ECE 3040B Microelectronic Circuits

Exam 1

September 20, 2001

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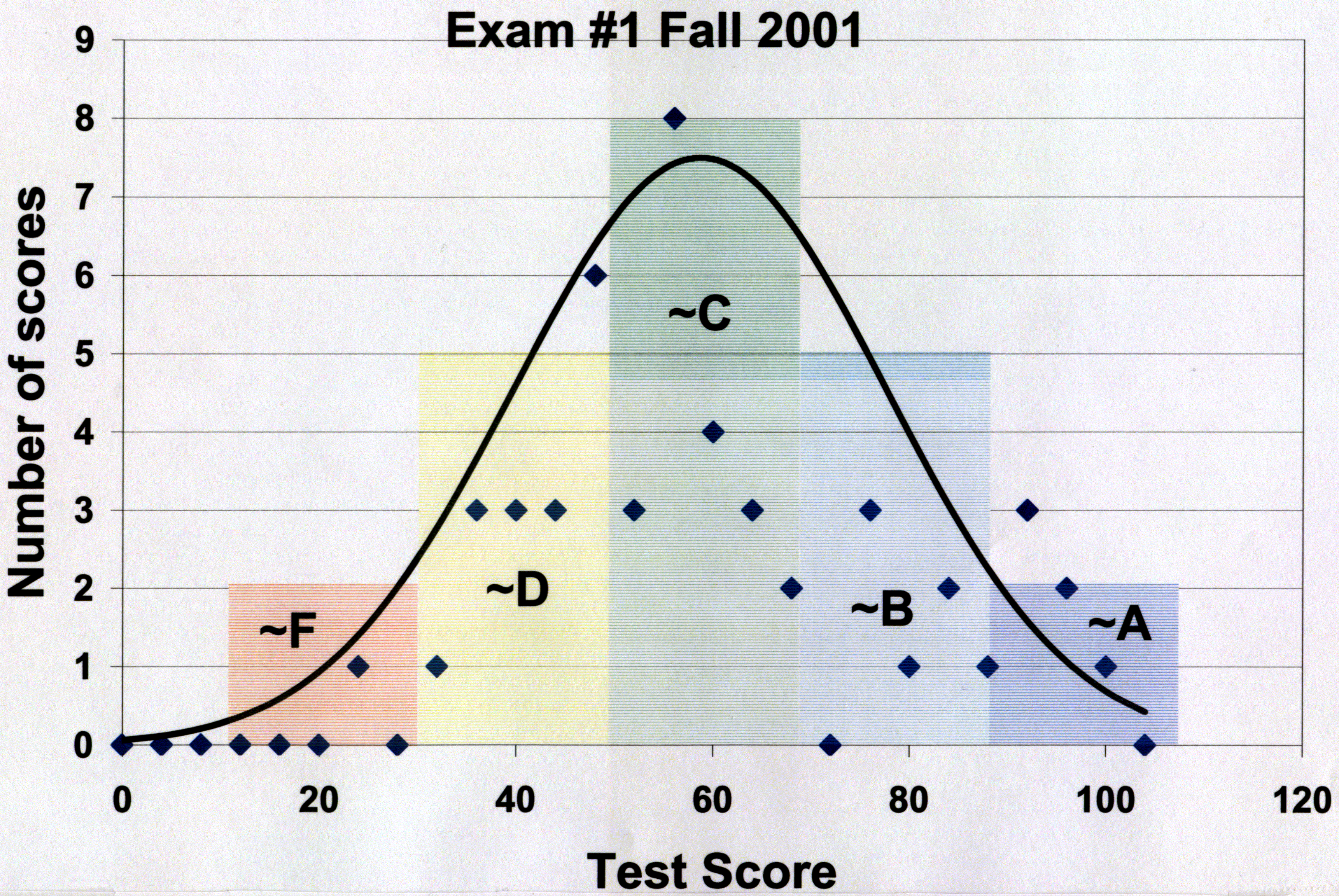
Print your name clearly and largely: Solutions

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 in this exam plus 5 point bonus. 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:



Class Totals	Problem # ==>	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14	#15	#16	#17	Bonus	Bonus
Number of Tests=	50																			
Point Value of problem=		2	2	2	2	2	3	3	3	3	3	5	5	5	5	5	25	25	5	5
Individual Problem Average=		84.0	96.0	94.0	90.0	98.0	62.0	68.0	96.0	64.0	86.0	95.6	80.4	87.6	65.6	70.4	50.6	44.7	8.0	0.0
Exam Average=	58.6																			
Exam Standard Deviation=	18.9																			
Exam Max=	100.0																			
Exam Min=	22.0																			

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

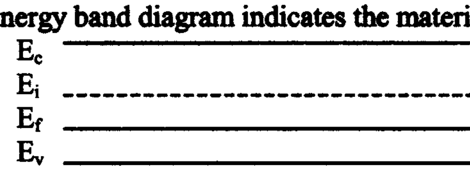
1.) (2-points) True or False: Drift current results from movement of electrons and holes in response to and applied electric field.
2.) (2-points) True or False: The unit of kT is energy and can be expressed in electron volt (eV) or joules (J).
3.) (2-points) True or False: If Magnesium (Mg is group 2 element) is used to dope GaN (Ga is group 3, N is group 5), a p-type semiconductor will result if the Mg replaces a Ga atom.
4.) (2-points) True or False: A n-type Silicon semiconductor has more electrons than holes AND has more holes than an intrinsic silicon semiconductor.
5.) (2-points) True or False: Silicon is a compound semiconductor.

