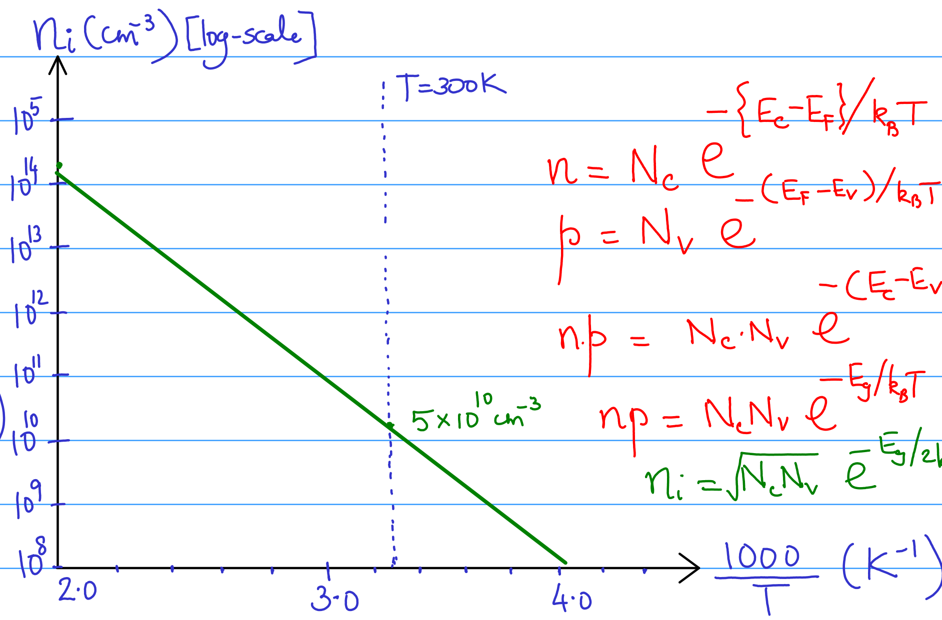
Assignment 03

Q1. A silicon sample is doped with 10^{17} As atoms cm^{-3}. What is the equilibrium hole density at 300K? Where is E_F relative to E_c? [Assume: $n_i = 1.5 \times 10^{10}\, cm^{-3}$ and $N_c = 1\times 10^{19}\, cm^{-3}$]

Q2. A silicon bar 0.1 cm long and $100\,\mu m^2$ in cross-sectional area is doped with $10^{17}\, cm^{-3}$ phosphorus atoms. Calculate the electron density at 300K. Find the current at 300K with 10V applied. [Assume: Mobility of electrons at 300K = $100\, cm^2 V^{-1} s^{-1}$.

Q3. The following figure shows variation of intrinsic charge-carrier density n_i with the temperature. Use the data to estimate the band-gap of the semiconductor.



$$n_i = \left(\sqrt{N_c N_v}\right)\left(e^{-\frac{E_g}{2k_BT}}\right)$$

$$\ln(n_i) = \frac{-E_g}{2k_BT} + \ln\left(\sqrt{N_c N_v}\right)$$

$$\underbrace{\ln(n_i)}_{Y} = \underbrace{\left(\frac{-E_g}{2000k_B}\right)}_{M}\underbrace{\frac{1000}{T}}_{X} + \underbrace{\ln\left(\sqrt{N_c N_v}\right)}_{C}$$

$$Y = M X + C$$

Slope $M = \frac{-E_g}{2000k_B}$

$$n = N_c\, e^{-\{E_c - E_F\}/k_BT}$$

$$p = N_v\, e^{-(E_F - E_v)/k_BT}$$

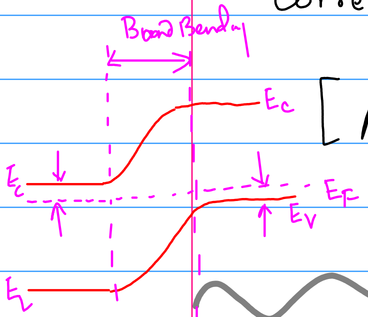
$$n.p = N_c \cdot N_v\, e^{-(E_c - E_v)/k_BT}$$

$$np = N_c N_v\, e^{-E_g/k_BT} \quad \because E_g = E_c - E_v$$

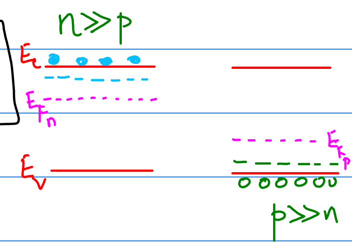
$$n_i = \sqrt{N_c N_v}\; e^{-E_g/2k_BT}$$

