微电子器件物理
PN结的电流特性

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PN结的连续性方程

$$\nabla \bullet E = q\left(p - n + N_D^+ - N_A^-\right)$$

能带图

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_N - r_N + g_N$$

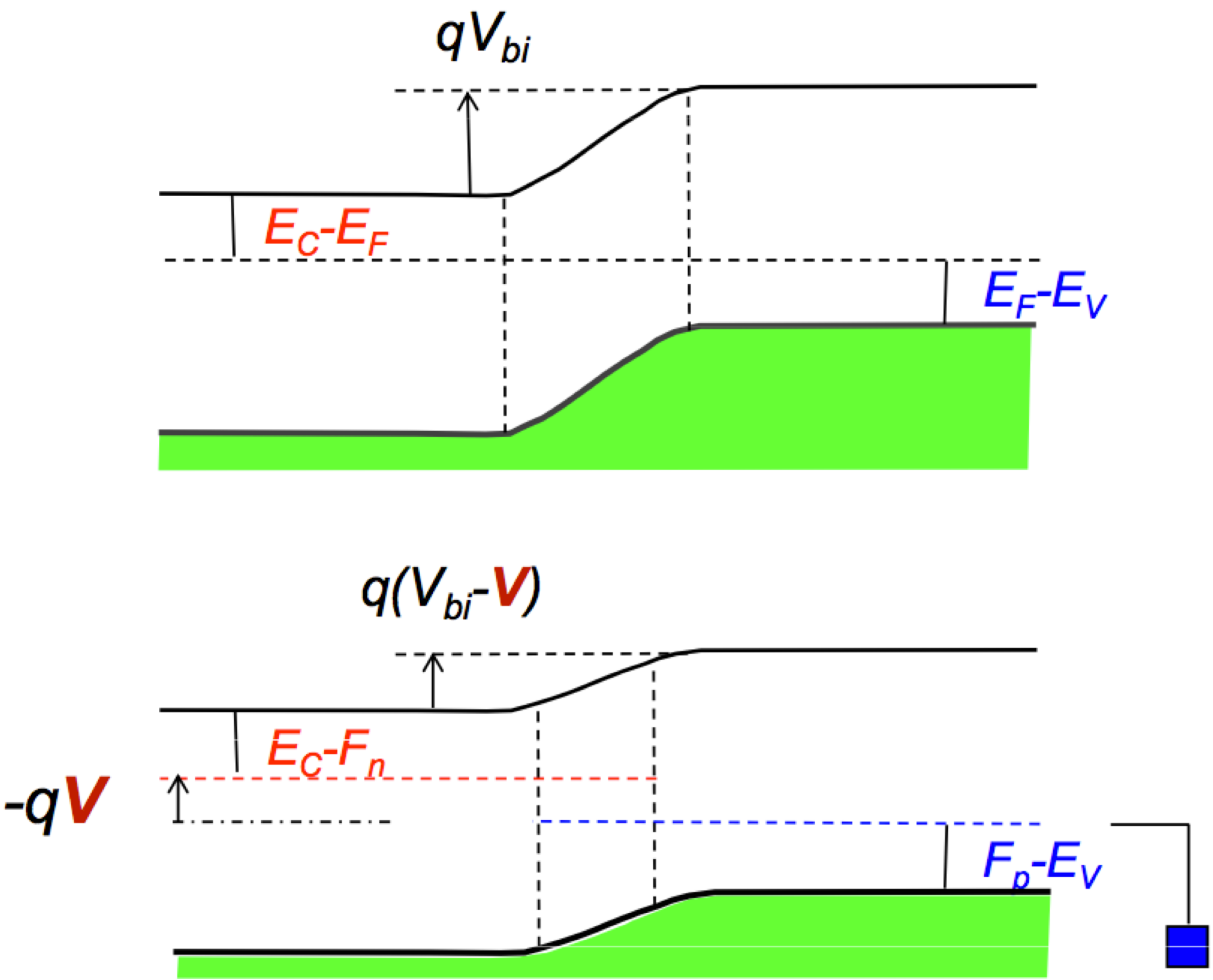
$$\mathbf{J}_N = qn\mu_N E + qD_N \nabla n$$

$$\frac{\partial p}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_P - r_P + g_P$$

