

**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 : Drift

Q1) Let us consider an intrinsic Si slab of length 0.1um at room temperature (T=300 K).

(Select Experiment #1 for this question)

- (a) Dope the semiconductor to $N_a = 1e14 /cm^3$ and ramp voltage from 0 to 2V. Comment on the I-V characteristics.
- (b) Now dope the semiconductor to $N_d = 1e14 /cm^3$ and ramp voltage from 0 to 2V. Comment on the I-V characteristics.
- (c) Generate v_d (cm/sec) vs E (V/cm) curves for holes and electron from (a) and (b). What is the saturation velocity?
- (d) Extract electron (μ_n) and hole (μ_p) mobility values from the figure generated above.

Q2) Now, let us consider an Si slab of length 0.5 um. (Select Experiment #1 for this question)

- (a) At room temperature, dope it N-type (N_d) in steps from $1e14/cm^3$ to $1e18/cm^3$. Calculate electron mobility (μ_n) for each doping level.
- (b) Similarly dope the semiconductor P-type (N_a) in steps from $1e14/cm^3$ to $1e18/cm^3$. Calculate hole mobility (μ_p) for each doping level.
- (c) Plot μ_n vs N_d and μ_p vs N_a . Why do mobility values reduce at high doping levels ?
- (d) For each doping level in (a) vary temperature (T) from 200 K to 500K.
- (e) For each doping level in (b) vary temperature (T) from 200K to 500K.
- (f) Plot μ_n vs T and μ_p vs T at different doping levels. Why does mobility increase with decreasing temperature?

Concept: Diffusion

Q3) Consider a Si slab of length 4 um at room temperature. Let light shine on the left edge with a penetration depth of 0.1 um. The e-h pair generation rate due to light shining be, $G = 1e23 /cm^3.s$. In reality the minority carrier life times are in the order of few hundreds of micro-seconds. Diffusion length (L_p) calculated using

$L_p = \sqrt{D_p \times \tau_p}$, where D_p and τ_p are diffusion coefficient and minority carrier life time.

- (a) Calculate the diffusion length for a
 1. n- type semiconductor slab with $\tau_p = 10 \mu s$. What is the hole diffusion coefficient provided bulk silicon hole mobility is $450 \text{ cm}^2 \text{ V}^{-1}\text{s}^{-1}$ at 300K.
 2. p- type semiconductor slab with $\tau_n = 10 \mu s$. What is the electron diffusion coefficient provided bulk silicon electron mobility is $1400 \text{ cm}^2 \text{ V}^{-1}\text{s}^{-1}$ at 300K.

How does this length compare with the actual device lengths ?

(b) To understand the phenomena of diffusion we can choose a ratio for D_p / L_p where D_p is the diffusion coefficient and L_p is the minority diffusion length. This ratio for device simulation must be kept small which is governed by the minority carrier life time

according to this formula :
$$\frac{L_p}{\tau_p} = \frac{D_p}{L_p}$$

Using the calculated diffusion coefficients from part (a), what value for minority carrier life time must be set to obtain a diffusion length of around $1\mu\text{m}$?

Now set $\tau_n = 1\text{ns}$ and $\tau_p = 1\text{ns}$ (for simulation purpose) and do the following simulations.

(c) If the semiconductor is doped N-type $N_d = 1 \times 10^{15} / \text{cm}^3$. Do low level injection conditions prevail inside the illuminated bar. Explain?

(d) Sketch excess minority carrier concentration and compare with simulated result. Calculate hole diffusion coefficient, D_p from this result.

(e) Suppose the semiconductor was P-type $N_a = 1 \times 10^{15} / \text{cm}^3$. Do low level injection conditions prevail inside the illuminated bar?

(f) Sketch excess minority carrier concentration and compare with simulated result. Calculate electron diffusion coefficient, D_n from this result.

How do the values of diffusion coefficient calculated compare with the values from part (a).

Concept: Quasi-Fermi Level

Q4) Consider a Si slab of $1\mu\text{m}$ length at room temperature ($T = 300\text{K}$). Light is shone at the top of it with generation rate at the surface, $G = 2 \times 10^{20} / \text{cm}^3 \cdot \text{s}$. (as shown in figure 1)

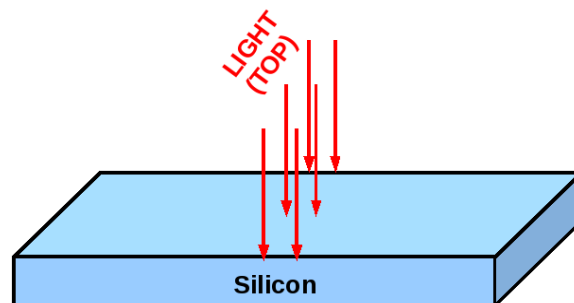


Figure 1: Light shining on a silicon slab

(a) Let the semiconductor be intrinsic and shine light from $0.4\mu\text{m}$ to $0.6\mu\text{m}$. Sketch the quasi Fermi levels and compare with simulated result. Why does f_p (Quasi Fermi level for

holes) show more dip than f_n (Quasi Fermi level for electrons)? (You can use other results to support your answer)

(b) Now shine light on the left half of the slab. (set light start at 0.0um and light end at 0.5um). Perform the simulation. Sketch the band diagrams and quasi Fermi levels expected and compare. Explain the physical reason and support it using the results from the tool.

(c) Now repeat the same experiment on the right half of the slab. (set light start at 0.5um and light end at 1.0um). Sketch the band diagrams and quasi Fermi levels expected and compare.

(d) What do you observe in the transient current characteristics for (b) and (c)? Explain the physical reason.