# ECE 3040 Microelectronic Circuits

*Exam 1*

*February 7, 2002*

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Print your name clearly and largely: Solutions

**Instructions:**
Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back) as well as a calculator. There are 100 total points. Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I cannot read it, it will be considered a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

***First 25%*** **Multiple Choice and True/False (Circle the letter of the most correct answer)**

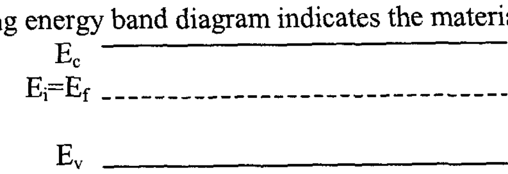
1.) (2-points) True or False: In equilibrium, an electric field can NOT exist, otherwise a current would have to flow.
2.) (2-points) True or False: A semiconductor has an energy bandgap greater than a metal and less than an insulator.
3.) (2-points) True or False: To obtain a p-type elemental group four semiconductor, you need to dope with an element group five of the periodic table.
4.) (2-points) True or False: In equilibrium, if the electron density is increased by doping, the hole density must also increase to maintain charge balance.
5.) (2-points) True or False: GaP (gallium phosphide with Ga being a group III element and P being from group V) is a binary compound semiconductor.

Select the **best** answer for 6-10:

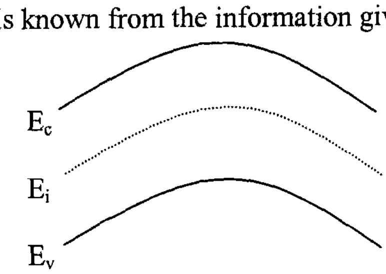
6.) (3-points) The probability that a state is UNOCCUPIED is given by:
   a.) The Fermi-Dirak integral of order 1/2
   b.) The fermi-distribution function
   c.) The density of states function
   d.) (1-f(E)) where f(E)=the fermi-distribution function

7.) (3-points) If a given state at energy $E=E_f$ has a density of states equal to 2e6 $cm^{-3}$ $eV^{-1}$, the then number of electrons occupying this state (within an energy range dE) is:
   a.) 1e6 $cm^{-3}$
   b.) 2e6 $cm^{-3}$
   c.) 1 $cm^{-3}$
   d.) 0.5 $cm^{-3}$
   e.) This question is not fair!

8.) (3-points) The following energy band diagram indicates the material is:
   a.) p-type
   b.) n-type
   c.) intrinsic
   d.) Silicon




9.) (3-points) For to the following band diagram, what is known from the information given:
   a.) The device is bent.
   b.) There is an electric field in this material
   c.) There is no current flow in this device
   d.) There is no diffusion current in this material.




10.) (3-points) In equilibrium:
   a.) The drift current is equal in magnitude and in the same direction as the diffusion current.
   b.) The drift current is equal in magnitude and opposite in direction as the diffusion current.
   c.) There is always no drift current.
   d.) There is always no diffusion current.

If you read over the previous tests on the web you are very happy right now because this is the same exact question as last semester.

***Second 25%*** Short Answer ("Plug and Chug"):

For the following problems (11-14) use the following material parameters:

$n_i$=5e9 cm$^{-3}$ $N_D$=6.1e16 cm$^{-3}$ donors $N_A$=6e12 cm$^{-3}$ acceptors.

Electron mobility, $\mu_n$ = 1600 cm$^2$/Vsec Hole mobility , $\mu_p$ = 480 cm$^2$/Vsec

Temperature=27 degrees C

11.) (10-points) Assuming total ionization, what is the electron and hole concentrations and is the material p or n-type?

$N_D >> N_A \quad N_D >> n_i$

$$\boxed{\begin{aligned} n_o &\approx N_D = 6.1e16 \ cm^{-3} \\ p_o &= \frac{n_i^2}{N_D} = \frac{(5e9)^2}{6.1e16} = 409.8 \ cm^{-3} \end{aligned}}$$

12.) (15-points) If 9 Volts is placed across a resistor with area 0.00456 cm$^2$ and 0.1cm length. What is the electron current density, and hole current density in the material?

| electrons | Holes |
|---|---|
| $\rho_n = \frac{1}{q\mu_n n}$ | $\rho_p = \frac{1}{q\mu_p p}$ |
| $= \frac{1}{(1.6e-19)1600(6.1e16)}$ | $= \frac{1}{(1.6e-19)480(409.8)}$ |
| $= 0.064 \ \Omega\text{-cm}$ | $= 3.18e13 \ \Omega\text{-cm}$ |

$J = \sigma E$

$E = \rho_n J_n$

$\frac{9V}{0.1cm} = (0.064 \ \Omega cm) J_n$

$\boxed{J_n = 1405 \ A/cm^2}$

$J_p = \frac{9V}{0.1cm}\left(\frac{1}{3.18e13}\right)$

$\boxed{J_p = 2.83 \ pA/cm^2}$

***Third 25%*** Problems (3rd 25%)

13.) (25-points total)

A semiconductor at room temperature (27 degrees C) has the following parameters:

Hole Diffusion coefficient, $D_p$=11.86 $cm^2$/Sec

Electron Diffusion coefficient, $D_n$=33.625 $cm^2$/Sec

$N_d$=1.07e15 $cm^{-3}$

Substrate intrinsic concentration, $n_i$=1e10 $cm^{-3}$

@ 27°C, $kT = 0.0259$ eV

The sample is initially held in a dark room (no illumination)

a.) (5 points) Assuming total ionization, what are the equilibrium electron and hole concentrations?