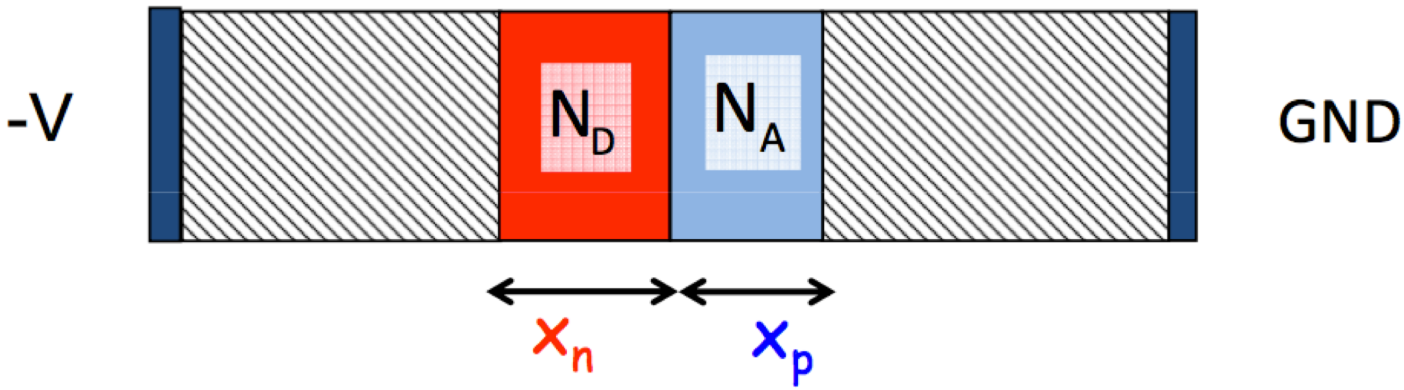
$$\mathbf{J}_P = qp\mu_P E - qD_P \nabla p$$

