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**Problem 2.31** Find the equilibrium electron and hole concentrations and the location of the Fermi energy relative to the intrinsic energy in silicon at 27 °C, if the silicon contains the following concentrations of shallow dopants.

- a)  $1 \times 10^{16} \text{ cm}^{-3}$  boron atoms
- b)  $3 \times 10^{16} \text{ cm}^{-3}$  arsenic atoms and  $2.9 \times 10^{16} \text{ cm}^{-3}$  boron atoms.

**Solution**

- a) Boron atoms are acceptors, therefore  $N_a = 10^{16} \text{ cm}^{-3}$ . Since these are shallow acceptors and the material is not compensated, degenerate or close to intrinsic, the hole density equals the acceptor density:

$$p \approx 10^{16} \text{ cm}^{-3}$$

Using the mass action law we then find the electron density

$$n = n_i^2/p = 1 \times 10^4 \text{ cm}^{-3}$$

The Fermi energy is then obtained from:

$$E_F - E_i = kT \ln \frac{n}{n_i} = 0.0259 \ln \frac{10^4}{10^{10}} = -357 \text{ meV}$$

- b) Arsenic atoms are donors, therefore  $N_d = 2.9 \times 10^{16} \text{ cm}^{-3}$  and  $N_a = 3 \times 10^{16} \text{ cm}^{-3}$

Since these are shallow acceptors and the material is not degenerate or close to intrinsic, the electron density approximately equals the difference between the donor and acceptor density

$$n \approx N_d - N_a = 10^{15} \text{ cm}^{-3}$$

Using the mass action law we then find the hole density

$$p = n_i^2/n = 1 \times 10^5 \text{ cm}^{-3}$$

The Fermi energy is then obtained from:

$$E_F - E_i = kT \ln \frac{n}{n_i} = 0.0259 \ln \frac{10^{15}}{10^{10}} = 298 \text{ meV}$$

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