

This quiz is aimed for 1-1/2 hours with 30 minutes allocated for checking your paper. This quiz will be picked up at 9:00 P.M.

You are permitted 1 - 8 1/2" x 11" formula sheet without any derivations or problem solutions. The formula sheet must be handed in with your quiz (and will be returned with this quiz). If either

1. your formula sheet violates these constraints

OR

2. you are NOT using a formula sheet

RAISE YOUR HAND AND INFORM A PROCTOR NOW!

If you do not inform a proctor that you are taking the quiz without a formula sheet, it is your responsibility to staple the formula sheet to the quiz when handing in your exam.

All work should be done on these sheets. On your desk top and seats should be this exam, one formula sheet, computation aid, and writing instruments **ONLY**. All other material should be stored under the seats.

If you are unsure about alternate interpretation of a problem, **ASK A PROCTOR**.

While the parts of a problem are related, many do not "chain" together, latter parts of a problem can usually be done even though earlier parts are not done successfully. If you cannot, or do not have time to solve a problem numerically, **CLEARLY** indicate the appropriate formulas and the method of solution.

If a problem states "Explain briefly" or "Show all work", full credit will not be allocated without the information requested. An explanation, when not required, can be helpful in allocation of partial credit.

THINK ! ! ! ! GOOD LUCK!!

Must hand in all quiz pages and formula sheet. When a [] appears, circle the correct answer or answers.

(Below is information after your exam is returned.)

Grade Record Check

Total _____

PS1 _____

1 (39) _____ pg. 2-4

PS2 _____

2 (30) _____ pg. 5-7

3 (31) _____ pg. 8-10

If you believe that you have been graded unfairly, the following procedure is to be followed:

1. Review the solutions in the library.
2. Type, print or write legibly a paragraph describing your complaint on a separate page and submit to a staff member by October 10 with your original work as returned to you.

After October 10 all grades for the first part of the course will be considered finalized.

35.423 Semiconductor Electron Devices
Quiz I

1. [6] (a) An ionized donor atom in a semiconductor is

positive
negative
neutral

. Also, in silicon,

it has a valence of

3
4
5

.

[5] (b) The space charge neutrality in a semiconductor means

all the positive charges equals all the negative charges
electron and hole concentrations are the same
donor and acceptor concentrations are the same
the semiconductor is at thermal equilibrium
none of the above

[5] (c) [True or False]

“All semiconductors have covalent bonds only.”

A brief explanation is needed for partial credit.

Compound semiconductors have ionic component in their chemical bonds.

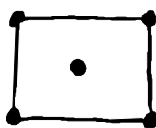
[6] (d) If a semiconductor has an equal concentration of donor and acceptor atoms, the electron conc.

is $\left[\begin{array}{c} N_D \\ n_i \\ \frac{n_i^2}{N_D} \end{array} \right]$ at thermal equilibrium and the hole concentration is such that $\left[\begin{array}{c} p_0 = n_0 \\ p_0 = N_A \\ \frac{n_i^2}{N_D} \end{array} \right]$. Under

what condition(s) will the semiconductor be p-type? Explain briefly.

at low temperatures (in the freeze-out region), when the acceptor level is shallower than the donor level.

[4] (e) Calculate the areal atomic density of the (100) plane of the silicon lattice. (The lattice constant of silicon is 0.543 nm.)



4 corner atoms \rightarrow 1 atom
 1 center atom \rightarrow 1 atom
 area = $(0.543 \times 10^{-7} \text{ cm})^2 = 2.95 \times 10^{-15} \text{ cm}^2$
 Areal atomic density = $2 / 2.95 \times 10^{-15} \text{ cm}^2 = 6.78 \times 10^{14} \text{ cm}^{-2}$

[6] (f) Low-level injection means

- steady state only
- excess carrier concentration is larger than minority carrier concentration
- excess carrier concentration is smaller than majority carrier concentration
- excess carrier concentration is smaller than donor or acceptor concentration

and under this condition, the minority carriers are transported by

- diffusion
- drift
- either diffusion or drift
- cannot be determined
- none of the above

Name: _____

[4] (g) A good recombination level cannot be a good dopant level because

a good recombination is near the middle of the bandgap for equal e^- and h^+ capture rates while a good dopant level needs to be near the band edges for maximum ionization.

[3] (h) True or False] Every silicon atom in the diamond cubic lattice has exactly four nearest neighbors.