Select the <u>best</u> answer for 6-10:

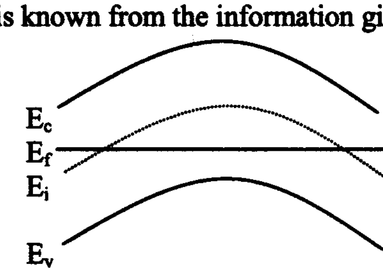
6.) (3-points) Given Si, C and Ge are all from group 4, which of the following semiconductors is a valid semiconductor representation of a ternary compound semiconductor?
  a.) Si
  b.) $Ge_{0.5}C_{0.5}$
  c.) $Si_{0.25}Ge_{0.35}C_{0.40}$
  d.) $Si_3Ge_3C_4$

7.) (3-points) The valence band...
  a.) ...is mostly filled with electrons.
  b.) ...is mostly empty.
  c.) ...is higher in energy than the conduction band.
  d.) ...is above the fermi energy in a degenerately doped semiconductor.

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 no 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.
  e.) I hear Wal-Mart™ is hiring sales clerks – that could be my new career.

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

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

n_i=1e16 cm^{-3} N_D=1.1e16 cm^{-3} donors N_A=2e16 cm^{-3} acceptors.

Effective density of states in the conduction band is N_C=1e19 cm^{-3}

Effective density of states in the valence band is N_V=2e19 cm^{-3}

Electron mobility, μ_n = 800 cm^2/Vsec Hole mobility, μ_p = 200 cm^2/Vsec

Temperature=27 degrees C

11.)(5-points) Assuming total ionization, what is the electron and hole concentrations and is the material p or n-type?

$N_A > N_D$

$$p = \frac{N_A - N_D}{2} + \sqrt{\left(\frac{N_A - N_D}{2}\right)^2 + n_i^2}$$

$$= \frac{2e16 - 1.1e16}{2} + \sqrt{\left(\frac{2e16 - 1.1e16}{2}\right)^2 + 1e16^2}$$

$$\boxed{p = 1.54e16\ cm^{-3}} \longrightarrow \boxed{p > n \Rightarrow p\text{-type}}$$

$$n = \frac{n_i^2}{p} = \frac{(1e16)^2}{1.54e16} \Rightarrow \boxed{n = 6.46e15\ cm^{-3}}$$

12.)(5-points) What is E_f-E_v (where E_f is the fermi energy and E_v is the top of the valence band)?

$$p = N_V e^{(E_V - E_f)/kT}$$

$$E_V - E_f = kT \ln\left(\frac{p}{N_V}\right)$$

$$= 0.0259 \ln\left(\frac{1.54e16}{2e19}\right)$$

$$= -0.185\ eV$$

$$\boxed{E_f - E_V = 0.185\ eV}$$

13.)(5-points) What length of material is needed to make a resistor with resistance 1000 ohms using a cylinder with cross-sectional area 0.0001 cm^2.

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

$$= \frac{1}{q[(800)6.46e15 + (200)1.54e16]}$$

$$= 0.76\ \Omega\text{-cm}$$

$$R = \frac{\rho L}{A}$$

$$1000 = \frac{(0.76\ \Omega\text{-cm})L}{0.0001\ cm^2}$$

$$\boxed{L = 0.132\ cm \text{ or } 1320\ \mu m}$$

14.) (5-points) If 10~~,000~~ Volts is placed across the resistor in part 13, what are the electron current density, hole current density and the electron drift velocity? (If you found no answer in part 13, then use a resistor length of 1 cm in your calculation).

Note: No diffusion! $J_n = q\,(\mu_n E)\,n$ $\qquad J_p = q\,(\mu_p E)\,n$

$$v_d|_{electrons} = (800\ cm^2/Vsec)(75.757\ V/cm)$$

$$\boxed{v_d = 6.06 \times 10^4\ cm/sec}$$

$$E = \frac{10\ V}{0.132\ cm} = 75.757\ V/cm$$

$$J_n = (1.6e{-19})(800)(75.757)(6.46e15)$$

$$J_n = 62.6\ A/cm^2$$

$$J_p = (1.6e{-19})(200)(75.757)(1.54e16)$$

$$J_p = 37.3\ A/cm^2$$

15.) (5-points) A semiconductor is doped with 5e19 cm^{-3} very deep acceptors (large binding energy) which are only partially ionized at room temperature. If the fermi energy is 0.1eV above the valence band, and the acceptor energy (E_A) is 0.16 eV above the valence band, what is the number of ionized acceptors in this material? You can assume the degeneracy factor, g_A=4. Hint: do not make this problem harder than it is.

