808.

Problem 53.35 (RHK)

Pure silicon at 300 K has an electron density in the conduction band of $1.5\times10^{16}\ \mathrm{m^{-3}}$ *and an equal density of holes in the valence band. Suppose that one of every* 1.0×10^{17} *silicon atoms is replaced by a phosphorous atom.* (a) *We have to find the charge carrier density due to addition of phosphorous. Assume that all donor electrons are in conduction band.* (b) *We have to find the ratio of the charge carrier density in the doped silicon to that for pure silicon.*

Solution:

(a)

We will calculate first the number density of silicon atoms before it is doped with phosphorous. It is given by

$$n_{\mathrm{Si}} = \frac{N_A \rho_{\mathrm{Si}}}{M_{\mathrm{Si}}}.$$

We use the following physical data for silicon:

molar mass, $M_{\mathrm{Si}} = 28.1\ \mathrm{g\ mol^{-1}}$, mass density of silicon, $\rho_{\text{Si}} = 2.33 \text{ g cm}^{-3}$.

We find

$$n_{\text{Si}} = \frac{N_A \rho_{\text{Si}}}{M_{\text{Si}}} = \frac{6.02\times10^{23} \text{ mol}^{-1} \times 2.33\times10^{3} \text{ kg m}^{-3}}{28.1\times10^{-3} \text{ kg mol}^{-1}}$$

$$= 4.99\times10^{28} \text{ atoms per cubic meter.}$$

It is given that silicon is doped with phosphorous by adding one phosphorous atom for every 1.0×10^{17} silicon atoms. Therefore, the number of phosphorous atoms per cubic meter in the doped silicon will be

$$n_{\text{P}} = \frac{4.99\times10^{28}}{1.0\times10^{7}} \text{ m}^{-3}$$

$$= 4.99\times10^{21} \text{ m}^{-3}.$$

As each phosphorous atom contributes one electron to the conduction band, the charge carrier density in the doped silicon will be $4.99\times10^{21} \text{ m}^{-3}$.

(b)

The pure silicon at 300 K has an electron density in the conduction band of $1.5\times10^{16} \text{ m}^{-3}$ and an equal density of holes in the valence band. Therefore, the charge carrier density in pure silicon is

$$2\times1.5\times10^{16} \text{ m}^{-3} = 3.0\times1.5\times10^{16} \text{ m}^{-3}.$$

The ratio of the charge carrier density in the doped silicon to that for pure silicon will therefore be

$$\frac{4.99\times10^{21}}{3.0\times10^{16}}=1.66\times10^{5}\ .$$