Chapter 5-2 Quantitative electrostatic relationships

We make the analysis in 1 dimension, even though actual diode as shown may not be a one-dimensional system. This makes the analysis simple. The metallurgical junction is located at $x = 0$.

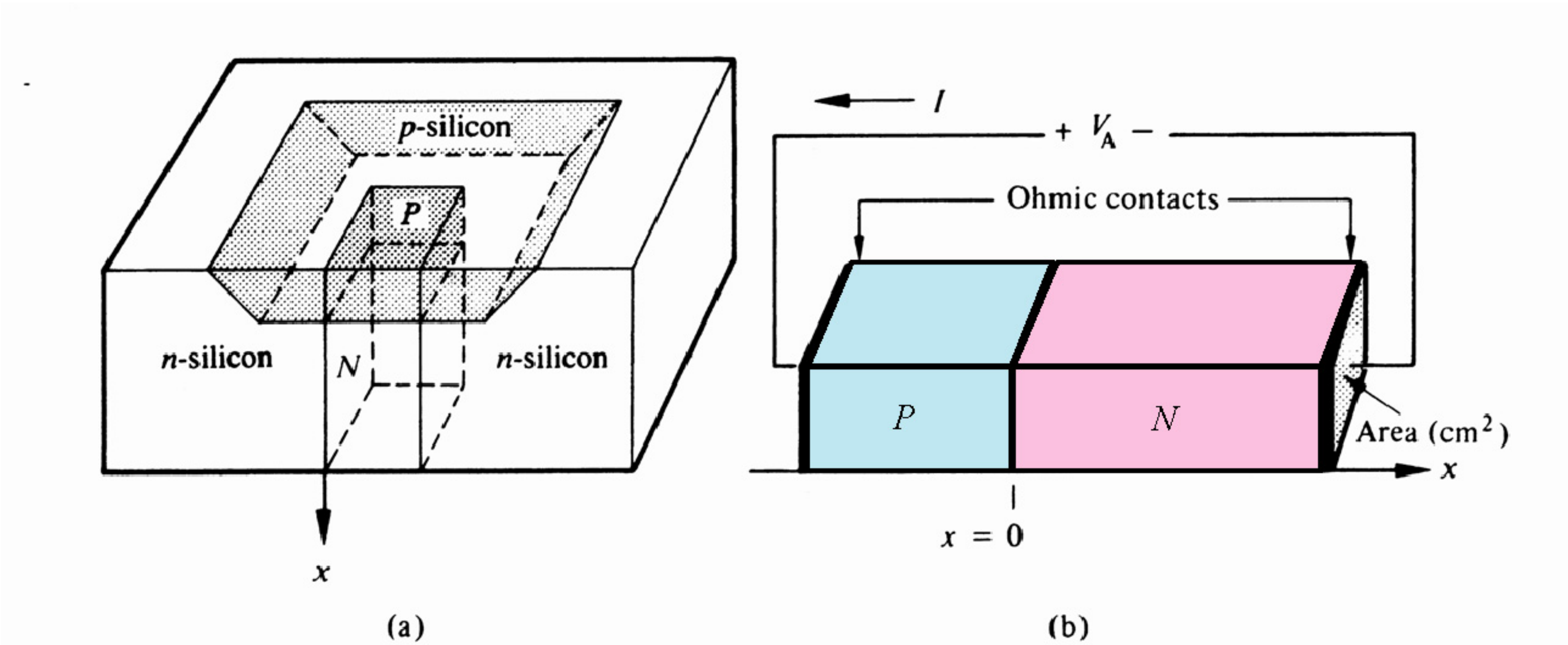


Figure 5.8

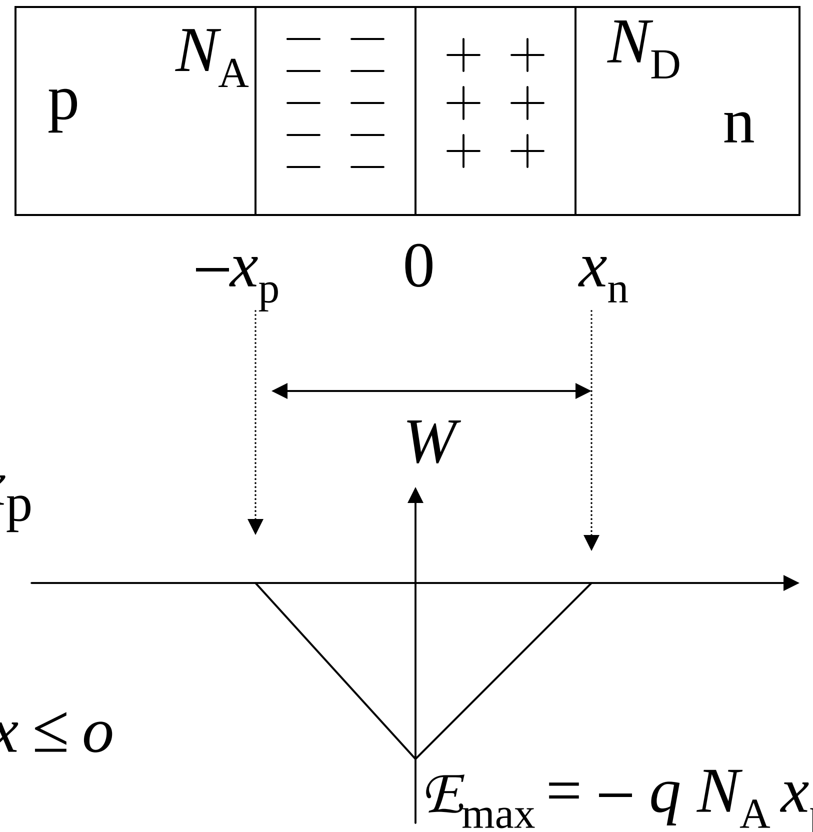
Quantitative analysis: Electric field $\mathcal{E}$

$$\frac{d\mathcal{E}}{dx} = \frac{\rho}{\varepsilon} \quad \text{where} \quad \varepsilon = K_s \varepsilon_0$$

$$= -\frac{q}{\varepsilon} N_A \qquad -x_p < x < 0$$

$$= \frac{q}{\varepsilon} N_D \qquad 0 < x < x_n$$

$$= 0 \qquad x > x_n \; ; \; x < -x_p$$



$$\mathcal{E}_{max} = -\,q\, N_A\, x_p/\varepsilon$$
$$= -\,q\, N_D\, x_n/\varepsilon$$

$$\mathcal{E}(x) = -\frac{qN_A}{\varepsilon}(x_p + x) \qquad -x_p \le x \le o$$

$$= -\frac{qN_D}{\varepsilon}(x_n - x) \qquad 0 \le x \le x_n$$

$$= 0 \qquad x < -x_p; \quad x > x_n$$

Relationship between x_n and x_p

$\mathcal{E}_{max} = -q N_A x_p / \varepsilon = -q N_D x_n / \varepsilon$