Q4. Justify why holes are found at the top of the valance band, whereas electrons are found at the bottom of the conduction band.

Q5. A silicon sample is doped with $6\times10^{15}\ cm^{-3}$ donor atoms from one end and with $2\times10^{15}\ cm^{-3}$ acceptor atoms from other end. Find the position of Fermi energy level w.r.t. corresponding band edge (E_c or E_v) at 300K.



[Assume: $N_c = N_v = 1\times10^{19}\ cm^{-3}$ at 300K]

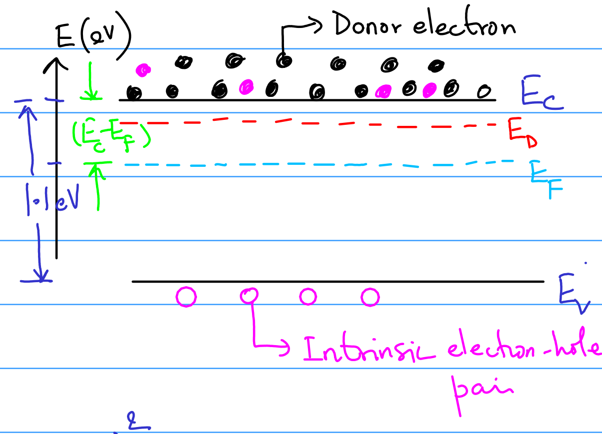


— Discussion

Q1 A silicon sample is doped with 10^{17} As atoms cm^{-3}. What is the equilibrium hole density at 300K? Where is E_F relative to E_c? [Assume: $n_i = 1.5\times10^{10}\ cm^{-3}$ and $N_c = 1\times10^{19}\ cm^{-3}$]

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

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



at equilibrium. $\quad p\cdot n = n_i^2$

$$p = \frac{n_i^2}{n} = \frac{(1.5\times10^{10}\ cm^{-3})^2}{10^{17}\ cm^{-3}} = 2.25\times10^{3}\ cm^{-3}$$

at any Temp T,

$$n = N_c\, e^{-(E_c - E_F)/k_B T}$$

$$\frac{n}{N_c} = e^{-(E_c - E_F)/25\,meV}$$

$$\frac{10^{17}\,cm^{-3}}{10^{19}\,cm^{-3}} = e^{-(E_c-E_F)/25meV}$$

$$10^{-2} = e^{-(E_c-E_F)/25meV}$$

$$\ln 10^{-2} = -\frac{(E_c-E_F)}{25meV}$$

$$2.303 \log_{10} 10^{-2} = -\frac{(E_c-E_F)}{25meV}$$

$$(\cancel{-}2)(2.303) = \cancel{-}(E_c-E_F)/25me$$

$$\boxed{E_c - E_F = 115.15\ meV}$$

$$\boxed{E_c - E_F = 0.115\,eV}$$

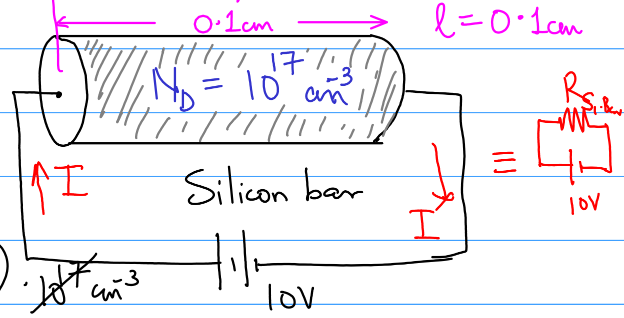
Q2. A silicon bar 0.1 cm long and $100\,\mu m^2$ in cross-sectional area is doped with $10^{17}\,cm^{-3}$ phosphorus atoms. Calculate the electron density at 300K. Find the current at 300K with 10V applied. [Assume: Mobility of electrons at 300K = $100\ cm^2 V^{-1} s^{-1}$.

