Introduction to Semiconductor Devices
(Purdue University EE 305/606)
Supplemental Homework Exercises

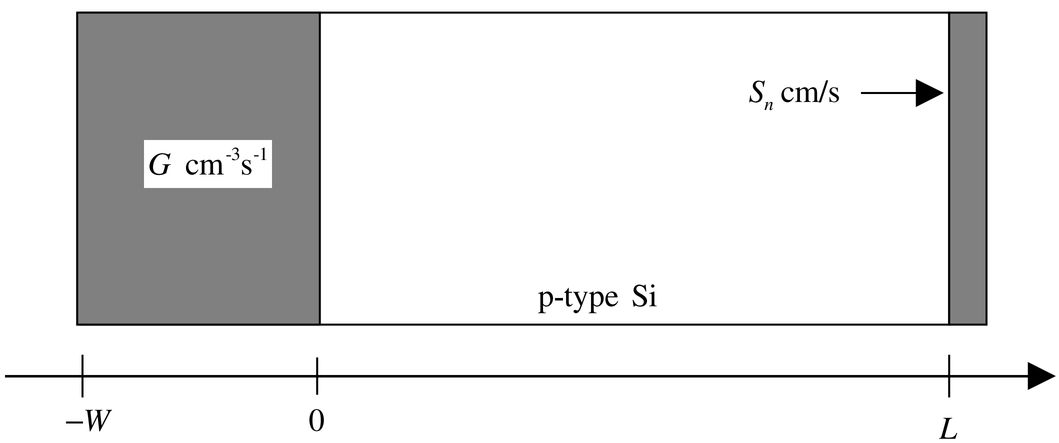
Tutorial questions based on Drift-Diffusion Lab v1.0 available online at http://www.nanohub.org.

Reference book: Semiconductor Device Fundamentals by Robert E. Pierret (Chapter 3)

Concept:Diffusion and Ambipolar Diffusion in Uniform Semiconductor

The purpose of these exercises is to familiarize you with minority carrier diffusion in semiconductors. Recall that for a uniformly doped, p-type semiconductor with a uniform electron-hold generation rate of G elecron-hole pairs /cm^3.s, the excess minority carrier (electron) density is, $\Delta n = G\tau_n$, where τ_n is the minority carrier lifetime.

Now consider a semiconductor as shown below.



Assume that the electron-hole generation rate is G for $x \le 0$ and that the contact at $x = L$ is specified by a minority carrier surface recombination velocity, S_n. Our objective is to determine the $\Delta n(x)$ profile for $x > 0$. We will do this with the computer simulation tool, Drift-Diffusion Lab, on www.nanoHUB.org, but before doing a computer simulation, we should always know what to expect, so we begin with an analytical calculation.

1) Assume that $\Delta n = G\tau_n$ for $x \le 0$ (this is an approximation that ignores edge effects near $x = 0$.). Also assume that the diffusion length, $L_n = \sqrt{D_n \tau_n} << L$ and that $S_n \to \infty$. Derive an expression for $\Delta n(x)$ for $x > 0$. Make a sketch of the result.

2) Repeat problem 1) but this time assume that the diffusion length, $L_n = \sqrt{D_n \tau_n} >> L$ and that $S_n \to \infty$. Derive an expression for $\Delta n(x)$ for $x > 0$. Make a sketch of the result.

3) Repeat problem 2) but this time assume that that $S_n = 0$. Derive an expression for $\Delta n(x)$ for $x > 0$. Make a sketch of the result.

Now that we know what to expect, we are ready to do a numerical simulation with the simulation tool, Drift-Diffusion Lab, on the nanoHUB.
(Turn ON *Surface Recombination to set* S_n)
For the exercises below, assume:

0 $N_A = 1 \times 10^{15}$ *cm*$^{-3}$ *for the bulk doping*
G = 2e20 cm3 –s
L+W = 10um
W=1um
T = 300K
μ_p *~1300 cm2 /V.s*
μ_n *~ 460 cm2/V.s*

4) Choose the minority carrier lifetime, τ_n, so that L_n =2um. (Also set $\tau_n = \tau_p$ and $S_n = 10^7$ in the simulation.) Run the simulation and examine $\Delta n(x)$. Compare the numerical result to the analytical result and discuss the similarities and differences.

5) For the simulation of problem 4), examine the minority carrier current density, $J_n(x)$. Explain why the plots have the shape that it does.

6) Choose the minority carrier lifetime, τ_n, so that L_n =50um. (Also set $\tau_n = \tau_p$ and $S_n = 10^7$ in the simulation in the simulation.) Run the simulation and examine $\Delta n(x)$. Compare the numerical result to the analytical result and discuss the similarities and differences.

7) For the simulation of problem 6), examine the minority carrier current density, $J_n(x)$. Explain why the plots have the shape that it does.

8) Excess electronics, $\Delta n(x)$, should attract excess holes, $\Delta p(x)$. We expect that the attraction of opposite charges should lead to a semiconductor that is approximately neutral, $\Delta n(x) \approx \Delta p(x)$.. Rerun problem 4) and examine $\Delta n(x)$ and $\Delta p(x)$. You will note that they are a little different. Explain the difference. HINT: you may also want to examine the electric field profile and the space charge density and think about the consequences of the fact that electrons and holds have different mobilities.