VE320 Intro to Semiconductor Devices

Chapter 7

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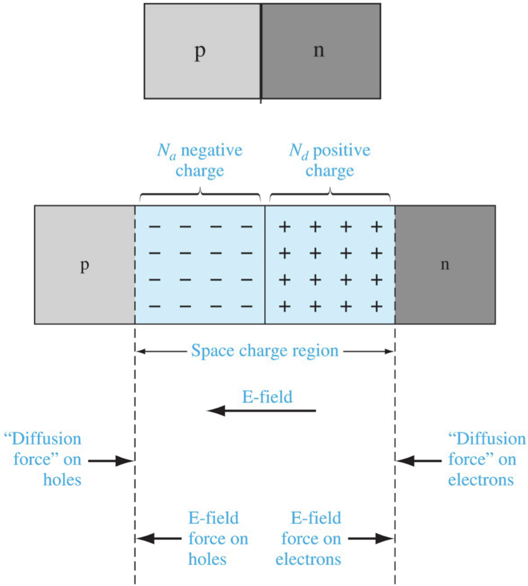
Contents

Structure of pn Junction



Energy-band Diagram

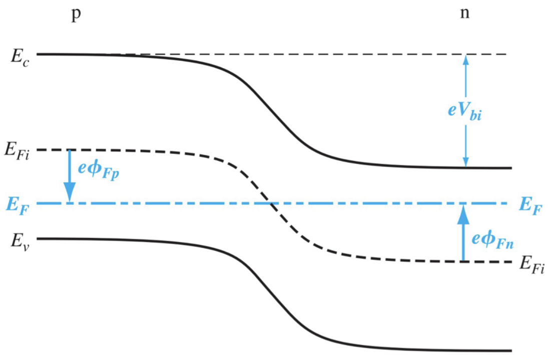
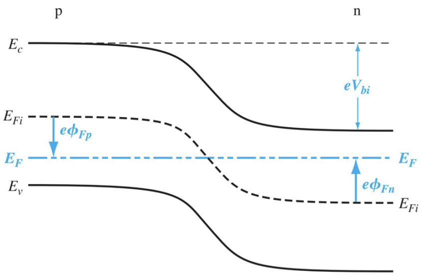


Figure: Energy-band diagram of a pn junction in thermal equilibrium

Built-in Potential Barrier



$$V_{bi} = |\Phi_{Fn}| + |\Phi_{Fp}|$$
$$= \frac{kT}{e}\ln\left(\frac{N_a N_d}{n_i^2}\right) = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

where $V_t = kT/e$ is the thermal voltage.

Electric Field

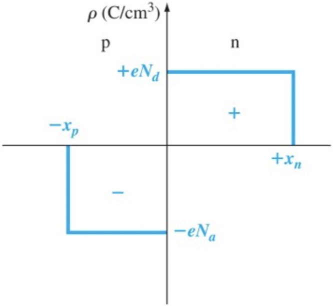


Figure: space charge density

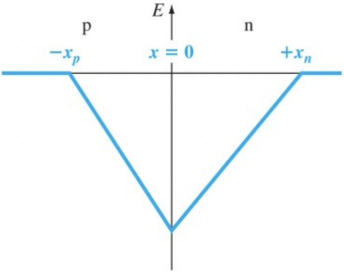


Figure: electric field

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

$$\frac{d^2\Phi(x)}{dx^2} = -\frac{\rho(x)}{\epsilon_s} = -\frac{dE(x)}{dx} \quad (\epsilon_s : \text{Dielectric constant})$$

Electric Filed

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

When x = 0:

$$N_a x_p = N_d x_n$$

Maximum electric field intensity at x=0:

$$E_{\max} = -\frac{eN_a x_p}{\epsilon_s} = -\frac{eN_d x_n}{\epsilon_s}$$

Electric Potential

Suppose $\Phi(x) = 0$ when $x = -x_p$:

$$\Phi(x) = \begin{cases} \dfrac{eN_a}{2\epsilon_s}(x + x_p)^2, & -x_p \leq \quad x \leq \quad 0 \\ \dfrac{eN_d}{\epsilon_s}(x_n \cdot x - \dfrac{x^2}{2}) + \dfrac{eN_a}{2\epsilon_s}x_p^2, & 0 \leq \quad x \leq \quad x_n \end{cases}$$

