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_BT = 0.0258 eV (0.026 eV), silicon has intrinsic concentration n_i = 1 (or 1.5) x 10^{10} cm^{-3}. and recombination lifetimes: τ_n, τ_p = 1 μsec.

Note permittivity of free space $\varepsilon_o = 8.85\times10^{-14}$ F/cm; magnitude of electron charge $q = 1.6\times10^{-19}$ Coul

VI. Equations:

$p_{op} = i\hbar d/dx$ $\quad$ $f_{FD}(E) = 1/[1 + \exp(E-E_F)/k_BT]$

22

$n = n_i\exp[(E_F-E_i)/k_BT]$. $\quad$ $p = n_i\exp[(E_i-E_F)/k_BT]$

$J_n = q\mu_n n\mathcal{E} + qD_n dn/dx$ $\quad$ $J_p = q\mu_p p\mathcal{E} - qD_p dp/dx$

$U_n = (n_p-n_{po})/\tau_n$ $\quad$ $U_p = (p_n-p_{no})/\tau_p$

$C = \varepsilon_s/W$ $\quad$ $D/\mu = k_BT/q$ $\quad$ $L = \sqrt{(D\tau)}$ $\quad$ $E = Q\,V$

$\partial p/\partial t = -1/q\ \partial J_p/\partial x - p'/\tau_p$ $\quad$ $\partial n/\partial t = -1/q\ \partial J_n/\partial x - n'/\tau_n$

$\partial p/\partial t = D_p\ \partial^2 p/\partial x^2 - p'/\tau_p$ $\quad$ $\partial n/\partial t = D_n\ \partial^2 n/\partial x^2 - n'/\tau_n$

$p' = p - p_o = g_{opt}\tau_p$ $\quad$ $n' = n - n_o = g_{opt}\tau_n$

1. . An electron has a kinetic energy of 2 eV (electron volt). What is its energy in Joules? For full credit, show your work.

$J = C \times V$

$W = qV = 1.6 \times 10^{-19}$ Coul $\times 2V$

2

$2eV = 3.2 \times 10^{-19}$ Joule.

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

$p = N_A = 10^{18}$ cm^{-3}

2

3. . The silicon in the question above is now compensation doped with donors $N_D = 2x10^{17}$ cm^{-3}. What is the new concentration of holes?

$p = N_A - N_D = 10^{18}$ cm^{-3} $- 2 \times 10^{17}$ cm^{-3}

2

$= 8 \times 10^{17}$ cm^{-3}

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

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

2

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

$$n = 10^{17}\ cm^{-3} = n_i\, e^{(E_F - E_i)/kT}$$

4

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

$$7 \times 2.3 = 16.1$$

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

$$= 0.41\ eV$$

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

4

$$\sigma = nq\mu = 10^{16}\ cm^{-3} \times 1.6\times10^{-19}\ C \times 8.5\times10^3\ \frac{cm^2}{V\text{-}s}$$

$$= 8.5 \times 1.6\ S/cm$$

$$\sigma = 14\ S/cm$$

7. A piece of silicon at room temperature (300K) is doped with donors to $N_D = 10^{17}$ cm^{-3}. The sample is uniformly illuminated with a generation rate of EHPs: $g_{opt} = 10^{22}$ cm^{-3}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) $n' = p' = g_{opt}\tau_n = 10^{22}\ \text{cm}^{-3}\text{s}^{-1} \times 10^{-6}\ \text{sec}$

2 $= 10^{16}\ \text{cm}^{-3}$

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

2 $= 1.1 \times 10^{17}\ \text{cm}^{-3}$

c) $p_o = \frac{n_i^2}{N_D} = \frac{10^{20}\ \text{cm}^{-6}}{10^{17}} = 10^{3}\ \text{cm}^{-3}$

2

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

$= 10^{16}\ \text{cm}^{-3}$