

Practice Problem 1

We simply calculate the effective density of states N_c and N_v by

$$N_c = 2 \left(\frac{2\pi m_e^* kT}{h^2} \right)^{3/2} \quad \text{and} \quad N_v = 2 \left(\frac{2\pi m_h^* kT}{h^2} \right)^{3/2}$$

Thus

$$\begin{aligned} N_c &= 2 \left[\frac{2\pi (1.08 \times 9.1 \times 10^{-31} \text{ kg})(1.38 \times 10^{-23} \text{ J K}^{-1})(300 \text{ K})}{(6.63 \times 10^{-34} \text{ J s})^2} \right]^{3/2} \\ &= 2.81 \times 10^{25} \text{ m}^{-3} \quad \text{or} \quad 2.81 \times 10^{19} \text{ cm}^{-3} \end{aligned}$$

and

$$\begin{aligned} N_v &= 2 \left[\frac{2\pi (0.60 \times 9.1 \times 10^{-31} \text{ kg})(1.38 \times 10^{-23} \text{ J K}^{-1})(300 \text{ K})}{(6.63 \times 10^{-34} \text{ J s})^2} \right]^{3/2} \\ &= 1.16 \times 10^{25} \text{ m}^{-3} \quad \text{or} \quad 1.16 \times 10^{19} \text{ cm}^{-3} \end{aligned}$$

The intrinsic concentration is

$$n_i = (N_c N_v)^{1/2} \exp\left(-\frac{E_g}{2kT}\right)$$

so that

$$\begin{aligned} n_i &= [(2.81 \times 10^{19} \text{ cm}^{-3})(1.16 \times 10^{19} \text{ cm}^{-3})]^{1/2} \exp\left[-\frac{(1.10 \text{ eV})}{2(300 \text{ K})(8.62 \times 10^{-5} \text{ eV K}^{-1})}\right] \\ &= 1.0 \times 10^{10} \text{ cm}^{-3} \end{aligned}$$

The conductivity is

$$\sigma = en\mu_e + ep\mu_h = en_i(\mu_e + \mu_h)$$

that is,

$$\begin{aligned} \sigma &= (1.6 \times 10^{-19} \text{ C})(1.0 \times 10^{10} \text{ cm}^{-3})(1350 + 450 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}) \\ &= 2.9 \times 10^{-6} \Omega^{-1} \text{ cm}^{-1} \end{aligned}$$

The resistivity is

$$\rho = \frac{1}{\sigma} = 3.5 \times 10^5 \Omega \text{ cm}$$

Practice Problem 2

For the intrinsic case, we apply

$$\sigma = en\mu_e + ep\mu_h = en(\mu_e + \mu_h)$$

so
$$\sigma = (1.6 \times 10^{-19} \text{ C})(1.0 \times 10^{10} \text{ cm}^{-3})(1350 + 450 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1})$$
$$= 2.88 \times 10^{-6} \Omega^{-1} \text{ cm}^{-1}$$

Since $L = 1 \text{ cm}$ and $A = 1 \text{ cm}^2$, the resistance is

$$R = \frac{L}{\sigma A} = \frac{1}{\sigma} = 3.47 \times 10^5 \Omega \quad \text{or} \quad 347 \text{ k}\Omega$$

When the crystal is doped with 1 in 10^9 , then

$$N_d = \frac{N_{\text{Si}}}{10^9} = \frac{5 \times 10^{22}}{10^9} = 5 \times 10^{13} \text{ cm}^{-3}$$

At room temperature all the donors are ionized, so

$$n = N_d = 5 \times 10^{13} \text{ cm}^{-3}$$

The hole concentration is

$$p = \frac{n_i^2}{N_d} = \frac{(1.0 \times 10^{10})^2}{(5 \times 10^{13})} = 2.0 \times 10^6 \text{ cm}^{-3} \ll n_i$$

Therefore,

$$\sigma = en\mu_e = (1.6 \times 10^{-19} \text{ C})(5 \times 10^{13} \text{ cm}^{-3})(1350 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1})$$
$$= 1.08 \times 10^{-2} \Omega^{-1} \text{ cm}^{-1}$$

Further,

$$R = \frac{L}{\sigma A} = \frac{1}{\sigma} = 92.6 \Omega$$

Practice Problem 3

This semiconductor has been compensation doped with excess acceptors over donors, so

$$N_a - N_d = 10^{17} - 10^{16} = 9 \times 10^{16} \text{ cm}^{-3}$$

$$p = N_a - N_d = 9 \times 10^{16} \text{ cm}^{-3}$$

The electron concentration

$$n = \frac{n_i^2}{p} = \frac{(1.0 \times 10^{10} \text{ cm}^{-3})^2}{(9 \times 10^{16} \text{ cm}^{-3})} = 1.1 \times 10^3 \text{ cm}^{-3}$$

Practice Problem 4

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

For intrinsic Si,

$$n_i = N_c \exp\left[-\frac{(E_c - E_{Fi})}{kT}\right]$$

whereas for doped Si,

$$n = N_c \exp\left[-\frac{(E_c - E_{Fn})}{kT}\right] = N_d$$

where E_{Fi} and E_{Fn} are the Fermi energies in the intrinsic and n -type Si. Dividing the two expressions,

$$\frac{N_d}{n_i} = \exp\left[\frac{(E_{Fn} - E_{Fi})}{kT}\right]$$

so that

$$E_{Fn} - E_{Fi} = kT \ln\left(\frac{N_d}{n_i}\right) = (0.0259 \text{ eV}) \ln\left(\frac{10^{16}}{1.0 \times 10^{10}}\right) = 0.36 \text{ eV}$$

so that

$$E_{Fn} - E_{Fi} = kT \ln\left(\frac{N_d}{n_i}\right) = (0.0259 \text{ eV}) \ln\left(\frac{10^{16}}{1.0 \times 10^{10}}\right) = 0.36 \text{ eV}$$

When the wafer is further doped with boron, the acceptor concentration is

$$N_a = 2 \times 10^{17} \text{ cm}^{-3} > N_d = 10^{16} \text{ cm}^{-3}$$

The semiconductor is compensation doped and compensation converts the semiconductor to p -type Si. Thus

$$p = N_a - N_d = (2 \times 10^{17} - 10^{16}) = 1.9 \times 10^{17} \text{ cm}^{-3}$$

For intrinsic Si,

$$n_i = N_v \exp\left[-\frac{(E_{Fi} - E_v)}{kT}\right]$$

whereas for doped Si,

$$p = N_v \exp\left[-\frac{(E_{Fp} - E_v)}{kT}\right] = N_a - N_d$$

where E_{Fi} and E_{Fp} are the Fermi energies in the intrinsic and p -type Si, respectively. Dividing the two expressions,

$$\frac{p}{n_i} = \exp\left[-\frac{(E_{Fp} - E_{Fi})}{kT}\right]$$

so that

$$\begin{aligned} E_{Fp} - E_{Fi} &= -kT \ln\left(\frac{p}{n_i}\right) = -(0.0259 \text{ eV}) \ln\left(\frac{1.9 \times 10^{17}}{1.0 \times 10^{10}}\right) \\ &= -0.43 \text{ eV} \end{aligned}$$