UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE 130 / EE 230A, Fall 2013 Prof. Liu

**Homework Assignment #6**

Due at the beginning of class on Thursday 10/10/13

**Problem 1: pn Junction -- Carrier Concentration and Current Component Profiles**

Consider a Si pn step junction maintained at room temperature with applied voltage $V_A = (kT/q)\cdot ln(10^{10}) \cong 0.60$ V. The p-side and n-side dopant concentrations $N_A = 10^{17}$ cm$^{-3}$ and $N_D = 10^{18}$ cm$^{-3}$, respectively. (You may assume that each side is uncompensated.) The minority carrier recombination lifetimes are $\tau_n = 10^{-6}$ s and $\tau_p = 10^{-6}$ s on the p-side and n-side, respectively.

**(a)** Calculate the minority carrier concentrations at the edges of the depletion region.

**(b)** Calculate the minority carrier diffusion lengths on the p-side and on the n-side.
Hint: Use the values of carrier mobilities from Lecture 4 Slide 17.

**(c)** Based on your answers to (a) and (b), sketch the minority carrier concentration profiles on a semi-log plot, assuming that each side is much longer than the minority-carrier diffusion length.

**(d)** Derive expressions for the minority-carrier diffusion current in the quasi-neutral regions. Sketch the electron and hole current density components ($J_N$ and $J_P$, respectively) as a function of distance on both sides of the junction. Indicate the values of $J_N$ and $J_P$ in the depletion region, as well as the total current density $J$.

**Problem 2: pn Junction -- *I-V* Characteristics**

Consider a Si pn$^+$ step junction with p-side doping $N_A = 10^{17}$ cm$^{-3}$ (uncompensated) and area $A = 10^{-2}$ cm$^2$. The electron recombination lifetime in the p-side is $\tau_n = 10^{-6}$ s.

**(a)** Compute the ideal diode current at $T = 300$K for
- **(i)** $V_A = -5$ V
- **(ii)** $V_A = +0.1$ V
- **(iii)** $V_A = +0.5$ V
- **(iv)** $V_A = +0.8$ V

**(b)** Assuming that $\tau_n$ does not vary significantly with temperature, repeat (a) for $T = 400$K.
Hint: Do not forget to take into account the dependence of mobility (and hence diffusion constant) on temperature – see Lecture 4 Slide 18. Also, you should account for the temperature dependence of the energy bandgap of Si: $E_G = 1.205 - 2.8\times10^{-4}(T)$ for $T > 300$K (from HW#2, Problem 4).

**(c)** Based on your answers in parts (a) and (b), sketch the diode *I-V* characteristics (on a linear scale) for $T = 300$K and $T = 400$K. Describe the key changes in the diode *I-V* characteristic with increasing temperature.

**Problem 3: Narrow-Base Diode**

Consider a Si pn$^+$ step junction maintained at room temperature with cross-sectional area $A = 10^{-2}$ cm$^2$. The p-side and n-side dopant concentrations $N_A = 10^{17}$ cm$^{-3}$ and $N_D = 10^{19}$ cm$^{-3}$, respectively. (You may assume that each side is uncompensated.) The minority carrier recombination lifetimes are $\tau_n = 10^{-6}$ s and $\tau_p = 10^{-6}$ s on the p-side and n-side, respectively. The width of the quasi-neutral n-type region is 0.1 μm, for $V_A = 0$ V. (The p-side is much longer than the electron diffusion length.)

**(a)** Is this a narrow-base diode? **Justify your answer.**

**(b)** Calculate the diode saturation current $I_0$.

**(c)** What value of applied bias $V_A$ is required to obtain a diode current of 1 mA?

**Problem 4: pn Junction Reverse Breakdown**

Consider a Si p$^+$n step junction with n-side doping $N_D = 10^{17}$ cm$^{-3}$ maintained at room temperature:

**(a)** Calculate the breakdown voltage $V_{BR}$, assuming that the critical electric field $\mathcal{E}_{CR} = 7\times10^5$ V/cm.

**(b)** Calculate the depletion width at the breakdown voltage.

**(c)** What is the dominant breakdown mechanism? Explain briefly.

**(d)** How would $V_{BR}$ change if the temperature were to be increased? Explain briefly.