ECE 3040 Microelectronic Circuits

Exam 1

September 23, 2019

Dr. W. Alan Doolittle

Print your name clearly and largely: Solutions

Instructions:
DO NOT REMOVE ANY SHEETS FROM THIS EXAM! Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 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. ***Turn in your notes sheet placed under your exam.*** Report any and all ethics violations to the instructor. A periodic table is supplied on the last page. 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 30% Multiple Choice and True/False
(Circle the letter of the most correct _answer or answers_)

1.) (1-points): What is your best Ga Tech or Technology focused pickup line?

2.) (2-points) True or [✓ False:] All other things considered equal, the energy bandgap is generally larger in semiconductors made from large atoms that are spaced far apart.

3.) (2-points) [✓ True] or False: The diffusion coefficient describes a materials relative ease of motion for electrical carriers to diffuse from a region of high concentration to a region of low concentration.

4.) (2-points) [✓ True] or False: According to the density of states function, there will never be an electron occupying the energy exactly at the conduction band edge.

5.) (2-points) [✓ True] or False: One reason we care about the crystal structure is it allows us to calculate the atomic density and thus an upper limit of the electron density possible in a material.

6.) (2-points) True or [✓ False:] The Schottky-Read-Hall minority carrier lifetime describes the average time that an electron-hole pair will exist before it recombines directly across the bandgap.

7.) (2-points) [✓ True] or False: The Fermi-probability distribution function describes the probability a state (should it exist at all) at energy E is occupied.

8.) (2-points) True or [✓ False:] The Fermi-probability distribution can be approximated by the ~~Fermi-Dirac Integral of order ½~~ Boltzman distribution function if E>3kT.

9.) (2-points) True or [✓ False:] At absolute zero Kelvin, a semiconductor will have exactly ½ its carriers that it has at room temperature.

10.)(2-points) True or [✓ False:] Since the absorption coefficient has units of (1/cm) large absorption is described mathematically by a small absorption coefficient.

11.)(2-points) [✓ True] or False: Thermal generation is responsible for creating the carriers mathematically described by the intrinsic concentration.

12.)(2-points) True or [✓ False:] For a semiconductor to be in thermal equilibrium, it cannot have a drift current (i.e. a current driven by an electric field).

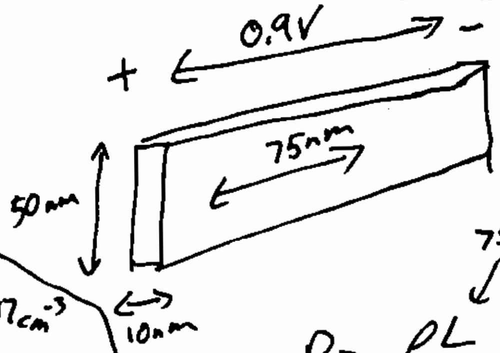
13.)(2-points) [✓ True] or [✓ False:] A hole is a professor who makes so many true false questions ☺ .

Short Answer ("Plug and Chug"):

For the following problem use the following material parameters and <u>assuming total ionization</u>:

For InP:
n_i=1.3e7 cm^{-3} N_D=1.8e13 cm^{-3} donors N_A=1.6e17 cm^{-3} acceptors
$m_p^*=0.6m_o$ $m_n^*=0.08m_o$
E_G=1.344 eV Electron mobility, μ_n = 900 cm^2/Vsec Hole mobility , μ_p = 120 cm^2/V-sec
Temperature=27 degrees C

14.)(10-points) A new device called a finFET has a rectangular shape 10 nm (1 nm = 1e-9 m) wide, 50 nm tall and 75 nm in length. It can be considered a semiconductor resistor and is made from the semiconductor above biased on two longest opposing sides (longest dimension) with 0.9 volts. Determine <u>both</u> the electron and hole <u>currents</u> flowing in the device.



$$\rho_p = \frac{1}{q\,\underset{120\,cm^2/V\text{-}sec}{\underset{\uparrow}{\mu_p}}\,\underset{\sim N_A = 1.6e17\,cm^{-3}}{\underset{\uparrow}{p}}}$$

$$\rho_n = \frac{1}{q\,\underset{900\,cm^2/V\text{-}sec}{\underset{\uparrow}{\mu_n}}\,n} \quad n \rightarrow \sim \frac{n_i^2}{N_A} \downarrow 1.06e\text{-}3\ cm^{-3}$$

$$R = \frac{\rho \overset{75\times10^{-7}\,cm}{\overset{\downarrow}{L}}}{\underset{[(50\times10^{-7}\,cm)\times(10\times10^{-7}\,cm)]}{\underset{\uparrow}{A}}}$$

