*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 eight (8) 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 (24 points)

Consider a uniformly doped p-type silicon bar 1 mm by 1 mm in cross section. You are told that the equilibrium hole concentration, p_o, in this sample is 10^{16} cm^{-3}, and that it contains boron with a concentration of 1.5 x 10^{16} cm^{-3} along with another dopant of unknown identity and concentration. The minority carrier lifetime is 10^{-5} s, $n_i = 10^{10}$ cm^{-3}, $\mu_e = 1600$ cm^2/V-s, and $\mu_h = 600$ cm^2/V-s.

(a) What is the type and concentration of the other dopant? Suggest a possible identity for this other dopant.

Type: ____________________

Concentration: __________________ cm^{-3}

Possible identity: ________________

(b) What is the room temperature resistivity, , in this sample?

Resistivity, : ___________________ Ohm-cm

(c) If this sample is illuminated with a steady state light generating 10^{19} hole-electron pairs/cm^3-s uniformly throughout its bulk, what will the excess hole and electron populations be?

p' = _____________________ cm^{-3}

n' = _____________________ cm^{-3}

(d) If the illumination is extinquished at time, t = 0, write an expression for the time dependence of n' valid for t > 0.

n'(t) = _________________________ for t> 0

Problem 1 continues on the next page

Problem 1 continued

(e) Consider now that a slice 10 µm thick is cut from the sample and ohmic contacts are formed on each surface. This specimen is again illuminated as before. Assume that the minority carrier diffusion length is much greater than 10 µm, and derive an expression for the excess minority carrier profile in the sample.

Profile: ______________________________ cm^{-3}

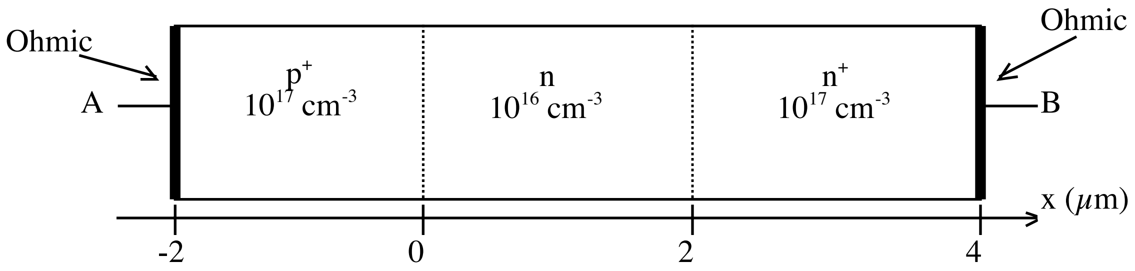
(f) If the illumination in Part (e) is extinquished at time t = 0, would the time rate of decay of the profile you found above be faster than, similar to, or slower than the rate you found in Part (d)? Do not try to write an equation to get an answer, but think about what is going on and reason your way to a qualitative answer. Explain your answer.

Faster _____ Similar_____ Slower_____ because:

End of Problem 1

Problem 2 (40 points)

In the silicon diode structure sketched below the net acceptor concentration, N_A, for $-2\mu m < x < 0$ is 10^{17} cm^{-3}, and the net donor concentration, N_D, is 10^{16} cm^{-3} for $0 < x < 2$ µm, and 10^{17} cm^{-3} for 2 µm $< x < 4$ µm. Throughout the device μ_e is 1600 cm^2/V-s and μ_h is 600 cm^2/V-s at room temperature; the intrinsic carrier concentration, $n_i = 10^{10}$ cm^{-3}, and the dielectric constant, $= 10^{-12}$ F/cm.



(a) (i) What is the electrostatic potential in the p-region, relative to that of intrinsic silicon?

$_p$ = _______ Volts

(ii) What is the built-in potential at the p-n junction?

$_{b,p\text{-}n}$ = _________________ Volts

(iii) What is the potential step at x = 2 µm, between the two n-regions?

$_{b,n\ \ n+}$ = ________________ Volts

(iv) If the potential step in going from the ohmic contact metal to the p-region is -0.5 V (i.e., the potential in the metal is 0.5 V greater than in the p-Si), what is the step in going from the contact metal to the n+ region?

$_{b,m\ \ n+}$ = ________________ Volts

Problem 2 continues on the next page

Problem 2 continued

(b) What is the depletion region width on the n-side of the junction when the depletion region width on the p-side, x_p, is as indicated below?

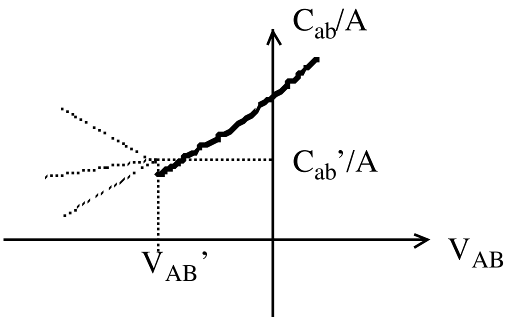
(i) $x_p = 0.15\ \mu m$

x_n = ____________ μm

(ii) $x_p = 0.3\ \mu m$

x_n = ____________ μm

(c) When the small signal capacitance of this diode is measured as a function of V_{AB}, when V_{AB} is less than zero so the diode is reverse biased, it (the capacitance) is found to decrease smoothly as the level of reverse bias increases until $x_n = 2\ \mu m$, when the slope changes. This behavior is illustrated in the plot below.



