ECE 3040 Microelectronic Circuits

Exam 1

Important Note: This exam was designed for 1 hour class time due to the summer semester

June 11, 2002

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Print your name clearly and largely: Solution

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!

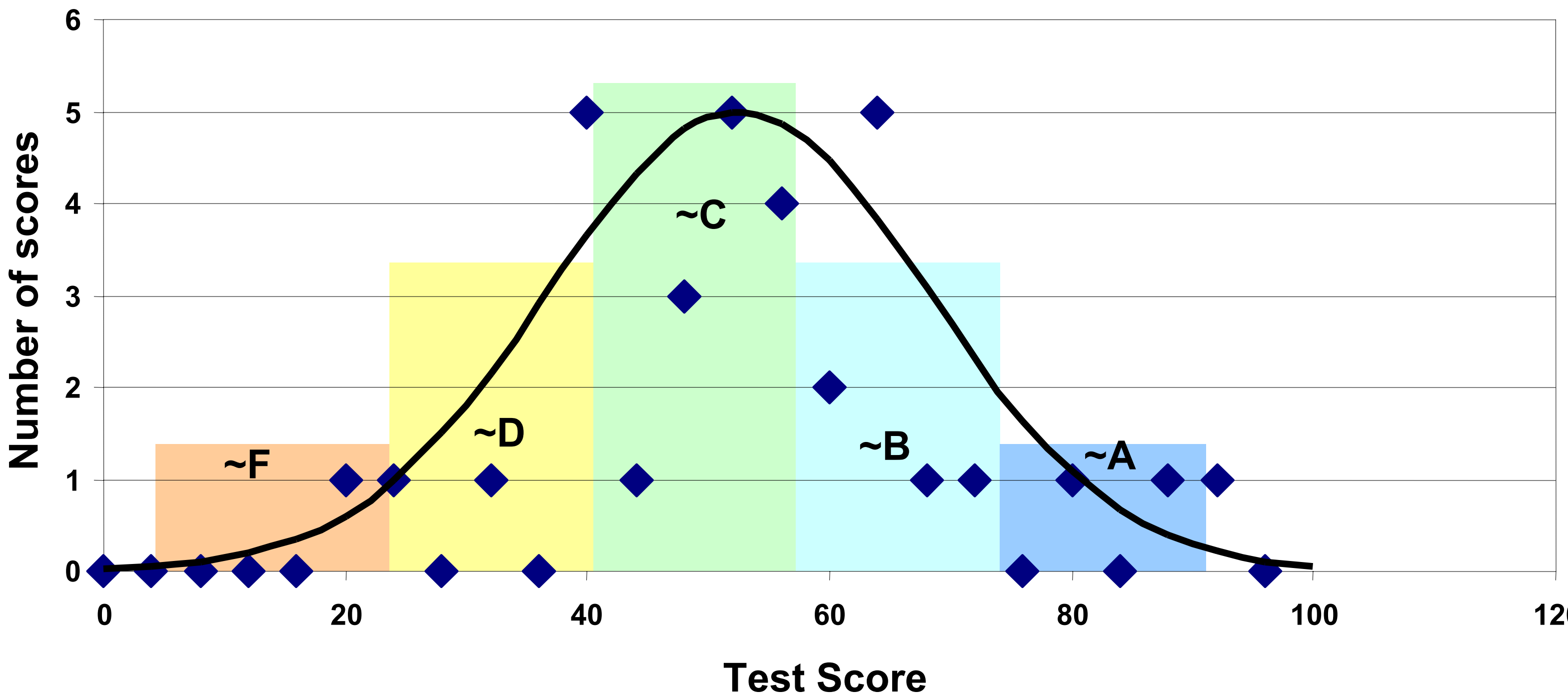
Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

Summer 2002 Exam 1 Statistics

Class Totals	Problem # ==>	#1	#2	#3a	#3b	#3c	#3d	#3e	#4	#5	#6	#7
Number of Tests=	35	33										
Point Value of problem=		2	2	4	4	4	4	5	15	10	25	25
Individual Problem Average=		94.3	77.1	68.6	80.0	82.9	71.4	45.1	60.2	87.1	28.9	48.5
Exam Average=	52.5	52.45455										
Exam Standard Deviation=	15.8	15.77595										
Exam Max=	89.0	89										
Exam Min=	17.0	17										

