ECSE-2210 Microelectronics Technology
Homework 3 – Solution

1. At thermal equilibrium, $n\,p \approx n_i^{\,2}$

   At 300 K, $n = 10^{17}$ cm^{-3}, $n_i = 10^{10}$ cm^{-3}, $p = 10^{3}$ cm^{-3}

   At 200 K, $n = 10^{17}$ cm^{-3}, $n_i = 10^{5}$ cm^{-3}, $p = 10^{-7}$ cm^{-3}

   That is, the hole concentration at 200 K is extremely small. You will find only one hole in a volume of 10^7 cm^3 of Si !

2. a) At room temperature in Si, $n_i = 10^{10}$ cm^{-3}. Thus here $N_D >> N_A$, $N_D >> n_i$ and
   $n = N_D = 10^{15}$ cm^{-3}

   $p = n_i^{\,2} / N_D = 10^{5}$ cm^{-3}

   b) Since $N_D << N_A$, $N_A >> n_i$

   $p = N_A = 10^{16}$ cm^{-3}

   $n = n_i^{\,2} / N_A = 10^{4}$ cm^{-3}

   c) Here we must retain both N_D and N_A, but N_D-$N_A >> n_i$

   $n = N_D - N_A = 10^{15}$ cm^{-3}

   $p = n_i^{\,2} / (N_D - N_A) = 10^{5}$ cm^{-3}

   d) We deduce from Figure 2.20 that, at 450 K, n_i (Si) $\approx 5 \times 10^{13}$ cm^{-3}. Clearly, n_i is comparable to N_D and we must use Eq. 2.29a

   $n = N_D/2 + [\,(N_D/2) + n_i^{\,2}]^{1/2} = 1.21 \times 10^{14}$ cm^{-3}

   $p = n_i^{\,2} / n = 2.07 \times 10^{13}$ cm^{-3}

e) We conclude from figure 2.20, that at 650 K, $n_i = 10^{16}\ \text{cm}^{-3}$ Here $n_i >> N_D$

$p = n_i = 10^{16}\ \text{cm}^{-3}$

$n = n_i = 10^{16}\ \text{cm}^{-3}$

3)

(i) As established in the text [Eq.(2.36)],

$$E_i = \frac{E_c + E_v}{2} + \frac{3}{4}kT\ln(m_p^*/m_n^*)$$

Taking m_p^*/m_n^* to be temperature independent and employing the values listed in Table 2.1, one concludes

part	T(K)	kT (eV)	E_i displacement from midgap (eV)
(a-c)	300	0.0259	−0.0073
(d)	450	0.0388	−0.0109
(e)	650	0.0560	−0.0158

Alternatively, the m_p^*/m_0 and m_n^*/m_0 versus T fit-relationships cited in Exercise 2.4 may be used to compute the m_p^*/m_n^* ratio. One finds

part	T(K)	m_p^*/m_n^*	kT (eV)	E_i displacement from midgap (eV)
(a-c)	300	0.680	0.0259	−0.0075
(d)	450	0.703	0.0388	−0.0103
(e)	650	0.719	0.0560	−0.0139

(ii) $E_F - E_i$ is computed using the appropriate version of Eq.(2.37) or (2.38).

(a) $E_F - E_i = kT\ln(N_D/n_i) = 0.0259\ln(10^{15}/10^{10}) = 0.298$ eV

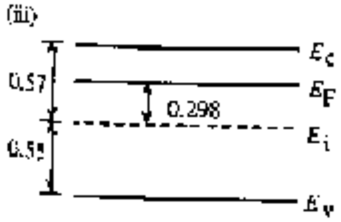
(b) $E_i - E_F = kT\ln(N_A/n_i) = 0.0259\ln(10^{16}/10^{10}) = 0.358$ eV

(c) $E_F - E_i = kT\ln[(N_D-N_A)/n_i] = 0.0259\ln(10^{15}/10^{10}) = 0.298$ eV

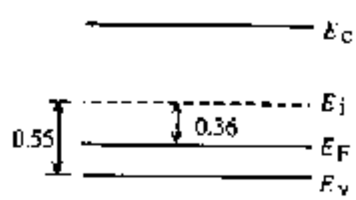
(d) $E_F - E_i = kT\ln(n/n_i) = 0.0388\ln(1.21\times10^{14}/5\times10^{13}) = 0.034$ eV

(e) $E_F - E_i = kT\ln(n/n_i) \cong 0$ ...($n \cong n_i$)

(iii)



(a) and (c)



(b)