# DISPOSITIVI ELETTRONICI

## *[Formulario Esame]*

A CURA DI ALESSANDRO PAGHI

**PROFESSORE:** Giovanni Pennelli ( http://www.iet.unipi.it/g.pennelli/ )

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

**FREQUENTAZIONE:** NC.

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# DIODO

Origine Diffusiva:

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

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

Regione semiconduttore:

B. LUNGA

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

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

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

B. LUNGA

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

Break Down

$E_{BD} = \frac{qN_B x_n}{\epsilon_{Si}}$, $N_B x_n = N_D x_n$

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

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

Circuito equivalente:

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

$Cdiff = \frac{dQ}{dV}$, $Q_n = q\int_x^{\infty} \delta_p(x)\,dx$

$\tau_{diff} = \frac{V_T}{I_D}$, $\tau_{diff} \cdot Cdiff = \tau_p$

Banda Quasi-neutra

$\delta_n = \delta_p = \frac{n_i^2}{N_D}\left(e^{\frac{V}{V_T}} - 1\right)$

$\delta_n << n_{no}$, $\delta_p >> p_{no}$

B. CORTA

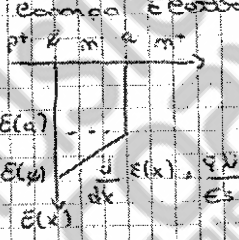
$\delta_p(x)_N = \frac{n_i^2}{N_D}\left(e^{\frac{V}{V_T}} - 1\right)\left(1 - \frac{x}{W_n - x_n}\right)$

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

B. Corta

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

Campo Elettrico

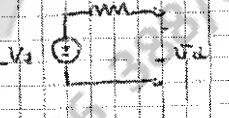



$\frac{\mathcal{E}(b) + \mathcal{E}(a)}{2} \cdot a = V_0 - V$

$\frac{\mathcal{E}(b) - \mathcal{E}(a)}{a} = q\frac{N_D}{\epsilon_{Si}}$

$\frac{dV}{dx} \mathcal{E}(x) = \frac{qN_D}{\epsilon_{Si}}$

$V < V_{BD}$




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

$\ell = W_n - x_n$

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

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BJT

$\beta_F = \frac{I_C}{I_B}$, $\alpha_F = \frac{I_C}{I_E}$, $\beta_F = \frac{\tau_n}{\tau_T}$

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

$\alpha_F = \gamma_E \cdot \alpha_T$, $\gamma_E = \frac{I_{Cn}}{I_{Cn} + I_{CEp}}$

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

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

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

$\beta_{F_{emitter}} = \beta_F(W_{emett})$

$I_B = \frac{Q_B}{\tau_n} = qS\frac{1}{\tau_n}\frac{\delta_n(x_p) + \delta_n(W)}{2} \cdot W$

$I_C = qSD_n\frac{1}{\delta x}\delta_n(x) = qSD_n\frac{\delta_n(x) - \delta_n(W)}{W}$

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

$W_{emett} = W_{BE_0} + x_{pBE} + x_{pBC}$, $\tau_{transm} = \frac{W^2}{2D_n}$

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

Sat: $I_C = \frac{V_{CC}}{R_C}$, $Q_B(t_1)$: $I_C t_1$, $Q_B(t = \infty) = I_B \tau_n$

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

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

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

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MOS

$V_{TH} = \frac{\sqrt{2\varepsilon_{Si} q N_A 2\psi_B}}{C_{ox}} + 2\psi_B + \phi_{MS} - \frac{Q_{ox}}{C_{ox}}$ (Qox in Si - SiO2)

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

$\phi_{M^+} = \chi$, $\quad \phi_{M^+} = \chi + \frac{E_G}{q}$ $\quad n_i = \sqrt{N_C N_V}\, e^{-E_G/2kT}$

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

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

$Q_{Si}(t = 0^+) = Q_W(V_S)$ $\quad Q_W(V_S) = \sqrt{2\varepsilon_{Si} q N_A V_S}$

