Department of Electrical and Computer Engineering, Cornell University

ECE 3150: Microelectronics

Spring 2015

Homework 3 **Due on Feb. 12, 2015 at 5:00 PM**

Suggested Readings:

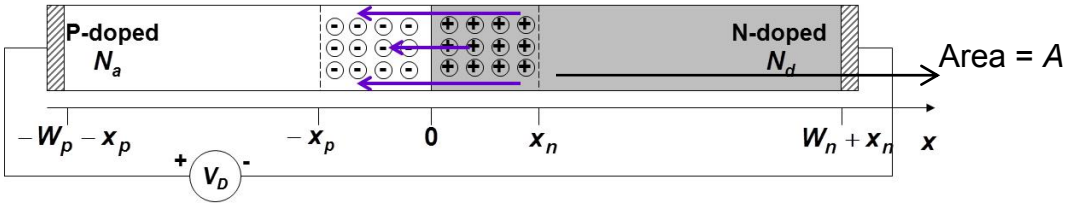
a) Lecture notes

Important Note:

1) MAKE SURE THAT YOU INDICATE THE UNITS ASSOCIATED WITH YOUR NUMERICAL ANSWERS. OTHERWISE NO POINTS WILL BE AWARDED.
2) Lab 1 is scheduled for the week of Feb. 09
3) Unless noted otherwise, always assume room temperature.

Problem 3.1: (PN Diodes in forward bias)

Consider the following PN diode structure.



$W_n = W_p = 2\ \mu\text{m}$

$N_d = 10^{16}\ 1/\text{cm}^3$

$\tau_p = \tau_n = \infty$

$\mu_n = 930\ \text{cm}^2/\text{V} - \text{s}$

$\mu_p = 310\ \text{cm}^2/\text{V} - \text{s}$

$A = 10^{-4}\,\text{cm}^2$

If $V_D = 0.476\ \text{V}$, then:

a) What is the TOTAL hole density (in #/cm^3) at $x = W_n + x_n$ (at the metal contact)?

b) What is the TOTAL hole density (in #/cm^3) at $x = x_n$ (at the edge of the depletion region)?

c) What is the total positive charge (in Coulombs) due to the excess holes that got injected into the N-side from the P-side in steady state?

d) What is the hole current density $J_p(0)$ at $x = 0$ (in Amps/cm^2)?

e) If the total negative charge (in Coulombs) due to the excess electrons, which got injected into the P-side from the N-side, in steady state is one-half of the total positive charge (in Coulombs) due to the excess holes that got injected into the N-side from the P-side in steady state (and found in part (c) above) then what is the doping N_a on the P-side of the diode?

f) Find the total diffusion capacitance C_d (in Farads) of the PN diode at the bias point?

g) What is the ratio of the electron current density $J_n(0)$ at $x = 0$ to the hole current density $J_p(0)$ at $x = 0$?

h) Plot (with proper units and labels) the electron and the hole current densities in the entire device (pay attention to the sign as well as the magnitude).

i) Find the diffusion component $J_p^{diff}(x)$ of the hole current density $J_p(x)$ in the range $-W_p - x_p < x < -x_p$ on the P-side of the junction (in Amps/cm^2) ?

j) Using your answer in part (i), find the drift component $J_p^{drift}(x)$ of the hole current density $J_p(x)$ in the range $-W_p - x_p < x < -x_p$ on the P-side of the junction (in Amps/cm^2)?

k) The drift component $J_p^{drift}(x)$ of the hole current density $J_p(x)$ in the range $-W_p - x_p < x < -x_p$ on the P-side of the junction can be written as,

$$J_p^{drift}(x) = q\mu_h\left(p_{po} + p'(x)\right)E_x \approx q\mu_h p_{po} E_x$$

Using your answer in part (j), Find the electric field in the quasi-neutral P-side (units: V/cm)? Of course, you will find that the field is non-zero. But it should be small. So quasi-neutral regions do have non-zero fields after all – they are just small.

l) Find the diode current (in Amps)?

m) Suppose you needed to redesign the PN diode such that the electron current contribution to the total diode current is 5 times larger than the hole current contribution to the total diode current. How will you choose the doping N_a of the P-side (in #/cm^3) to achieve this objective?

Now suppose $V_D = -0.476$ V, and assume as before that $W_n = W_p = 2\ \mu$m (i.e. ignore the variation in the depletion region size when going from forward to reverse bias), then:

n) What is the TOTAL hole density (in #/cm^3) at $x = W_n + x_n$ (at the metal contact)?

o) What is the TOTAL hole density (in #/cm^3) at $x = x_n$ (at the edge of the depletion region)?

p) Find and plot (with proper units and labels) the electron and the hole current densities in the entire device (pay attention to the sign as well as the magnitude).

q) Find the diffusion component $J_p^{diff}(x)$ of the hole current density $J_p(x)$ in the range $-W_p - x_p < x < -x_p$ on the P-side of the junction (in Amps/cm^2) ?

r) Using your answer in part (q), find the drift component $J_p^{drift}(x)$ of the hole current density $J_p(x)$ in the range $-W_p - x_p < x < -x_p$ on the P-side of the junction (in Amps/cm^2)?

s) The drift component $J_p^{drift}(x)$ of the hole current density $J_p(x)$ in the range $-W_p - x_p < x < -x_p$ on the P-side of the junction can be written as,

$$J_p^{drift}(x) = q\mu_h\left(p_{po} + p'(x)\right)E_x \approx q\mu_h p_{po}E_x$$

Using your answer in part (r), Find the electric field in the quasi-neutral P-side (units: V/cm)?

t) Find the diode current (in Amps)?