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

EE 130 / EE 230A Prof. Liu
Fall 2013

Homework Assignment #3
Due at the beginning of class on Thursday 9/19/13

Problem 1: Carrier Mobility – Dependence on Temperature
Suppose you need to make a sensor for measuring the ambient outside temperature in Berkeley ($10^{o}C \leq T \leq 40^{o}C$) based on the change in resistance of a bar-shaped piece of silicon that is uniformly and non-degenerately doped.

(a) Is it preferable to use a low level (*e.g.* 10^{15} cm^{-3}) of doping, or a high level (*e.g.* 10^{18} cm^{-3}) of doping? Explain briefly.

(b) If the silicon bar is doped with phosphorus to a concentration of 10^{16} cm^{-3} and has resistance $R = 100\Omega$ at $T = 300K$, estimate the sensitivity (dR/dT in Ω per ^{o}C) of the sensor at $T = 300K$. How does the sensitivity change with increasing temperature?

Problem 2: Carrier Drift
A silicon sample doped with boron is maintained at $T = 300K$. When an electric field with strength 1×10^{3} V/cm is applied to the sample, the electron drift velocity is 1.2×10^{6} cm/sec.

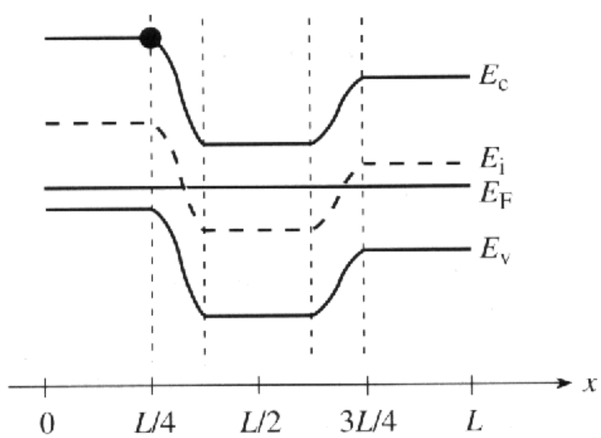
(a) Estimate the boron concentration in this sample.

(b) What is the mean free path of an electron in this sample? **Note: 1 kg cm^{2}/V/s/C = 10^{-4} sec**

(c) What is the resistivity of this sample?

(d) Qualitatively (no calculations required), how would your answer to (c) change if this sample were to be additionally doped with 1×10^{17} cm^{-3} phosphorus atoms? Explain briefly.

Problem 3: Non-Uniformly Doped Semiconductor
A silicon sample maintained under equilibrium conditions at $T = 300K$ is characterized by the energy band-diagram below:



a) Sketch the electrostatic potential $V(x)$ inside the semiconductor as a function of x.

b) Sketch the electric field $\mathcal{E}(x)$ inside the semiconductor as a function of x.

c) Suppose the electron pictured in the diagram moves back and forth between $x = 0$ and $x = L$ without changing its total energy. Sketch the kinetic energy and potential energy of the carrier as a function of x.
d) Roughly sketch n and p versus x
e) On the same set of coordinates, make a rough sketch of the electron drift-current density and the electron diffusion-current density as a function of position. Briefly explain how you arrived at your sketch.

Problem 4: Generation and Recombination of Mobile Charge Carriers

Assume that the energy level associated with defects within a Si sample is near midgap (*i.e.* $E_T \approx E_i$) so that $n_1 \approx p_1 \approx n_i$ (ref. Lecture 5 Slide 24) and that τ_n is comparable to τ_p. Setting $\Delta n = \Delta p$, show that the general-case R-G relationship

$$-\frac{\partial \Delta n}{\partial t} = -\frac{\partial \Delta p}{\partial t} = \frac{pn - n_i^2}{\tau_p(n+n_1) + \tau_n(p+p_1)}$$

reduces to the special-case relationships

$$\frac{\partial n}{\partial t} = -\frac{\Delta n}{\tau_n} \quad \textbf{for electrons in p-type material} \qquad \frac{\partial p}{\partial t} = -\frac{\Delta p}{\tau_p} \quad \textbf{for holes in n-type material}$$

when **low-level injection** conditions prevail.