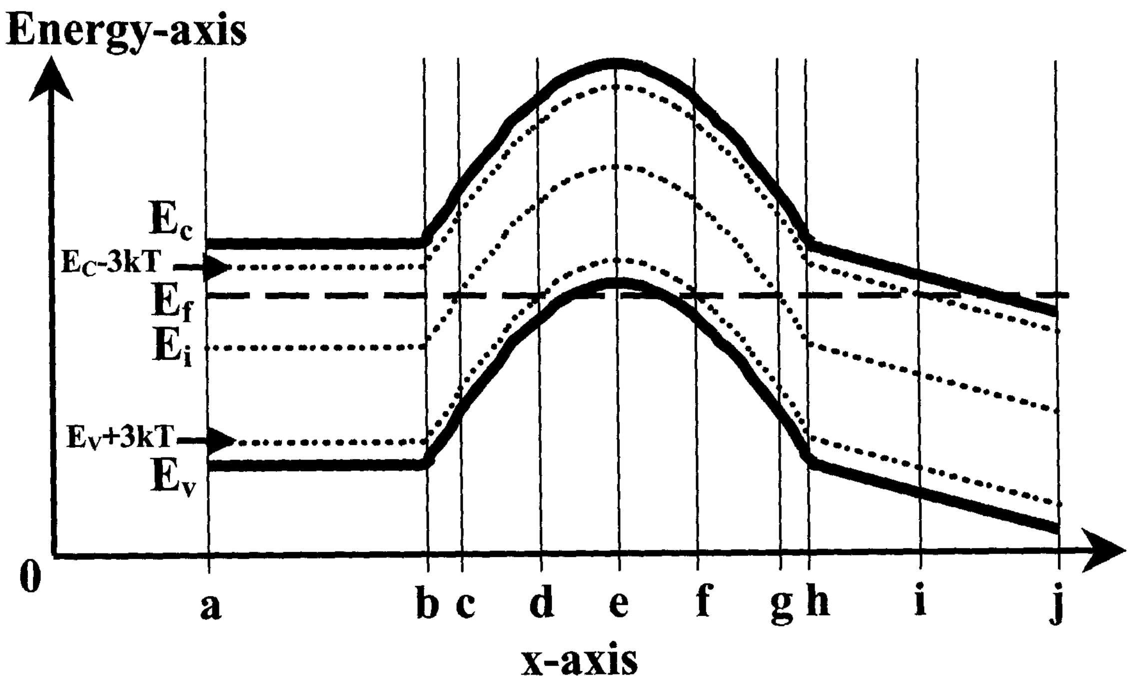


First 25% **Multiple Choice, True/False and short answer (Circle the letter of the most correct answer)**

1.) (2-points) True or False In an insulator the amount of energy required to free a valence electron and let it move throughout the material is smaller than in a metal.

2.) (2-points) True or False: In $In_{0.1}Ga_{0.9}N$ there are 9 gallium (Ga) atoms for every 10 nitrogen atoms (N).

3.) (21 points total)
Select the **best** answer:
Given a semiconductor at room temperature (27 degrees C) has the following parameters and energy band diagram:
Hole Diffusion coefficient, D_p=11.86 cm^2/Sec
Electron Diffusion coefficient, D_n=33.625 cm^2/Sec
Substrate intrinsic concentration, n_i=1e10 cm^{-3}



a.) (4-points) Which regions contain nonzero electric fields?
- I. a<x<b, and point e
- II. Everything except region a<x<b and point e
- III. a<x<c and g<x<j
- IV. c<x<g
- V. d<x<f and i<x<j
- VI. a<x<b and h<x<j
- VII. c<x<d and f<x<g

Continued on the next page...

b.) (4-points) Which regions are n-type?

I. $a<x<b$, $h<x<j$, point e
II. Everything except region $a<x<b$ and point e
III. $a<x<c$ and $g<x<j$
IV. $c<x<g$
V. $d<x<f$ and $i<x<j$
VI. $a<x<b$ and $h<x<j$
VII. $c<x<d$ and $f<x<g$

c.) (4-points) Which regions are p-type?

I. $a<x<b$, $h<x<j$, point e
II. Everything except region $a<x<b$ and point e
III. $a<x<c$ and $g<x<j$
IV. $c<x<g$
V. $d<x<f$ and $i<x<j$
VI. $a<x<b$ and $h<x<j$
VII. $c<x<d$ and $f<x<g$

d.) (4-points) Which regions are degenerate?

I. $a<x<b$, $h<x<j$, point e
II. Everything except region $a<x<b$ and point e
III. $a<x<c$ and $g<x<j$
IV. $c<x<g$
V. $d<x<f$ and $i<x<j$
VI. $a<x<b$ and $h<x<j$
VII. $c<x<d$ and $f<x<g$

e.) (5-points) If the slope of E_i for the region $h<x<j$ is 1000 eV/cm what is the electron drift velocity at point i ? (Hint: Be careful of your units.)

$$\mathcal{E} = \frac{1}{q}\underbrace{\frac{dE_i}{dx}}_{\text{need this in Joules}} = \frac{1}{q}\left(\frac{1000\,eV}{cm}\right)\left(\frac{1.6e\text{-}19\ J}{eV}\right) = \frac{1000\ J}{cm}\ \frac{1.6e\text{-}19}{1.6e\text{-}19\ Coulomb}$$

$$V = J/Coulomb$$

$$= \frac{1000\ V}{cm}$$

$$v_{d_n} = \mathcal{E}\mu_n = \frac{1000\ V}{cm}\left(\frac{D_n}{\frac{kT}{q}}\right) = \frac{1000\,V}{cm}\left(\frac{33.625\ cm^2/s}{0.0259\ V}\right)$$

$$\boxed{v_{d_n} = 1.29e6\ cm/s}$$

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

4.) (15-points)

n_i=1e10 cm^{-3} N_D=6.1e17 cm^{-3} donors N_A=6e14 cm^{-3} acceptors.

