ECE 3040 Microelectronic Circuits

Exam 1

February 20, 2006

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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:

4:50
5:15 ⇒ 25 minutes

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

1.) (3-points) True or False: MBE and MOCVD are tools used to create semiconductors that have variable bandgaps.
2.) (3-points) True or False: All other things being equal, a semiconductor with a small electron effective mass will have a larger mobility than one with a large effective mass.
3.) (3-points) True or False: To calculate the density of states for a degenerate semiconductor requires the use of fermi-dirac distribution functions.
4.) (3-points) True or False: An indirect bandgap material (such as Germanium and Silicon) is extremely efficient as a light absorber for solar cells and photodiodes.
5.) (3-points) True or False: Light of wavelength of 1 um will be transparent to a semiconductor with a bandgap of 2 eV.
6.) (3-points) True or False: When a semiconductor is heated it expands. Based on the theory of bandgap dependence on the interatomic spacing, the bandgap of the semiconductor will increase with increasing temperature.
7.) (3-points) True or False: The total ionization assumption always predicts fewer free carriers than the partial ionization assumption.

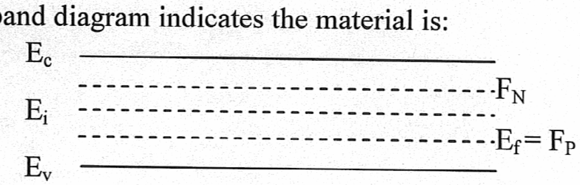
Select the **best** answer or answers for 6-10:

8.) (4-points) A "new" semiconductor consists of fictitious group III elements Cl, Em, So and group V elements Ns, Uc and Ks. If the composition of Cl is 7 times So and Em is 2 times So and equal → the material has amounts of Ns, Uc and Ks, to within 1%, what is the correct reduced semiconductor notation for this remarkable compound?
a.) ClEmSoNsUcKs
b.) $Cl_{0.333}Em_{0.333}So_{0.333}Ns_{0.333}Uc_{0.333}Ks_{0.333}$
c.) $Cl_{0.7}Em_{0.2}So_{0.1}Ns_{0.333}Uc_{0.333}Ks_{0.333}$
d.) $Cl_{0.35}Em_{0.1}So_{0.05}Ns_{0.165}Uc_{0.165}Ks_{0.165}$
e.) The correct answer is not given as a choice. The correct answer is ______________.

9.) (4-points) A face centered cubic metal has a lattice constant of 5 angstroms. Assuming one electron is contributed per atom, what is the electron density in the metal?
a.) 1.6×10^{22} cm^{-3}
b.) 8×10^{21} cm^{-3}
c.) 3.2×10^{22} cm^{-3}
d.) 2.4×10^{22} cm^{-3}
e.) Is Clemson accepting applications?

$(6\times 1/2)+(8\times 1/8)=4$ atoms / cube
Volume $(5\times10^{-8}\,cm)^3$
$\Rightarrow \dfrac{4}{(5\times10^{-8})^3} = 3.2\times10^{22}\,cm^{-3}$

10.)(4-points) The following energy band diagram indicates the material is:
a.) n-type
b.) In equilibrium
c.) intrinsic
d.) p-type
e.) In low level injection



Second 27% Short Answer ("Plug and Chug"):
For the following problems (11-12) use the following material parameters:

n_i=1e-14 cm^{-3} N_A=1e18 cm^{-3} acceptors m_p^*=1.2m_o m_n^*=0.2m_o
Acceptor Binding Energy=0.16 eV E_G=3.4 eV Valence band degeneracy factor, g_A=4
Electron mobility, μ_n = 900 cm^2/Vsec Hole mobility , μ_p = 10 cm^2/Vsec
Temperature= 27 degrees C

11.)(10-points) If the fermi level is located at Ev+0.1eV, what is the ionized impurity concentration?

$$N_A^- = \frac{N_A}{1+g_A e^{(E_A-E_f)/kT}} \doteq \frac{1e18\ cm^{-3}}{1+4e^{(0.16-0.1)/0.0259}}$$

$$N_A^- = 2.4\times10^{16}\ cm^{-3}$$

12.) (17-points) What is conductivity of the semiconductor?