$N_A x_p = N_D x_n$

Net charge on p-side = Net charge on n-side

Depletion layer width: $W = x_n + x_p$

$$x_n = W \frac{N_A}{N_A + N_D} \qquad x_p = W \frac{N_D}{N_A + N_D}$$

If $N_A >> N_D$, then $W \approx x_n$ and if $N_A << N_D$, then $W \approx x_p$

Built-in voltage: V_{bi}

$$\mathcal{E} = -\frac{dV}{dx} \qquad \text{or} \qquad V_{bi} = -\int_{-x_p}^{x_n} \mathcal{E}(x)\, dx$$

$$V_{bi} = -\{\text{area under } \mathcal{E} \text{ versus } x \text{ curve}\}$$

$$= -(1/2)\,\{W\,(-q\,N_D\,x_n/\varepsilon)\,\}$$

$$= (q/2\varepsilon)\,N_D\,x_n\,W$$

$$= \frac{1}{2}\,\frac{q}{\varepsilon}\left(\frac{N_A N_D}{N_A + N_D}\right) W^2 \qquad \text{since} \qquad x_n = W\,\frac{N_A}{N_A + N_D}$$

$$W = \left[\frac{2\varepsilon}{q}\left(\frac{N_A + N_D}{N_A N_D}\right) V_{bi}\right]^{1/2}$$

Quantitative analysis: Electrostatic potential

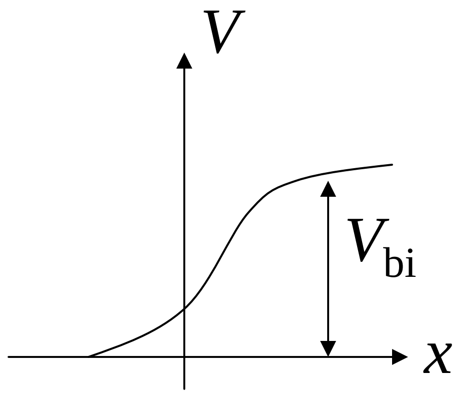
$$\frac{\mathrm{d}V}{\mathrm{d}x} = \frac{qN_\mathrm{A}}{\varepsilon}(x_\mathrm{p} + x) \qquad -x_\mathrm{p} \le x \le 0$$