Electron mobility, μ_n = 1600 cm^2/Vsec Hole mobility , μ_p = 480 cm^2/Vsec

Temperature=27 degrees C

Assuming total ionization, if 9 Volts is placed across a resistor with area 0.00456 cm^2 and 0.2cm length. What is the electron current density, and hole current density in the material?

$\mathcal{E} = \frac{9V}{.2cm} = 45 V/cm$

$N_d >> N_A >> n_i$ so we can use

$n \approx N_d = 6.1e17\ cm^{-3}$

$p = \frac{n_i^2}{n} = \frac{1e20}{6.1e17} = 164\ cm^{-3}$

$J_p = q\mu_p p\mathcal{E} = 1.6e\text{-}19\ (480)(164)(45)$

$\boxed{J_p = 5.6e\text{-}13\ A/cm^2}$

$J_n = q\mu_n n\mathcal{E} = 1.6e\text{-}19\ (1600)(6.1e17)(45)$

$\boxed{J_n = 7027\ A/cm^2}$

5.) (10-points) If the donor concentration in problem 4 would have been 5.9e14 cm-3, what would be the electron and hole concentrations?

$N_D = 5.9e14\ cm^{-3}$

$$p = \frac{6e14 - 5.9e14}{2} + \sqrt{\left(\frac{6e14-5.9e14}{2}\right)^2 + (1e10)^2}$$

$\boxed{p = 1e13\ cm^{-3}}$

$n = \frac{n_i^2}{p}$

$= \frac{(1e10)^2}{1e13}$

$\boxed{n = 1e7\ cm^{-3}}$

Third 25%

6.) (25 points) Given the density of states in the conduction band given by,

$$g_c(E) = \frac{m_n^*\sqrt{2m_n^*(E-E_c)}}{\pi^2\hbar^3}, E \geq E_c \text{ with } unit \equiv \left(\frac{Number\ of\ States}{cm^3}\right) \Big/ eV$$

and the fermi-distribution function given by,

$$f(E) = \frac{1}{1+e^{(E-E_F)/kT}} \quad where\ E_F \equiv Fermi\ energy \Longrightarrow f(E) \approx e^{-(E-E_F)/kT}$$

and assuming a non-degenerate semiconductor at what energy above the conduction band has the highest concentration of electrons?

Hint: An approximation to the fermi-distribution due to the semiconductor being non-degenerate may be very helpful.

states/cm^{-3}/eV:

$$g_c(E)f(E) = \frac{m_n^*\sqrt{2m_n^*(E-E_c)}}{\pi^2\hbar^3}e^{-(E-E_F)/kT}$$

$$= A(E-E_c)^{1/2}e^{-(E-E_F)/kT}, \quad A = \frac{m_n^*\sqrt{2m_n^*}}{\pi^2\hbar^3}$$

To find the maxima, take the derivative + set this equal to zero.

$$\frac{d[g_c(E)f(E)]}{dE} = 0 = \frac{A}{2(E-E_c)^{1/2}}e^{-(E-E_F)/kT} - \frac{A}{kT}(E-E_c)^{1/2}e^{-(E-E_F)/kT}$$

divide through by $Ae^{-(E-E_F)/kT}$

$$\frac{1}{2\sqrt{E-E_c}} = \frac{\sqrt{E-E_c}}{kT}$$

Now solving for the energy, E that creates this maxima,

$$E = E_c + \frac{kT}{2}$$

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

7.) (25-points)

A p-type silicon wafer, with intrinsic concentration n_i=1e10 cm^{-3}, of thickness 500 um is uniformly doped with 10^{16} cm^{-3} acceptors. A force that has existed for a very long time extracts all the electrons from the x=0 side of the wafer. Assuming an infinite minority carrier lifetime and the material held in the dark determine the excess electron concentration in the wafer for all positions assuming the material is in equilibrium at x=500 um.

$\Rightarrow \frac{\partial \Delta n_p}{\partial t} = 0$

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

$G_L = 0$

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: $\Delta n_p(x) = Ae^{-x/L_n} + Be^{+x/L_n} + G_L\tau_n$

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

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

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: $\Delta n_p = G_L\tau_n$

General Solution:

$$\cancel{\frac{\partial \Delta n_p}{\partial t}}^{\,0} = D_n \frac{d^2 \Delta n_p}{dx^2} - \cancel{\frac{\Delta n_p}{\tau_n}}^{\,0} + \cancel{G_L}^{\,0}$$

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

Apply B.C.:

$$\Delta n_p(x=0) = A = -\frac{n_i^2}{N_A} = -10^4\ cm^{-3}$$

$n(x=0) = 0$

$n_o + \Delta n = 0$

$\Delta n = -n_o$

$\Delta n = -\frac{n_i^2}{N_A}$

$$\Delta n_p(x = \underline{0.05cm}) = 0 \Leftarrow (\text{equilibrium})$$

$$0 = -10^4 + B(0.05)$$

$$B = 2e5\ cm^{-2}$$

$$\boxed{\therefore \Delta n_p(x) = 2e5\,x - 10^4 \quad cm^{-3}}$$