$\rho_p = 0.325\,\Omega\text{-}cm$

$\rho_n = 6.57e18\,\Omega\text{-}cm$

$R_p = 488{,}281\,\Omega$ $R_n = 9.86e24\,\Omega$

$$I = \frac{V \rightarrow 0.9}{R}$$

$$\boxed{I_p = 1.84\,\mu A}$$

$$\boxed{\begin{array}{l} I_n = 9.1e\text{-}26\ A \\ \text{Not Measurable!} \end{array}}$$

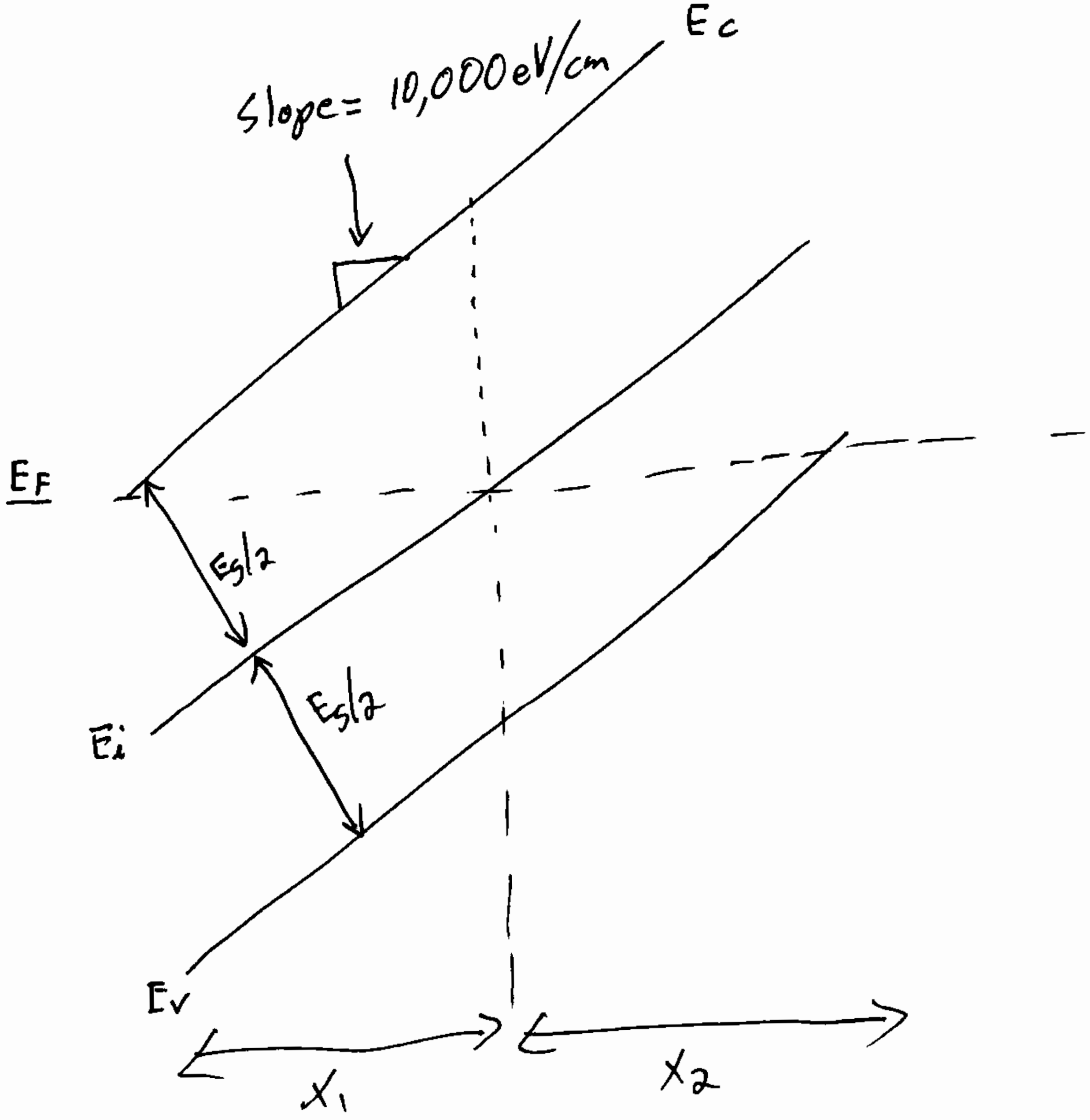
Section 3 (more short answer)

15.) (15-points total) Draw a semiconductor energy band diagram showing E_c, E_v, E_f, and E_i that satisfies ALL of the following characteristics:

A.) 10,000 V/cm built in electric field that is constant throughout its length.

B.) The semiconductor has an equal effective mass for electrons and holes.