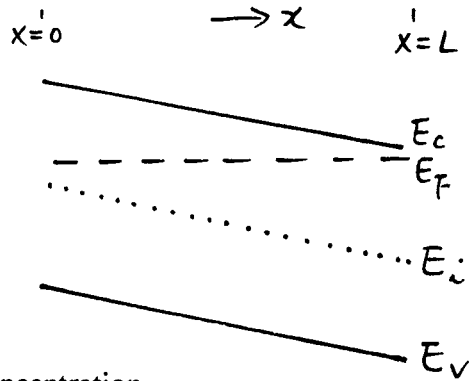
[4] (i) (Bonus) A

degenerate
<u>compensated</u>
heavily doped
indirect
none of the above

 semiconductor has both donor and acceptor atoms

present.

2. An energy band diagram of a semiconductor in thermal equilibrium is shown below, doped with a donor concentration dependent on x .



[5] (a) The donor concentration

- increases with increasing x
- decreases with increasing x
- peaks near $x = L/2$
- is constant
- cannot be determined information given

[5] (b) The electric field intensity is

- zero throughout since we are in thermal equilibrium
- increases in magnitude with increasing x
- decreases in magnitude with increasing x
- peaks near $x = L/2$
- is constant
- cannot be qualitatively discussed with the information given

$$\xi \propto \frac{dE_i}{dx}$$

[5] (c) The hole concentration

- increases with increasing x
- decreases with increasing x
- peaks near $x = L/2$
- is constant
- cannot be determined information given

Name: SOLUTION

- [5] (d) If the minimum and maximum donor concentrations are 10^{14} and 10^{18} cm^{-3} respectively, calculate the respective Fermi levels with respect to the intrinsic level.

$$E_F - E_i = kT \ln \left(\frac{N_D}{n_i} \right)$$

$$E_f - E_i \text{ (for } 10^{14} \text{ cm}^{-3}\text{)} = \underline{0.24} \text{ eV}$$

$$E_f - E_i \text{ (for } 10^{18} \text{ cm}^{-3}\text{)} = \underline{0.48} \text{ eV}$$

- [5] (e) The diffusion component of the hole current is in the

[in the +x direction
in the -x direction
in either +x or -x direction
cannot be determined information given]

while the drift component is in the

[in the +x direction
in the -x direction
in either +x or -x direction
cannot be determined information given]

Name: _____

- [5] (g) Assume now that uniform illumination is put over the sample and $\tau_n = \tau_p = 10^{-6}$ sec. ^{what is} ~~The Fermi level~~ at is the maximum generation rate [electron-hole pairs per cm^3] to keep the injection low level? (Hint: How large can the excess carrier concentration be while maintaining low-level injection?)

$$N_D (\text{min}) = 10^{14} \text{ cm}^{-3} \text{ so } \delta n (\text{max}) \approx 10^{13} \text{ cm}^{-3} = \delta p (\text{max})$$

$$\text{Since } \delta n = G \tau_n,$$

$$G_{\text{max}} = \frac{\delta n}{\tau_n} = 10^{19} \text{ EHP/cm}^3$$

$$G = 10^{19} \text{ EHP/cm}^3$$

- [8] (h) (Bonus) Calculate and sketch the electron and hole Quasi-Fermi levels under the maximum generation rate described in (g).

Since the injection level is low, $F_n - E_i(x=0) = 0.24 \text{ eV}$

$E_F - \bar{E}_i|_{x=0} = F_n - E_i|_{x=0}$ and $E_i - F_p(x=0) = 0.18 \text{ eV}$

$E_F - \bar{E}_i|_{x=L} = F_n - E_i|_{x=L}$ $F_n - E_i(x=L) = 0.48 \text{ eV}$

$E_i - F_p(x=L) = 0.18 \text{ eV}$

At $x=0$, $p = p_0 + \delta p \approx 10^{13} \text{ cm}^{-3}$

$$E_i - F_p = kT \ln\left(\frac{p}{n_i}\right) \approx 0.18 \text{ eV}$$

At $x=L$, $p = p_0 + \delta p \approx 10^{13} \text{ cm}^{-3}$

$$E_i - F_p \approx 0.18 \text{ eV}$$

3. A piece of p-type silicon of length L and cross-sectional area A is uniformly doped. We are given boundary conditions that at $x = 0$, a constant density of excess electrons is maintained so that $\delta n(x, t)|_{x=0} = \delta n(0, t) = \Delta n$ and $\delta n(x, t)|_{x=L} = \delta n(L, t) = 0$ for all time where $\Delta n \ll N_A$ is maintained. No carrier generation but a uniform, if any, recombination is assumed within the semiconductor.

