19

Electronic Materials

19–1 A current of 10 A is passed through a 1-mm-diameter wire 1000 m long. Calculate the power loss if the wire is made of (a) aluminum, (b) silicon, and (c) silicon carbide. (See Table 19–1).

Solution: Power $= I^2R = I^2\ell/\sigma A = (10\ A)^2(100{,}000\ \text{cm})/(\pi/4)(0.1\ \text{cm})^2\sigma$

Power $= 1.273 \times 10^9/\sigma$

The electrical conductivity of each material is given in Table 19–1:

(a) $P_{Al} = 1.273 \times 10^9/3.77 \times 10^5 = 3380$ watt

(b) $P_{Si} = 1.273 \times 10^9/5 \times 10^{-6} = 2.546 \times 10^{14}$ watt

(c) $P_{SiC} = 1.273 \times 10^9/10^{-1}$ to 10^{-2}
$= 1.273 \times 10^{10}$ to 1.273×10^{11} watt

19–4 The power lost in a 2-mm-diameter copper wire is to be less than 250 W when a 5-A current is flowing in the circuit. What is the maximum length of the wire?

Solution: $P = I^2R = I^2\ell/\sigma A = 250$ W

$\ell = 250\sigma A/I^2 = (250)(5.98 \times 10^5)(\pi/4)(0.2)^2/(5)^2$
$= 1.88 \times 10^5$ cm $= 1.88$ km

19–5 A current density of 100,000 A/cm^2 is applied to a gold wire 50 m in length. The resistance of the wire is found to be 2 ohm. Calculate the diameter of the wire and the voltage applied to the wire.

Solution: $J = I/A = \sigma V/\ell = 100{,}000$ A/cm^2

$V = 100{,}000\ell/\sigma = (100{,}000)(5000\ \text{cm})/4.26 \times 10^5 = 1174$ V

19–7 Suppose we estimate that the mobility of electrons in silver is 75 cm²/V · s. Estimate the fraction of the valence electrons that are carrying an electrical charge.

Solution: The total number of valence electrons is:

$$n_T = \frac{(4 \text{ atoms/cell})(1 \text{ electron/atom})}{(4.0862 \times 10^{-8} \text{ cm})^3} = 5.86 \times 10^{22}$$

The number of charge carriers is:

silver

$$n = \sigma/q\mu = (6.80 \times 10^5)/(1.6 \times 10^{-19})(75) = 5.67 \times 10^{22}$$

The fraction of the electrons that carry the electrical charge is:

$$n/n_T = 5.67 \times 10^{22}/5.86 \times 10^{22} = 0.968$$

19–8 A current density of 5000 A/cm² is applied to a magnesium wire. If half of the valence electrons serve as charge carriers, calculate the average drift velocity of the electrons.

Solution: The total number of valence electrons is:

$$n_T = \frac{(2 \text{ atoms/cell})(2 \text{ electrons/atom})}{(3.2087 \times 10^{-8})^2(5.209 \times 10^{-8})\cos 30} = 8.61 \times 10^{22}$$

The actual number of charge carriers is then 4.305×10^{22}.

$$\bar{v} = J/nq = (5000 \text{ A/cm}^2)/(4.305 \times 10^{22})(1.6 \times 10^{-19})$$
$$= 0.7259 \text{ cm/s}$$

19.14 **Solution:** $\rho_{room} = 6.24 \times 10^{-6}$ ohm · cm $\quad \alpha = 0.006$ ohm · cm/°C

$$\rho_{zero} = (6.24 \times 10^{-6})[1 + (0.006)(0 - 25)] = 5.304 \times 10^{-6}$$

We wish to double the conductivity, or halve the resistivity to 2.652×10^{-6} ohm · cm. The required temperature is:

$$2.652 \times 10^{-6} = (6.24 \times 10^{-6})[1 + (0.006)(T - 25)]$$
$$-0.575 = 0.006(T - 25) \quad \text{or} \quad T = -70.8°\text{C}$$