正向电流和反向电流

PN结的正向偏置



耗尽区宽度



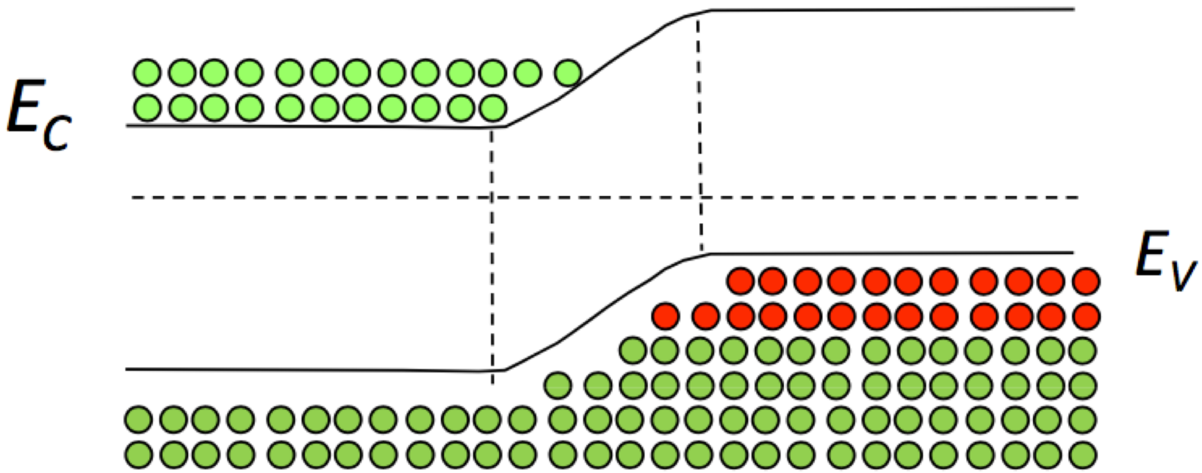
$$N_D x_n = N_A x_p$$

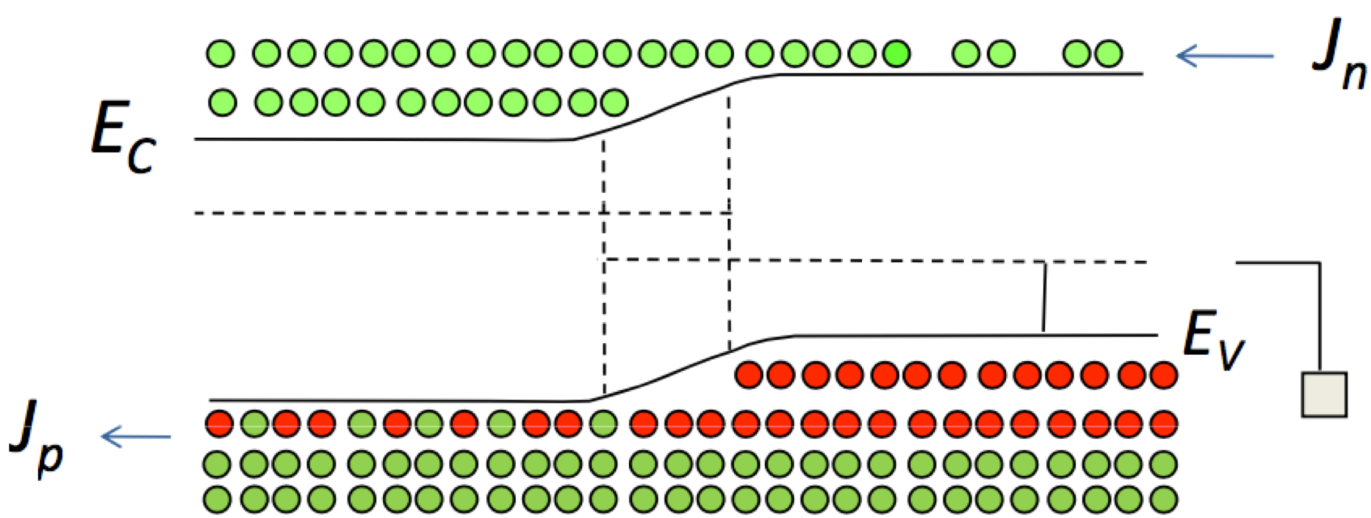
$$q\left(V_{bi} - V\right) = \frac{qN_D x_n^{\ 2}}{2k_s\varepsilon_0} + \frac{qN_A x_p^{\ 2}}{2k_s\varepsilon_0}$$

$$x_n = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_A}{N_D\left(N_A + N_D\right)}\left(V_{bi} - V\right)}$$

$$x_p = \sqrt{\frac{2k_s\varepsilon_0}{q}\frac{N_D}{N_A\left(N_A + N_D\right)}\left(V_{bi} - V\right)}$$

