Assignment3

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1. (a) $f(E_F) = \dfrac{1}{1+e^{(E_F - E_F/kT)}} = \dfrac{1}{2}$

   (b) $f(E_c + kT) = \dfrac{1}{1+e^{(E_c+kT-E_c)/kT}} = \dfrac{1}{1+e} = 0.269$

   (c) $f(E_c + kT) = 1 - f(E_c + kT)$

   $\Rightarrow f(E_c + kT) = \dfrac{1}{2}$

   $\Rightarrow \dfrac{1}{1+e^{(E_c+kT-E_F)/kT}} = \dfrac{1}{2}$

   $\Rightarrow E_c + kT - E_F = 0$

   $\Rightarrow E_F = E_c + kT$

2. (a) $N_c = 2\left[\dfrac{m_n^* kT}{2\pi\hbar^2}\right]^{3/2} = 2\left[\dfrac{(9.11\times10^{-31}\times1.18)(0.0259)}{(2\pi)(4.14\times10^{-15}/2\pi)^2}\right]^{3/2}$

   $= 2.06\times10^{-3}$ states/cm^3·eV

   (b) $N_v = 2\left[\dfrac{m_p^* kT}{2\pi\hbar^2}\right]^{3/2} = 2\left[\dfrac{(9.11\times10^{-31}\times0.81)(0.0259)}{(2\pi)(4.14\times10^{-15}/2\pi)^2}\right]^{3/2}$

   $= 1.17\times10^{-3}$ states/cm^3·eV

3. (a) $n = p = n_i = 10^{10}$ cm^{-3}

   (b) Since $N_D \ll N_A,\ N_D \ll n_i$

   $n \approx N_D = 10^{13}$ cm^{-3}

   $p \approx n_i^2/N_D = 10^7$ cm^{-3}

   (c) Since $N_A \ll N_D,\ N_A \ll n_i$

   $n \approx N_D = 10^{17}$ cm^{-3}

$p \approx n_i^2/N_D = 10^3 \text{ cm}^{-3}$

(d) $p = \dfrac{N_A - N_D}{2} + \left[\left(\dfrac{N_A - N_D}{2}\right)^2 + n_i^2\right]^{1/2} \approx N_A - N_D = 2 \times 10^{17} \text{ cm}^{-3}$

$n = n_i^2/p = 5 \times 10^2 \text{ cm}^{-3}$

(e) $E_i = \dfrac{E_c + E_v}{2} + \dfrac{3}{4} kTln\left(\dfrac{m_p^*}{m_n^*}\right) = \dfrac{E_c + E_v}{2} - 0.0073$

$E_i - E_F = kTlnN_A/n_i = 0.0259ln(10^{17}/10^{10}) = 0.417$

Then $E_F = E_i - 0.47 = \dfrac{E_c + E_v}{2} - 0.4243$

Assume $E_v = 0$, which implies $E_c = E_G$

$E_F = \dfrac{E_G}{2} - 0.4243 = \dfrac{1.12}{2} - 0.4243 = 0.1357 \text{ eV} > E_v + 3kT$

So E_F is in the nondegenerate area.

4. From $E_i = \dfrac{E_c + E_v}{2} + \dfrac{3}{4} kTln\left(\dfrac{m_p^*}{m_n^*}\right)$ and $E_G = E_c - E_v$, we can derive that

$E_i - E_v = \dfrac{E_G}{2} + \dfrac{3}{4} kTln\left(\dfrac{m_p^*}{m_n^*}\right)$

$E_c - E_i = \dfrac{E_G}{2} + \dfrac{3}{4} kTln\left(\dfrac{m_p^*}{m_n^*}\right)$

(a) Si at 300K with $m_n^* = 1.182m_0$ and $m_p^* = 0.81m_0$

$E_i - E_v = 0.5673 \text{ eV}$

$E_c - E_v = 0.5527 \text{ eV}$

(b) GaAs at 300K with $m_n^* = 0.067m_0$ and $m_p^* = 0.524m_0$

$E_i - E_v = 0.60 \text{ eV}$

$E_c - E_v = 0.52 \text{ eV}$

5. (a)

(b) E_i will lie above the midgap.
Because DOS is smaller in the conduction band, equal number of states in two bands can be filled only if E_i lies close to E_c.

(c) $E_i = \dfrac{E_c + E_v}{2} + \dfrac{3}{4} kTln\left(\dfrac{m_p^*}{m_n^*}\right) = \dfrac{E_c + E_v}{2} + 0.04$

So E_i lies 0.04eV above the midgap.

(d) $N_c = 2\left[\dfrac{m_n^* kT}{2\pi\hbar^2}\right]^{3/2} = 4.26 \times 10^{17}\ \text{cm}^{-3}$

$N_v = 2\left[\dfrac{m_p^* kT}{2\pi\hbar^2}\right]^{3/2} = 9.41 \times 10^{18}\ \text{cm}^{-3}$

For nondegenerate semiconductors

$E_v + 3kT \leq E_F \leq E_c - 3kT$

$n = N_c e^{(E_F - E_c)/kT} \leq N_c e^{-3}$

$p = N_c e^{(E_v - E_F)/kT} \leq N_v e^{-3}$

Also, for n-type GaAs, $n \approx N_D$; for p-type GaAs, $p \approx N_A$. Then

$(N_D)_{max} \approx N_c e^{-3} = 2.21 \times 10^{16}\ \text{cm}^{-3}$

$(N_A)_{max} \approx N_v e^{-3} = 4.68 \times 10^{17}\ \text{cm}^{-3}$