b.) (10 points) What are the total electron and hole concentration under an illumination level that that results in a quasi-fermi level for electrons ($F_N$) that is 0.318 eV above the intrinsic energy level and a quasi-fermi level for holes ($F_P$) that is 0.3 eV below the intrinsic energy level.

c.) (10 points) Is the material under illumination in "low-level injection" or "high-level injection". Concisely explain your answer.

a) $$\boxed{n_o = 1.07e15\ cm^{-3}} \quad (N_D >> N_A,\ N_D >> n_i)$$

$$\boxed{p_o = \frac{n_i^2}{N_D} = \frac{1e20}{1.07e15} = 9.3e4\ cm^{-3}}$$

b) $$F_N - E_i = 0.318\ eV$$

$$E_i - F_p = 0.3\ eV$$

$$n = n_i e^{(F_N - E_i)/kT} = 1e10\, e^{0.318/.0259}$$

$$\boxed{n = 2.15e15\ cm^{-3}}$$

$$p = n_i e^{(E_i - F_p)/kT} = 1e10\, e^{0.30/0.0259}$$

$$\boxed{p = 1.07\ e15\ cm^{-3}}$$

c) Is in High level injection (Not Low-level)

$n > n_o$ !

Pulling all the concepts together for a useful purpose: ($4^{th}$ 25%)

14.) (25-points)

Light is absorbed in a silicon wafer of thickness 500 um. The wafer is p-type and is uniformly doped with $10^{16}$ $cm^{-3}$ acceptors. The light has been on for a very long time and is absorbed throughout the material according to the function $G_L = G_{LO}e^{-\alpha x}$ $cm^{-3}/sec$ where the absorption coefficient, $\alpha$, is 1000 $cm^{-1}$. x=0 is the top surface of the wafer, x=500 μm is the back surface of the wafer. Determine the excess electron concentration in the wafer for all positions if the top surface of the wafer is maintained at an excess electron concentration of 2e14 $cm^{-3}$ while the back surface is kept at an excess electron concentration of 0 $cm^{-3}$?

$\Delta n$

$\frac{\partial \Delta n}{\partial t} = 0$

$\frac{\partial^2 \Delta n}{\partial x^2} \neq 0$

In Class $\tau = \infty$, $G_{Lo} = 1e21 \frac{cm^{-3}}{sec}$ $D_n = 10\,cm^2/sec$

additional Information

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} - \frac{\Delta n_p}{\tau_n}$ General Solution is: $\Delta n_p(x) = Ae^{-x/L_n} + Be^{+x/L_n}$

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} - \frac{\Delta n_p}{\tau_n} + G_L$ General Solution is: $\Delta n_p(x) = Ae^{-x/L_n} + Be^{+x/L_n} + G_L\tau_n$

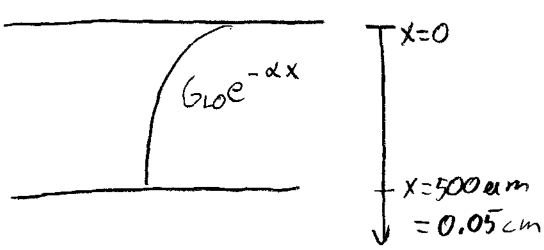
Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2}$ General Solution is: $\Delta n_p(x) = A + Bx$

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} + G_L$ General Solution is: $\Delta n_p(x) = Ax^2 + Bx + C$

Given: $0 = D_n \frac{d^2 \Delta n_p}{dx^2} + G_{LO}f(x)$ General Solution is: $\Delta n_p(x) = \left[\frac{G_{LO}}{D_N}\iint f(x)\,dx\,dx\right] + Bx + C$

Given: $\frac{d\Delta n_p}{dt} = -\frac{\Delta n_p}{\tau_n}$ General Solution is: $\Delta n_p(t) = \Delta n_p(t=0)e^{-t/\tau_n}$

Given: $0 = -\frac{\Delta n_p}{\tau_n} + G_L$ General Solution is: $\Delta n_p = G_L\tau_n$




$\alpha = 1000\ cm^{-1}$

$$\cancel{\frac{\partial \Delta n}{\partial x}}^{0} = D_N \frac{\partial^2 \Delta n}{\partial x^2} - \cancel{\frac{\Delta n}{\tau_n}}^{0} + G_{Lo}e^{-\alpha x}$$

$$\frac{\partial^2 \Delta n}{\partial x^2} = -\frac{G_{Lo}}{D_N}e^{-\alpha x}$$

$$\frac{\partial \Delta n}{\partial x} = +\frac{G_{Lo}}{D_N \alpha}e^{-\alpha x} + B$$

$$\Delta n(x) = Bx + C - \frac{G_{Lo}}{D_n \alpha^2}e^{-\alpha x}$$

Extra work can be done here, but clearly indicate which problem you are solving.

$$\Delta n(x=0) = 2e14\ cm^{-3}$$

$$2e14\ cm^{-3} = C - \frac{G_{L0}}{D_n \alpha^2}$$

$$2e14 = C - \frac{1e21}{10\,(1000)^2}$$

$$\underline{C = 3e14\ cm^{-3}}$$

$$\Delta n(x=0.05\ cm) = 0$$

$$0 = B(0.05) + 3e14 - \frac{1e21}{10\,(1000)^2}\, e^{-1000(0.05)}$$

$$-B(0.05) = \underline{3e14} - \cancel{1.93e{-8}} \rightarrow \sim 0$$

$$B = -6e15\ cm^{-3}$$

$$\boxed{\Delta n(x) = 3e14 - 6e15x - 1e14\, e^{-1000x}\ cm^{-3}}$$

<u>Note</u>: Due to $\tau_n = \infty$, Generation profile has little effect on $\Delta n(x)$ profile. for $x > 3\ um$ this term is negligible.