*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. Open book; 6.012 text and any other notes permitted.

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 nine (9) pages of this exam booklet 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** ____________

PROBLEM 2 ____________

PROBLEM 3 ____________

TOTAL

Problem 1 (20 points)

a) Consider a silicon wafer which is doped throughout with 10^{16} cm^{-3} arsenic atoms, and which in addition is doped with 10^{17} cm^{-3} boron atoms to a depth of 4 μm and with 10^{18} cm^{-3} phosphorous atoms to a depth of 2 μm. Taking the x-direction to be normal to the surface, what are the net doping type and concentration in the following three regions (6 pts. total):

i) 4 μm $< x$

Type _______ Net doping ____________

ii) 2 μm $< x <$ 4 μm

Type _______ Net doping ____________

iii) $0 < x$ 2 μm

Type _______ Net doping ____________

b) A uniform, n-type germanium bar ($N_D = 10^{15}$ cm^{-3}) in which the minority carrier lifetime is 10^{-6} s is excited with a constant illumination generating 10^{23} hole-electron pairs/cm^3-s throughout the sample. Does this illumination result in a large or a small change in the conductance of this sample, and why?

Large ______ Small _____ because

c) A certain p-type silicon bar is doped with a net acceptor concentration of 10^{17} cm^{-3}. If its temperature is increased from 300 K (room temperature) to 350 K, which quantity, the equilibrium hole concentration, p_o, the equilibrium electron concentration, n_o, or the intrinsic concentration, n_i, changes the most, and which changes the least, and why? (6 pts total)

i) Least changed: __________ because

ii) Most changed: __________ because

Problem 1 continues on the next page

Problem 1 continued

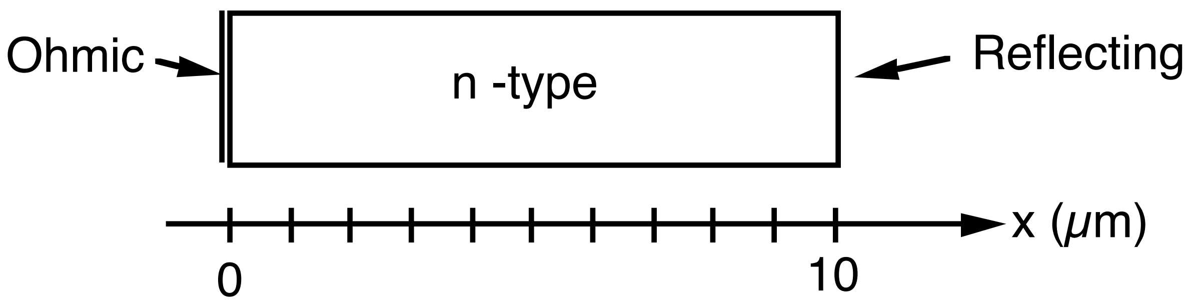
d) A polished sample of a certain semiconductor, call it Semiconductor A, is yellow and transparent, whereas a similar sample of another semiconductor, Semiconductor B, is gray and opaque. Which semiconductor has the larger energy gap? Explain your answer.

Semiconductor with largest energy gap: ______ because

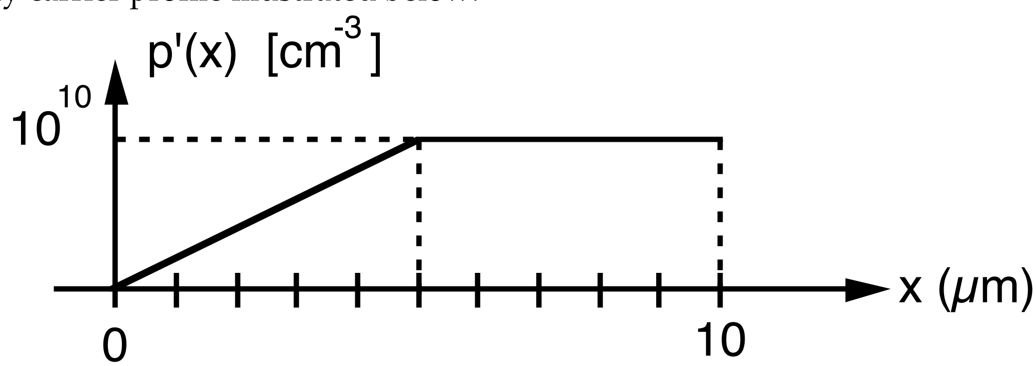
End of Problem 1

Problem 2 (36 points)

The n-type silicon sample illustrated below has an ohmic contact on one end and a reflecting boundary on the other. It is doped with $N_D = 5 \times 10^{16}$ cm^{-3}; the electron mobility, μ_e, is 1600 cm^2/V-s; the hole mobility, μ_h, is 600 cm^2/V-s; and the minority carrier diffusion length is 50 μm.