$$= \frac{qN_\mathrm{D}}{\varepsilon}(x_\mathrm{n} - x) \qquad 0 \le x \le x_\mathrm{n}$$

with the reference potential at $x = -x_\mathrm{p}$ set to zero

$$V(x) = \frac{qN_\mathrm{A}}{2\varepsilon}(x_\mathrm{p} + x)^2 \qquad -x_\mathrm{p} \le x \le 0$$

$$= V_\mathrm{bi} - \frac{qN_\mathrm{D}}{2\varepsilon}(x_\mathrm{n} - x)^2 \qquad 0 \le x \le x_\mathrm{n}$$



Step junction with $V_A \neq 0$

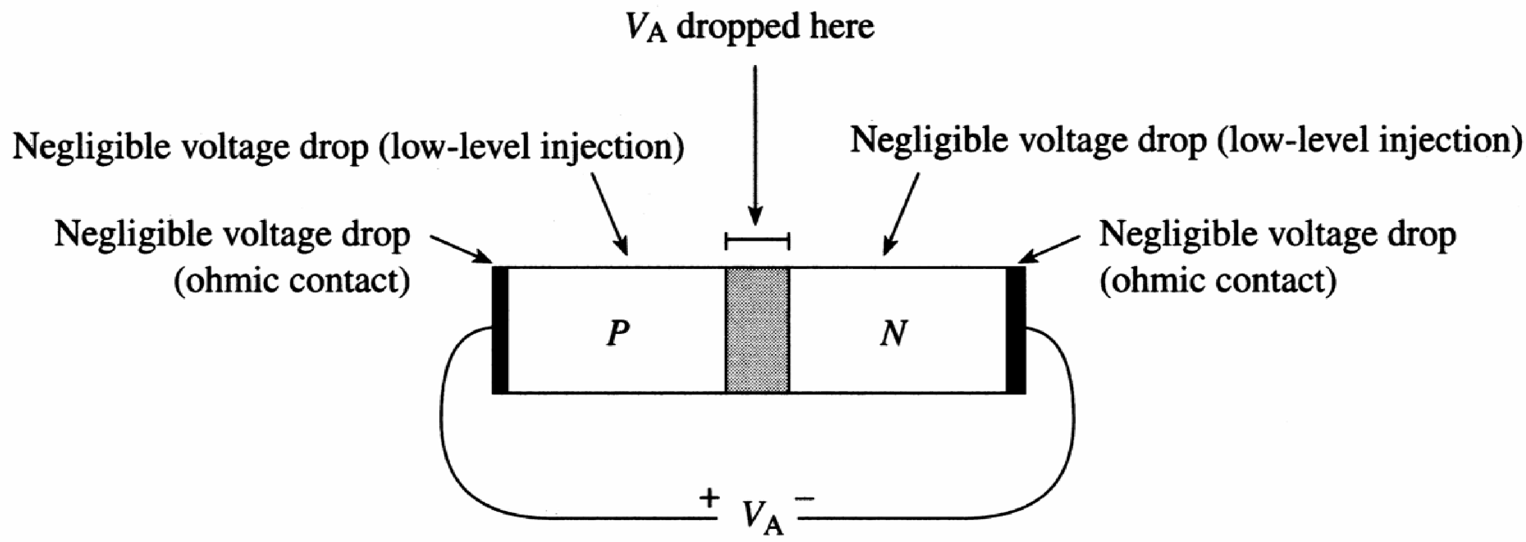


Figure 5.10

The equation for W is similar to the earlier equation except that V_{bi} is replaced by $V_{bi} - V_A$; (V_A is restricted to $V_A < V_{bi}$).

$$W = \left[\frac{2\varepsilon}{q} \left(\frac{N_A + N_D}{N_A N_D} \right) (V_{bi} - V_A) \right]^{1/2}$$

