

*- Alex J. Adams***5.2**

A p-type silicon material is to have a conductivity of $\sigma = 1.80 (\Omega\text{-cm})^{-1}$. If the mobility values are $\mu_n = 1250 \text{ cm}^2/\text{V-s}$ and $\mu_p = 380 \text{ cm}^2/\text{V-s}$, what must be the acceptor impurity concentration in the material?

$$\sigma = e \mu_p N_a$$

$$N_a = \frac{\sigma}{e \mu_p} = \frac{1.80}{1.6 \times 10^{-19} (380)} = 2.96 \times 10^{16} / \text{cm}^3$$

5.6

Consider a homogeneous gallium arsenide semiconductor at $T = 300 \text{ K}$ with $N_d = 10^{16} \text{ cm}^{-3}$ and $N_a = 0$. (a) Calculate the thermal-equilibrium values of electron and hole concentrations. (b) For an applied E-field of 10 V/cm , calculate the drift current density. (c) Repeat parts (a) and (b) if $N_d = 0$ and $N_a = 10^{16} \text{ cm}^{-3}$.

$$n_n = \frac{N_d - N_a}{2} + \sqrt{\left(\frac{N_d - N_a}{2}\right)^2 + n_i^2}$$

$$p_n = \frac{n_i^2}{n_n}$$

a.)

$$n_n = \frac{10^{16} - 0}{2} + \sqrt{\left(\frac{10^{16} - 0}{2}\right)^2 + (1.8 \times 10^6)^2}$$

$$n_n = 10^{16} / \text{cm}^3$$

$$p_n = \frac{n_i^2}{n_n} = \frac{(1.8 \times 10^6)^2}{10^{16}} = 3.24 \times 10^{-4} / \text{cm}^3$$

b.) $J = e \mu_n N_d E = 1.6 \times 10^{-19} (8500) (10^{16}) (10) = 136 \text{ A/cm}^2$

c.) $N_a > N_d$ p-type

$$p_p = \frac{10^{16}}{2} + \sqrt{\left(\frac{10^{16}}{2}\right)^2 + (1.8 \times 10^6)^2} = 10^{16} / \text{cm}^3$$

$$n_p = \frac{p_i^2}{p_p} = \frac{(1.8 \times 10^6)^2}{10^{16}} = 3.24 \times 10^{-4} / \text{cm}^3$$

$$J = 1.6 \times 10^{-19} (400) (10^{16}) (10) = 6.4 \text{ A/cm}^2$$

5.14 In a particular semiconductor material, $\mu_n = 1000 \text{ cm}^2/\text{V-s}$, $\mu_p = 600 \text{ cm}^2/\text{V-s}$, and $N_c = N_v = 10^{19} \text{ cm}^{-3}$. These parameters are independent of temperature. The measured conductivity of the intrinsic material is $\sigma = 10^{-6} (\Omega\text{-cm})^{-1}$ at $T = 300 \text{ K}$. Find the conductivity at $T = 500 \text{ K}$.

Conductivity $\sigma = e (\mu_n + \mu_p) n_i$ $\left| n_i^2 = N_c N_v \exp\left(-\frac{E_g}{kT}\right) \right|$

$$n_i = \frac{6}{e^{(u_n + u_p)}} = \frac{10^{-6}}{(1.6 \times 10^{-19})(1000 + 600)} = 3.9 \times 10^7 / \text{cm}^3$$

$$E_g = kT \ln \left(\frac{N_c N_v}{n_i^2} \right) = (26 \times 10^{-3}) \ln \left(\frac{(10^{19})(10^{19})}{(3.9 \times 10^7)^2} \right) = 1.122 \text{ eV}$$

$$kT = 26 \times 10^{-3} \left(\frac{500}{300} \right) = 0.432 \text{ eV}$$

$$n_i^2 = (10^{19})(10^{19}) \exp \left(-\frac{1.122}{0.432} \right) = 2.29 \times 10^{13} / \text{cm}^3$$

$$\sigma = (1.6 \times 10^{-19})(1000 + 600)(2.29 \times 10^{13}) = 5.86 \times 10^{-3} / \Omega \cdot \text{cm}$$

5.30 The steady-state electron distribution in silicon can be approximated by a linear function of x . The maximum electron concentration occurs at $x = 0$ and is $n(0) = 2 \times 10^{16} \text{ cm}^{-3}$. At $x = 0.012 \text{ cm}$, the electron concentration is $5 \times 10^{15} \text{ cm}^{-3}$. If the electron diffusion coefficient is $D_n = 27 \text{ cm}^2/\text{s}$, determine the electron diffusion current density.

$$J = e D_n \frac{dn}{dx} = e D_n \left(\frac{n(0) - n(0.012)}{0 - 0.012} \right)$$

$$J = (1.6 \times 10^{-19})(27) \left(\frac{(2 \times 10^{16}) - (5 \times 10^{15})}{0 - 0.012} \right)$$

$$= (1.6 \times 10^{-19})(27)(-1.25 \times 10^{18})$$

$$= -5.4 \text{ A/cm}^2$$

5.36 The total current in a semiconductor is constant and equal to $J = -10 \text{ A/cm}^2$. The total current is composed of a hole drift current and electron diffusion current. Assume that the hole concentration is a constant and equal to 10^{16} cm^{-3} and assume that the electron concentration is given by $n(x) = 2 \times 10^{15} e^{-x/L} \text{ cm}^{-3}$ where $L = 15 \mu\text{m}$. The electron diffusion coefficient is $D_n = 27 \text{ cm}^2/\text{s}$ and the hole mobility is $\mu_p = 420 \text{ cm}^2/\text{V}\cdot\text{s}$. Calculate (a) the electron diffusion current density for $x > 0$, (b) the hole drift current density for $x > 0$, and (c) the required electric field for $x > 0$.

$$J = -e D_n \frac{dn}{dx}$$

a.)

$$J = -e D_n \frac{d[2 \times 10^{15} e^{-x/L}]}{dx} = -2 \times 10^{15} (1.6 \times 10^{-19}) (27 e^{-x/(1.5 \times 10^{-4})})$$

$$J_n = -5.76 e^{-[6.7 \times 10^4]x} \text{ A/cm}^2$$

b.) For $x > 0$

$$J = J_n + J_p = -10 \text{ A/cm}^2$$

$$J_p = -10 - (-5.76 e^{-[6.7 \times 10^4]x})$$

$$J_p = 5.76 e^{-[6.7 \times 10^4]x} - 10 \text{ A/cm}^2$$

c.) For $x > 0$

$$J_p = e_p \mu_p E$$

$$E = \frac{J_p}{e_p \mu_p} = \frac{5.76 e^{-[6.7 \times 10^4]x} - 10}{1.6 \times 10^{-19} (10^{16}) (420)}$$

$$E = 8.57 e^{-[6.7 \times 10^4]x} - 14.88 \text{ V/cm}$$