We know we can simplify the continuity equation into the diffusion equation, which is

$$D_n \frac{\partial^2 \delta n(x)}{\partial x^2} - \frac{\delta n(x)}{\tau_n} = 0.$$

- [4] (a) The reason for the disappearance of the $\frac{\partial}{\partial t}$ term is because steady state
condition is assumed

- [5] (b) The

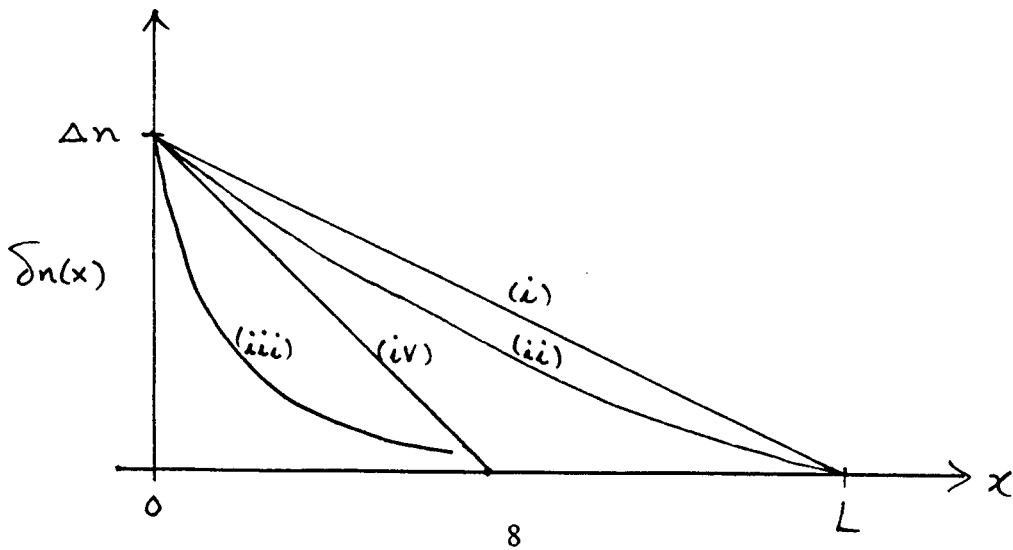
first term
<u>second term</u>
both terms

 represents bulk carrier recombination. Give a brief physical description

of minority carrier lifetime.

Minority carrier lifetime is the average time a minority carrier can travel within the semiconductor before recombination

- [6] (c) Shown below are four possible steady-state solutions for $\delta n(x, t) = \delta n(x)$.



Name: _____

The case (iv) cannot be a solution because it would require a larger recombination for $x > L/2$ than for $x < L/2$

The correct solution for any particular solution depends upon the relative magnitude of L and $L_n = \sqrt{D_n \tau_n}$ (diffusion length)
(express answer in terms of symbols in diffusion equation)

[4] (d) Case (i) is valid if $L_n \gg L$

Case (iii) is valid if $L_n \ll L$
(express answer in terms of symbols in diffusion equation)

[6] (e) The excess electrons injected into the semiconductor at $x = 0$ in case (i)

mostly recombine at $x = L$
mostly recombine within the material
remain at $x = 0$
are swept across the material by a large \mathcal{E}
move through the material mostly by diffusion

The excess electrons injected into the semiconductor at $x = 0$ in case (iii)

mostly recombine at $x = L$
mostly recombine within the material
remain at $x = 0$
are swept across the material by a large \mathcal{E}
move through the material mostly by diffusion

- [6] (f) Estimate the electron diffusion length for case (i) if L is $10\ \mu\text{m}$. State your assumptions and approximations.

$$L_n \gg L, \text{ say } L_n > 10L$$

$$L_n = \sqrt{D_n \tau_n} > 10L = 100\ \mu\text{m}$$

$$\tau_n \gg \frac{(10L)^2}{D_n} = 333\ \mu\text{sec}$$

- [4] (g) (Bonus) Under what condition will case (iv) can be a solution?

Non-uniform recombination.

Minority carrier lifetime is much shorter for $x > L/2$ than for $x < L/2$.