ECE 3040 Microelectronic Circuits

Exam 1

September 30, 2015

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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 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. 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 33%* Multiple Choice and True/False**
(Circle the letter of the most correct *answer or answers*)

1.) (3-points) True or False: Valence electrons hold the crystal together and do not directly participate in conduction of electricity.
2.) (3-points) True or False: A high mobility (due to less frequent collisions with atoms) results from a low atomic density.
3.) (3-points) True or False: States that lie far below the fermi-energy are most likely filled.
4.) (3-points) True or False: $Al_{0.1}In_{0.50}Ga_{0.40}N_{0.3}P_{0.4}As_{0.3}$ is not a valid semiconductor formula in standard semiconductor notation because it has too many atoms.
5.) (3-points) True or False: The probability of a hole existing in a state is mathematically described by one minus the fermi-distribution function evaluated at the energy of that state.
6.) (3-points) True or False: The density of states describes the likelihood of a state being occupied.
7.) (3-points) True or False: The fermi-energy can never be found inside the conduction band.

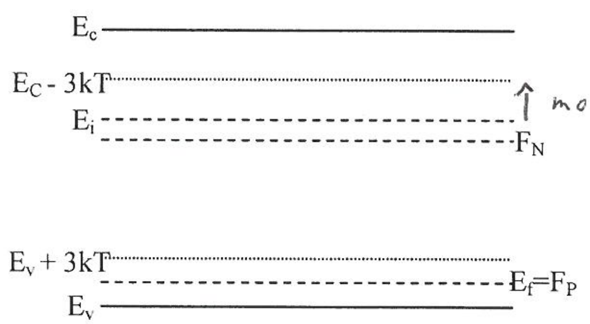
Select the **best** answer or answer**s** for 8-10:

8.) (4-points) Which of the following are true about diffusion currents ...
- a.) ... the equal the drift current in equilibrium
- b.) ... they are driven by electric field
- c.) ...they only happen when there is an imbalance (gradient) in carrier concentration
- d.) ... they are the smaller of the three types of current flow
- e.) ... they always balance (negate) the drift velocity

9.) (4-points) Which of the following are true about partial ionization.
- a.) You rarely need to be concerned with this since impurities are always totally ionized
- b.) The degeneracy factor for donors results from two electrons having the same momentum
- c.) The degeneracy factor for donors results from two electrons having the same spin (quantum numbers)
- d.) The further the ionization energy is toward the center of the bandgap, the higher the ionization probability
- e.) The degeneracy factor for acceptors is larger than that for donors because there are more valance bands than conduction bands

10.)(4-points) The following energy band diagram indicates the material is:
- a.) In equilibrium
- b.) Degenerate and n-type
- c.) Degenerate and p-type
- d.) Non-degenerate n-type
- e.) Non-degenerate p-type
- f.) In low level injection
- g.) In high level injection
- h.) $m_n^* > m_p^*$
- i.) $m_n^* < m_p^*$
- j.) In steady state

add before printing final copy → ~~k.) In Steady State~~



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$$E_i = \frac{E_g}{2} + \frac{3}{4}kT \ln\left(\frac{m_p^*}{m_n}\right)$$

$\Rightarrow m_p^* > m_n^*$

Second 17% Short Answer ("Plug and Chug"):
For the following problems (11-12) use the following material parameters and <u>assuming total ionization</u>:

For InP:
n_i=1.3e7 cm^{-3} N_D=1e15 cm^{-3} donors N_A=2e15 cm^{-3} acceptors $m_p^*=0.6m_o$ $m_n^*=0.08m_o$
E_G=1.344 eV Electron mobility, μ_n = 5000 cm^2/Vsec Hole mobility , μ_p = 150 cm^2/V-sec
Temperature=27 degrees C

11.)(7-points) Where is the fermi energy (relative to the valence band which is referenced to zero energy)?

$$p = \frac{N_A - N_D}{2} + \sqrt{\frac{(N_A-N_D)^2}{4} + n_i^2} = 1e15\ cm^{-3} \qquad n = \frac{n_i^2}{p} = \frac{(1.3e7)^2}{1e15} = 0.169\ cm^{-3}$$

$$E_i = \frac{E_g}{2} + \frac{3}{4}kT\ln\left(\frac{m_p^*}{m_n^*}\right) = 0.711eV$$

Several possible approaches

1) $p = 1e15 = 1.3e7\, e^{(E_i - E_f)/kT}$ **$E_f = 0.241eV$**

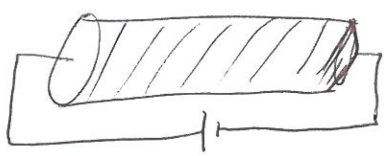
2) $n = 0.169 = 1.3e7\, e^{(E_f - E_i)/kT}$ **$E_f = 0.241eV$**

3) $N_c = 2.51\times10^{19}\left(\frac{m_n^*}{m_o}\right)^{3/2} = 5.679e17\ cm^{-3}$
$0.169 = n = N_c\, e^{(E_f - E_c)/kT}$ **$E_f = 0.239eV$**

4) $N_v = 2.59\times10^{19}\left(\frac{m_p^*}{m_o}\right)^{3/2}$
$1e15 = p = N_v\, e^{(E_v - E_f)/kT}$ **$E_f = 0.243eV$**

12.) (10-points) A 10 um ***<u>diameter</u>*** x 500 um long cylindrical semiconductor resistor is made from the semiconductor from problem 11. It is biased on two opposing sides (longest dimension) with 1.5 volt battery. Determine <u>both</u> the electron and hole <u>current</u> flowing in the device.