$n = n_i + N_D$

at 300K; $n = N_D = 10^{17}\ cm^{-3}$

$A = 100\,\mu m^2 = 100 \times 10^{-12}\ m^2 = 10^{-6}\ cm^2$

$l = 0.1\,cm$



$$\boxed{\sigma_n = e\mu n}$$

$$\sigma_n = 1.6\times10^{-19}\,C \cdot (100\,cm^2 V^{-1} s^{-1}) \cdot 10^{17}\,cm^{-3}$$

$$\sigma_n = 1.6\ cm^{-1}\ V^{-1} s^{-1}\ C$$

$$\rho_n = \frac{1}{\sigma_n} = \frac{1}{1.6}\ cm\ V s\ C^{-1}$$

$$\underset{\text{Silicon Bar}}{R} = \rho_n \frac{l}{A} = \frac{1}{1.6}\ \cancel{cm}\ V.s\ C^{-1} \cdot \frac{0.1\ \cancel{cm}}{10^{-6}\ \cancel{cm^2}}$$

$$R_{Si\text{-}Bar} = \frac{10^6}{1.6} = 6.25 \times 10^4\ V.s\ C^{-1}$$

$$\approx 62.5\ K\Omega$$

$$I = \frac{V_{app.}}{R_{Si\text{-}Bar}} = \frac{10\ \cancel{V}}{6.25 \times 10^4\ \cancel{V}.s C^{-1}}$$

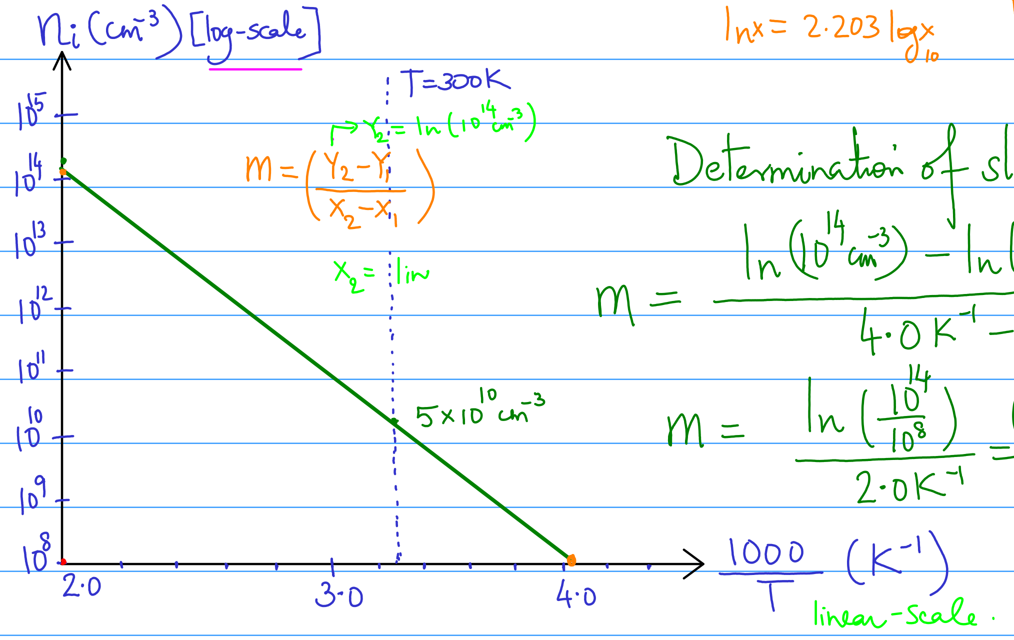
$$I = (\ \ ) \times 10^{-4} A = 160 \times 10^{-6} A = \underline{\underline{160 \mu A}}$$

$$\simeq \underline{0.16 mA}$$

Q3. The following figure shows variation of intrinsic charge-carrier density n_i with the temperature. Use the data to estimate the band-gap of the semiconductor.

