$$v_{dp} = \mu_p E; \quad v_{dn} = -\mu_n E$$

$$J_{drf} = e(\mu_n n + \mu_p p)E = \sigma E$$

$$\mu_p = \frac{v_{dp}}{E} = \frac{e\tau_{cp}}{m^*_{cp}}$$

$$\frac{1}{\mu} = \frac{1}{\mu_I} + \frac{1}{\mu_L}$$

$$\rho = \frac{1}{\sigma} = \frac{1}{e(\mu_n n + \mu_p p)}$$

$$J_{nx|dif} = eD_n \frac{dn}{dx}; \quad J_{px|dif} = -eD_p \frac{dp}{dx}$$

$$J = en\mu_n E + ep\mu_p E + eD_n \nabla n - eD_p \nabla p$$

$$\phi = \frac{1}{e}(E_F - E_{Fi}); \quad E_x = -\frac{d\phi}{dx} = \frac{1}{e}\frac{dE_{Fi}}{dx}$$

$$n_0 = n_i \exp\left[\frac{E_F - E_{Fi}}{k_B T}\right] \approx N_d(x)$$

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{k_B T}{e}$$

$$qE_y = qv_x B_z$$

$$V_H = E_H W$$

$$V_H = \frac{I_x B_z}{epd}; \quad V_H = -\frac{I_x B_z}{end}$$

$$p = \frac{I_x B_z}{edV_H}$$

$$\mu_p = \frac{I_x L}{epV_x W d}$$

$$n = -\frac{I_x B_z}{edV_H}$$

$$\mu_n = \frac{I_x L}{enV_x W d}$$

$$\nabla \cdot D = q(p - n + N_d^+ - N_a^-)$$

$$n = n_0 + \delta n; \quad p = p_0 + \delta p$$

$$\delta n = \delta p$$

$$n_i^2 = n_0 p_0 \implies p_0 = \frac{n_i^2}{n_0 = N_d}$$

$$\delta n(t) = \delta n(0) e^{-t/\tau_{n0}}$$

$$R'_p = \frac{\delta n(t)}{\tau_{n0}}; \quad R'_n = \frac{\delta n(t)}{\tau_{p0}}$$

$$\frac{\partial n}{\partial t} = -\frac{\partial F_n^-}{\partial x} + g_n - \frac{n}{\tau_{nt}}; \quad \frac{\partial p}{\partial t} = -\frac{\partial F_p^+}{\partial x} + g_p - \frac{p}{\tau_{nt}}$$

$$k_B = 1.381 \times 10^{-23} \text{ J K}^{-1} = 8.617 \times 10^{-5} \text{eVK}^{-1}$$

$$D_n \frac{\partial^2(\delta n)}{\partial x^2} + \mu_n E \frac{\partial(\delta n)}{\partial x} + g_n - \frac{\delta n}{\tau_{n0}} = \frac{\partial(\delta n)}{\partial t}$$

$$D_p \frac{\partial^2(\delta p)}{\partial x^2} + \mu_p E \frac{\partial(\delta p)}{\partial x} + g_p - \frac{\delta p}{\tau_{p0}} = \frac{\partial(\delta p)}{\partial t}$$

$$n_0 = n_i \exp\left(\frac{E_F - E_{Fi}}{k_B T}\right)$$

$$p_0 = n_i \exp\left(\frac{E_{Fi} - E_F}{k_B T}\right)$$

$$n_0 + \delta n = n_i \exp\left(\frac{E_{Fn} - E_{Fi}}{k_B T}\right)$$

$$p_0 + \delta p = n_i \exp\left(\frac{E_{Fi} - E_{Fp}}{k_B T}\right)$$

$$E_{Fn} - E_{Fin} = k_B T \ln \frac{n_0 + \delta n}{n_i}$$

$$E_{Fip} - E_{Fp} = k_B T \ln \frac{p_0 + \delta p}{n_i}$$

$$V_{bi} = |\phi_{Fn}| + |\phi_{Fp}| = \frac{k_B T}{e} \ln \frac{N_a N_d}{n_i^2}$$

$$W = x_n + x_p = \left\{\frac{2\epsilon_s V_{bi}}{e}\left[\frac{N_a + N_d}{N_a N_d}\right]\right\}^{1/2}$$

$$x_p = \frac{N_d x_n}{N_a}$$

$$x_n = \left\{\frac{2\epsilon_s V_{bi}}{e}\left[\frac{N_d}{N_a}\right]\left[\frac{1}{N_a + N_d}\right]\right\}^{1/2}$$

$$x_p = \left\{\frac{2\epsilon_s V_{bi}}{e}\left[\frac{N_a}{N_d}\right]\left[\frac{1}{N_a + N_d}\right]\right\}^{1/2}$$

$$E_{max} = \frac{-2(V_b i + V_R)}{W}$$

$$E = \begin{cases} -\frac{-eN_a}{\epsilon_s}(x + x_p) & -x_p \le x \le 0 \\ -\frac{-eN_d}{\epsilon_s}(x_n - x) & 0 \le x \le x_n \end{cases}$$

$$V_{bi} = |\phi(x = x_n)| = \frac{e}{e\epsilon_s}\left(N_d x_n^2 + N_a x_p^2\right)$$

$$C' = \left\{\frac{e\epsilon_s N_a N_d}{2(V_{bi} + V_R)(N_a + N_d)}\right\}^{1/2}$$

$$V_B = \frac{\epsilon_s E_{crit}^2}{2eN_B}$$

$$E_F = -k_B T \ln \frac{N_a}{N_d}; \quad E_F = E_g + k_B T \ln \frac{N_d}{N_a}$$

$$n_p = n_{p0} \exp \frac{eV_a}{k_B T}$$

$$p_n = p_{n0} \exp \frac{eV_a}{k_B T}$$