$$N_A^- = \frac{N_A}{1 + g_A e^{(E_A - E_F)/kT}}$$

$$= \frac{5e\,19}{1 + 4e^{(0.16 - 0.1)/0.0259}}$$

$$\boxed{N_A^- = 1.2\,e18\ cm^{-3}}$$

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

16.) (25-points total)

A semiconductor has the following parameters:

Hole Diffusion coefficient, D_p=~~X~~ cm^2/Sec

Hole Mobility, μ_p=200 cm^2/VSec → 5.18

$$\frac{kT}{q} = \frac{D_p}{\mu_p}$$

Substrate relative Dielectric Constant, $\varepsilon_{r\text{-semiconductor}}$=$K_S$=11.7

Dielectric Constant of free space, ε_O =8.854e-14 F/cm

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

The hole concentration in NON-EQUILIBRIUM in the material is maintained at

$p(x)=1e15e^{(x/100\ um)}$ cm^{-3} for x = 0 to x = 100 um

a.) **(20 points) Plot and label (label the maximum and minimum values) the hole current density if an electric field of 10~~00~~ V/cm is applied across the material.**

b.) **(5 points) Explain why we cannot determine the electron concentration as a function of position.**

a)

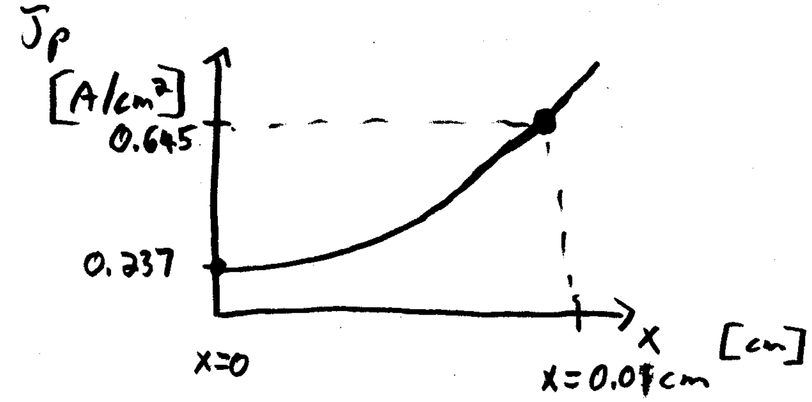
$$J_p = q\,\mu_p\,p\,\vec{E} - q\,D_p\,\nabla p$$

$$= (1.6e\text{-}19)(200)(10)\left[1e15\,e^{x/0.01cm}\right] -$$

$$(1.6e19)(5.18)\left[\frac{1e15}{0.01}\,e^{x/0.01}\right]$$

$$= \left[0.32 - 0.0828\right] e^{x/0.01cm}$$

$$= 0.237\,e^{x/0.01cm} \quad A/cm^2$$



b) In non-equilibrium, $np \neq n_i^2$

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

17.) (25-points)

Light is absorbed in a silicon wafer of thickness 500 um (the wafer is similar to that passed around in class). The wafer is p-type and is uniformly doped with 10^{17} cm^{-3} acceptors. The light has been on for a very long time and can be approximated as being absorbed uniformly throughout the material. If the excess HOLE generation rate is 10^{17} cm^{-3}/sec and the minority carrier lifetime is 1 milliseconds (1e-3 seconds); $\mu_n = 1000\ cm^2/Vsec$

$\frac{\partial \Delta n_p}{\partial t} = 0$ for part b.)

a.) (4 points) Should the absorption coefficient be large or small for such a condition to occur?

b.) (5 points) What is the excess electron concentration for all positions in the wafer.

uniform absorption $\Rightarrow$ uniform Δn

c.) (16 points) What would be the electron concentration as a function of time for all times after the light is turned off?

Bonus: (5 points-no partial credit on this bonus) Determine what electron current density flows in the material. Support your answer thoroughly for credit.

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: $\frac{d\Delta n_p}{dt} = -\frac{\Delta n_p}{\tau_n}$ 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: $\Delta n_p = G_L\tau_n$

Almost Identical to the problem done in class!

a.) $I = I_o e^{-\alpha x}$ $\rightarrow$ α must be small for weak absorption

$G(x,\lambda) = G_{Lo}e^{-\alpha x}$

$G(x,\lambda) \Rightarrow G_{Lo}$ if $\alpha \rightarrow 0$

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

$\Delta n_p = G_L \tau_n$

$\Delta n_p = 10^{17}\left(\frac{cm^{-3}}{s}\right)(1e\text{-}3\ sec)$

$\boxed{\Delta n_p = 10^{14}\ cm^{-3}}$

c.) See next page

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

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

General Solution:

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

equal to value just before the light was turned off

$$\Longrightarrow \boxed{\Delta n_p(t) = 10^{14} e^{-(t/1e\text{-}3)} \ cm^{-3}}$$

Bonus: Uniformly doped $\Longrightarrow$ No Electric field

$$J_n = q D_n \nabla n$$

uniform doping

uniform illumination/Generation

$$= q D_n \frac{d(n_0 + \Delta n)}{dx}$$

$$\Rightarrow J_n = q D_n (0)$$

$$\boxed{J_n = 0 \ A/cm^2}$$