*YOUR NAME*________________________________

Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology

6.012 Electronic Devices and Circuits

Exam No. 1

Notes:

1. Unless otherwise indicated, assume room temperature and that kT/q is 0.025 V. You may also approximate [(kT/q) ln 10] as 0.06 V.
2. Closed book; one sheet (2 pages) of notes permitted (to be handed with exam).
3. All of your answers and any relevant work must appear on these pages. Any additional paper you hand in will not be graded.
4. Make reasonable approximations and assumptions. State and justify any such assumptions and approximations you do make.
5. Be careful to include the correct units with your answers when appropriate.
6. Be certain that you have all eight (8) pages of this exam booklet <u>and</u> the formula sheet, and make certain that you write your name at the top of this page in the space provided.

6.012 Staff Use Only			
	PROBLEM 1	____________	(out of a possible 35)
	PROBLEM 2	____________	(out of a possible 30)
	PROBLEM 3	____________	(out of a possible 35)
	TOTAL		

Problem 1 - (35 points)

This problem concerns a specimen of gallium arsenide, GaAs, which has 2×10^{16} cm^{-3} donors and an unknown number of acceptors.

A measurement is made on the specimen and it is found that it is p-type with an equilibrium hole concentration, p_o, of 5×10^{17} cm^{-3}.

At room temperature in GaAs, the intrinsic carrier concentration, n_i, is 10^7 cm^{-3}, the hole mobility, μ_h, is 300 cm^2/V-s, and the electron mobility, μ_e, is 4000 cm^2/V-s. The minority carrier lifetime, τ_{min}, is 10^{-9} s.

a) [6 pts] What is the net acceptor concentration, N_A (= N_a - N_d), in this sample, and what is the total acceptor concentration, N_a?

N_A = ______________________ cm^{-3}

N_a = ______________________ cm^{-3}

b) [4 pts] What is the equilibrium electron concentration, n_o, in this sample at room temperature?

n_o = ______________________ cm^{-3}

c) [4 pts] What is the electrostatic potential, ϕ, in this sample at room temperature relative to intrinsic gallium arsenide?

ϕ = ______________________ V

d) [4 pts] What is the electrical conductivity, σ_o, of this sample in thermal equilibrium at room temperature?

σ_o = ______________________ S/cm

Problem 1 continues on the next page

Problem 1 continued

e) [5 pts] This sample is illuminated by a steady state light which generates hole-electron pairs uniformly throughout its bulk, and the conductivity of the sample is found to increase by 1% (that is, to 1.01 σ_o). What are the excess hole and electron concentrations, p' and n', in the illuminated sample, assuming that the illumination has been on for a long time?

p' = n' = ______________________ cm^{-3}

f) [4 pts] What is the optical generation rate, G_L, in Part e? Note: If you could not evaluate p' and n' in Part e, give an algebraic expression in terms of p' and n'.

G_L = ____________________ hole-electron pairs/cm^3-s^1

g) [4 pts] If the illumination in Part e is extinquished at t = 0, write an expression for the sample conductivity as a function of time for t > 0. Express your answer in terms of σ_o , rather than the numerical value.

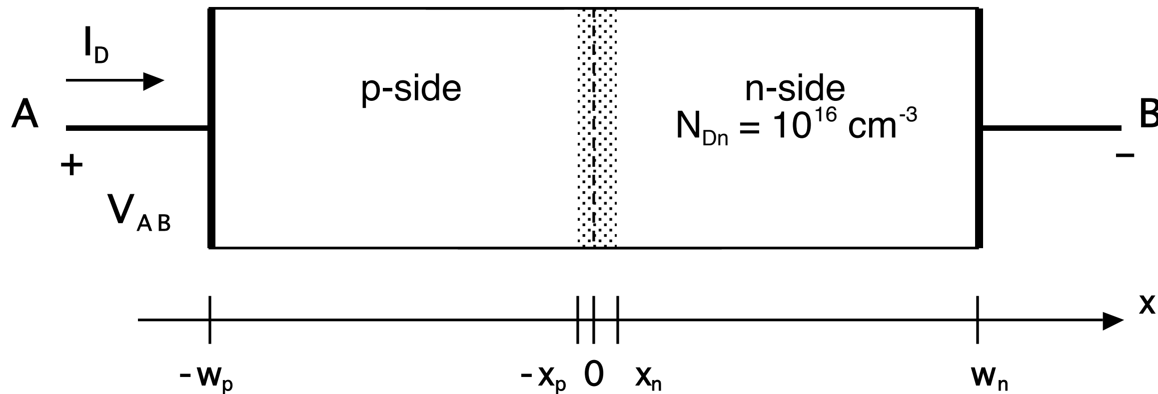
$\sigma(t)$ = ______________________ S/cm

h) [4 pts] What is the minority carrier diffusion length, L_{min}, in this sample?