$\ln x = 2.203 \log_{10} x$ $\log_{10} x^m = m \log_{10} x$

plot of: n_i Vs $\frac{1000}{T}$



Determination of slope 'm'

$$m = \frac{\ln(10^{14}\,cm^{-3}) - \ln(10^{8}\,cm^{-3})}{4.0\,K^{-1} - 2.0\,K^{-1}}$$

$$m = \frac{\ln\left(\frac{10^{14}}{10^{8}}\right)}{2.0\,K^{-1}} = \frac{(2.303)(6)}{2.0\,K^{-1}}$$

$$n \cdot p = n_i^2$$

$$n = N_c\, e^{-(E_c - E_F)/k_B T}$$

$$p = N_v\, e^{-(E_F - E_v)/k_B T}$$

E_c

$E_g = E_c - E_v$

E_v

$$n \cdot p = N_c \cdot N_v\, e^{-(E_c - E_v)/k_B T} = n_i^2$$

$$n_i = \underbrace{\sqrt{N_c N_v}}_{K}\; e^{-\frac{E_g}{2k_B T}}$$

$$n_i = K e^{-E_g/2k_BT}$$

$$\boxed{\underbrace{\ln(n_i)}_{Y} = \underbrace{\ln K}_{\text{Intercept}} - \frac{E_g}{2k_BT}}$$

$$\boxed{Y = -mX + C}$$

$$X = \frac{1000}{T}$$

Where $m = \dfrac{E_g}{2000\, k_B}$

$$E_g = 2000 \cdot (\underbrace{1.38 \times 10^{-23}\ J\,K^{-1}}_{k_B}) \cdot (m)$$

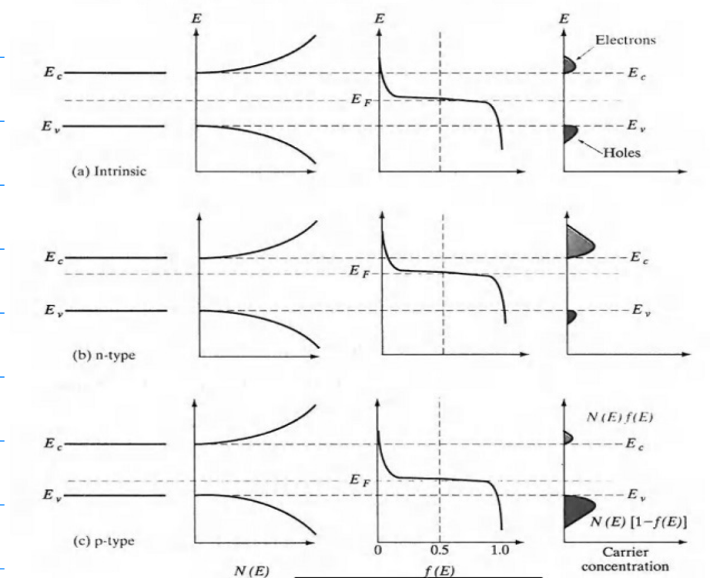
$$E_g = 2000 \cdot (1.38 \times 10^{-23}\ J\,\cancel{K}^{-1}) \cdot (2.303 \times 3)\cancel{K}$$

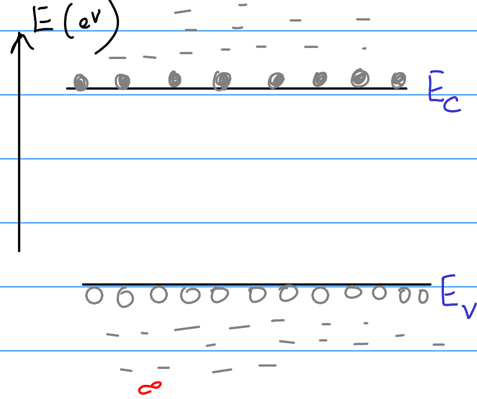
$$E_g = (2000 \times 1.38 \times 2.303 \times 3) \times 10^{-23} \cdot J$$

$$E_g(\text{in eV}) = \frac{(2000 \times 1.38 \times 2.303 \times 3) \times 10^{-23}}{1.6 \times 10^{-19}}\ eV$$

$$\boxed{E_g(\text{in eV}) = 1.19\ eV}$$

Q4. Justify why holes are found at the top of the valance band, whereas electrons are found at the bottom of the conduction band.