准费米能级





边界条件

$$\Delta n(0^+) = n(0^+)_{V_G} - n(0^+)_{V_G=0}$$

$$= \frac{n_i^2}{N_A}\left(e^{qV_A\beta} - 1\right)$$

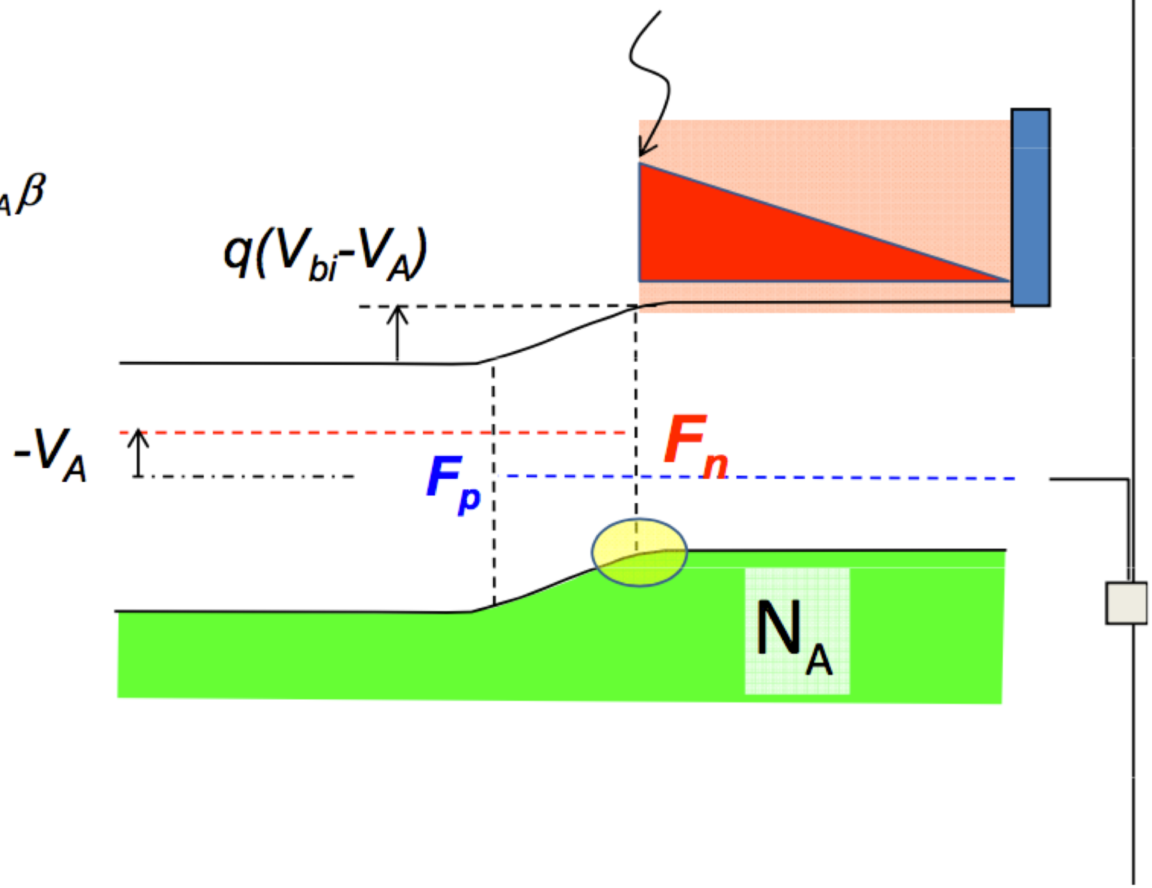
$$n(x=0^+) = n_i\, e^{(F_n - E_i)\beta}$$