L_{min} =____________________ cm

End of Problem 1

Problem 2 (30 points)



The p- and n-sides of the silicon p-n diode shown above are each 2 μm wide; the depletion regions on either side of the junction are both much narrower than this and their widths can be neglected relative to 2 μm; $L_{min} >> 2$ μm. . The n-side has a net donor concentration, N_{Dn}, of 10^{16} cm^{-3}. The hole and electron mobilities, μ_h and μ_e, are 600 cm^2/V-s and 1600 cm^2/V-s, respectively, throughout the device. (Ignore any dependence of the mobilities on doping level.) The cross-sectional area of the diode is 10^{-4} cm^2.

a) When the bias voltage, V_{AB}, is 0.48 V, what are the following quantities?

i) [3 pts] The total hole population at the contact on the right end of the device, w_n.

$p(w_n)$ = ________________________ cm^{-3}

ii) [4 pts] The total hole population at the edge of the depletion region on the n-side, x_n.

$p(x_n)$ = ________________________ cm^{-3}

iii) [4pts] The excess hole charge stored in the quasi neutral region, QNR, on the n-side of the diode, $q_{QNR,n\text{-}side}$.

$q_{QNR,n\text{-}side}$ = ______________________ coul

iv) [4pts] The net hole current density crossing the junction, $J_h(0)$.

$J_h(0)$ = ______________________ A/cm^2

Problem 2 continues on the next page

Problem 2 continued

b) You are not told explicitly the doping level of the p-side of this diode, N_{Ap}, but you are told that the <u>total</u> minority carrier (electron) population at the edge of the depletion region on the p-side, $n(-x_p)$ is one tenth that of the <u>total</u> minority carrier (hole) population at x_n, $p(x_n)$, when the applied voltage, V_{AB}, is 0.48 V, that is $p(x_n)/n(-x_p) = 10$.

i) [4pts] What must the net acceptor concentration on the p-side, N_{Ap}, be?

N_{Ap} = ____________________ cm^{-3}

ii) [4 pts] What is the magnitude of the ratio of the excess electron charge, $q_{QNR,p\text{-}side}$, stored on the p-side of this diode to the excess hole charge, $q_{QNR,\ n\text{-}side}$, stored on the n-side at this bias?

$| q_{QNR,p\text{-}side} / q_{QNR,n\text{-}side} |$ = ________________________

iii) [4 pts] What is the ratio of the net electron current density crossing the junction, $J_e(0)$, to the net hole current density, $J_h(0)$, at this bias point?

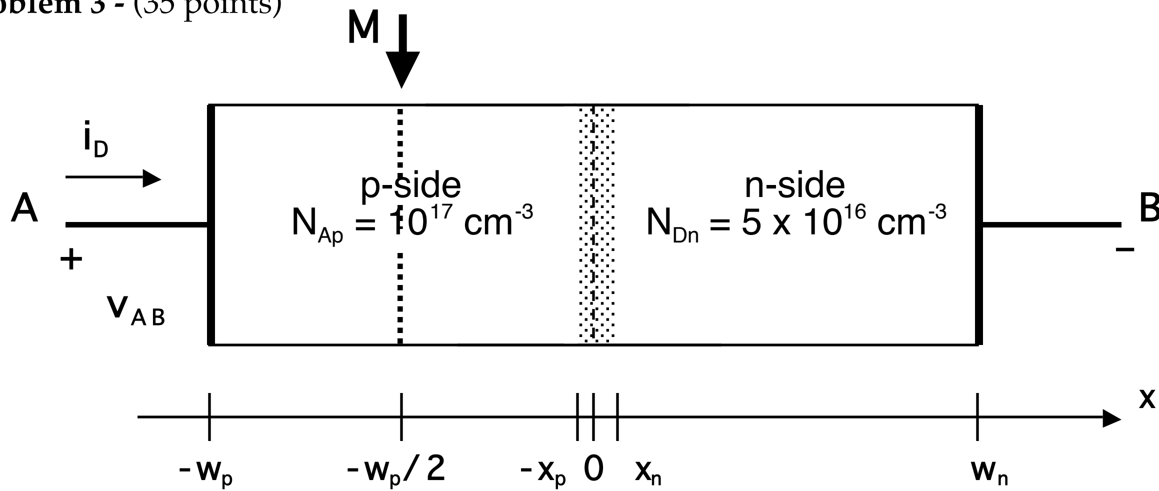
$J_e(0)/J_h(0)$ = ________________________ A/cm^2

iv) [3pts] What is the total potential step going from the quasi-neutral region on the p-side to the quasi-neutral region on the n-side of the <u>biased</u> junction?

