Physical Electronics
Homework #3
Due on: 25th October, 2013

1. An n-type Silicon sample contains a donor concentration of $N_d = 10^{16}$ cm$^{-3}$. The minority carrier hole lifetime is found to be $\tau_{p0} = 20 \mu$s.

   a. What is the lifetime of the majority carrier electrons?
   b. Determine the thermal-equilibrium generation rate for electrons and holes in this material.
   c. Determine the thermal-equilibrium recombination rate for electrons and holes in this material.

**Solution:**

(a) Recombination rates are equal:

\[
\frac{n_0}{\tau_{n0}} = \frac{p_0}{\tau_{p0}}
\]

\[
n_0 = N_d = 10^{16} \text{ cm}^{-3}
\]

\[
p_0 = \frac{n_i^2}{n_0} = \frac{(1.5 \times 10)^{10}}{10^{16}} = 2.25 \times 10^4 \text{ cm}^{-3}
\]

So:

\[
\frac{10^{16}}{\tau_{n0}} = \frac{2.25 \times 10^4}{20 \times 10^{-6}}
\]

\[
\tau_{n0} = 8.89 \times 10^6 \text{ s}.
\]

(b) Generation Rate = Recombination Rate
Therefore:

\[
G = \frac{2.25 \times 10^4}{20 \times 10^{-6}} = 1.125 \times 10^9 \text{ cm}^{-1} \text{s}^{-1}
\]

(c) $R = G = 1.125 \times 10^9 \text{ cm}^{-3} \text{s}^{-1}$
2. (a) A sample of semiconductor has a cross-sectional area of $1\text{cm}^2$ and a thickness of $0.1\text{cm}$. Determine the number of electron-hole pairs that are generated per unit volume per unit time by the uniform absorption of $1\text{ Watt}$ of light at a wavelength of $6300\text{Å}$. Assume each photon creates one electron-hole pair. (b) If the excess minority carrier lifetime is $10\mu\text{s}$, what is the steady-state excess carrier concentration?

**Solution:**

a) $E = h\nu = h\frac{c}{\lambda} = \frac{(6.626\times10^{-34})(3\times10^8)}{(6300\times10^{-10})} = 3.15\times10^{-19}\text{J}$. This is the energy of 1 photon.

Now,

$1W = 1\text{J/s} = 3.17\times10^{18}\frac{\text{photons}}{s}$

Volume = $(1)(0.1) = 0.1\text{cm}^3$

Then,

$g = \frac{3.17\times10^{18}}{0.1} = 3.17\times10^{19}\text{e-h pairs/cm}^3 - \text{s}$

b) $\delta n = \delta p = g\tau = (3.17\times10^{19})(10\times10^{-6})$

$\delta n = \delta p = 3.17\times10^{14}\text{cm}^{-3}$

3. A sample of Ge at $T = 300\text{K}$ has a uniform donor concentration of $2\times10^{13}\text{ cm}^{-3}$. The excess carrier lifetime is found to be $\tau_p = 24 \mu\text{s}$. Determine the ambipolar diffusion coefficient and the ambipolar mobility. What are the electron and hole lifetimes?

**Solution:**

For Ge: $T = 300\text{K}$, $n_i = 2.4\times10^{13}\text{ cm}^{-3}$

$$n = \frac{N_d}{2} + \sqrt{\frac{N_d^2}{2} + n_i^2} = 10^{13} + \sqrt{(10^{13})^2 + (2.4\times10^{13})^2} = 3.6\times10^{13}\text{ cm}^{-3}$$
Also,
\[ p = \frac{n_i^2}{n} = \frac{(2.4 \times 10^{13})^2}{3.6 \times 10^{13}} = 1.6 \times 10^{13} \text{cm}^{-3} \]

We have:
\[ \mu_n = 3900, \mu_p = 1900 \]
\[ D_n = 101, D_p = 49.2 \]

Therefore:
\[ D' = \frac{D_n D_p (n+p)}{D_n n + D_p p} = \frac{(101)(49.2)(3.6 \times 10^{13} \text{cm}^{-3} + 1.6 \times 10^{13} \text{cm}^{-3})}{(101)(3.6 \times 10^{13} \text{cm}^{-3}) + (49.2)(1.6 \times 10^{13} \text{cm}^{-3})} = 58.4 \text{ cm}^2 \text{s}^{-1} \]

Also,
\[ \mu' = \frac{\mu_n \mu_p (p-n)}{\mu_n n + \mu_p p} = \frac{(3900)(1900)(1.6 \times 10^{13} \text{cm}^{-3} - 3.6 \times 10^{13} \text{cm}^{-3})}{(3900)(3.6 \times 10^{13} \text{cm}^{-3}) + (1900)(1.6 \times 10^{13} \text{cm}^{-3})} = -868 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1} \]

Now,
\[ \frac{n}{\tau_n} \frac{\tau_p}{\tau_n} = \frac{3.6 \times 10^{13}}{1.6 \times 10^{13}} = 24 \mu \text{s} \]

\[ \tau_n = 54 \mu \text{s}. \]

4. Consider a Silicon material doped with \(3 \times 10^{16} \text{cm}^{-3}\) donor atoms. At \(t=0\), a light source is turned on, producing a uniform generation rate of \(g' = 1 \times 10^{20} \text{cm}^{-3} \text{s}^{-1}\). At \(t = 2 \times 10^{-6} \text{s}\), the light source is turned off. The excess carrier lifetime is found to be \(\tau_{p_0} = 1 \mu \text{s}\). Determine the excess minority carrier concentration as a function of time for \(0 \leq t \leq \infty\).

**Solution:**

n-type Silicon, For \(0 \leq t \leq 2 \times 10^{-6} \text{s}\)
\[ \delta p = g' \tau_{p_0} [1 - \exp(-\frac{t}{\tau_{p_0}})] \]
\[ \delta n = (1 \times 10^{20})(1 \times 10^{-6})[1 - \exp(-\frac{t}{\tau_{p_0}})] \]
\[ \delta p = (10^{14})[1 - \exp(-\frac{t}{\tau_{p0}})] \] where \( \tau_{p0} = 1 \times 10^{-6} \text{s} \)

At \( t = 2 \times 10^{-6} \text{s} \),

\[ \delta p(2\mu s) = 10^{14}[1 - \exp(-\frac{2}{1})]\]

\[ \delta n(2\mu s) = 0.865 \times 10^{14} \text{cm}^{-3} \]

For \( t > 2 \times 10^{-6} \text{s} \),

\[ \delta n(2\mu s) = 0.865 \times 10^{14} \text{cm}^{-3}[\exp(-\frac{(t-2 \times 10^{-6})}{\tau_{n0}})] : \tau_{p0} = 1 \times 10^{-6} \text{s} \]