1. Experimental results show that the band gap energy ($E_g$) in silicon decreases with temperature ($T$). As we discussed in class, $E_g$ vs. $T$ is modeled by an empirical relation in SPICE simulator and is given by:

$$E_g(T) = 1.160 - \frac{7.02 \times 10^{-4} T^2}{T + 1108} \text{ (eV)}$$

Here, $T$ is in Kelvin.

(a) **Compute** and **plot** $E_g$ for $0 \leq T \leq 600$.

(b) From the plot **extract** $E_g(T = 300 \, ^o\text{K})$.

(c) $E_g$ vs. $T$ is, also, modeled by a polynomial equation that predicts more accurate value of $E_g$ at 300$^o$K.

$$E_g(T) = 1.206 - 2.73 \times 10^{-4} T \text{ (eV)}$$

**Compute** $E_g(T)$ using the polynomial equation and **plot** $E_g$ vs. $T$ on the same graph as in part (a). **Show** the range of temperature at which the polynomial equation is valid. **Extract** the correct value of $E_g(T = 300^o\text{K})$ from the polynomial equation.

2. An n-type semiconductor is doped with $N_D = 1 \times 10^{15} \text{ cm}^{-3}$ and has the minority-carrier lifetime = 1 $\mu$sec. (Given: $n_i = 10^{10} \text{ cm}^{-3}$, $\mu_n = 1345 \text{ cm}^{-2}/\text{V-sec}$, and $\mu_p = 458 \text{ cm}^{-2}/\text{V-sec}$).

(a) **Calculate** the steady-state electron and hole concentrations under light that creates $10^{20} \text{ cm}^{-3} \text{ sec}^{-1}$ electron-hole pairs.

(b) **Calculate** and **sketch** the position of equilibrium $E_F$ relative to $E_i$.

(c) **Calculate** and **sketch** the position of quasi-Fermi levels $E_{FN}$ and $E_{FP}$ relative to $E_i$.

(d) **Compare** the position of equilibrium Fermi level in part (b) with that of the steady state quasi-Fermi levels under the light in part (c). **What** are the similarities and differences? **EXPLAIN**.

3. Consider an ideal short-base diode with a uniform cross-section and constant doping on either side of the junction. The diode is made from 1.5 ohm-cm p-type and 0.5 ohm-cm n-type materials. The length of the p-type material is 10 $\mu$m and that of the n-type is 2 $\mu$m.

(a) **What** is the built-in voltage?
(b) Calculate the density of the minority carriers at the edge of the space-charge region when the applied voltage is 0.6 V.

(c) Under the applied bias of part (b), sketch the majority and minority carriers versus distance on both sides of the junction.

(d) Under the applied bias of part (b), sketch the majority and minority carrier currents versus distance on both sides of the junction.

4. An ion-implanted IC resistor is shown below. The doping concentrations for the n- and p-type regions are \( N_D = 2.5 \times 10^{16} \text{ cm}^{-3} \) and \( N_A = 2.5 \times 10^{15} \text{ cm}^{-3} \), respectively. The junction depth \( X_j = 0.4 \mu m \), the width of the n-type region is \( W = 2.5 \mu m \), and its length is \( L = 20 \mu m \). The contact regions are each \( 3W \times 3W \) in area as shown in Figure below.

(a) Calculate the depletion width \( X_{no} \) for \( V_D = 0 \).

(b) Calculate the sheet resistance of the n-type region.

(c) Assuming the DC voltage \( V_D = 0 \), calculate the depletion capacitance, \( C_D \) in \( fF \) between the n-region and the p-type substrate.

(d) Draw a simple small-signal model of the ion-implanted resistor for the case with \( V_D = 0 \).

5. Consider the structure shown below which can be regarded as two PN junctions connected back to back.

(a) Draw the equilibrium band diagram. Calculate and label all barrier heights and depletion region widths.

(b) Draw e-field vs. position for the structure shown in part (a). Calculate and label all significant points.