This sample is excited with constant, low-level illumination creating the excess minority carrier profile illustrated below:

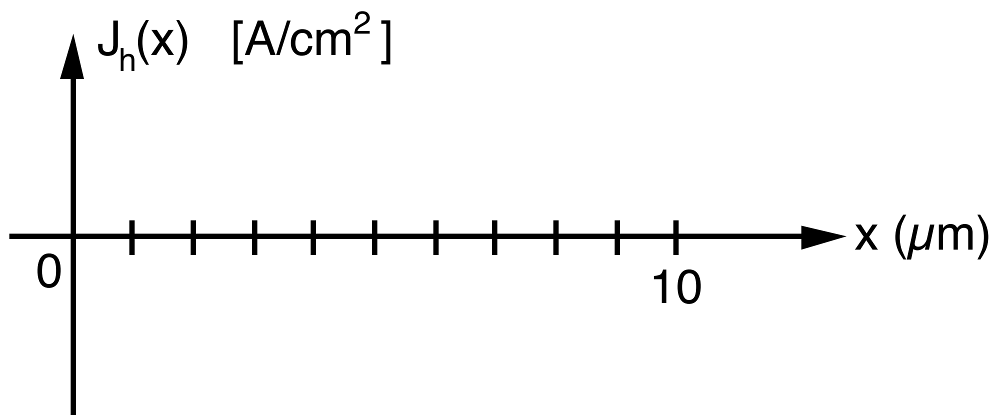


a) Use the information given above to calculate the minority carrier lifetime in this sample.

τ_{min} = ____________

b) On the axes provided below sketch the current densities requested. Indicate the magnitude and sign of the current density at appropriate points on your sketches.

