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ECE3030 - HW3

1) $f(E) = \frac{1}{1+e^{(E-E_f)/kT}}$ $k = 8.62\times10^{-5}\ eV/K = 1.38\times10^{-23}\ J/k$

a) $E = E_f + kT \rightarrow f(E) = \frac{1}{1+e^{(kT)/kT}} = \frac{1}{1+e^1} = \boxed{0.26894}$

$e^1 = 2.718$

$1-0.26894$

Unoccupied probability $\boxed{0.73106}$ ✓

b) $E = E_f + 4kT \rightarrow f(E) = \frac{1}{1+e^4} = \boxed{0.07986}$ X -1

$e^4 = 54.59$

c) $E = E_f + 9kT \rightarrow f(E) = \frac{1}{1+e^9} = \boxed{1.2339\times10^{-4}}$ ✓

$e^9 = 8103.08$

2) $T = 300k$ $n_0 = 7\times10^{15}\ cm^{-3}$

a) $n_0 = N_c e^{-(E_c-E_F)/kT} \rightarrow E_c - E_F = kT\ln\left(\frac{N_c}{n_0}\right)$

$E_c - E_F = (8.617\times10^{-5})(300)\ln\left(\frac{2.8\times10^{19}}{7\times10^{15}}\right) = \boxed{0.2144\ eV}$ ✓

b) $E_F - E_v = E_c - E_v - (E_c - E_F)$ and $E_G = E_c - E_v$

$E_F - E_v = E_G - (E_c - E_F) = 1.12 - 0.2144 = \boxed{0.906\ eV}$ ✓

c) $n_0 p_0 = n_i^2 \rightarrow p_0 = \frac{n_i^2}{n_0} = \frac{(1.5\times10^{10})^2}{7\times10^{15}} = \boxed{3.2142\times10^4\ cm^{-3}}$ ✓

d) Since $p_0 < n_0$, the minority carriers are $\boxed{\text{holes}}$ ✓

e) $n_0 = n_i e^{(E_c-E_F)/kT}$ $n_0 p_0 = n_i^2 \longrightarrow E_F - E_i = kT\ln\left(\frac{n_0}{n_i}\right)$

$E_F - E_i = (8.617\times10^{-5})(300)\ln\left(\frac{7\times10^{15}}{1.5\times10^{10}}\right) = \boxed{0.3374\ eV}$ ✓

3)

$n_o p_o = n_i^2 \qquad n_o = N_d + \frac{n_i^2}{N_a}$

a) $T = 300\,k \qquad N_d = 10^{15}\,cm^{-3} \qquad N_a = 4\times10^{15}\,cm^{-3}$

$n_o = 10^{15} + \frac{(1.5\times10^{10})^2}{4\times10^{15}} = \boxed{1.00625\times10^{15}\,cm^{-3}}$ electron concentration -1

$p_o = \frac{n_i^2}{n_o} = \frac{(1.5\times10^{10})^2}{1.00625\times10^{15}} = \boxed{2.236\times10^{5}\,cm^{-3}}$ hole concentration -1

b) $T = 300\,k \qquad N_d = 3\times10^{16}\,cm^{-3} \qquad N_a = 0\,cm^{-3}$

$n_o = \boxed{3\times10^{16}\,cm^{-3}}$ electron concentration ✓

$p_o = \frac{(1.5\times10^{10})^2}{3\times10^{16}} = \boxed{7500\,cm^{-3}}$ hole concentration ✓

c) $T = 300\,k \qquad N_d = N_a = 2\times10^{15}\,cm^{-3}$

$n_o = N_d - N_a = \boxed{0\,cm^{-3}}$ X -2

No conduction carriers

$p_o = \boxed{0\,cm^{-3}}$ X

d) $T = 375\,k \qquad N_d = 0\,cm^{-3} \quad N_a = 4\times10^{15}\,cm^{-3}$

X -1

$n_o = \frac{n_i^2}{N_a} = \frac{(1.5\times10^{10})^2}{4\times10^{15}} = \boxed{5.625\times10^{4}\,cm^{-3}}$ electron concentration

$p_o = \frac{n_i^2}{n_o} = \frac{(1.5\times10^{10})^2}{56250} = \boxed{4\times10^{15}\,cm^{-3}}$ ✓ hole concentration

e) $T = 450\,k \qquad N_d = 10^{14}\,cm^{-3} \qquad N_a = 0$

$n_o = \boxed{10^{14}\,cm^{-3}}$ ✓ electron concentration

$p_o = \frac{(2.5\times10^{13})^2}{10^{14}} = \boxed{6.25\times10^{12}\,cm^{-3}}$ hole concentration

X -1

4) $E_G = 1.11\,eV$ $\quad n_i = 1.5\times10^{10}\,cm^{-3}$ $\quad E_c - E_F = 0.20\,eV$

a) $n_0 = N_c e^{-(E_c-E_F)/KT} = 2.8\times10^{19}\cdot e^{(0.2)/(8.617\times10^{-5}\times300)} = 1.2222\times10^{16}\,cm^{-3}$

$N_c = 2.8\times10^{19}$

$N_d \approx n_0 \approx \boxed{1.2222\times10^{16}\,cm^{-3}}$ ✓

b) $N_a = 10^{16}\,cm^{-3}$

$n_0 = N_d - N_a \longrightarrow N_d = n_0 + N_a = 1.2222\times10^{16} + 10^{16} = 2.2222\times10^{16}$

$\Delta N_d = N_d - N_a = 2.2222\times10^{16} - 10^{16} = \boxed{1.2222\times10^{16}\,cm^{-3}}$ X −2

5) The effective mass of electrons in the Γ-valley of GaAs is smaller and results in higher mobility. ✓

If electrons are promoted from Γ to L valley, their effective mass increases, mobility decreases, and conductivity decreases. ✓

6) $L = 2\,cm$ $\quad A = 0.1\,cm^2$ $\quad N_d = 10^{15}\,cm^{-3}$ $\quad R = 90\,\Omega$ $\quad v_{sat} = 10^7\,cm/s$ $\quad E_{sat} = 10^5\,V/cm$

$v_d = \mu_n E$ $\quad E = \frac{V}{L}$ $\quad \mu_n = 1350\,cm^2/V\text{-}s$ $\quad I = \frac{V}{R}$

a) $V = 100V$ $\quad E = \frac{V}{L} = \frac{100}{2} = 50\,V/cm$ $\quad V_d = 1350\cdot50 = \boxed{67500\,cm/s}$

$I = \frac{V}{R} = \frac{100}{90} = \boxed{1.11\,A}$ ✓

b) $V = 200V$ $\quad E = \frac{V}{L} = \frac{200}{2} = 100\,V/cm$ $\quad V_d = 1350\cdot100 = \boxed{135000\,cm/s}$

$I = \frac{V}{R} = \frac{200}{90} = \boxed{2.22\,A}$ ✓

c) $V = 10^6\,V$ $\quad E = \frac{V}{L} = \frac{10^6}{2} = 5\times10^5\,V/cm$ ← above saturation field ($10^5\,V/cm$) $\quad V_d = V_{sat} = \boxed{10^7\,cm/s}$

$I = \frac{V}{R} = \frac{10^6}{90} = \boxed{1.11\times10^4\,A}$ X −1 $\quad I = A q n v_{sat}$ −2

Current is linearly proportional to Voltage until the drift velocity reaches saturation ✓