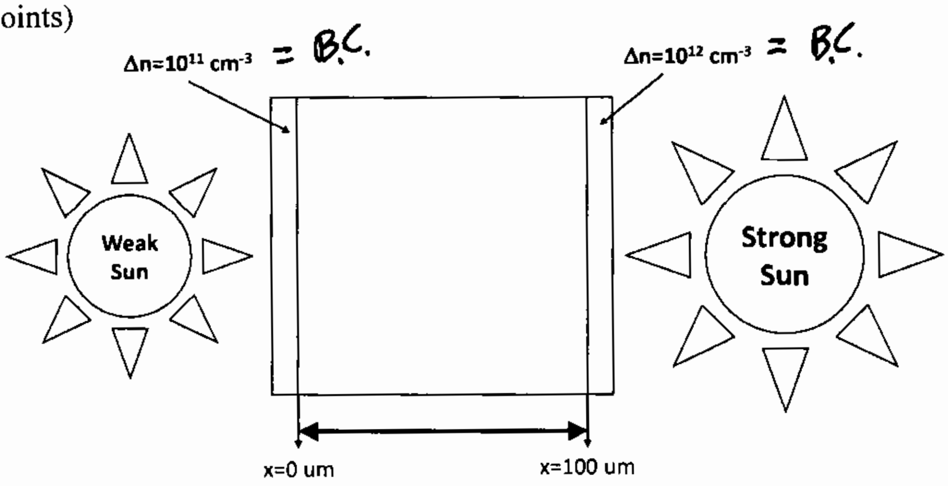
C.) The material is in equilibrium with half it's length being p-type and half its length being n-type.



$X_1 = X_2$

Pulling all the concepts together for a useful purpose:

16.) (50-points)



A 100 um long slab of semiconductor is to be used as part of a solar cell used in a solar system with two suns, one weaker than the other. Each sun's sunlight is very high energy and is all absorbed in regions x<0 for the weak sun and x>100 um for the strong sun. Since the last time a democratic politician ran without offering free stuff to bribe voters (a very long time – probably since President John Kennedy but we will assume infinity), excess minority carriers have been injected at x=0 and x=100 um such that the excess carrier concentration for x<0 is 1×10^{11} cm^{-3} and for x>100 um is 1×10^{12} cm^{-3}. The semiconductor is doped p-type with an acceptor concentration of 1e15 cm^{-3}, has an intrinsic concentration of 1e10 cm^{-3} and has a minority carrier lifetime that we will consider as infinite. If the semiconductor is held at room temperature (27 degrees C), determine the minority carrier diffusion current density at all positions in the semiconductor $(0 \geq x \underset{\leq}{\cancel{\geq}} 100$ um). Assume a minority carrier mobility of 100 cm²/Vsec.

Steady State

$\tau_n = \infty$

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

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

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

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: $\Delta n_p(x) = \left[-\frac{G_{LO}}{D_N}\iint f(x)dx^2\right] + Bx + C$

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

$$D_n = \mu_n \frac{kT}{q}$$
$$= (100\,\text{cm}^2/\text{V-sec})(0.0259)$$
$$= 2.59\,\text{cm}^2/\text{sec}$$

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

General Solution is: $\Delta n_p = G_L \tau_n$

$$\Delta n(x) = A + Bx$$

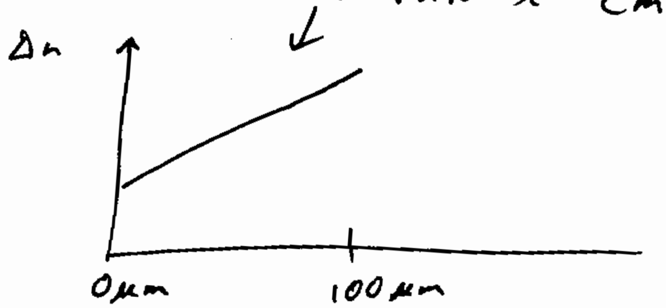
B.C. 1: $\Delta n(x=0) = 10^{11}\,cm^{-3} = A$

B.C. 2: $\Delta n(x=100\,\mu m) = 10^{12}\,cm^{-3} = 10^{11} + B(100e\text{-}4cm$

$$B = 9\,e13\ cm^{-3}$$

~~$\Delta n(x) = 10^{11} +$ [illegible]~~

$$\Delta n(x) = 10^{11} + 9\times10^{13}x \quad cm^{-3}$$



$$J_n = q D_n \nabla n$$

$$J_n = q \underset{\substack{\uparrow \\ 2.59\ cm^2/sec}}{D_n} (9\times10^{13}) \quad A/cm^2$$

$$\boxed{J_n = 37.3\ \mu A}$$