19.33 **Solution:** $n = \sigma/q\mu_h = 500/(1.6 \times 10^{-19})(400) = 7.81 \times 10^{18}$

$$7.81 \times 10^{18} = \frac{(4 \text{ Ga atoms/cell})(x \text{ vacancies/Ga atom})}{(5.65 \times 10^{-8} \text{ cm})^3}$$

$x = 0.000352$ vacancies/cell

Therefore there are 0.999648 As atoms per one Ga atom.

$$\text{at\% As} = \frac{0.999648}{1 + 0.999648} \times 100 = 49.991\%$$

$$\text{wt\% As} = \frac{(49.991)(74.9216)}{(49.991)(74.9216) + (50.009)(69.72)} \times 100 = 51.789\%$$

$$\frac{x \text{ g Ni}}{x + 1000 \text{ g Ga}} \times 100 = 51.789 \quad \text{or} \quad x = 1074 \text{ g As}$$

19–28 For germanium, silicon, and tin, compare, at 25°C, the number of charge carriers per cubic centimeter, the fraction of the total electrons in the valence band that are excited into the conduction band, and the constant n_0.

For germanium:

$$n_{Ge} = \frac{(8\ \text{atoms/cell})(4\ \text{electrons/atom})}{(5.6575 \times 10^{-8}\ \text{cm})^3} = 1.767 \times 10^{23}/\text{cm}^3$$

From Table 19–6, we can find the conductivity and mobilities for germanium. The number of excited electrons is then:

$$\begin{aligned} n_{\text{conduction}} &= \sigma/q(\mu_e + \mu_h) = 0.02/(1.6 \times 10^{-19})(3800 + 1820) \\ &= 2.224 \times 10^{13} \end{aligned}$$

$$\text{fraction} = 2.224 \times 10^{13}/1.767 \times 10^{23} = 1.259 \times 10^{-10}$$

$$\begin{aligned} n_0 &= n/\exp(-E_g/2kT) \\ &= 2.224 \times 10^{13}/\exp[-0.67/(2)(8.63 \times 10^{-5})(298)] \\ &= 1.017 \times 10^{19} \end{aligned}$$

For silicon:

$$n_{Si} = \frac{(8\ \text{atoms/cell})(4\ \text{electrons/atom})}{(5.4307 \times 10^{-8}\ \text{cm})^3} = 1.998 \times 10^{23}/\text{cm}^3$$

$$\begin{aligned} n_{\text{conduction}} &= \sigma/q(\mu_e + \mu_h) = 5 \times 10^{-6}/(1.6 \times 10^{-19})(1900 + 500) \\ &= 1.302 \times 10^{10} \end{aligned}$$

$$\text{fraction} = 1.302 \times 10^{10}/1.998 \times 10^{23} = 6.517 \times 10^{-14}$$

$$\begin{aligned} n_0 &= n/\exp(-E_g/2kT) \\ &= 1.302 \times 10^{10}/\exp[-1.107/(2)(8.63 \times 10^{-5})(298)] \\ &= 2.895 \times 10^{19} \end{aligned}$$

For tin:

$$n_{Sn} = \frac{(8\ \text{atoms/cell})(4\ \text{electrons/atom})}{(6.4912 \times 10^{-8}\ \text{cm})^3} = 1.170 \times 10^{23}/\text{cm}^3$$

$$\begin{aligned} n_{\text{conduction}} &= \sigma/q(\mu_e + \mu_h) = 0.9 \times 10^{5}/(1.6 \times 10^{-19})(2500 + 2400) \\ &= 1.148 \times 10^{20} \end{aligned}$$

$$\text{fraction} = 1.148 \times 10^{20}/1.170 \times 10^{23} = 9.812 \times 10^{-4}$$

$$\begin{aligned} n_0 &= n/\exp(-E_g/2kT) \\ &= 1.148 \times 10^{20}/\exp[-0.08/(2)(8.63 \times 10^{-5})(298)] \\ &= 5.44 \times 10^{20} \end{aligned}$$