$Q_{Si}(t = +\infty) = Q_W(2\psi_B) + Q_m$ $\quad Q_m = -C_{ox}(V_{GB} - V_{TH})$

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

Se $Q_{ox} = a \frac{t_{ox}}{2}$ da Si - SiO2: $V_{TH} = \frac{\sqrt{2\varepsilon_{Si} q N_A 2\psi_B}}{C_{ox}} + 2\psi_B - \frac{Q_{ox}}{C_{ox}} \frac{t_{ox}}{2}$

$n_S = n_0 e^{\frac{V_S - V_{SB}}{V_T}}$ $\quad$ Giunzione di uscita BD:

$I_{DS\,TRIODO} = \mu_n C_{ox} \frac{W}{L}\left(V_{GS} - V_{TH} - \frac{V_{DS}}{2}\right) V_{DS}$ $\quad I_{BD} = I_{OBD}\left(e^{\frac{V_{BD}}{V_T}} - 1\right)$

$I_{DS\,VCR} = \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH}) V_{DS}$ $\quad I_{OBD} = qS \frac{D_n}{L_n} \frac{n_i^2}{N_{AB}}$

$I_{DS\,SAT} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2$ $\quad$ Saturazione velocità:

$V_{DS\,SAT} = V_{DS} - V_{TH}$ $\quad \mathcal{E} = \frac{V_{DS}}{L} > \mathcal{E}_C$

$g_m = \frac{\partial}{\partial V_{GS}} I_{DS}$, $\quad g_d = \frac{\partial}{\partial V_{DS}} I_{DS}$ $\quad I_{DS} = \mu_n C_{ox} W \mathcal{E}_C (V_{GS} - V_{TH})$

$I_{DS} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L_{eff}} (V_{GS} - V_{TH})^2$ $\quad v_{sat} = \mu_n \mathcal{E}_C$, $\quad \tau_T = \frac{L}{v_{sat}}$, $\quad f_T = \frac{1}{2\tau}$

$L_{eff} = L - W(V_{PD})$ $\quad I_{DS} = \frac{Q_{TOT}}{2\tau}$, $\quad |Q_{TOT}|_{VCR} = WL C_{ox}(V_{GS} - V_{TH})$

$W = \sqrt{\frac{2\varepsilon_{Si}}{q} \frac{1}{N_A}(V_{PD} - V_{PD})}$ $\quad$ Potenziale canale:

$V_{PD} = V_{DD} - (V_{DS} - V_{DS\,SAT})$ $\quad \frac{1}{2} \mu_n C_{ox} \frac{W}{L}(V_{GS} - V_{TH})^2 = \mu_n C_{ox} \frac{W}{y}(V_{GS} - V_{TH} - V(y)) V(y)$

$V_{PD} = \frac{kT}{q} \ln\left(\frac{N_S N_A}{n_i^2}\right)$ $\quad V(y) = (V_{GS} - V_{TH1})\left(1 - \sqrt{1 - \frac{y}{L}}\right)$

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

$V_{SB} \neq 0$

$V_{GB\,min} = \frac{\sqrt{2\varepsilon_{Si} q N_A (2\psi_B + V_{SB})}}{C_{ox}} + 2\psi_B + V_{SB}$ $\quad$ Se non avessimo avuto l'inversione:

$V_{GS\,min} = V_{TH} = V_{GB\,min} - V_{SB}$ $\quad Q_m = 0$

$V_{DS} \neq 0$: $\quad Q_W(V_S)$

Se $V_{DB} = 0$, MOS da controllo $\quad V_S = V_{GB} = \frac{\sqrt{2\varepsilon_{Si} q N_A V_S}}{C_{ox}} + V_S$

$V_{SD\,min} = V_{GB\,min}$

$I_{SD} = \mu_n C_{ox} \frac{W}{L}\left[(V_{GB} - V_{SD\,min}) V_{SD} + \frac{V_{SD}^2}{2}\right]$ $\quad i_{GS}(t) = \frac{d}{dt} Q(t)$

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

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

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# DISPOSITIVI ELETTRONICI

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