DISPOSITIVI ELETTRONICI

[Formulario Esame]

A CURA DI ALESSANDRO PAGHI

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LINK AL CORSO ANNO 2016/2017: http://www.iet.unipi.it/g.pennelli/dispositivi_materiale-didattico.html

FREQUENTAZIONE: NC.

DIODO

Drift Diffusion:

$$J_n(x) = q\mu_n n\,\mathcal{E}(x) + qD_n \frac{d}{dx} n(x)$$

$$J_p(x) = q\mu_p p\,\mathcal{E}(x) - qD_p \frac{d}{dx} p(x)$$

Basso Iniezione

$$\delta n = \delta p = \frac{n_i^2}{N_D}\left(e^{\frac{V}{V_T}} - 1\right)$$

$$\delta n \ll n_{n0}, \quad \delta p \gg p_{n0}$$

Profilo minoritari:

B. LUNGA

$$\delta p(x)_N = \frac{n_i^2}{N_D}\left(e^{\frac{V}{V_T}} - 1\right) e^{-\frac{x}{L_p}}$$

$$\delta n(x)_P = \frac{n_i^2}{N_A}\left(e^{\frac{V}{V_T}} - 1\right) e^{\frac{x}{L_n}}$$

B. CORTA

$$\delta p(x)_N = \frac{n_i^2}{N_D}\left(e^{\frac{V}{V_T}} - 1\right)\left(1 - \frac{x}{W_n - x_n}\right)$$

$$\delta n(x)_P = \frac{n_i^2}{N_A}\left(e^{\frac{V}{V_T}} - 1\right)\left(1 - \frac{x}{W_p - x_p}\right)$$

Corrente $I = I_0\left(e^{\frac{V}{V_T}} - 1\right)$

B. LUNGA

$$I_0 = qS\frac{D_p}{L_p}\frac{n_i^2}{N_D} + qS\frac{D_n}{L_n}\frac{n_i^2}{N_A}$$

B. CORTA

$$I_0 = qS\frac{D_p}{W_n - x_n}\frac{n_i^2}{N_D} + qS\frac{D_n}{W_p - x_p}\frac{n_i^2}{N_A}$$

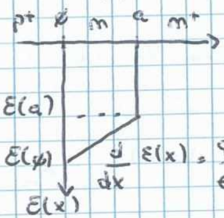
Break Down

$$\mathcal{E}_{BD} = \frac{qN_A x_p}{\epsilon_{si}}, \quad N_A x_p = N_D x_n$$

$$x_n = W \cdot \frac{N_A}{N_A + N_D}$$

$$W = \sqrt{\frac{2\epsilon_{si}}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)\left(V_0 - V_{BD}\right)}$$

Campo Elettrico



$$\frac{d}{dx}\mathcal{E}(x) = \frac{qN_D}{\epsilon_{si}}$$

$$\frac{\mathcal{E}(0) + \mathcal{E}(a)}{2} \cdot a = V_0 - V$$

$$\frac{\mathcal{E}(0) - \mathcal{E}(a)}{a} = q\frac{N_D}{\epsilon_{si}}$$

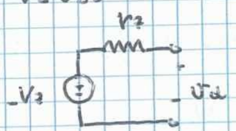
Circuito equivalente:

$$C_W = \frac{\epsilon_{si} \cdot S}{W}$$

$$C_{diff} = \frac{dQ}{dV}, \quad Q = q\int_0^{+\infty} \delta p(x)\, dx$$

$$r_{diff} = \frac{V_T}{I_d}, \quad r_{diff} \cdot C_{diff} = \tau_p$$

$V < V_{BD}$



$$r_z = \rho \cdot \frac{l}{S}$$

$$l = W_n - x_n$$

$$\rho = \frac{1}{\sigma_n} = (qN_D\mu_n)^{-1}$$

BJT

$$\beta_F = \frac{I_C}{I_B}, \quad \alpha_F = \frac{I_C}{I_E}, \quad \beta_{F\,n^+pn} = \frac{\tau_n}{\tau_T}$$

