Problem 2.13 The resistivity of a silicon wafer at room temperature is 5 Ωcm. What is the doping density? Find all possible solutions.

Solution Starting with a initial guess that the conductivity is due to electrons with a mobility of 1400 cm^2/V-s, the corresponding doping density equals:

$$N_d \cong n = \frac{1}{q\mu_n \rho} = \frac{1}{1.6\times 10^{-19}\times 1400\times 5} = 8.9 \text{ x } 10^{14} \text{ cm}^{-3}$$

The mobility corresponding to this doping density equals

$$\mu_n = \mu_{\min} + \frac{\mu_{\max} - \mu_{\min}}{1 + (\frac{N_d}{N_r})^{\alpha}} = 1366 \text{ cm}^2\text{/V-s}$$

Since the calculated mobility is not the same as the initial guess, this process must be repeated until the assumed mobility is the same as the mobility corresponding to the calculated doping density, yielding:

$$N_d = 9.12 \text{ x } 10^{14} \text{ cm}^{-3} \text{ and } \mu_n = 1365 \text{ cm}^2\text{/V-s}$$

For p-type material one finds:

$$N_a = 2.56 \text{ x } 10^{15} \text{ cm}^{-3} \text{ and } \mu_p = 453 \text{ cm}^2\text{/V-s}$$

Problem 2.18 Consider the problem of finding the doping density, which results in the maximum possible resistivity of silicon at room temperature. (n_i = 10^{10} cm^{-3}, μ_n = 1400 cm^2/V-sec and μ_p = 450 cm^2/V-sec.)

Should the silicon be doped at all or do you expect the maximum resistivity when dopants are added?

If the silicon should be doped, should it be doped with acceptors or donors (assume that all dopant are shallow).

Calculate the maximum resistivity, the corresponding electron and hole density and the doping density.

Solution Since the mobility of electrons is larger than that of holes, one expects the resistivity to initially decrease as acceptors are added to intrinsic silicon.

The maximum resistivity (or minimum conductivity) is obtained from:

$$\frac{d\sigma}{dn} = q\frac{d(\mu_n n + \mu_p p)}{dn} = q\frac{d(\mu_n n + \mu_p n_i^2 / n)}{dn} = 0$$

which yields:

$$n = \sqrt{\frac{\mu_p}{\mu_n}} n_i = 0.57\, n_i = 5.7 \text{ x } 10^9 \text{ cm}^{-3}$$

The corresponding hole density equals p = 1.76 n_i = 1.76 x 10^9 cm^{-3} and the amount of acceptors one needs to add equals N_a = 1.20 n_i = 1.20 x 10^9 cm^{-3}. The maximum resistivity equals:

$$\rho_{max} = \frac{1}{q(\mu_n n + \mu_p p)} = \frac{1}{q n_i 1587} = 394 \text{ k}\Omega\text{cm}$$

Problem 2.20 The electron density in silicon at room temperature is twice the intrinsic density. Calculate the hole density, the donor density and the Fermi energy relative to the intrinsic energy. Repeat for $n = 5\ n_i$ and $n = 10\ n_i$. Also repeat for $p = 2\ n_i$, $p = 5\ n_i$ and $p = 10\ n_i$, calculating the electron and acceptor density as well as the Fermi energy relative to the intrinsic energy level.

Solution The hole density is obtained using the mass action law:

$$p = n_i^2/n$$

The doping density is obtained by requiring charge neutrality

$$N_d - N_a = n - p$$

The Fermi energy is obtained from:

$$E_F - E_i = kT \ln(n/n_i)$$

yielding:

	$n = 2\ n_i$	$n = 5\ n_i$	$n = 10\ n_i$
p	$n_i/2$	$n_i/5$	$n_i/10$
$N_d - N_a$	$1.5\ n_i$	$4.8\ n_i$	$9.9\ n_i$
$E_F - E_i$	$kT \ln(2)$	$kT \ln(5)$	$kT \ln(10)$
	$p = 2\ n_i$	$p = 5\ n_i$	$p = 10\ n_i$
n	$n_i/2$	$n_i/5$	$n_i/10$
$N_d - N_a$	$-1.5\ n_i$	$-4.8\ n_i$	$-9.9\ n_i$
$E_F - E_i$	$-kT \ln(2)$	$-kT \ln(5)$	$-kT \ln(10)$

Problem 2.28 Electrons in silicon carbide have a mobility of 1000 cm^2/V-sec. At what value of the electric field do the electrons reach a velocity of 3×10^7 cm/s? Assume that the mobility is constant and independent of the electric field. What voltage is required to obtain this field in a 5 micron thick region? How much time do the electrons need to cross the 5 micron thick region?

Solution The electric field is obtained from the mobility and the velocity:

$$\mathcal{E} = \frac{\mu}{v} = \frac{1400}{3 \times 10^7} = 30 \text{ kV/cm}$$

Combined with the length one finds the applied voltage.

$$V = \mathcal{E} L = 30{,}000 \times 5 \times 10^{-4} = 15 \text{ V}$$

The transit time equals the length divided by the velocity:

$$t_r = L/v = 5 \times 10^{-4}/3 \times 10^7 = 16.7 \text{ ps}$$