Homework 3

Monday, October 4, 2021 1:00 PM

"I pledge my honor I have abided by the Stevens Honor system."

\- Alex Gaskins

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?

$$\sigma = e\mu_p N_a$$

$$N_a = \frac{\sigma}{e\mu_p} = \frac{1.80}{1.6\times10^{-19}(380)} = \boxed{2.96\times10^{16}/\text{cm}^3}$$

5.6 Consider a homogeneous gallium arsenide semiconductor at $T = 300$ 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.)

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

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

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

b.) $J = e\mu_n N_d E = 1.6\times10^{-19}(8500)(10^{16})(10) = \boxed{136\ A/cm^2}$

c.) $N_a > N_d$ p-type

$$p_p = \frac{10^{16}}{2} + \sqrt{\left(\frac{10^{16}}{2}\right)^2 + (1.8\times10^6)^2} = \boxed{10^{16}/cm^3}$$

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

$$J = 1.6\times10^{-19}(400)(10^{16})(10) = \boxed{6.4\ A/cm^2}$$

5.14 In a particular semiconductor material, $\mu_n = 1000$ cm²/V-s, $\mu_p = 600$ cm²/V-s, and $N_C = N_V = 10^{19}$ cm^{-3}. These parameters are independent of temperature. The measured conductivity of the intrinsic material is $\sigma = 10^{-6}$ $(\Omega\text{-cm})^{-1}$ at $T = 300$ K. Find the conductivity at $T = 500$ K.

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

conductivity

$$n_i = \frac{\sigma}{e(\mu_n + \mu_p)} = \frac{10^{-6}}{(1.6\times10^{-19})(1000+600)} = 3.9\times10^{9}/cm^3$$

$$E_g = kT \ln\left(\frac{N_c N_v}{n_i^2}\right) = \left(26\times10^{-3}\right) \ln\left(\frac{(10^{19})(10^{19})}{(3.9\times10^{9})^2}\right) = 1.122\ eV$$

$$kT = 26\times10^{-3}\left(\frac{500}{300}\right) = 0.0432\,eV$$

$$n_i^2 = (10^{19})(10^{19})\exp\left(\frac{-1.122}{0.0432}\right) = 2.29\times10^{13}/cm^3$$

$$\sigma = (1.6\times10^{-19})(1000+600)(2.29\times10^{13}) = \boxed{5.86\times10^{-3}/\Omega\cdot cm}$$

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 $n(0) = 2 \times 10^{16}\ cm^{-3}$. At $x = 0.012$ cm, the electron concentration is $5 \times 10^{15}\ cm^{-3}$. If the electron diffusion coefficient is $D_n = 27\ cm^2/s$, determine the electron diffusion current density.

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

$$J = (1.6\times10^{-19})(27)\left(\frac{(2\times10^{16}) - (5\times10^{15})}{0 - 0.012}\right)$$

$$= (1.6\times10^{-19})(27)(-1.25\times10^{18})$$

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

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 $10^{16}\ \text{cm}^{-3}$ 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 $\mu_p = 420\ \text{cm}^2/\text{V-s}$. 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.)

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

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

b.) For $x > 0$

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

$$J_p = -10 - (-5.76 e^{-[6.7 \times 10^2]x})$$

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

c.) For $x > 0$

$$J_p = e p \mu_p E$$

$$E = \frac{J_p}{e p \mu_p} = \frac{5.76 e^{-[6.7 \times 10^2]x} - 10}{1.6 \times 10^{-19} (10^{16})(420)}$$

$$\boxed{E = 8.57 e^{-[6.7 \times 10^2]x} - 14.88\ V/cm}$$