$$\beta_F = \frac{\alpha_F}{1 - \alpha_F}$$

$$\alpha_F = \gamma_E \cdot \alpha_T, \quad \gamma_E = \frac{I_{En}}{I_{En} + I_{SEp}}$$

$$\alpha_T = \frac{1}{1 + \frac{W^2}{2L_n^2}}$$

$$I_{En} = qS\frac{D_n}{W}\frac{n_i^2}{N_{AB}}$$

$$I_{SEp} = qS\frac{D_p}{L_p}\frac{n_i^2}{N_{DE}}$$

$$\beta_{F_{min}} = \beta_F(W_{met})$$

$$I_B = \frac{Q}{\tau_n} = qS\frac{1}{\tau_n}\frac{\delta n(0) + \delta n(W)}{2} \cdot W$$

$$I_C = qSD_n\frac{d}{dx}\delta n(x) = qSD_n\frac{\delta n(0) - \delta n(W)}{W}$$

$$\delta n(0) = \frac{n_i^2}{N_{AB}}\left(e^{\frac{V_{BE}}{V_T}} - 1\right), \quad \delta n(W) = \frac{n_i^2}{N_{AB}}\left(e^{\frac{V_{BC}}{V_T}} - 1\right)$$

$$W_{met} = W_{eff} + x_{pBE} + x_{pBC}, \quad \tau_{T\,npn} = \frac{W^2}{2D_n}$$

$$x_{pBE} = W_{BE} \cdot \frac{N_{DE}}{N_{DE} + N_{AB}}$$

SAT: $I_C = \frac{V_{CC}}{R_C}$, $Q_B(t) = I_C\tau_T$, $Q_B(t=0^-) = I_B\tau_n$

t_{S0}: $Q_B(t) = Q_B(t=0^-)\, e^{-t_{S0}/\tau_n}$

t_{on}: $Q_B(t) = Q_B(t=0^-)\left(1 - e^{-t_{on}/\tau_n}\right)$

t_{inv}: $Q_B(t) = Q_B(t=0^-)\left(2e^{-t/\tau_n} - 1\right)$

MOS

$$V_{TH} = \frac{\sqrt{2\varepsilon_{si} q N_A 2\psi_B}}{C_{ox}} + 2\psi_B + \phi_{MS} - \frac{Q_{ox}}{C_{ox}} \quad (Q_{ox} \text{ in } Si - SiO_2)$$

$\phi_{MS} = \phi_M - \phi_S$ $\qquad \psi_B = V_T \ln\left(\frac{N_A}{n_i}\right)$, $\quad C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$

$\phi_{M_{n^+}} = \chi$, $\quad \phi_{M_{p^+}} = \chi + \frac{E_G}{q}$ $\qquad n_i = \sqrt{N_C N_V}\, e^{-E_G/2KT}$

$\phi_S = \chi + \frac{E_G}{2q} + \psi_B$ $\qquad N_C(T) = N_C(300K) \cdot \left(\frac{T}{300}\right)^{3/2}$

$$V_{GB} = \frac{\sqrt{2\varepsilon_{si} q N_A V_S}}{C_{ox}} + V_S \rightarrow V_S$$

$Q_{si}(t = 0^+) = Q_W(V_S)$ $\qquad Q_W(V_S) = -\sqrt{2\varepsilon_{si} q N_A V_S}$

$Q_{si}(t = +\infty) = Q_W(2\psi_B) + Q_n$ $\qquad Q_n = -C_{ox}(V_{GB} - V_{TH})$

$\mathcal{E}_{si} = -\frac{Q_{si}}{\varepsilon_{si}}$, $\quad \mathcal{E}_{ox} = -\frac{Q_{si} + Q_{ox}}{\varepsilon_{si}}$