Effects of forward and reverse bias

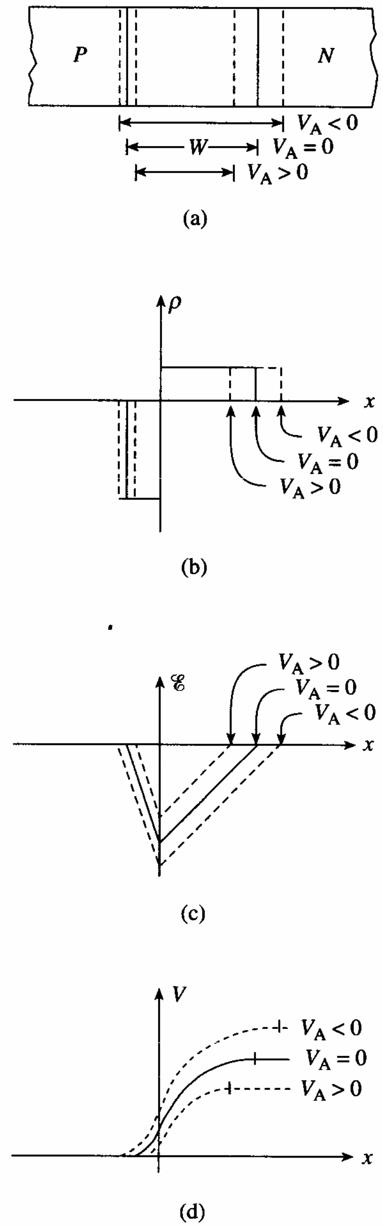
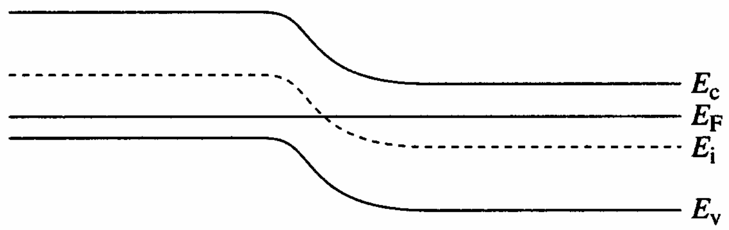
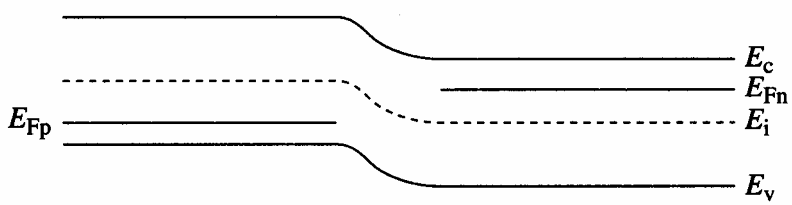


Figure 5.11

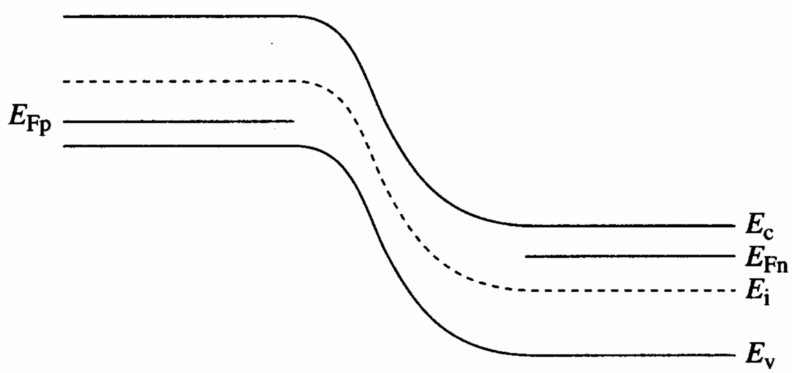
PN-junction energy-band diagrams



(a) Equilibrium ($V_A = 0$)



(b) Forward bias ($V_A > 0$)



(c) Reverse bias ($V_A < 0$)

Figure 5.12

Example 1

Consider the following diode. Calculate the maximum electric field, $\mathcal{E}_{max}$, the location of $\mathcal{E}_{max}$, the depletion layer width W, x_n and x_p and the built-in voltage, V_{bi}. Carefully plot the charge density, electric field, and the potential as a function of x.

$N_D = 2\times10^{16}$ cm^{-3} $N_A = 1\times10^{16}$ cm^{-3}	$N_A = 3\times10^{17}$ cm^{-3} $N_D = 2\times10^{17}$ cm^{-3}

Also, calculate the depletion layer width and the maximum electric field if a reverse voltage of 10 V is applied across the diode.

What will be W if $V_A = 0.5$ V?

Example 2

Consider the diode of Example 1. Calculate the depletion layer width and the maximum electric field if a reverse voltage of 10 V is applied across the diode. Calculate the depletion layer width in the n-side and p-side under this biased condition.

What will be W if $V_A = 0.5$ V?

What happens if we apply $V_A > V_{bi}$?