VE320 Intro to Semiconductor Devices Chapter 7

Ziyi Wang

UM-SJTU Joint Institute

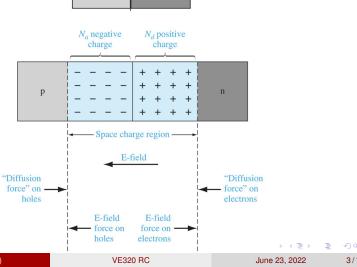
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 - Basic Structure of the pn junction
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 - Reverse applied bias

Structure of pn Junction



n

p

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Energy-band Diagram

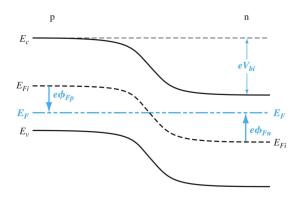
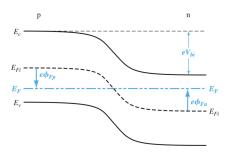


Figure: Energy-band diagram of a pn junction in thermal equilibrium

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Built-in Potential Barrier

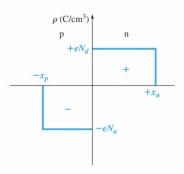


$$egin{aligned} V_{bi} &= |\Phi_{Fn}| + |\Phi_{Fp}| \ &= rac{kT}{e} \ln \left(rac{N_a N_d}{n_i^2}
ight) = V_t \ln \left(rac{N_a N_d}{n_i^2}
ight) \end{aligned}$$

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

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Electric Field



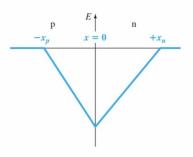


Figure: space charge density

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

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

When x = 0:

$$N_a x_p = N_d x_n$$

Maximum electric field intensity at x=0:

$$E_{\mathsf{max}} = -rac{eN_a x_p}{\epsilon_{\mathcal{S}}} = -rac{eN_d x_n}{\epsilon_{\mathcal{S}}}$$



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Electric Potential

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

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

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

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



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Space Charge Width

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

The total depletion region:

$$W = x_n + x_p$$

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

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Reverse Bias

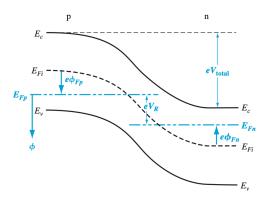


Figure: Energy-band diagram of a pn junction under reverse bias

$$V_{\mathsf{total}} = |\Phi_{\mathit{Fn}}| + |\Phi_{\mathit{Fp}}| + V_{\mathit{R}} = V_{\mathit{bi}} + V_{\mathit{R}}$$

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W and E

$$W = \left[rac{2\epsilon_s(V_{bi} + V_R)}{e} \left(rac{N_a + N_d}{N_a N_d}
ight)
ight]^{1/2}$$
 $E_{ ext{max}} = -\left[rac{2e(V_b i + V_R)}{\epsilon_s} \left(rac{N_a N_d}{N_a + N_d}
ight)
ight]^{1/2}$
 $E_{ ext{max}} = rac{-2(V_{bi} + V_R)}{W}$



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Junction Capacitance

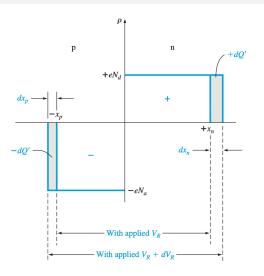


Figure: Change of depletion region width with a change in reverse-bias voltage

Junction Capacitance

$$C' = \frac{dQ'}{dV_R}$$

$$= eN_d \frac{dx_n}{dV_R}$$

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

$$= \frac{\epsilon_s}{W}$$

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One-sided Junction

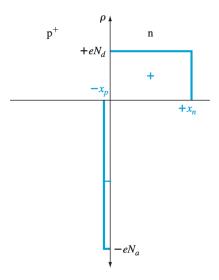


Figure: One-sided p^+n junction, p^+

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One-sided Junction

$$egin{align} W &pprox \left[rac{2\epsilon_s(V_{bi}+V_R)}{eN_d}
ight]^{1/2} \ C' &pprox \left[rac{e\epsilon_sN_d}{2(V_{bi}+V_R)}
ight]^{1/2} \ \left(rac{1}{C'}
ight)^2 &= rac{2(V_{bi}+V_R)}{e\epsilon_sN_d} \ \end{aligned}$$



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