Cheat Sheet

Constants

$N_A = 6.02 \times 10^{23}$ molecules/mole
$k = 1.38 \times 10^{-23}$ J/K
$= 8.62 \times 10^{-5}$ ev/K
$q = 1.60 \times 10^{-19}$ C
$m_0 = 9.11 \times 10^{-31}$ kg
$\epsilon_0 = 8.85 \times 10^{-14}$ F/cm
Si: $\epsilon_r = 11.8$
SiO2: $\epsilon_r = 3.9$
Si: $n_i = 1.5 \times 10^{10}\ cm^{-3}$

$h = 6.63 \times 10^{-34}$ Js
$= 4.14 \times 10^{-15}$ eVs
$kT = 0.0259$ eV
$c = 2.998 \times 10^{10}$ cm/s
$\mathring{A} = 10^{-8}$ cm
1 eV $= 1.6 \times 10^{-19}$ J
Si: $E_g = 1.12\ eV$
Si: $\phi_m \approx \chi = 4.05\ eV$
Si: $\mu_n = 1350\ cm^2/Vs$, $\mu_p = 480\ cm^2/Vs$

Formulas

	Classical Mechanics	Quantum Mechanics
Position	x	x
Momentum	$p = mv$	$\frac{\hbar}{j}\frac{\partial}{\partial x}$
Energy	$E = KE + PE = \frac{1}{2}mv^2 + PE$	$-\frac{\hbar}{j}\frac{\partial}{\partial t}$

$p = mv = \hbar\vec{k} = \frac{h}{\lambda}$
$E = hv = \hbar\omega$
$E = \frac{1}{2}mv^2 = \frac{1}{2}\frac{p^2}{m} = \frac{\hbar}{2m^*}\vec{k}^2$
$m^* = \frac{\hbar^2}{\frac{d^2E}{d\vec{k}^2}}$
$f(E) = \frac{1}{e^{(E-E_F)/kT}+1} \approx e^{(E_F-E)/kT}$
$n_0 = N_c f(E_C)$
$N_c = 2(\frac{2\pi m_n^* kT}{h^2})^{3/2}$
$N_v = 2(\frac{2\pi m_p^* kT}{h^2})^{3/2}$
$p_0 = N_v f(E_v)$
$n_i = N_c e^{-(E_C-E_i)/kT} = \sqrt{N_c N_v} e^{-E_g/2kT}$
$p_i = N_v e^{-(E_i-E_C)/kT}$
$E = \frac{mq^4}{2K^2\hbar^2}$

$E_N = KE + PE = E_c + E(k) = -\frac{mq^4}{K^2 n^2 \hbar^2}$
$\langle Q \rangle = \int_{-\infty}^{\infty} \psi^* Q_{op} \psi \, d\vec{x}$
$Eg(x) = \int_{-\infty}^{\infty} g(x)P(x)dx$
$L = \sqrt{D\tau}$
$\rho = \frac{1}{\sigma}$
$R = \frac{\rho L}{wt}$
$J = \frac{I}{A}$
$J = J_n + J_p + C\frac{dV}{dt} = \sigma\varepsilon$
$J_n(x) = q\mu_n n(x)\varepsilon(x) + qD_n\frac{dn(x)}{dx}$
$J_p(x) = q\mu_p p(x)\varepsilon(x) - qD_p\frac{dp(x)}{dx}$
$\frac{kT}{q} = \frac{D}{\mu}$

Equilibrium

$n_0 = n_i e^{(E_F-E_i)/kT}$
$p_0 = n_i e^{(E_i-E_F)/kT}$
$n_0 p_0 = n_i^2$

Potential Well

$\psi = A\sin Kx$
$K = \frac{\sqrt{2mE}}{\hbar}$

$\frac{d^2}{dx^2}\psi(x) + \frac{2m}{\hbar^2}E\psi(x) = 0$

Steady State

$$n = N_c e^{-(E_C-F_n)/kT} = n_i e^{(F_n-E_i)/kT}$$
$$p = N_v e^{-(F_p-E_v)/kT} = n_i e^{(E_i-F_p)/kT}$$
$$np = n_i^2 e^{(F_n-F_p)/kT}$$