$$p(x=0^+) = n_i\, e^{-(F_p - E_i)\beta}$$

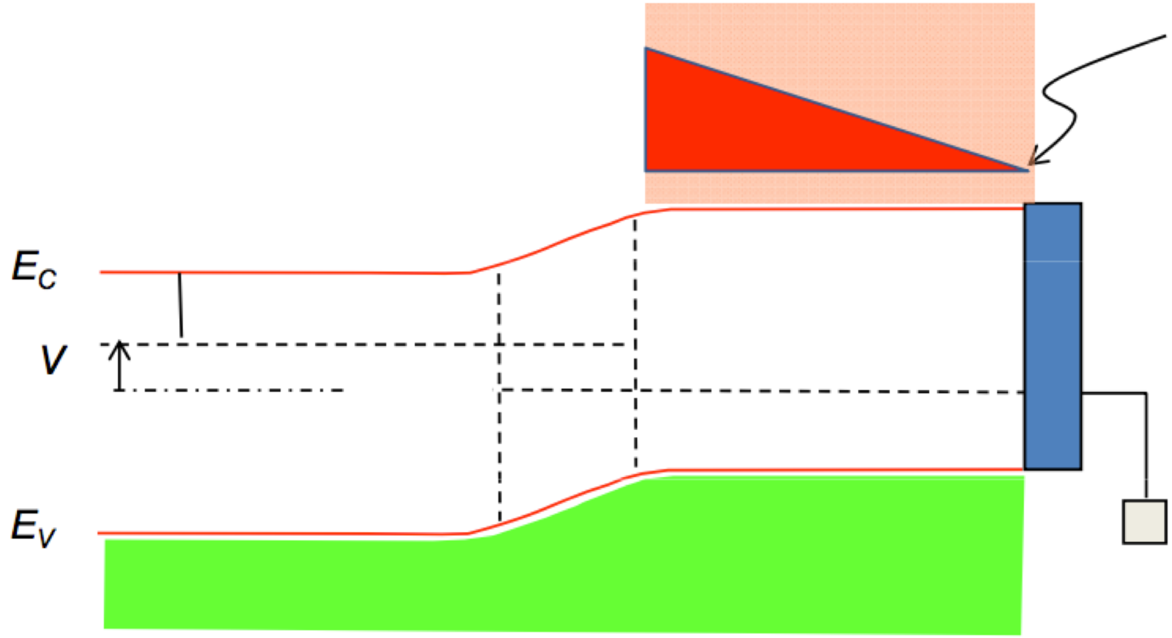
$$np = n_i^2 e^{(F_n - F_p)\beta} = n_i^2 e^{qV_A\beta}$$

$$p(0^+) = N_A$$

$$n(0^+) = \frac{n_i^2}{N_A} e^{qV_A\beta}$$



边界条件



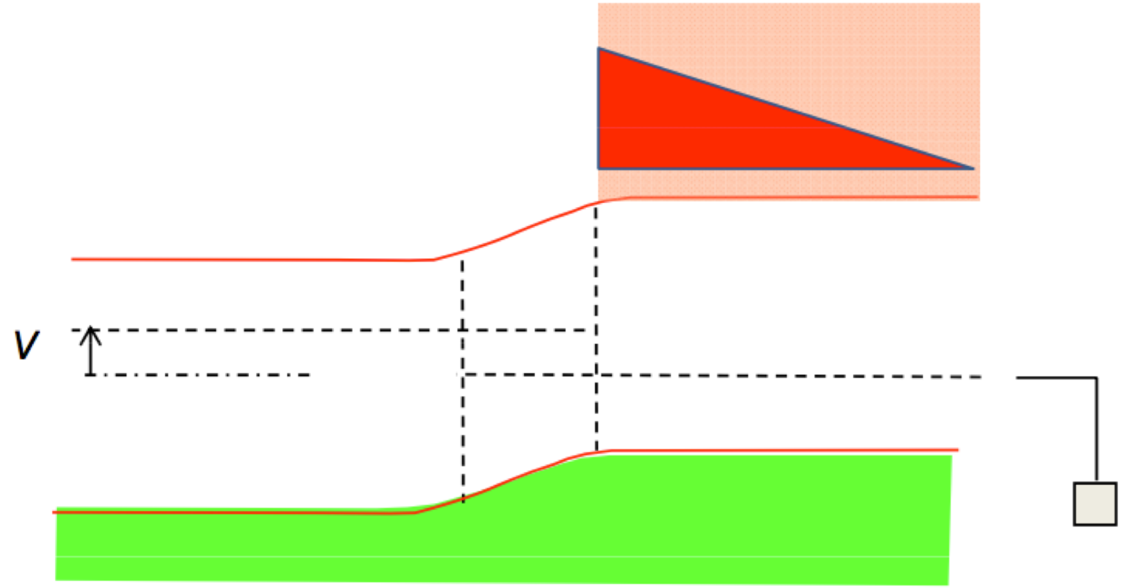
$$n(x = W_p) \approx \frac{n_i^2}{N_A}$$