$A = \pi(5\times10^{-4}\,cm)^2 = 7.854e\text{-}7\ cm^2$
$L = 500\times10^{-4}\ cm$



$$\rho = \frac{1}{q(\mu_n n + \mu_p p)} \qquad R = \frac{\rho L}{A}$$

$\rho_n = \frac{1}{q\mu_n n}$ $\rho_p = \frac{1}{q\mu_p p} = 41.66\ \Omega\text{-cm}$
$\rho_n = 7.4e15\ \Omega\text{-cm}$

$$R_n = \frac{\rho_n L}{A} = 4.71e20\ \Omega$$
massive

$$R_p = \frac{\rho_p L}{A} = \frac{(41.66)(5\times10^{-2})}{7.854e\text{-}7}$$
$R_p = 2.65e6\ \Omega$

$I_n = \frac{V}{R_n} = 3.2e\text{-}21A$ ← practically zero!

$I_p = \frac{V}{R_p} = 0.565\ \mu A$

Section 3 (more short answer)

13.)(10-points total) The material in problems 11 and 12 is exposed to the sun's light (like in a solar cell) that generates 2e16 cm^{-3} extra minority carriers.

a) (2 points) Is this low level or high level injection?

$\Delta p = 2 \times 10^{16} > 1e15$ so High Level

↑ po

b) (8 points) Draw the 1 dimensional energy band diagram showing the placement of both the quasi-fermi levels (numeric answer) relative to E_i, E_c, and E_v.

$n = 0.169 + 2e16$

$n = 2e16$

$n = 1.3e7\, e^{(F_n - E_i)/kT}$ (n_i)

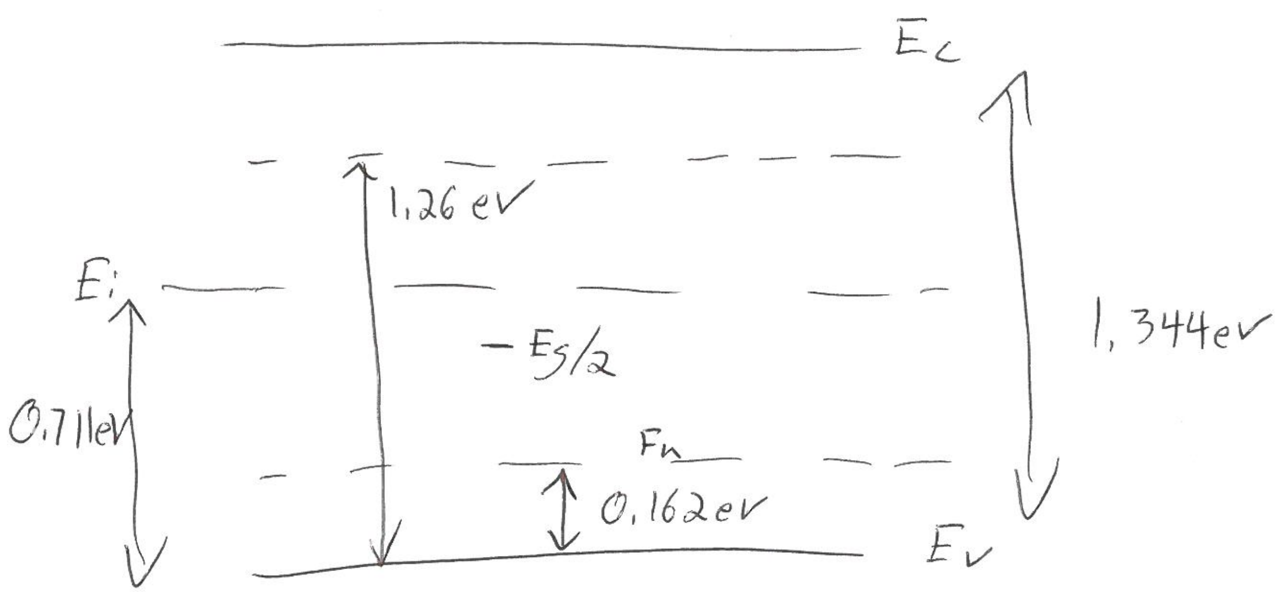
$F_n = 1.26\,eV$

$p = 1e15 + 2e16$ (p_o, Δp)

$p = 2.1e16$

$p = 1.3e7\, e^{(E_i - F_p)/kT}$ (n_i)