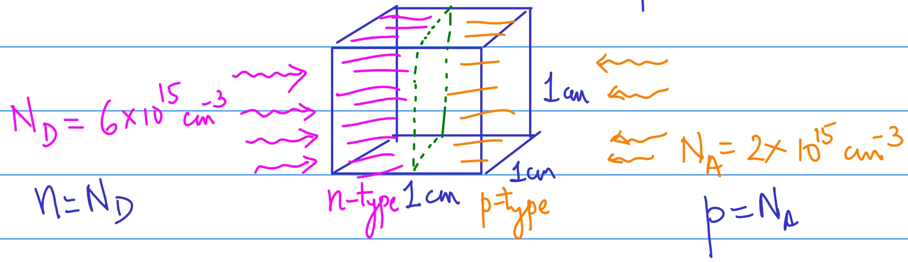
$$n = \int_{E_c}^{\infty} f(E)\cdot D_n(E)\cdot dE$$

$p =$

Q5. A silicon sample is doped with $6\times10^{15}\,cm^{-3}$ donor atoms from one end and with $2\times10^{15}\,cm^{-3}$ acceptor atoms from other end. Find the position of Fermi energy level w.r.t. corresponding band edge (E_c or E_v) at 300K.

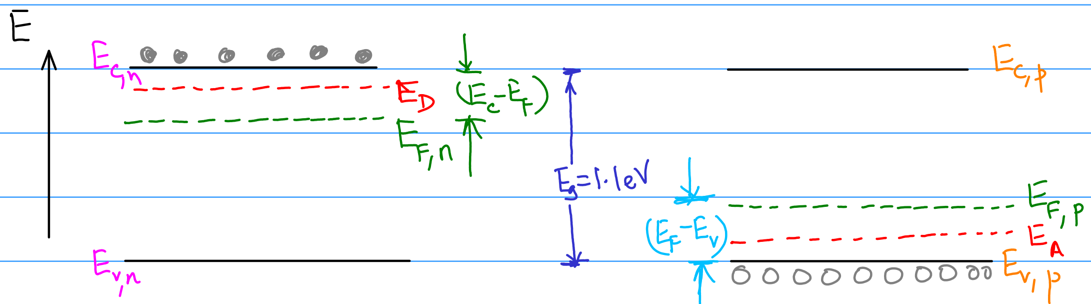
[Assume: $N_c = N_v = 1\times10^{19}\,cm^{-3}$ at 300K]

$1\,cm^3$ Silicon sample:



$n = N_D$

$p = N_A$



Since, $T = 300K$

$k_BT = 25\,meV$

✓ $n = N_c\, e^{-(E_c - E_F)/k_BT}$ — (1)

✓ $p = N_v\, e^{-(E_F - E_v)/k_BT}$ — (2)

$\boxed{np = n_i^2}$

$n = N_D = 6\times10^{15}\ cm^{-3}$; $N_c = 1\times10^{19}\ cm^{-3}$

substituting in eq^n (1)

$$6\times10^{15}\ cm^{-3} = 1\times10^{19}\ cm^{-3}\ e^{-(E_c - E_F)/25\,meV}$$

$\Rightarrow$ find $E_c - E_F = 185.4\ meV \approx 0.18\,eV$

Similarly,

$p = N_A = 2\times10^{15}\ cm^{-3}$

$N_v = 1\times10^{19}\ cm^{-3}$

$$2\times10^{15}\ cm^{-3} = 1\times10^{19}\ cm^{-3}\ e^{-(E_F - E_v)/25\,meV}$$

$\Rightarrow$ find $E_F - E_v = 212.9\ meV \approx 0.2\,eV$