(i) Which of the four dashed curves best illustrates the variation of the capacitance for $V_{AB} < V_{AB}'$? Explain your answer.

_____ A _____ B _____ C because:

(ii) What is C_{ab}' / A?

C_{ab}' / A = ___________________ F/cm^2

Problem 2 continues on the next page

Problem 2 continued

(iii) What is V'_{AB} ?

V'_{AB} = _______________ Volts

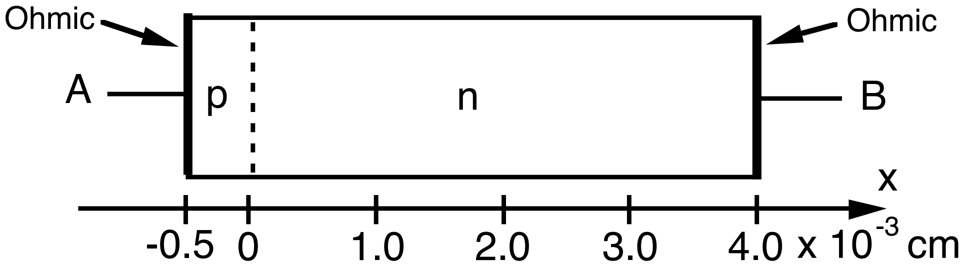
(d) What is the location and value of the peak electric field when x_n, the depletion width on the n-side of the junction, is 2.2 μm?

E_{peak} = ______________________ at x = __________ μm

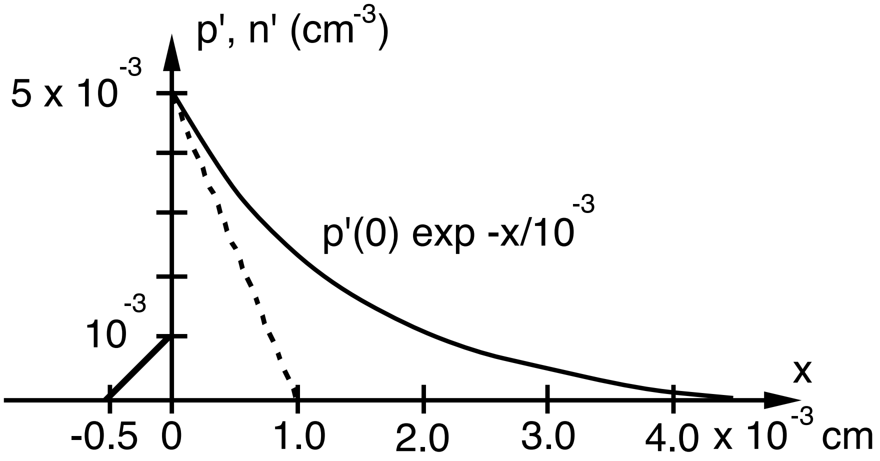
End of Problem 2

Problem 3 (36 points)

This problem concerns the silicon p-n diode illustrated below. The p-side of this diode is 5 µm long and doped to a level of 10^{18} cm^{-3}; the n-side is 40 µm long. Throughout the device the minority carrier lifetime is 10^{-7} s, $n_i = 10^{10}$ cm^{-3}, the mobility of holes is 400 cm^2/V-s, and the mobility of electrons is 1200 cm^2/V-s. (**Note:** These may not be the usual values you use for mobility.)



When a bias, V_{AB}, is applied to this diode, the resulting excess electron and hole distributions are as illustrated below (the depletion region widths have been neglected):



(a) What is n_{po}, the equilibrium electron population on the p-side of this diode?

n_{po} = __________________ cm^{-3}

(b) What is V_{AB}, the applied voltage?

V_{AB} = __________________ Volts

(c) What is N_{Dn}, the doping level on the n-side of this diode?

N_{Dn} = __________________ cm^{-3}

Problem 3 continues on the next page

Problem 3 continued

(d) What is $J_e(x)$, the electron current density on the p-side of the diode (that is, for $x < 0$) at this bias level? You may neglect the depletion region width in your calculation and expression.

$J_e(x)$ = ________________ A/cm^2

(e) What is $J_h(x)$, the hole current density on the n-side of the diode (that is, for $x > 0$) at this bias level? You may neglect the depletion region width in your calculation and expression.

$J_h(x)$ = ________________ A/cm^2

(f) What is J_{TOT}, the total current density in the diode at this bias level?

J_{TOT} = ________________ A/cm^2

(g) (i) Approximately what fraction of the holes crossing the junction from the p-side into the n-side recombine at the ohmic contact at x = 40 µm? Explain.

Approx. Fraction: ___________________

(ii) Approximately what fraction of the electrons crossing the junction from the n-side into the p-side recombine at the ohmic contact at x = - 5 µm? Explain.

Approx. Fraction: ___________________

(iii) What approximately is the total rate of hole-electron pair recombination per unit area occuring on the p-side of the junction?

Approx. Rate ________________ pairs/cm^2-s^1

End of Problem 3

End of the Exam