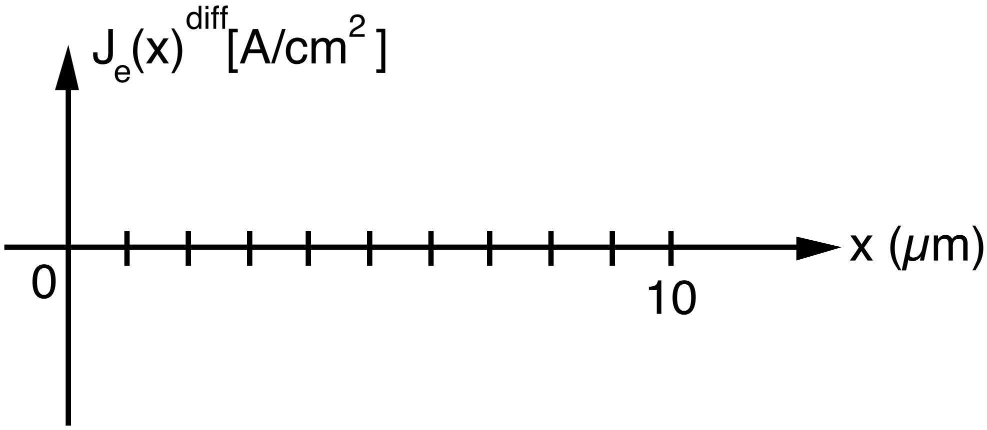
i) Total hole current density, $J_h(x)$



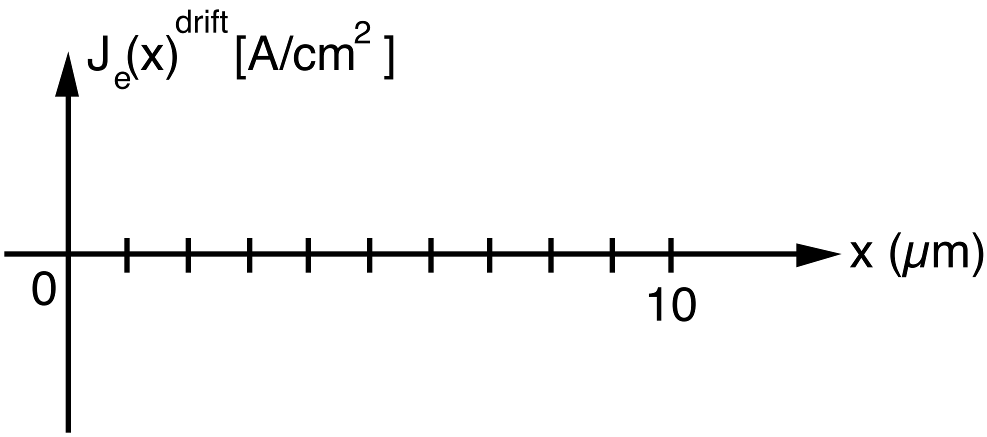
Problem 2 continues on the next page

Problem 2 continued

ii) Electron <u>diffusion</u> current density, $J_e(x)^{diff}$



iii) Electron <u>drift</u> current density, $J_e(x)^{drift}$



c) Derive an expression for the generation function, $g_l(x)$.

$g_l(x)$ = ______________________

d) i) What is the total rate of hole-electron recombination, R, per unit cross-sectional area in the bulk of the sample (i.e., excluding that occuring at the ohmic contact)?

R(in bulk) = ______________________ pairs/cm^2-s

Problem 2 continues on the next page

Problem 2 continued

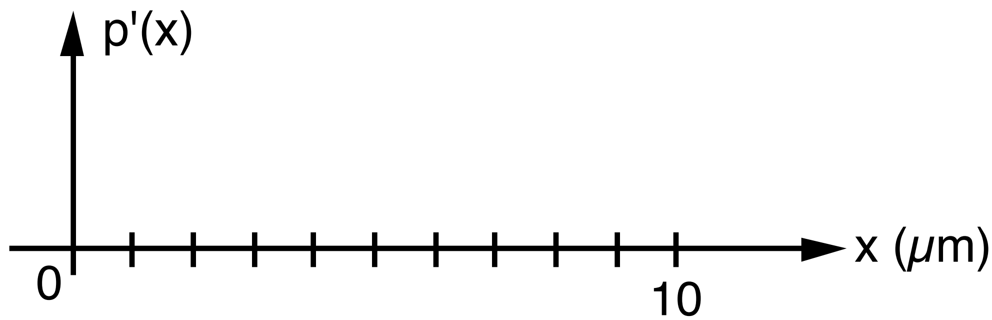
ii) Where do most of the optically generated hole-electron pairs recombine and what fraction of the total number of optically generated pairs recombine there ?

Location: _______________

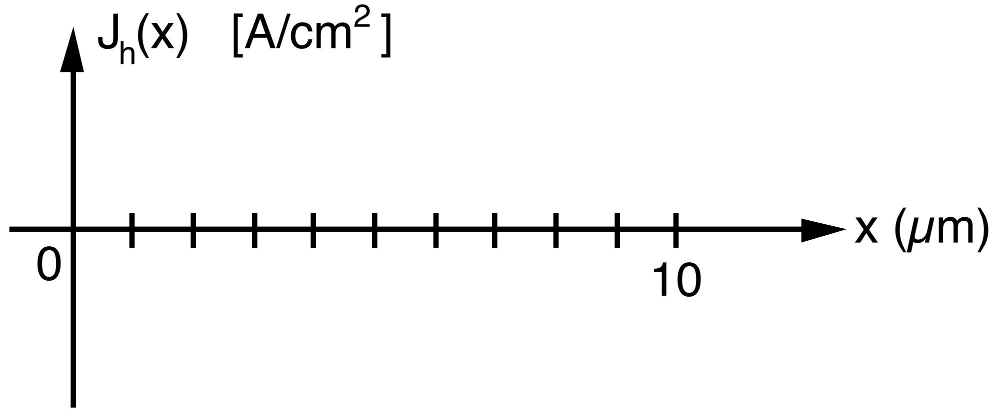
Fraction: _______________

e) The sample is now damaged by proton (hydrogen ion) bombardment in order to reduce the minority carrier lifetime significantly; by doing this the minority carrier diffusion length is reduced to 1 μm.

i) Assuming that the optical generation function remains unchanged (i.e., is the same as it was previously) what would you expect the excess carrier profile to look like with this shorter minority carrier diffusion length? Answer by sketching the profile in this new situation on the axes provide below. You should be quantititative with regard to the x-axis variation, but you need only be qualitiative about the magnitude of p', i.e. indicate if p'(5 μm) is larger or smaller than in the earlier situation.



