List of Selected Formulae

(1) P-N junction:

$$V_{bi}=\frac{kT}{q}\ln\frac{N_A N_D}{n_i^2};\ N_A x_p = N_D x_n;\quad W=\sqrt{\frac{2\varepsilon_s}{q}[\frac{1}{N_A}+\frac{1}{N_D}](V_{bi}-V)};\ x_n=\frac{N_A W}{N_A+N_D};\quad x_p=\frac{N_D W}{N_A+N_D}$$

$$\xi_m=\frac{qN_D x_n}{\varepsilon_S}=\frac{qN_A x_p}{\varepsilon_S};\quad C_j=\frac{\varepsilon_S}{W}=\sqrt{\frac{q\varepsilon_S N_a N_d}{2(V_{bi}-V)(N_a+N_d)}};\ L_p=\sqrt{D_p\tau_p}$$

$$J=J_n(-x_p)+J_p(x_n)=(\frac{qD_p p_{no}}{L_p}+\frac{qD_n n_{po}}{L_n})\left(e^{qV/kT}-1\right)$$

(2) Bipolar Junction Transistor:

$$\gamma\equiv\frac{I_{Ep}}{I_E}=\frac{I_{Ep}}{I_{Ep}+I_{En}};\quad \alpha_T\equiv\frac{I_{Cp}}{I_{Ep}};\qquad \alpha_0=\gamma\alpha_T;\qquad \beta_0=\frac{\alpha_0}{1-\alpha_0};\quad I_C=\alpha_0 I_E+I_{CBO};$$

$$I_{CEO}=(1+\beta_0)I_{CBO};\qquad p_n(x)=p_{no}e^{qV_{EB}/kT}(1-\frac{x}{W});\qquad \gamma=\frac{1}{1+\frac{D_E}{D_p}\cdot\frac{N_B}{N_E}\cdot\frac{W}{L_E}};$$

$$I_{Ep}=qA\frac{D_p p_{n0}}{W}e^{(qV_{EB}/kT)};\ I_{En}=qA\frac{D_E n_{E0}}{L_E}(e^{qV_{EB}/kT}-1);\quad I_{Cn}=qA\frac{D_C n_{C0}}{L_C};$$

$$p_{n0}\cdot N_B=n_{E0}\cdot N_E=n_{C0}\cdot N_C=n_i^2;\qquad \tau_B=\frac{W^2}{2D_p};\quad f_T=\frac{1}{2\pi\tau_B}.$$

For pnp BJT:

$$n_E(x)=n_{EO}+n_{EO}\left(e^{qV_{EB}/kT}-1\right)\exp\left(\frac{x+x_E}{L_E}\right)\qquad n_C(x)=n_{CO}-n_{CO}\exp\left(-\frac{x-x_C}{L_C}\right)\qquad p_n(x)=p_n(0)\left[1-\frac{x}{W}\right]$$

(3) MOS diode and MOSFET:

$$q\phi_{ms}=q\phi_m-q\phi_s=q\phi_m-\left(q\chi+\tfrac{E_g}{2}+q\Psi_B\right)$$

$$\psi_s=2\psi_B=\frac{2kT}{q}\ln(\frac{N_A}{n_i});\ W_m^2=\frac{2\varepsilon_s(2\psi_B)}{qN_A}=\frac{4\varepsilon_s kT}{q^2N_A}\ln(\frac{N_A}{n_i});\ V_T=\frac{qN_A W_m}{C_o}+2\psi_B;$$

$$\frac{C}{C_0}=\frac{1}{\sqrt{1+\frac{2\varepsilon_{ox}^2 V}{qN_A\varepsilon_s d^2}}};\qquad \frac{1}{C_{\min}}=\frac{d}{\varepsilon_{ox}}+\frac{W_m}{\varepsilon_s};\qquad V_{FB}=\phi_{ms}-\frac{(Q_f+Q_m+Q_{ot})}{C_0}.$$

Enhancement mode NMOS

$I_D = K_n[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}]$ for $V_{DS} < V_{GS} - V_T$; $V_T = \frac{qN_A W_m}{C_0} + 2\psi_B$ when $V_{FB} = 0$;

$I_D = \frac{K_n}{2}(V_{GS} - V_T)^2$ for $V_{DS} \geq V_{GS} - V_T$; $K_n = \mu_n C_{ox} \frac{W}{L}$.

(4) <u>Thermal oxidation</u>:

$t_{ox}^2 + At_{ox} = B(t+\tau)$; $\tau = \frac{t_{oxi}^2}{B} + \frac{t_{oxi}}{B/A}$. $t_{ox} = \frac{-A + \sqrt{A^2 + 4B(t+\tau)}}{2}$

(5) <u>Diffusion</u>

Constant source diffusion: $N(z,t) = N_s erfc(\frac{z}{2\sqrt{Dt}})$; $Q = \frac{2}{\sqrt{\pi}} N_s \sqrt{Dt}$

Limited source diffusion: $N(z,t) = \frac{Q}{\sqrt{\pi Dt}} \exp[-\frac{z^2}{4Dt}]$;

For pre-deposition: $Q = 2N_s \sqrt{\frac{Dt}{\pi}}$; Diffusion coefficient $D = D_O \exp(-\frac{E_a}{kT})$

(6) <u>Ion implantation</u>:

<u>Before Annealing</u> <u>After annealing</u>

$N(x) = \frac{Q}{\sqrt{2\pi}\Delta R_p} \exp[-\frac{(x-R_p)^2}{2\Delta R_p^2}]$ $N(x) = \frac{Q}{\sqrt{2\pi}(\Delta R_p^2 + 2Dt)^{1/2}} \exp[-\frac{(x-R_p)^2}{2(\Delta R_p^2 + 2Dt)}]$

$Q = \int_0^\infty N(x)\,dx = \sqrt{2\pi} N_p \Delta R_p$

<u>Silicon oxide for masking</u>

$N(t_{ox}) = N_p \exp\left[-\frac{(t_{ox} - R_p)^2}{2\Delta R_p^2}\right] < \frac{N_B}{10}$

$t_{ox} \geq R_p + \Delta R_p \sqrt{2\ln\left(\frac{10N_p}{N_B}\right)}$

Table of Physical Constants

Physical Constant	Symbol	Value	Units
Electronic charge	q	1.6×10^{-19}	C
Boltzmann's constant	k	8.62×10^{-5} 1.38066×10^{-23}	eV/K J/K
Planck's constant	h	6.626×10^{-34}	J·s
Permittivity of free space	ε_0	8.85×10^{-14}	F/cm
Dielectric constant of Si	ε_{Si}	11.7	-
Dielectric constant of SiO_2	ε_{ox}	3.9	-
Electron Mass	m	9.11×10^{-31}	kg
Speed of Light	c	3×10^{8}	m/s
Bandgap of Si at 300 K	E_g	1.12	eV
Intrinsic carrier concentration in Si at 300 K	n_i	1.5×10^{10}	cm^{-3}