

- 6.31** Consider a p-type silicon semiconductor at  $T = 300$  K doped at  $N_a = 5 \times 10^{15} \text{ cm}^{-3}$ .  
 (a) Determine the position of the Fermi level with respect to the intrinsic Fermi level.  
 (b) Excess carriers are generated such that the excess carrier concentration is 10 percent of the thermal-equilibrium majority carrier concentration. Determine the quasi-Fermi levels with respect to the intrinsic Fermi level. (c) Plot the Fermi level and quasi-Fermi levels with respect to the intrinsic level.

➤ First, find the electron and hole concentrations at thermal equilibrium.

From Table B.4,  $n_i = 1.5 \times 10^{10} \text{ cm}^{-3}$  and  $E_g = 1.12 \text{ eV}$  for silicon (Si) at 300 K.

Since  $N_a \gg n_i$ , we have p-type Si where  $p_0 \cong N_a \Rightarrow \boxed{p_0 = 5 \times 10^{15} \text{ cm}^{-3}}$ .

Per (4.43),  $n_0 = n_i^2 / p_0 = (1.5 \times 10^{10})^2 / 5 \times 10^{15} \Rightarrow \boxed{n_0 = 4.5 \times 10^4 \text{ cm}^{-3}}$ .

a) For p-type silicon, we can use equation (6.84b)  $p_0 = n_i e^{(E_{Fi} - E_F)/k_B T}$  to get

$$E_{Fi} - E_F = k_B T \ln(p_0 / n_i) = 8.617333 \times 10^{-5} \text{ eV/K (300 K)} \ln(5 \times 10^{15} / 1.5 \times 10^{10})$$

$$\Rightarrow \boxed{E_{Fi} - E_F = 0.32876 \text{ eV}}$$

b) We are given  $\delta p = \delta n = 0.1 p_0 = 0.1(5 \times 10^{15}) = 5 \times 10^{14} \text{ cm}^{-3}$ .

Per (6.85a),  $n_0 + \delta n = n_i e^{(E_{Fn} - E_{Fi})/k_B T}$  for the minority electrons. This leads to

$$E_{Fn} - E_{Fi} = k_B T \ln\left(\frac{n_0 + \delta n}{n_i}\right) = 8.617333 \times 10^{-5} \text{ eV/K (300 K)} \ln\left(\frac{4.5 \times 10^4 + 5 \times 10^{14}}{1.5 \times 10^{10}}\right)$$

$$\Rightarrow \boxed{E_{Fn} - E_{Fi} = 0.26923 \text{ eV}}$$

Per (6.85b),  $p_0 + \delta p = n_i e^{(E_{Fi} - E_{Fp})/k_B T}$  for the majority holes. This leads to

$$E_{Fi} - E_{Fp} = k_B T \ln\left(\frac{p_0 + \delta p}{n_i}\right) = 8.617333 \times 10^{-5} \text{ eV/K (300 K)} \ln\left(\frac{5 \times 10^{15} + 5 \times 10^{14}}{1.5 \times 10^{10}}\right)$$

$$\Rightarrow \boxed{E_{Fi} - E_{Fp} = 0.33122 \text{ eV}}$$

c)