$$\Delta n(x = W_p) = 0$$

边界条件

$$D_N \frac{d^2 n}{dx^2} = 0$$

$$\Delta n(x,t) = C + Dx$$



$$x = W_p, \quad \Delta n(x = W_p) = 0 \Rightarrow C = -DW_p$$

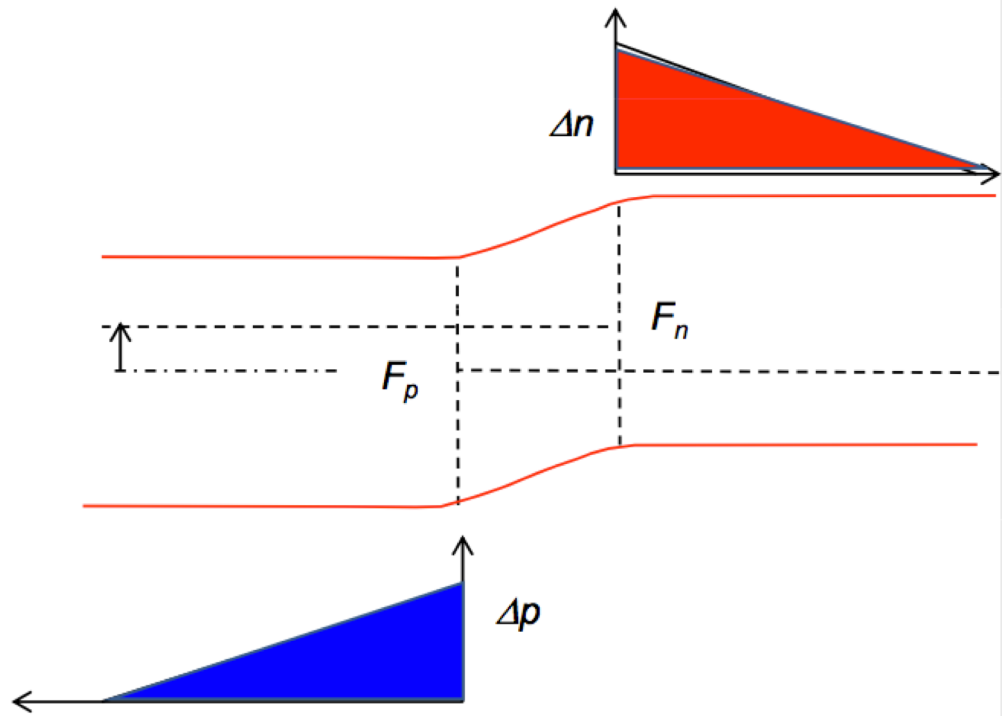
$$x = 0', \quad \Delta n(x = 0) = \frac{n_i^2}{N_A}\left(e^{qV_A\beta} - 1\right) = C$$

$$\Delta n(x,t) = \frac{n_i^2}{N_A}\left(e^{qV_A\beta} - 1\right)\left(1 - \frac{x}{W_p}\right)$$

电子电流和空穴电流

$$\Delta n(x)=\frac{n_i^2}{N_A}\left(e^{qV_A\beta}-1\right)\left(1-\frac{x}{W_p}\right)$$

$$\mathbf{J}_N=qn\mu_N\mathcal{E}+qD_N\nabla n$$



$$J_n=qD_n\left.\frac{dn}{dx}\right|_{x=0}=-\frac{qD_n}{W_p}\frac{n_i^2}{N_A}\left(e^{qV_A\beta}-1\right)$$

$$J_p=-qD_p\left.\frac{dp}{dx}\right|_{x=0'}=-\frac{qD_p}{W_n}\frac{n_i^2}{N_D}\left(e^{qV_A\beta}-1\right)$$

