American University of Beirut

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

EECE 310 – Electronics Fall 2007 – 2008

Homework 5

Assume T = 300 degrees K

1. The maximum drift velocity of carriers in silicon is approximately 10^7 cm/sec.

a) What is the maximum drift current density that can be supported in an *p*-type silicon sample with a doping level of 5×10^{15} cm^{-3} ?
b) What is the conductivity of the silicon sample?
c) What is the corresponding voltage drop across the sample if it has a length of 100 μm?

2. The hole concentration in a silicon sample is described by:

$$p(x) = 10^3 + 10^{16}\exp(-x/L_p) \text{ holes/cm}^3$$

in which L_p is equal to 1.2 μm.

a) Find the diffusion current density for holes as a function of distance if D_p = 12 cm^2/sec.
b) What is the diffusion current at $x = L_p/2$ if the cross sectional area is 100 μm^2 ?

3. A PN junction diode is doped with $N_A = 2\times10^{16}$ cm^{-3} on the *p* side and $N_D = 3\times10^{15}$ cm^{-3} on the *n* side.

a) What are the hole densities in the *p*-type and in the *n*-type regions?
b) What are the free electron densities in the *p*-type and in the *n*-type regions?
c) What is the built-in potential barrier?

A reverse voltage of 5 V is now applied across the PN junction, with the N material is connected to the higher potential.

d) Find the width of the depletion region.
e) Find the depletion capacitance (per unit area).

I)

a) p-type: holes are majority carriers.

- Doping level: $N_A = 5\times10^{15}\ cm^{-3}$

- at 300 K ; $n_i = 1.5\times10^{10}\ cm^{-3}$.

- $p = N_A = 5\times10^{15}\ cm^{-3}$

- $n = \frac{n_i^2}{N_A} = 45000\ cm^{-3}$

- $V_{drift\,e^-} = V_{de^-} = \mu_n E$; $V_{drift\,holes} = V_{dh^+} = \mu_p E$

- Holes majority $\Rightarrow V_{drift(max)} = V_{dh^+} = 10^7\ cm/sec$.

- $\frac{V_{de^-}}{V_{dh^+}} = \frac{\mu_n}{\mu_p} = \frac{1350}{480} \Rightarrow V_{de^-} = 2.8125\times10^7\ cm/sec$

- $J_{max} = J_n + J_p = qn V_{de^-\,max} + qp V_{dh^+\,max} = (1.6\times10^{-19})[45000\times2.8\times10^7 + 5\times10^{15}\times 10^7 cm/s]$
$= 8000\ A/cm^2$

b) $\sigma = qp\mu_p + qn\mu_n = (1.6\times10^{-19})(5\times10^{15}\times480 + 45000\times1350) = 0.384\ \Omega^{-1}.cm^{-1}$

OR $\sigma = \frac{J}{E} = \frac{\mu_p J}{V_{dh^+}} = \frac{480\times8000}{10^7} = 0.384\ \Omega^{-1}.cm^{-1}$

c) $\Delta V = E.L = (\frac{10^7}{480})\times100\mu m = 208.33V$

II

a) $J_p = -q D_p \frac{dp}{dx}$

$\therefore \frac{dp}{dx} = \frac{d}{dx}(10^3 + 10^{16} e^{\frac{-x}{L_p}}) = -\frac{10^{16}}{L_p} e^{\frac{-x}{L_p}}$

$J_p = -1.6\times10^{-19}\times12\times\frac{-10^{16}}{1.2\times10^{-4} cm} e^{\frac{-x}{L_p}} = 160\, e^{\frac{-x}{L_p}}\ A/cm^2 = 160\, e^{\frac{-x}{1.2\mu m}}\ A/cm^2$

b) $I_{diff\,x=\frac{L_p}{2}} = A \cdot J_{p\,x=\frac{L_p}{2}} = 100\times10^{-8}\times160\, e^{-1/2} = 97\mu A$.

III a) In the p-type:

- $p_p = N_A = 2\times10^{16}\ cm^{-3}$

In the n-type:

- $p_n = \frac{n_i^2}{n} = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{3\times10^{15}} = 75000\ cm^{-3}$

b) In the p-type.

- $n_p = \frac{n_i^2}{N_A} = \frac{(1.5\times10^{10})^2}{2\times10^{16}} = 11250\ cm^{-3}$

- In the n-type

$n_n = N_D = 3\times10^{15}\ cm^{-3}$

c) $V_0 = V_T \ln\left[\frac{N_A N_D}{n_i^2}\right] = \frac{KT}{q}\ln\left[\frac{N_A N_D}{n_i^2}\right]$

$= (25.8\times10^{-3})\ln\left[\frac{6\times10^{31}}{(1.5\times10^{10})^2}\right] = 0.678\ V$

d) Width of depletion region $= W = x_n + x_p = \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)(V_0+V_R)}$

$W = \sqrt{\frac{2\times11.7\times8.854\times10^{-14}}{1.6\times10^{-19}}\cdot\left(\frac{1}{2\times10^{16}}+\frac{1}{3\times10^{15}}\right)(0.678+5)}$

$= 1.679\times10^{-4}\ cm = 1.679\ \mu m$

e) $C_j = \frac{\varepsilon_s A}{W_{dep}} \Rightarrow \frac{C_j}{A} = \frac{\varepsilon_s}{W_{dep}} = 6.17\ nF$