^2}, t_{dNV} = \frac{C_T U_{DD}}{-K_p(U_{DD} - U_{GS0p})^2}$$

JFET

$$I_D = I_{DSS}(1 - \frac{U_{GS}}{U_P})^2(1 + \lambda U_{DS})$$

$$U_p = \frac{U_{GSB}\sqrt{\frac{I_{DA}}{I_{DB}}} - U_{GSA}}{\sqrt{\frac{I_{DA}}{I_{DB}}} - 1}$$

$$\lambda = \frac{I_{DA} - I_{DB}}{I_{DB}U_{DSA} - I_{DA}U_{DSB}}$$

$$g_m = \frac{2I_{DSS}}{-U_P}(1 - \frac{U_{GS}}{U_P}), r_d = \frac{U_{DS} + 1/\lambda}{I_D}$$

Bipolarni tranzistori

(npn)Ravnotežne konc.
$$n_{0B} = \frac{n_i^2}{p_{0B}} = \frac{n_i^2}{N_{AB}} \left[cm^{-3} \right]$$

$$p_{0E} = \frac{n_i^2}{n_{0E}} = \frac{n_i^2}{N_{DE}} \left[cm^{-3} \right]$$

Rubne konc.
$$n_{B0} = n_{0B} \exp\left(\frac{U_{BE}}{U_T} \right)$$

$$p_{E0} = p_{0E} \exp\left(\frac{U_{BE}}{U_T} \right)$$

Difuzijske strje
$$I_{pE} = qSD_{pE} \frac{p_{E0}}{w_E}, D_{pE} = \mu_{pE} U_T \left[cm^{-3}/s \right]$$

$$I_{nE} = qSD_{nB} \frac{n_{B0}}{w_B}, D_{nB} = \mu_{nB} U_T \left[cm^{-3}/s \right]$$

Faktor injekcije
$$\gamma = \frac{I_{nE}}{I_{nE} + I_{pE}} = \frac{I_{nE}}{-I_E}, I_E = -\frac{I_{pE}}{(1-\gamma)}$$

Bazni faktor
$$\beta^* = 1 - \frac{1}{2}\left(\frac{w_B}{L_{nB}} \right)^2 = 1 - \frac{1}{2}\left(\frac{w_B}{\sqrt{D_{nB}\tau_{nB}}} \right)^2 = 1 - \frac{I_R}{I_{nE}}$$

Faktor strujnog pojačanja
$$\alpha = \frac{I_C}{-I_E} = \frac{I_{nC}}{I_{nE} + I_{pE}} = \beta^* \gamma \quad \text{SZB}$$

Istosmjerni faktor
$$\beta = \frac{I_C}{I_B} = \frac{I_{nC}}{I_{pE} + I_R} = \frac{\beta^*}{\frac{1}{\gamma} - \beta^*} = \frac{\alpha}{1-\alpha} \quad \text{SZE}$$

Struje
$$I_B + I_C + I_E = 0 \quad I_E < 0, I_B, I_C > 0$$
$$I_{nC} = I_{nE} \beta^*$$
$$I_R = I_{nE} - I_{nC}$$
$$I_E = -\left(I_{nE} + I_{pE} \right)$$
$$I_B = I_{pE} + I_R - I_{CB0}$$
$$I_C = I_{nC} + I_{CB0}$$

Površina
$$Q_{nB} = qS \frac{n_{B0} w_B}{2} \left[As \right]$$

$$I_R = \frac{Q_{nB}}{\tau_n}$$

$$I_{nE} = qS\mu_n U_T \frac{n_{B0}}{w_B}$$

(pnp)Ravnotežne konc.	$$n_{0E} = \frac{n_i^2}{p_{0E}} = \frac{n_i^2}{N_{AE}} \left[cm^{-3}\right]$$
	$$p_{0B} = \frac{n_i^2}{n_{0B}} = \frac{n_i^2}{N_{DB}} \left[cm^{-3}\right]$$
Rubne konc.	$$n_{E0} = n_{0E} \exp\left(\frac{U_{EB}}{U_T}\right)$$
	$$p_{B0} = p_{0B} \exp\left(\frac{U_{EB}}{U_T}\right)$$
Difuzijske strje	$$I_{nE} = qSD_{nE}\frac{n_{E0}}{w_E}, D_{nE} = \mu_{nE}U_T \left[cm^{-3}/s\right]$$
	$$I_{pE} = qSD_{pB}\frac{p_{B0}}{w_B}, D_{pB} = \mu_{pB}U_T \left[cm^{-3}/s\right]$$
Faktori	$$\gamma = \frac{I_{pE}}{I_{pE} + I_{nE}} = \frac{I_{pE}}{I_E}$$
	$$\beta^* = \frac{I_{pC}}{I_{pE}} = 1 - \frac{I_R}{I_{pE}} = 1 - \frac{1}{2}\left(\frac{w_B}{\sqrt{D_{pB}\tau_{pB}}}\right)^2$$
	$$\alpha = \frac{I_C}{-I_E}, \beta = \frac{I_C}{I_B}$$
	$$Q_{pB} = qS\frac{p_{B0}w_B}{2}$$
	$$I_{pE} = qSD_{pB}\frac{p_{B0}}{w_B}$$
	$$I_R = \frac{Q_{pB}}{\tau_n}$$
Struje	$$I_E > 0, I_B, I_C < 0$$
	$$I_E = I_{pE} + I_{nE}$$
	$$I_C = -I_{pC} + I_{CB0}$$
	$$I_B = -I_{nE} - I_R - I_{CBO} = -I_E - I_C$$
	$$I_R = I_{pE} - I_{pC}$$