ECE 441 HW1 Soln.

1.3 (a) Given: $N_D = 10^{16}/cm^3$. As.

From Table 1.5, $E_C - E_D = 0.049\,eV$. —(A)

From Table 1.4, $n_i = 3.87\times10^{16}\,T^{3/2}\exp\left(-\frac{7014}{T}\right)$ —(B) (in cm^{-3})

$$E_g = 1.17 - \frac{4.73\times10^{-4}T^2}{T+651} \quad \text{(in eV)} \quad \text{—(C)}$$

$$N_D^+ = N_D\left(1 - \frac{1}{1+\frac{1}{g_D}\exp\left(\frac{E_D-E_F}{kT}\right)}\right) \quad \therefore g_D = 2 \text{ for Si}; \quad N_D^+ = \frac{N_D}{2}$$

$$\therefore \frac{1}{2} = 1 - \frac{1}{1+\frac{1}{2}\exp\left(\frac{E_D-E_F}{kT}\right)}$$

Solve to get $\exp\left(\frac{E_D-E_F}{kT}\right) = 2$

Note that I can write this as:

$$\exp\left(\frac{E_D-E_C}{kT}\right)\underbrace{\exp\left(\frac{E_C-E_i}{kT}\right)}_{\frac{\frac{1}{2}E_g}{kT}}\exp\left(\frac{E_i-E_F}{kT}\right) = 2 \quad \text{—(D)}$$

Charge neutrality: $n + \cancel{N_A^-}^{\,0} = p + N_D^+$

$$n = n_i\exp\left(\frac{E_F-E_i}{kT}\right); \quad p = n_i\exp\left(\frac{E_i-E_F}{kT}\right)$$

Plugging these into $n - p = N_D^+$:

$$\frac{N_D}{2} = n_i\left(\exp\left(\frac{E_F-E_i}{kT}\right) - \exp\left(\frac{E_i-E_F}{kT}\right)\right) \quad \text{—(E)}$$

Solving (A), (B), (C), (D) & (E) simultaneously gives $\boxed{T \approx 100K}$

→ For the p-type, $N_a = 10^{15}/cm^3$

Now: $N_a^- = N_A\left(\frac{1}{1+g_A\exp\left(\frac{E_A-E_F}{kT}\right)}\right)$ ... $g_A = 4$, $N_A^+ = \frac{N_A}{2}$.

Solving, we get: $\exp\left(\frac{E_A-E_F}{kT}\right) = \frac{1}{4}$ —(F)

Charge neutrality: $N_A^- = p - n$ $(N_D = 0)$, $N_A^- = \frac{1}{2} N_A$

This gives: $\frac{N_A}{2} = n_i\left(\exp\left(\frac{E_i - E_F}{kT}\right) - \exp\left(\frac{E_F - E_i}{kT}\right)\right)$ — (G)

Again, for (F), note that $E_A - E_F = \underbrace{(E_A - E_V)}_{\substack{-0.045\,eV \\ \text{for B.}}} + \underbrace{(E_V - E_i)}_{-\frac{1}{2}E_G} + (E_i - E_F)$

Solving as before, $\boxed{T \approx 80.6K}$

(b) Using Eq (B), setting $n_i = 10 N_D$, and solving, $\boxed{T \approx 777K}$
" $n_i = 10 N_A$ " ", $\boxed{T \approx 636K}$

(c) At 300K, $n_i = 1.41 \times 10^{10}\,cm^{-3}$ OR. $1.45 \times 10^{10}\,cm^{-3}$ by table 1.3
thus, for the n-type, $p = \frac{n_i^2}{N_D} = \boxed{19881\,/cm^3}$ or $\boxed{21025\,/cm^3}$

For the p-type, $n = \frac{n_i^2}{N_A} = \boxed{198810\,/cm^3}$ or $\boxed{210250\,/cm^3}$

(d) n-type: $E_F - E_i = kT \ln\left(\frac{n}{n_i}\right)$.
Note: $E_F - E_i = (E_F - E_V) + \underbrace{(E_V - E_i)}_{-\frac{1}{2}E_g}$.

$\therefore E_F - E_V = \frac{1}{2}E_g + kT\ln\left(\frac{n}{n_i}\right)$. Let $n = N_D$. $E_g = 1.124\,eV$. (by Table 1.
$= \boxed{0.909\,eV}$ $n_i = 1.45 \times 10^{10}/cm^3$

p-type: $E_i - E_F = kT\ln\left(\frac{p}{n_i}\right)$
$E_i - E_F = (E_i - E_V) + (E_V - E_F)$
$\therefore E_F - E_V = \frac{1}{2}E_g - kT\ln\left(\frac{p}{n_i}\right)$
$= \boxed{0.274\,eV}$

Both together: $n \approx N_D - N_A = 9 \times 10^{15}$. Using the eqn above:
$\boxed{E_F - E_V = 0.907\,eV}$

2. MULLER AND KAMINS 1.11 . Parts (a) and (b).

(a) Si replacing Ga $\Rightarrow$ extra electron $\Rightarrow$ Donor $N_D = 0.05 \times 10^{10} = 5 \times 10^{8}$ [cm^{-3}];

Si replacing As $\Rightarrow$ One less electron $\Rightarrow$ Acceptor $N_A = 0.95 \times 10^{10} = 9.5 \times 10^{9}$ [cm^{-3}].

(b) $p \simeq N_A - N_D = (9.5 - 0.5) \times 10^{9} = 9.0 \times 10^{9}$ [cm^{-3}] $\gg n_i = 9.0 \times 10^{6}$ [cm^{-3} for GaAs @ 300 K]

$$n = \frac{n_i^2}{p} = 9 \times 10^{3} \text{ [cm}^{-3}\text{]}$$

$$E_F - E_V = k_B T \ln\left[\frac{N_V}{p}\right] = k_B T \ln\left[\frac{7 \times 10^{18}}{9 \times 10^{9}}\right] = 0.53 \text{ [eV]}$$