Suggested Readings:

a) Lecture notes

Important Note:
1) MAKE SURE THAT YOU INDICATE THE UNITS ASSOCIATED WITH YOUR NUMERICAL ANSWERS. OTHERWISE NO POINTS WILL BE AWARDED.
2) Lab 1 is scheduled for the week of Feb. 12
3) Unless noted otherwise, always assume room temperature.

Problem 2.1: (Currents in semiconductors)

Consider a doped semiconductor in thermal equilibrium in which the electrostatic potential (with respect to intrinsic silicon) has been measured and found to be as indicated in the figure below. Assume that \( \mu_n = 1000 \text{ cm}^2/\text{V} \cdot \text{s} \) and \( \mu_p = 500 \text{ cm}^2/\text{V} \cdot \text{s} \).

![Graph showing electrostatic potential vs distance](image)

a) Plot the electron and hole concentrations (with units) vs \( x \) for \( 0 \leq x \leq 6 \mu\text{m} \).
b) Plot the electric field (with units) vs $x$ for $0 \leq x \leq 6 \, \mu m$.

c) Calculate and plot the electron drift current density (with units) vs $x$ for $0 \leq x \leq 6 \, \mu m$.

d) Calculate and plot the electron diffusion current density (with units) vs $x$ for $0 \leq x \leq 6 \, \mu m$.

**Problem 2.2: (Resistance engineering in semiconductors)**

![Silicon slab diagram]

a) Consider a piece of P-doped silicon with an area $A$ equal to 1.0 sq-$\mu m$ and length $L$ equal to 10 $\mu m$. It is required that the resistance of this piece be 100 $\Omega$. If the hole diffusivity is $D_p$ is 27 cm$^2$/s, find the p-doping necessary to achieve the desired resistance value.

**Problem 2.3: (Photoconductors)**

A photoconductor is a device that changes its resistance when exposed to light.

![Light and Silicon slab diagram]

Consider a device consisting of a piece of P-doped silicon ($N_a = 10^{15}$ cm$^{-3}$) with an area $A$ equal to 1.0 sq-$\mu m$ and length $L$ equal to 1 $\mu m$. The electron and the hole mobilities are 1000 and 300 cm$^2$/V-s, respectively. The minority carrier lifetime $\tau_n$ is 1 $\mu s$.

a) What is the resistance of the device under no light illumination?
b) Suppose the device is exposed to light and which illuminates the device uniformly. Light illumination results in electron-hole generation rate $G_L$ of $10^{20} \text{1/(cm}^3\text{-s)}$. Find the resistance of the device under this light illumination? Assume that the light was turned on in the remote past.

In many schemes used for optical communications, light intensity is modulated in time. We will assume in the parts that follow that the light induced generation rate $G_L(t)$ is time-dependent and the time dependence is sinusoidal at a frequency $\omega$ and can be expressed in terms of a phasor:

$$G_L(t) = g_\ell + \text{Re}\left\{g_\ell e^{j\omega t}\right\} = g_\ell (1 + \cos \omega t)$$

c) As a result of the time-dependent illumination, the excess electron and hole concentrations are time-dependent and can be written as,

$$n'(t) = n'_\text{DC} + \text{Re}\left\{n'(\omega) e^{j\omega t}\right\}$$
$$p'(t) = p'_\text{DC} + \text{Re}\left\{p'(\omega) e^{j\omega t}\right\}$$

Find expressions that relate the phasors $n'(\omega)$ and $p'(\omega)$ to $g_\ell$ in steady state.

The current in the circuit, under the time-dependent illumination, is also time-dependent and given by,

$$I(t) = I_\text{DC} + \text{Re}\left\{i(\omega) e^{j\omega t}\right\}$$

d) Find an expression for $I_\text{DC}$?

e) Find an expression that relates the current phasor $i(\omega)$ to $g_\ell$.

f) You would have noticed in part (e) that the magnitude $|i(\omega)|$ of the current phasor decreases with the frequency $\omega$. The magnitude $|i(\omega)|$ is the largest when $\omega \approx 0$. At what frequency $\omega$ (in rad/s) would the squared-magnitude $|i(\omega)|^2$ of the current phasor decrease to half its value at $\omega \approx 0$? Hint: try to relate this frequency to the minority carrier lifetime.

**Lesson:** The minority carrier lifetime in this photoconductor device sets the upper limit for the frequencies at which this device can be used for optical communications.