# ECE 255 Spring 2019

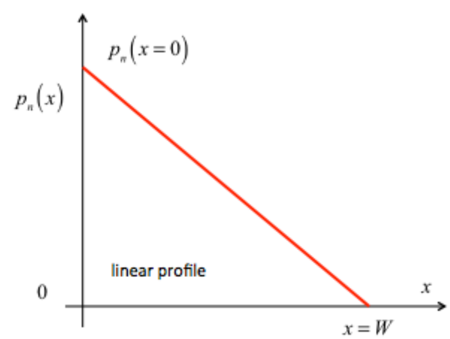
## Homework 2

## Due 5:00 PM **Tuesday**, Jan 22 in MSEE 180 Dropbox

1) As shown in the figure below, minority carrier holes are injected into an N-type Si layer of width, $W$. (We will see later that this can be done with a PN junction.) Assume that $p_n(x=0)=10^{14}\text{ cm}^{-3}$, $p_n(x=W)=0$, $\mu_p=300\text{ cm}^2/\text{V-s}$, $W=100\text{ nm}$, and that $T$ = 300 K. Answer the following questions.

1a) Compute the sign and magnitude of the hole **current density** in A/cm$^2$.

1b) What is the sign and magnitude of the average hole velocity at $x$ = 0? Hint: The current density is proportional to the average velocity.




2) Assuming the linear profile of minority carriers as shown in the figure above, derive an expression for the average time it takes for holes to diffuse across a region of thickness, W. This is called the "transit time," $t_t$. Hint: Remember that current is charge divide by time, so $I=Q/t_t$, where $Q$ is the total minority carrier hole charge in the N-region.

3) The relationship $J=\sigma\mathcal{E}$ is an alternative form of Ohm's law. Show that this is equivalent to the ECE-201 version ($V = IR$), by considering a uniformly doped, rectangular bar of semiconductor material with length $L$ (along direction of current flow) and cross-sectional area A (perpendicular to current flow). You may assume that the electric field, $\mathcal{E}$, is uniform along the length of the bar.

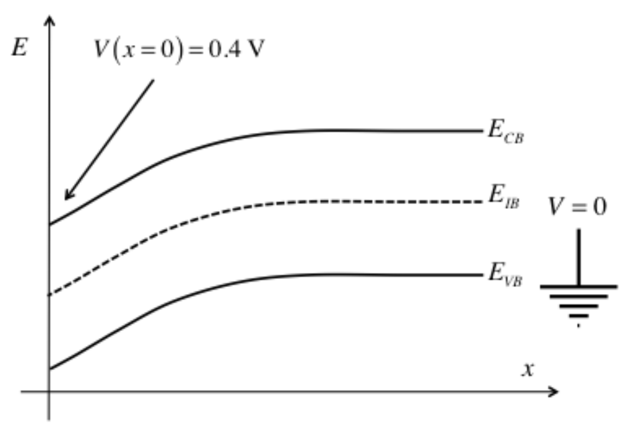
4) Assume a silicon resistor uniformly doped N-type at $N_D = 3\times10^{17}$ cm$^{-3}$. The temperature is 300 K and the mobility is $\mu_n = 500\,\text{cm}^2/\text{V-s}$. The resistor is 10 micrometers ( $\mu$m) long. The voltage at $x = 0$ is 0 V and the voltage at $x = 10\ \mu$m is 1.5 V. Answer the following questions.

4a) What is the average electron velocity in cm/s in the +x direction?

4b) What is the magnitude of the drift current density in A/cm$^2$?

4c) What is the direction of the drift current (+x or –x)?

5) Consider the equilibrium energy band diagram shown below. The semiconductor is silicon at 300 K with $n_i = 10^{10}$ cm$^{-3}$. The wafer is doped P-type at $N_A = 10^{18}$ cm$^{-3}$, so that for $x >> 0$ $p_B = 10^{18}$ cm$^{-3}$. Answer the following questions assuming that the dopants are fully ionized.




5a) What is the equilibrium electron density at $x = 0$?

5b) What is the equilibrium hole density at $x = 0$?

5c) What is the space charge density in C/cm$^3$ at $x = 0$? Be sure to include the sign.

6) Consider a PN junction in equilibrium with $N_A = 10^{17}$ cm$^{-3}$ and $N_D = 10^{18}$ cm$^{-3}$ at $T$ = 300 K. Answer the following questions.

6a) If the material is Si with $n_i = 1\times10^{10}$ cm$^{-3}$, what is the built-in potential, $V_{bi}$, of the PN junction?

6b) If the material is Si with $n_i = 1\times10^{10}$ cm$^{-3}$, but the doping on both sides of the junction is increased by 10X, what is the built-in potential, $V_{bi}$, of the PN junction?

6c) If the material is GaAs at $T$ = 300 K with $n_i = 2\times10^{6}$ cm$^{-3}$, with $N_A = 10^{17}$ cm$^{-3}$ and $N_D = 10^{18}$ cm$^{-3}$, what is the built-in potential, $V_{bi}$, of the PN junction?

6d) Compare your answers to the above questions to the band gap of the semiconductor.

7) Consider a silicon PN junction with $N_A = 10^{16}$ cm$^{-3}$ and $N_D = 10^{19}$ cm$^{-3}$ at T = 300 K, so that $n_i = 1\times10^{10}$ cm$^{-3}$. The thickness of the undepleted N-region is 100 nm and of the undepleted P-region is 200 nm. The electron mobility is 1200 cm$^2$/V-s, and the hole mobility is 70 cm$^2$/V-s. The area of the PN junction is 500 nm X 500 nm. Answer the following questions.

7a) What is the saturation current density, $I_S$, in A/cm$^2$?

7b) What voltage must be applied so that the diode current is $10^{-12}$ A?

7c) What voltage must be applied so that the diode current is $10^{-5}$ A?