$$\psi_H = \sqrt{\frac{2}{L}} \sin \frac{nm}{L} x$$
$$\psi_K(X) = U(k_x, x) e^{jKxX}$$

p-n

$$V_0 = \frac{kT}{q} \ln\left(\frac{N_a N_d}{n_i^2}\right)$$
$$\frac{p_p}{p_n} = \frac{n_n}{n_p} = e^{qV_0/kT}$$
$$W = \sqrt{\frac{2\epsilon(V_0-V)}{q}\left(\frac{N_a+N_d}{N_a N_d}\right)}$$
$$n = n_0 + \delta_n$$
$$p = p_0 + \delta_p$$
$$\delta_p(x_n) = \Delta p_n e^{-x_n/L_p}$$
$$\delta_n(x_p) = \Delta n_p e^{-x_p/L_n}$$

$$Q_+ = qAx_{n0}N_d = qAx_{p0}N_a$$
$$\varepsilon_0 = -\frac{q}{\varepsilon} x_{n0} N_d = -\frac{q}{\varepsilon} x_{p0} N_a$$
$$I_p = qA\frac{D_p}{L_p} p_n (e^{qV/kT} - 1)$$
$$I_n = qA\frac{D_n}{L_n} n_p (e^{qV/kT} - 1)$$
$$I_{op} = qAg_{op}(L_p + L_n + W)$$
$$\Delta\sigma = qg_{op}(\tau_n \mu_n + \tau_p \mu_p)$$
$$C_j = \frac{\epsilon A}{W}$$

One sided

$$x_{p0} = W \frac{N_d}{N_a + N_d}$$
$$x_{n0} = W \frac{N_a}{N_a + N_d}$$

BJT pnp

$$B = \frac{I_C}{I_{E_p}} = \operatorname{sech}\left(\frac{W_b}{L_p}\right)$$
$$\gamma = \frac{I_{E_p}}{I_{E_n} + I_{E_p}} = \left(1 + \frac{L_p^n n_n \mu_n^p}{L_n^p p_p \mu_p^n} \tanh\left(\frac{W_b}{L_p^n}\right)\right)^{-1}$$
$$\alpha = B\gamma$$
$$\beta = \frac{\alpha}{1-\alpha}$$
$$I_{E_p} = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{ctnh} \frac{W_b}{L_p} - \Delta p_C \operatorname{csch} \frac{W_b}{L_p}\right)$$
$$I_C = qA\frac{D_p}{L_p}\left(\Delta p_E \operatorname{csch} \frac{W_b}{L_p} - \Delta p_C \operatorname{ctnh} \frac{W_b}{L_p}\right)$$
$$I_B = qA\frac{D_p}{L_p}\left((\Delta p_E + \Delta p_C) \tanh \frac{W_b}{2L_p}\right)$$
$$\Delta p_E = p_n(e^{qV_{EB}/kT} - 1)$$
$$\Delta p_C = p_n(e^{qV_{CB}/kT} - 1)$$
$$I_C/I_E = \alpha$$
$$I_C/I_B = \beta$$

MOS

$$\frac{1}{2}\phi_s = \phi_F = \frac{kT}{q} \ln\left(\frac{N_a}{n_i}\right) = E_F - E_i$$
$$W_{min} = W\Big|_{V_0 - V = \phi_s}$$
$$C_i = \frac{\epsilon_i}{d}$$
$$C_d = \frac{\epsilon_s}{W}$$
$$C = \frac{C_i C_d}{C_i + C_d}$$
$$V_{FB} = \phi_{ms} - \frac{Q_i}{C_i}$$
$$Q_d = -qN_a W_m = -2(\epsilon_s q N_a \phi_F)^{1/2}$$
$$V_T = V_{FB} - \frac{Q_d}{C_i} + \phi_s$$
$$\Phi_s = \chi + \frac{E_g}{2} - \phi_F$$
$$I_D = \frac{\bar{\mu}_n Z C_i}{L}((V_G - V_T)V_D - \frac{1}{2}V_D^2)$$
$$I_{Dsat} = \frac{Z}{2L} \bar{\mu}_n C_i V_D^2$$

B Base Transportation Factor

γ Emitter Injection Efficiency

α Current Transfer Ratio

β Base to Collection Current Amplification Factor