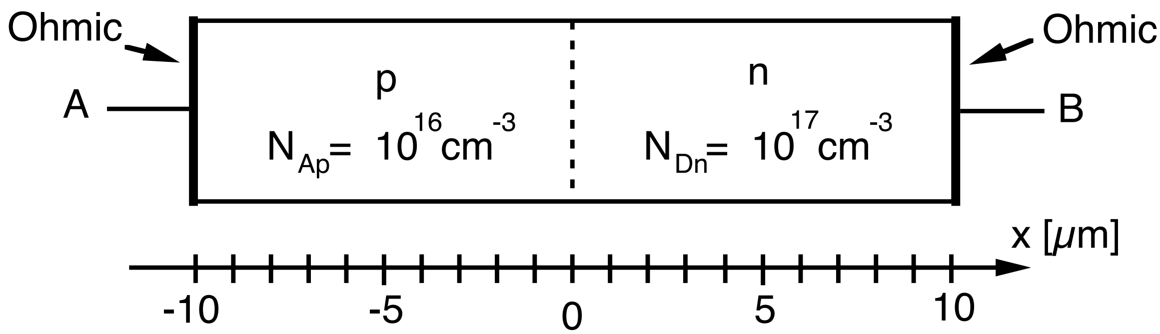
ii) On the axes provided below sketch and label the minority carrier current density along the length of the sample with this reduced minority carrier diffusion length.



End of Problem 2

Problem 3 (44 points)

This question concerns the silicon p-n junction diode illustrated below. Both sides of the diode are 10 μm long with a net acceptor concentration, N_{Ap}, of 10^{16} cm^{-3} on the p-side and an net donor concetration, N_{Dn}, of 10^{17} cm^{-3} on the n-side. Throughout the device the electron mobility is 1600 cm^2/V-s, and the hole mobility is 600 cm^2/V-s. The minority carrier diffusion lengths are both much larger than 10 μm. Neglect space charge layer generation and recombination when solving this problem.



a) What are the following electrostatic potentials, using intrinsic material as the zero reference for electrostatic potential?

i) Electrostatic potential, ϕ_n, in the quasineutral region on the n-side.

ϕ_n = ______________

ii) Electrostatic potential, ϕ_p, in the quasineutral region on the p-side.

ϕ_p = _______

iii) Built-in potential change, ϕ_b, across the junction.

ϕ_b = ______________

b) If the zero-bias depletion width on the p-side of the junction, x_{po}, is 0.3 μm, what is it on the n-side?

x_{no} = ____________________

Problem 3 continues on the next page

Problem 3 continued

c) A bias is applied to the diode leading to an excess minority carrier population at the edge of the depletion region on the p-side of the junction, $n'(-x_p)$ of 10^{14} cm^{-3}. Find the following quantities (you may assume x_n and x_p are much less than 10 μm in your calculations):

i) $p'(x_n)$, the excess hole population at the edge of the depletion region on the n-side of the junction

$p'(x_n)$ = ______________________

ii) $J_e(-x_p)$, the electron current density at the edge of the depletion region on the p-side of the junction.

$J_e(-x_p)$ = ______________________

iii) $J_h(x_n)$, the hole current density at the edge of the depletion region on the n-side of the junction.

$J_h(x_n)$ = ______________________

iv) $J_e(x_n)$, the electron current density at the edge of the depletion region on the n-side of the junction.

$J_e(x_n)$ = ______________________

d) With the bias as applied in Part (c), what is the corrresponding voltage drop across the junction, v_J? That is, if the total change in the electrostatic potential in going from $-x_p$ to x_n is written as $(\phi_b - v_J)$, what is v_J?

v_J = ____________________

Problem 3 continues on the next page

Problem 3 continued

e) With the bias as applied in Part (c) there is a current through the diode and there are ohmic voltage drops in the quasineutral regions on either side of the junction which we normally neglect. This question concerns those voltage drops.

i) Which side of this junction has the higher resistivity, the n-side or the p-side and what is that resistivity?

______ p-side ______ n-side

Resistivity, ρ = ___________

ii) Looking at the p-side of the junction and writting the resistance of the quasineutral region between -w_p and -x_p as R_p, which of the following is the correct expression for the ohmic voltage drop between -w_p and -x_p? Check the correct answer and explain your answer in the space provided below.

______ The total current times the resistance, $A \times J_{tot} \times R_p$

______ The total hole current times the resistance, $A \times J_{h,tot} \times R_p$

______ The hole drift current times the resistance, $A \times J_{h,\,drift} \times R_p$

Explanation:

End of Problem 3

End of Exam