When $x = x_n$, the potential is the same as the built-in potential barrier:

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

Space Charge Width

$$
\begin{cases}
x_n = & \left[\dfrac{2\epsilon_s(V_{bi})}{e}\left(\dfrac{N_a}{N_d}\right)\left(\dfrac{1}{N_a+N_d}\right)\right]^{1/2} \\
x_p = & \left[\dfrac{2\epsilon_s(V_{bi})}{e}\left(\dfrac{N_d}{N_a}\right)\left(\dfrac{1}{N_a+N_d}\right)\right]^{1/2}
\end{cases}
$$

The total depletion region:

$$
\begin{aligned}
W &= x_n + x_p \\
&= \left[\frac{2\epsilon_s(V_{bi})}{e}\left(\frac{N_a+N_d}{N_aN_d}\right)\right]^{1/2}
\end{aligned}
$$

Reverse Bias

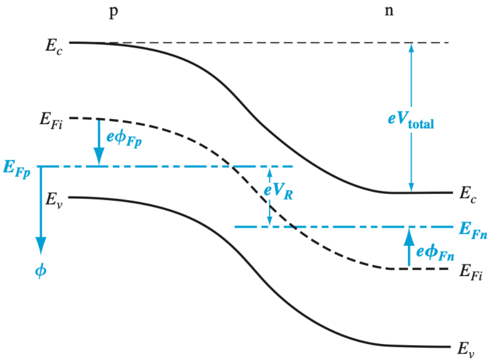


Figure: Energy-band diagram of a pn junction under reverse bias

$$V_{\text{total}} = |\Phi_{Fn}| + |\Phi_{Fp}| + V_R = V_{bi} + V_R$$

W and E

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

$$E_{\max} = -\left[\frac{2e(V_bi + V_R)}{\epsilon_s}\left(\frac{N_a N_d}{N_a + N_d}\right)\right]^{1/2}$$

$$E_{\max} = \frac{-2(V_{bi} + V_R)}{W}$$

Junction Capacitance

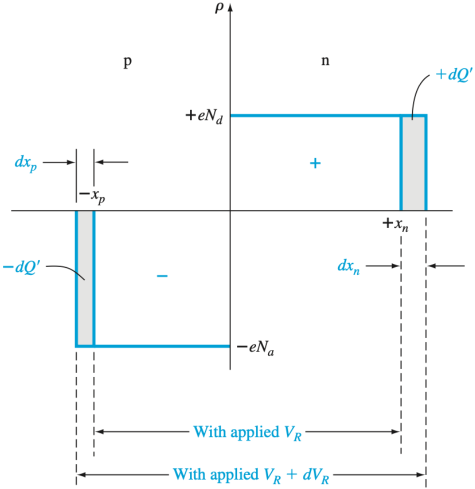


Figure: Change of depletion region width with a change in reverse-bias voltage

Junction Capacitance

$$
\begin{aligned}
C' &= \frac{dQ'}{dV_R} \\
&= eN_d \frac{dx_n}{dV_R} \\
&= \left[\frac{e\epsilon_s N_a N_d}{2(V_{bi} + V_R)(N_a + N_d)} \right]^{1/2} \\
&= \frac{\epsilon_s}{W}
\end{aligned}
$$

One-sided Junction

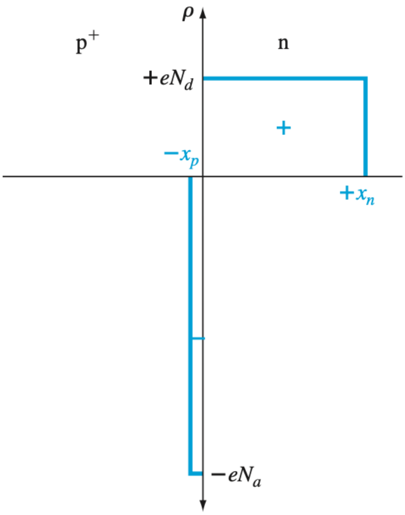


Figure: One-sided p^+n junction

One-sided Junction

$$W \approx \left[\frac{2\epsilon_s(V_{bi}+V_R)}{eN_d}\right]^{1/2}$$

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

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