$$N_c = 2.51\times10^{19}\left(\frac{m_n^*}{m_o}\right)^{3/2} cm^{-3} \quad @\ 27°C\ (300k)$$

$$N_v = 2.51\times10^{19}\left(\frac{m_p^*}{m_o}\right)^{3/2} cm^{-3}$$

$$N_c = 2.25\times10^{18}\ cm^{-3} \qquad N_v = 3.299\times10^{19}\ cm^{-3}$$

$$p = N_v e^{(E_v-E_f)/kT} = 3.299e^{(-0.1/0.0259)} = 6.944\times10^{17}\ cm^{-3}$$

$$n = N_c e^{(E_f-E_c)/kT} = 2.25\times10^{18} e^{(0.1-3.4)/0.0259}$$

$$= 1e-37\ cm^{-3}$$

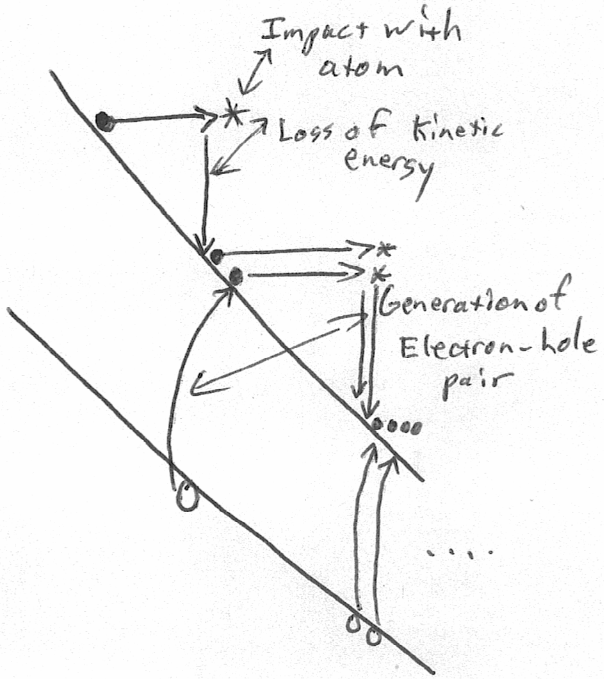
$$\sigma = q(\mu_n n + \mu_p p) \cong q\mu_p p = 1.6\times10^{-19}(10)\,6.944\times10^{17} cm^{-3}$$

$$\boxed{\sigma = 1.11 \quad \left[\frac{1}{\Omega\text{-cm}}\right]}$$

Note: since $p-N_A^- \neq N_D^+-n$, this can not be the correct fermi-level value but is good enough for this problem.

Third 25% Problems (3^{rd} 10%)

13.) (10-points total) Draw the energy band diagram of a semiconductor undergoing impact ionization showing the process of electron multiplication. You may either show electron multiplication in one diagram or show the time evolution of the process in multiple diagrams. Points will be deducted for unclear answers.



$$\frac{\partial^2(\Delta n_p)}{\partial x^2} = 0$$

Pulling all the concepts together for a useful purpose: (4th 30%)

14.) (30-points)
When the dinosaurs walked the planet, they turned on a light onto a 500 μm thick InP semiconductor held at room temperature (27 degrees C). The light uniformly generates 10^{20} additional holes per cm^3 per second. At a time, we will call t=0, a Clemson student trips on the power cord and the light is shut off. Determine the excess electron concentration in the InP for all positions at all times. Assume a minority carrier diffusion length of 0.1 μm and minority carrier diffusion coefficient at room temperature of 3.2 cm^2/sec.

$\Rightarrow G_L$

$\Delta n = \Delta p$

$$L_n = \sqrt{D_n \tau_n} = 0.1 = \sqrt{3.2\,\tau}$$

$$\tau = 3.125\,mS$$

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

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

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

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

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

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

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

For $t<0$:

$$\cancel{\frac{\partial(\Delta n_p)}{\partial t}} = D_N \cancel{\frac{\partial^2(\Delta n_p)}{\partial x^2}} - \frac{\Delta n_p}{\tau_n} + G_L$$

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

$$\Delta n_p = G_L \tau_n = (10^{20}\,cm^{-3}/s)(3.125\,mS)$$

$$\boxed{\Delta n_p = 3.125 \times 10^{17}\,cm^{-3}}$$

For $t>0$:

$$\frac{\partial(\Delta n_p)}{\partial t} = D_N \cancel{\frac{\partial^2(\Delta n_p)}{\partial x^2}}^{\,0} - \frac{\Delta n_p}{\tau_n} + \cancel{G_L}^{\,0}$$

$$\Delta n_p(t) = \Delta n_p(t=0)\,e^{-t/\tau_n}$$

$$\boxed{\Delta n_p(t) = 3.125 \times 10^{17}\, e^{-t/(3.125\times10^{-3})}\ cm^{-3}}$$