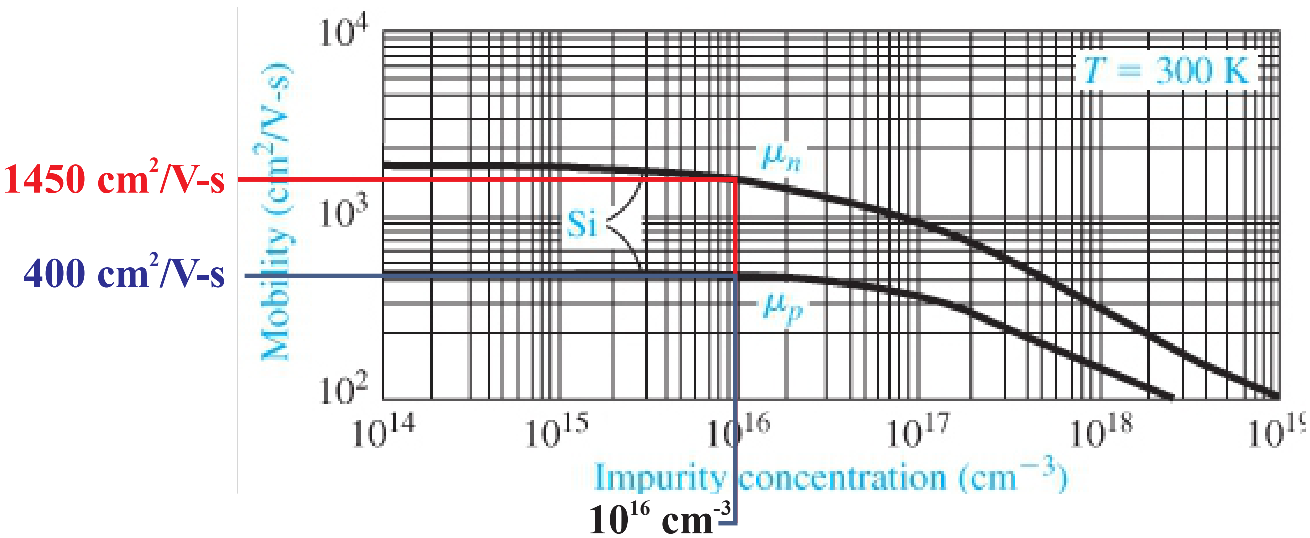
6.14 A bar of silicon at $T = 300$ K has a length of $L = 0.05$ cm and a cross-sectional area of $A = 10^{-5}$ cm^2. The semiconductor is uniformly doped with $N_d = 8 \times 10^{15}$ cm^{-3} and $N_a = 2 \times 10^{15}$ cm^{-3}. A voltage of 10 V is applied across the length of the material. For $t < 0$, the semiconductor has been uniformly illuminated with light, producing an excess carrier generation rate of $g' = 8 \times 10^{20}$ cm^{-3} s^{-1}. The minority carrier lifetime is $\tau_{p0} = 5 \times 10^{-7}$ s. At $t = 0$, the light source is turned off. Determine the current in the semiconductor as a function of time for $t \geq 0$.

- First, find the electron and hole mobilities at thermal equilibrium (Hint: use graph). Second, find the minority charge carrier concentration as a function of time. Third, find the conductivity as a function of time.

Impurity concentration $N_I = N_a + N_d = 2 \times 10^{15} + 8 \times 10^{15} = 10^{16}$ cm^{-3}. Using Figure 5.3 (below) for silicon, we get: **$\mu_n = 1450$ cm^2/V-s** and **$\mu_p = 400$ cm^2/V-s**.



Since $N_d > N_a$, the minority carriers are holes.

Per (6.56), for $t > 0$ $g' = 0$ + uniform δp wrt x

$$\frac{\partial(\delta p)}{\partial t} = D_p \underbrace{\frac{\partial^2(\delta p)}{\partial x^2}}_{\to 0 \text{ uniform illumin.}} - \mu_p \underbrace{E}_{\frac{10V}{0.05cm}} \underbrace{\frac{\partial(\delta p)}{\partial x}}_{0 \text{ uniform illum}} + \underbrace{g'}_{0} - \frac{\delta p}{\underbrace{\tau_{p0}}_{5\times10^{-7}s}}$$

$$\frac{\partial(\delta p)}{\partial t} + \frac{1}{\tau_{p0}} \delta p = 0 \Rightarrow \delta(t) = A e^{-t/\tau_{p0}}$$

For $t \leq 0$, semiconductor @ steady-state

$$\underbrace{\frac{\partial(\delta p)}{\partial t}}_{0} = D_p \underbrace{\frac{\partial^2(\delta p)}{\partial x^2}}_{0} - \mu_p E \underbrace{\frac{\partial(\delta p)}{\partial x}}_{0} + g' - \frac{\delta p}{\tau_{p0}}$$

$$0 = g' - \frac{\delta p}{\tau_{p0}} \Rightarrow \delta p = g'\tau_{p0}$$

Apply B.C., $\delta(0) = Ae^0 = g'\tau_{p0} \Rightarrow A = \underbrace{g'}_{8\times10^{20}}\underbrace{\tau_{p0}}_{5\times10^{-7}}$

$$\underline{\underline{\delta p(t) = 4\times10^{14} e^{-t/5\times10^{-7}} \text{ cm}^{-3} \quad t \geq 0}}$$

Per (5.20), $\sigma = e(\mu_n n + \mu_p p)$.

Per Table B.4, $n_i = 1.5\times10^{10} \text{ cm}^{-3}$ for Si @ 300K

$$n_0 \approx N_d - N_a = 8\times10^{15} - 2\times10^{15} = 6\times10^{15} \text{ cm}^{-3}$$

$$p_0 = \frac{n_i^2}{n_0} = \frac{(1.5\times10^{10})^2}{6\times10^{15}} = 37{,}500 \text{ cm}^{-3} \leftarrow \text{negligible}$$

$$\delta n(t) = \delta p(t) \quad \text{and} \quad n = n_0 + \delta n(t),\ p = \underbrace{p_0}_{\sim 0} + \delta p(t)$$

$$\sigma(t) = 1.602177\times10^{-19}\left[1450\left(6\times10^{15} + 4\times10^{14}e^{-t/\tau_{p0}}\right) + 400\left(37{,}500 + 4\times10^{14}e^{-t/\tau_{p0}}\right)\right]$$

$$= 1.394 + 0.092926\, e^{-t/\tau_{p0}} + \underbrace{2.4\times10^{-12}}_{\sim 0} + 0.0256348\, e^{-t/\tau_{p0}}$$

$$\underline{\underline{\sigma(t) = 1.394 + 0.1186\, e^{-t/5\times10^{-7}} \text{ S/cm} \quad t \geq 0}}$$

$$(5.22a) \quad I/A = \sigma(V/L) \Rightarrow I = \frac{\sigma A}{L} V$$

$$I = \left(1.394 + 0.1186\, e^{-t/5\times10^{-7}} \text{ S/cm}\right) 10^{-5} \text{ cm}^2 \frac{10 \text{ V}}{0.05 \text{ cm}}$$

$$I = 0.002788 + 0.0002372\, e^{-t/5\times10^{-7}} \text{ A} \quad t \geq 0$$

$$\underline{\underline{I(t) = 2.788 + 0.237\, e^{-t/5\times10^{-7}} \text{ mA} \quad t \geq 0}}$$