$\phi(x>x_n) - \phi(x<-x_p)$ = _____________Volts

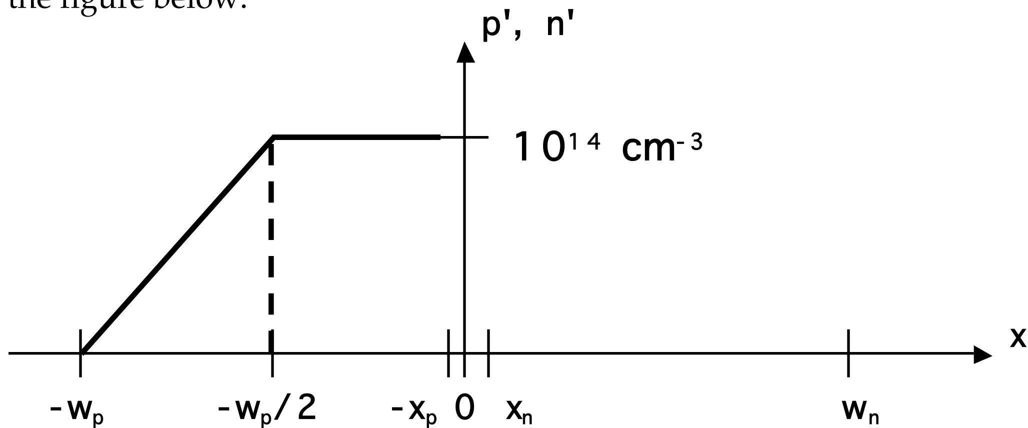
End of Problem 2

Problem 3 - (35 points)



The p-side of the p-n diode pictured above is 2 μm wide and has a net acceptor concentration, N_{Ap}, of 10^{17} cm^{-3}. The n-side is also 2 μm wide and has a net donor concentration, N_{Dn}, of 5 x 10^{16} cm^{-3}. The minority carrier diffusion lengths, L_e and L_h, are both much greater than 2 μm, and the hole and electron mobilities, μ_h and μ_e, are 600 cm^2/V-s and 1600 cm^2/V-s, respectively, throughout the device (independent of doping level). The cross-sectional area of the diode is 10^{-4} cm^2.

A constant bias, V_{AB}, is applied on this diode, and it is illuminated across the plane at x = - 1μm so that the resulting excess minority carrier concentration profile on the p-side is as illustrated in the figure below.



a) i) [6 pts.] What is the electron current density as a function of position, $J_e(x)$, on the p-side of this device, that is, for $-w_p < x < -x_p$?

$J_e(x)$ [Amps/cm^2]:

Problem 3 continues on the next page

Problem 3 continued

ii) [6 pts.] The optical generation function can be expressed mathematically as an impulse at $x = -w_p/2$ [$= -1\mu m$]: $g_L(x) = M\,\delta(x + w_p/2)$. What is the intensity, M, of the impulse excitation?

M = ____________________ hole-electron pairs/s-cm^2

b) i) [4 pts.] What is the excess hole concentration, p', at the ohmic contact on the right of the device at $x = w_n$?

$p'(w_n)$ = ____________________ cm^{-3}

ii) [4 pts.] What is the excess hole concentration, p', at the edge of the depletion region on the n-side of the device, that is at $x = x_n$?

$p'(x_n)$ = ____________________ cm^{-3}

iii) [4 pts.] What is the hole current density as a function of position, $J_h(x)$, on the n-side of this device, that is, for $x_n < x < w_n$? Assume $x_n << w_n$ for any calculations.

$J_h(x)$ [Amps/cm^2]:

c) [6 pts.] What is the total diode current, I_D, through the device when it is excited with light and biased in this way?

I_D = ____________________ Amps

Problem 3 continues on the next page

Problem 3e continued

d) [5 pts.] What is the value of the bias voltage, V_{AB}? [Note: This question could have been asked as Part a; the second figure gives you the information you need to answer it.]

V_{AB} = ____________________ Volts

End of Problem 3; End of Exam