Se Q_{ox} è a $\frac{t_{ox}}{2}$ da $Si - SiO_2$: $V_{TH} = \frac{\sqrt{2\varepsilon_{si} q N_A 2\psi_B}}{C_{ox}} + 2\psi_B - \frac{Q_{ox}}{\varepsilon_{ox}} \frac{t_{ox}}{2}$

$n_S = n_0\, e^{\frac{V_S - V_{SB}}{V_T}}$

$I_{DS_{triodo}} = \mu_n C_{ox} \frac{W}{L}\left(V_{GS} - V_{TH} - \frac{V_{DS}}{2}\right) V_{DS}$

$I_{DS_{VCR}} = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH}) V_{DS}$

$I_{DS_{SAT}} = \frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2$

$V_{DS_{SAT}} = V_{GS} - V_{TH}$

$g_m = \frac{\partial}{\partial V_{GS}} I_{DS}$, $\quad g_d = \frac{\partial}{\partial V_{DS}} I_{DS}$

$I_{DS} = \frac{1}{2}\mu_n C_{ox} \frac{W}{L_{eff}}(V_{GS} - V_{TH})^2$

$L_{eff} = L - W(V_{PD})$

$W = \sqrt{\frac{2\varepsilon_{si}}{q}\frac{1}{N_A}(V_{0PD} - V_{PD})}$

$V_{PD} = -V_{0P} - (V_{DS} - V_{DS_{SAT}})$

$V_{0PD} = \frac{KT}{q} \ln\left(\frac{N_D N_A}{n_i^2}\right)$

Corrente di perdita BD:

$I_{BD} = I_{0BD}\left(e^{\frac{V_{BD}}{V_T}} - 1\right)$

$I_{0BD} = q S \frac{D_n}{L_n} \frac{n_i^2}{N_{AB}}$

Saturazione v_{drift}:

$\mathcal{E} = \frac{V_{DS}}{L} > \mathcal{E}_c$

$I_{DS} = \mu_n C_{ox} W \mathcal{E}_c (V_{GS} - V_{TH})$

$v_{drift} = \mu_n \mathcal{E}_c$, $\quad \tau_T = \frac{L}{v_{drift}}$, $\quad f_T = \frac{1}{\tau_T}$

$I_{DS} = \frac{Q_{tot}}{\tau_T}$, $\quad |Q_{tot}|_{VCR} = WL C_{ox}(V_{GS} - V_{TH})$

Potenziale canale:

$\frac{1}{2}\mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2 = \mu_n C_{ox} \frac{W}{y}(V_{GS} - V_{TH} - V(y)) V(y)$

$V(y) = (V_{GS} - V_{TH})\left(1 - \sqrt{1 - \frac{y}{L}}\right)$

$Q_n(y) = -C_{ox}(V_{GS} - V_{TH} - V(y))$

$V_{SB} \neq 0$

$$V_{GB_{inv}} = \frac{\sqrt{2\varepsilon_{si} q N_A (2\psi_B + V_{SB})}}{C_{ox}} + 2\psi_B + V_{SB}$$

$V_{GS_{inv}} = V_{TH} = V_{GB_{inv}} - V_{SB}$

$V_{DS} < 0$:

Se $V_{DB} = 0$, MOS al contrario

$V_{GD_{inv}} = V_{GB_{inv}}$

$$I_{SD} = \mu_n C_{ox} \frac{W}{L}\left[(V_{GD} - V_{GD_{inv}}) V_{SD} - \frac{V_{SD}^2}{2}\right]$$

Se non arrivo all'inversione:

$Q_n = 0$

$Q_W(V_S)$

$V_S: V_{GB} = \frac{\sqrt{2\varepsilon_{si} q N_A V_S}}{C_{ox}} + V_S$

$i_{GS}(t) = \frac{d}{dt} Q(t)$

VCR: $i_{GS}(t) = \frac{d}{dt}\left(WL C_{ox}(V_{GS} - V_{TH})\right)$

$= WL C_{ox}\, \omega V_M \sin(\omega t)$