ECE 340 # Homework Assignment #6 **Fall 2015**

DUE: FRIDAY, OCTOBER 16, 2015

Print your **name** and **NetID** legibly. Follow the guidelines and format given in the syllabus. Staple multiple pages. Show all units. Homework must be turned in at the **beginning** of class and any late homework assignments will not be accepted. Please contact the course director, Professor Dallesasse, should any issues with late homework arise.

1. DIFFUSION IN P-TYPE SILICON

In a very long p-type Si bar with cross sectional area, $A = 5\,cm^2$, and $Na = 1E17\,cm^{-3}$, holes are injected such that the steady state excess hole concentration is $5E16\,cm^{-3}$ at x = 0. T = 300K in this problem.

(A). Given $\mu_p = 500\,cm^2/V-s$ and $\tau_p = 1E-10\,s$, calculate the diffusion coefficient and diffusion length of this Si sample.

(B). Write down an expression for excess hole with respect to position and draw it with labels such as Δp and L_p. With the aid of the sketch, derive an expression for the excess stored hole charge, Q_p and calculate Q_p.

(C). What is the maximum hole diffusion current and at which position does it take place?

(D). Calculate the steady state separation between E_c and E_{fp} at $x = 1E-5\,cm$.

2. DOPING GRADIENT AND ENERGY BAND BENDING

(A). An intrinsic Si sample of length $L = 5x_0$ is doped with donors from one side such that $N_d(x) = N_0 exp(-x/x_0)$, where $N_0 \gg n_i$ and x_0 is an arbitrary unit length. Sketch the equilibrium band diagram in the range, $0 \leq x \leq L$, and indicate the direction of resulting electric field. Also, is the electric field uniform?

(B). Repeat for acceptor doping with $N_a(x) = P_0 exp(-x/x_0)$, where $P_0 \gg n_i$. Is the electric field uniform?

(C). Repeat for $N_d(x) = -(N_0/5)(x/x_0) + N_0$ and $N_a(x) = -(P_0/5)(x/x_0) + P_0$. Is the electric field uniform?

(D). Please summarize: does linear doping profile produce uniform electric field? Why or why not?

3. THE DIFFUSION EQUATION

An n-type silicon sample doped with $N_d = 2E17\,cm^{-3}$ is in steady state with an excess hole concentration $\Delta p = 7E15\,cm^{-3}$ injected at $x = 0$. Assume the sample has a circular cross section with a diameter of $50\,\mu m$ and that $\mu_p = 600\,cm^2/V-s$ and $\tau_p = 2E-10\,s$.

(A). What is the hole concentration at a distance of $L_p/2$ into the semiconductor? A distance of $10L_p$?

(B). What is the hole current at each of the distances in part (b)?

(C). Starting from Eqn. 4-33b, derive an expression for $\Delta p_n(x)$ if the n-type silicon sample is of length L under steady state conditions assuming generation-recombination is negligible in the semiconductor and using the boundary conditions $\Delta p_n(0) = \Delta p_n$ and $\Delta p_n(L) = 0$. Rememer Δp_n stands for excess hole concentration in the n-region.

(C). Qualitatively speaking, for what lengths of semiconductor is this approximation (negligible generation-recombination) valid? Justify your answer given what you know about diffusion and generation-recombination processes within semiconductors.

4. More on doping profile and electric field

A bar of silicon has a donor doping profile of $n(x) = N_0 exp(-ax^2)$ where a is a constant. The doping level is high enough such that at any point the electron concentration $n = n(x)$.

(A). Derive an expressing for the built-in electric field as a function of x.

(B). If $a = 9E7\, cm^{-2}$, determine the position at which the electric field is $10^4\, V/cm$.

(C). Why is the electric field zero at $x = 0$?