$F_p = 0.162\,eV$

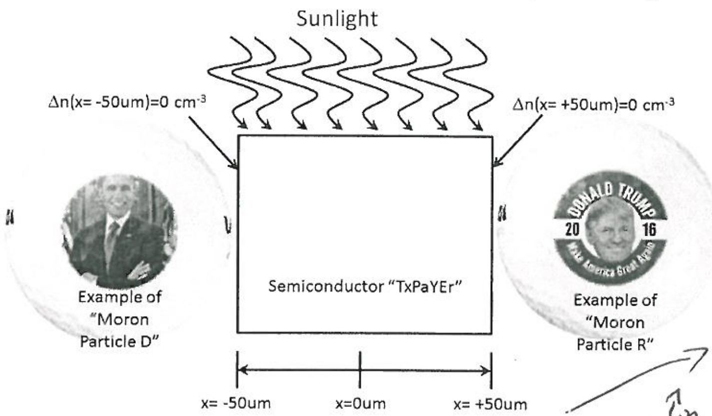


Pulling all the concepts together for a useful purpose:

14.) (40-points)

(Humor intended to Diffuse Test Tension. Apologies if the choice of "morons" offends.)

The world is made up of 4 types of particles; tiny electrons, protons, neutrons and gigantic morons. Morons are particles only found in government and have the ability to completely consume every other particle (electrons in this case). A 100 um length of a semiconductor named "TxPaYEr" has been constantly stuck between democrat morons and republican morons since February 3, 1913 when the 16th amendment was passed. The semiconductor is to be used in the presence of sunlight. The semiconductor is doped p-type with an acceptor concentration of 1e17 cm^{-3} and has a minority carrier lifetime of 10 microseconds. The sunlight is absorbed uniformly in the semiconductor generating an excess minority carrier concentration rate of 10^{20} cm^{-3}/sec. At both ends of the semiconductor (at +50 and -50 um), the democrat and republican morons act to steal minority carriers from the semiconductor "TxPaYEr" resulting in the excess electron concentration being zero at the semiconductor boundaries, $\Delta n(x= +50)=\Delta n(x= -50)=0cm^{-3}$. If the semiconductor is held at room temperature (27 degrees C), determine the minority carrier diffusion current density at all positions in the semiconductor (-50 um ≥ x ≥ 50 um). Assume a minority carrier mobility of 200 cm^2/Vsec and the intrinsic concentration is 1e14cm^{-3}.



BC Given!, easy

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

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: $\Delta n_p = G_L \tau_n$

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

$D_n = \mu_n\left(\frac{kT}{q}\right) = 5.18\ cm^2/sec$ $L_n = \sqrt{D_n \tau_n} = \sqrt{5.18(100e-6)} = 227.6\ \mu m$ $G_L \tau_n = (10^{20})(100e-6) = 1e16\ cm^{-3}$

BC:

1) $\Delta n(x=-50\mu m) = 0 = Ae^{50/227.6} + Be^{-50/227.6} + 1e16$

2) $\Delta n(x=+50\mu m) = 0 = Ae^{-50/227.6} + Be^{+50/227.6} + 1e16$

Setting 1) = 2)

$$Ae^{50/227.6} + Be^{-50/227} = Ae^{-50/227.6} + Be^{50/227.6}$$

$$A(e^{50/227.6} - e^{-50/227.6}) = B(e^{50/227.6} - e^{-50/227.6})$$

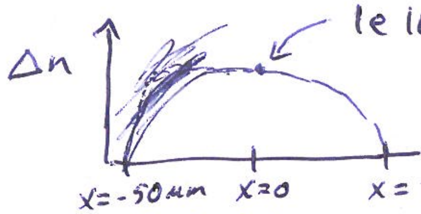
subing into 1) $A = B$

$$0 = A(e^{50/227.6} + e^{-50/227.6}) + 1e16$$

$$A = B = -4.88e15\ cm^{-3}$$

$$\boxed{\Delta n(x) = -4.88e15\left[e^{-x/227.6\mu m} + e^{+x/227.6}\right] + 1e16\ cm^{-3}}$$

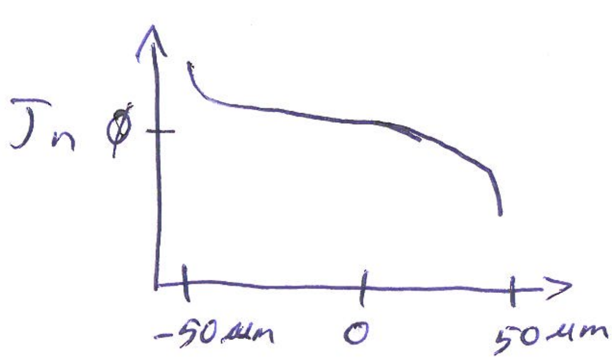
$1e16 - 2(4.88e15) = 2.4e14\ cm^{-3}$



Note: μm to cm conversion when taking derivative

$$J_n = q D_n \frac{\partial \Delta n(x)}{\partial x}$$

$$\boxed{J_n = 0.177\left[e^{-x/227.6} - e^{x/227.6}\right]\ A/cm^2}$$



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