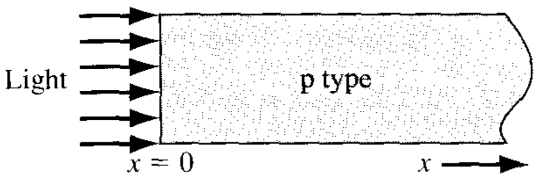
**6.21** In a p-type silicon semiconductor, excess carriers are being generated at the end of the bar at $x = 0$ as shown in Figure P6.19. The uniform doping concentrations are $N_a = 7 \times 10^{16}$ cm$^{-3}$ and $N_d = 2 \times 10^{16}$ cm$^{-3}$. The steady-state excess carrier concentrations at $x = 0$ are $\delta p(0) = \delta n(0) = 5 \times 10^{14}$ cm$^{-3}$. (Neglect surface effects.) The electric field is zero. Assume semiconductor parameters of $\tau_{n0} = \tau_{p0} = 10^{-6}$ s, $D_n = 25$ cm$^2$/s, and $D_p = 10$ cm$^2$/s. (*a*) Calculate $\delta n$ and the electron and hole diffusion current densities at $x = 0$. (*b*) Repeat part (*a*) for $x = 5 \times 10^{-3}$ cm. (*c*) Repeat part (*a*) for $x = 15 \times 10^{-3}$ cm.




First, find the excess minority carrier concentration for $x \geq 0$. Then, find the diffusion current densities for $x \geq 0$. Hint: What is the ambipolar diffusion coefficient (use to find diffusion current densities)?

From Table B.4, $n_i = 1.5 \times 10^{10}$ #/cm$^3$ for Si @ 300K.

$p_o \simeq N_a - N_d = 7\times10^{16} - 2\times10^{16} = 5\times10^{16}$ #/cm$^3$

(4.43) $n_o = n_i^2 / p_o = \dfrac{(1.5\times10^{10})^2}{5\times10^{16}} = 4500$ #/cm$^3$

Since $\delta n(0) = 5\times10^{14}$ cm$^{-3}$ $<<$ $p_o = 5\times10^{16}$ cm$^{-3}$

and $n_o << p_o$, we get (6.45) $D' = D_n = 25 \frac{cm^2}{s}$

and (6.46) $\mu' = \mu_n$. The applicable ambipolar transport eq'n (6.55) is

$$\frac{\partial(\delta n)}{\partial t} = D_n \frac{\partial^2(\delta n)}{\partial x^2} + \mu_n E \frac{\partial(\delta n)}{\partial x} + g' - \frac{\delta n}{\tau_{n0}}$$

For $E = 0$, $g' = 0$ $(x > 0)$, & $\frac{\partial(\delta n)}{\partial t} = 0$ (steady-state),

we can follow solution of Example 6.4

to get (6.65a) $\delta n(x) = \delta n(0)\, e^{-x/L_n}$ $\quad x \geq 0$

where $L_n = \sqrt{D_n \tau_{n0}} = \sqrt{25(10^{-6})} = 5\times10^{-3}$ cm $= 5\times10^{-5}$ m.

and $\delta n(0) = 5\times10^{14}$ cm$^{-3}$.

So, $\delta n(x) = 5\times10^{14}\, e^{-x/5\times10^{-5}}$ #/cm³ $x \geq 0$.

Note $\delta p(x) = \delta n(x)$.

Per (5.33), $J_{n|dif} = e D_n \frac{dn}{dx}$ where $D_n = D'$

$$J_{n|dif} = 1.602176634\times10^{-19}\left(0.0025\frac{m^2}{s}\right)\frac{d(n_0+\delta n(x))}{dx}$$

$$= 1.602176634\times10^{-19}(0.0025)\left[5\times10^{20}\left(\frac{-1}{5\times10^{-5}}\right)e^{-x/5\times10^{-5}}\right]$$

$$J_{n|dif}(x) = -4005.44\, e^{-x/5\times10^{-5}}\ A/m^2 \quad x \geq 0$$

Per (5.34), $J_{p|dif} = -e D_p \frac{dp}{dx}$. However, for ambipolar transport, $D_p = D' = D_n$ and $p = p_0 + \delta p(x) = p_0 + \delta n(x)$. Therefore, $J_{p|dif}(x) = -J_{n|dif}(x)$.

a) $J_{n|dif}(x=0) = -4005.44\ \frac{A}{m^2} = -0.4005\ A/cm^2$

$J_{p|dif}(x=0) = 4005.44\ A/m^2 = 0.4005\ A/cm^2$

b) $J_{n|dif}(x=5\times10^{-5}m) = -4005.44\, e^{-1} = -1473.5\ A/m^2 = -0.1474\ \frac{A}{cm^2}$

$J_{p|dif}(x=5\times10^{-5}m) = 1473.5\ A/m^2 = 0.1474\ \frac{A}{cm^2}$

c) $J_{n|dif}(x=15\times10^{-5}m) = -4005.44\, e^{-3} = -199.42\ A/m^2 = -0.01994\ A/cm^2$

$J_{p|dif}(x=15\times10^{-5}m) = 199.42\ A/m^2 = 0.01994\ A/cm^2$