总电流

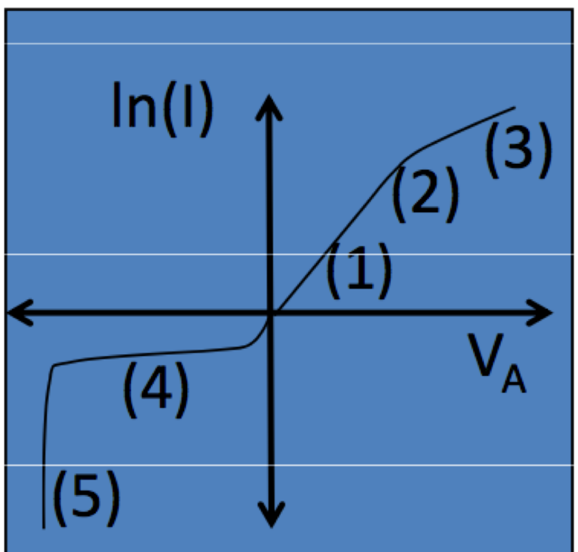
$$J_T = -q\left[\frac{D_n}{W_p}\frac{n_i^2}{N_A} + \frac{D_p}{W_n}\frac{n_i^2}{N_D}\right]\left(e^{qV_A\beta} - 1\right)$$

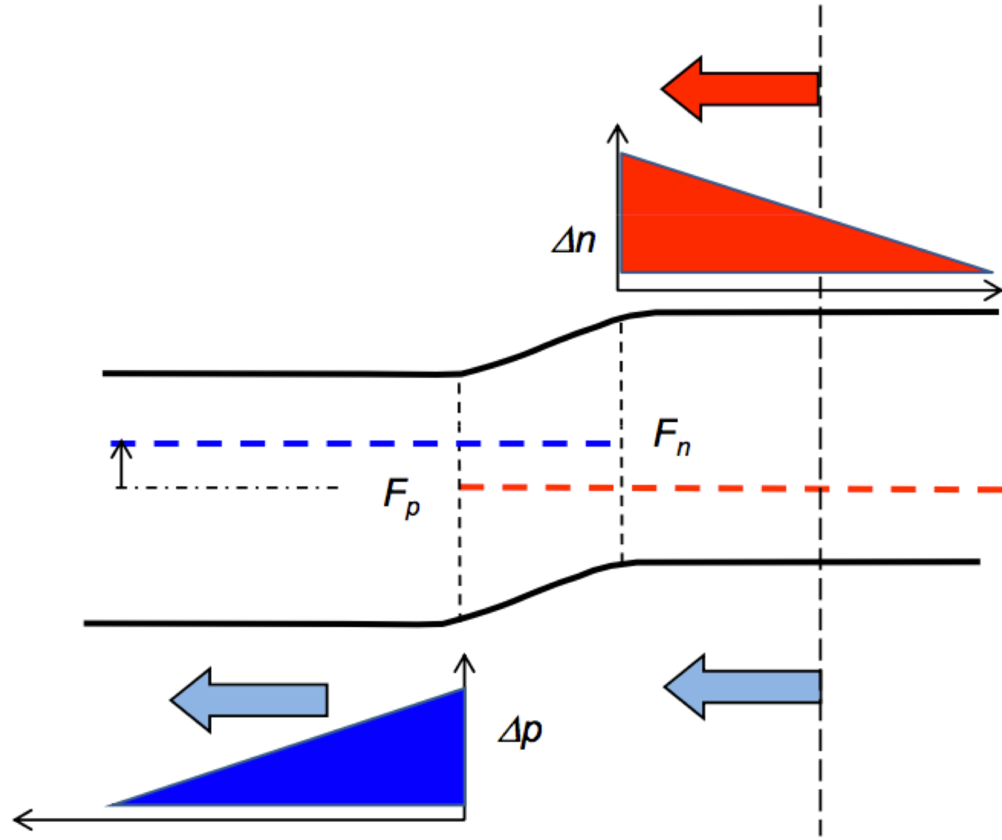
正向偏置

$$\ln J_T \approx qV_A/k_BT + \ln(const.)$$

反向偏置

$$J_T \approx const.$$





Thanks!
Q&A