ELEG 340 - Fall 08
Solid-State Electronics
Quiz 2

9 October 2008

NAME: Solution

Time Limit: 30 minutes

Closed Books and Notes. You may use your own calculator, but you may not loan or borrow calculators (ask proctor if you have questions). Put expression in a final form as best you can, and indicate final units (dimensions).

Guidelines:
I. Full credit requires giving the final dimensions/units for all numerical quantities that you calculate.

II. Show all work and calculations for full credit.

III. Accuracy to 2 significant figures is sufficient.

IV. Assume that the material is silicon at room temperature (300 K or 296 K), unless otherwise stated.

V. At room temperature (300K), thermal energy $k_B T = 0.0258$ eV (0.026 eV), silicon has intrinsic concentration $n_i = 1 \text{ (or 1.5) } \times 10^{10} \text{ cm}^{-3}$. and recombination lifetimes: $\tau_n, \tau_p = 1 \mu\text{sec}.$

Note permittivity of free space $\varepsilon_0 = 8.85 \times 10^{-14} \text{ F/cm};$ magnitude of electron charge $q = 1.6 \times 10^{-19} \text{ Coul}$

VI. Equations:

$p_{op} = i \hbar d/dx$

$n = n_i \exp[(E_F - E_i)/k_B T].$

$J_n = q \mu_n n \varepsilon + q D_n \partial n/\partial x$

$U_n = (n_p - n_{po})/\tau_n$

$C = \varepsilon_0 / W$

$D/\mu = k_B T/q$

$\partial p/\partial t = -1/q \partial J_p/\partial x - p'/\tau_p$

$\partial p/\partial t = D_p \partial^2 p/\partial x^2 - p'/\tau_p$

$p' = p - p_0 = g_{opt} \tau_p$

$f_{FD}(E) = 1/[1 + \exp(E - E_F)/k_B T]$

$p = n_i \exp[(E_F - E)/k_B T]$

$J_p = q \mu_p p \varepsilon - q D_p \partial p/\partial x$

$U_p = (p_n - p_{po})/\tau_p$

$L = \sqrt{(D \tau)}$

$E = Q V$

$\partial n/\partial t = -1/q \partial J_n/\partial x - n'/\tau_n$

$\partial n/\partial t = D_n \partial^2 n/\partial x^2 - n'/\tau_n$

$n' = n - n_0 = g_{opt} \tau_n$
1. An electron has a kinetic energy of 2 eV (electron volt). What is its energy in Joules? For full credit, show your work.

\[ W = qV = 1.6 \times 10^{-19} \text{Coul} \times 2 \text{V} \]

\[ 2 \text{eV} = 3.2 \times 10^{-19} \text{Joule} \]

2. A sample of silicon at room temperature (300K) is uniformly doped with acceptors to a concentration \( N_A = 10^{18} \text{cm}^{-3} \). What is the concentration of holes in the valence band?

\[ P = N_A = 10^{18} \text{cm}^{-3} \]

3. The silicon in the question above is now compensation doped with donors \( N_D = 2 \times 10^{17} \text{cm}^{-3} \). What is the new concentration of holes?

\[ P = N_A - N_D = 10^{18} \text{cm}^{-3} - 2 \times 10^{17} \text{cm}^{-3} \]

\[ = 8 \times 10^{17} \text{cm}^{-3} \]
4. A wafer of silicon at $T = 300$ K has a free electron concentration of $n = 1 \times 10^{17}$ cm$^{-3}$. What is the hole concentration?

$$p = \frac{n^2}{n} = \frac{10^{20} \text{ cm}^{-6}}{10^{17} \text{ cm}^{-3}} = 10^3 \text{ cm}^{-3}$$

5. For the silicon above, calculate the energy of the Fermi level, $E_F$ relative to the intrinsic level, $E_i$.

$$n = 10^{17} \text{ cm}^{-3} = n_i \left( \frac{E_F - E_i}{kT} \right)$$

$$E_F - E_i = \frac{kT \ln \frac{10^{17}}{10^{10}}}{10^{10}} = 0.026 \ln 10^{7}$$

$$= 0.26 \times 1.61 = 0.26 + 0.15$$

$$\approx 0.41 \text{ eV}$$

6. A sample of GaAs is n-type doped with $N_D = 1 \times 10^{16}$ cm$^{-3}$. The electron mobility is $\mu_n = 8500$ cm$^2$/V-s. Calculate the electrical conductivity, $\sigma$.

$$\sigma = n \mu = 10^{16} \text{ cm}^{-3} \times 1.6 \times 10^{-19} \text{C} \times 8.5 \times 10^3 \text{ cm}^2/\text{V-s}$$

$$= 8.5 \times 10^9 \text{ S/cm}$$

$$\sigma = 14 \text{ S/cm}$$
7. A piece of silicon at room temperature (300K) is doped with donors to \( N_D = 10^{17} \text{ cm}^{-3} \). The sample is uniformly illuminated with a generation rate of EHPs: \( g_{\text{opt}} = 10^{22} \text{ cm}^{-3} \text{s}^{-1} \). (a) what is the excess carrier concentration \( p' \) (or \( n' \))? (b) what is the total concentration of electrons? (c) what is the total concentration of holes?

a) \( n' = p' = g_{\text{opt}} t n = 10^{22} \text{ cm}^{-3} \text{s}^{-1} \times 10^{-6} \text{ sec} = 10^{16} \text{ cm}^{-3} \)

b) \( n = n_o + n' = N_D + n' = 10^{17} \text{ cm}^{-3} + 10^{16} \text{ cm}^{-3} = 1.1 \times 10^{17} \text{ cm}^{-3} \)

c) \( p_o = \frac{n'}{N_D} = \frac{10^{22} \text{ cm}^{-6}}{10^{17}} = 10^3 \text{ cm}^{-3} \)

\( p = p_o + p' = 10^3 \text{ cm}^{-3} + 10^{16} \text{ cm}^{-3} = 10^{16} \text{ cm}^{-3} \)