1) The doping profile for an n-type silicon wafer \( (N_D = 10^{15} \text{ cm}^{-3}) \) with a heavily doped thin layer at the surface (surface concentration, \( N_S = 10^{20} \text{ cm}^{-3} \)) is sketched below. Answer the following questions.

1a) Assume approximate space charge neutrality \( (n(x) \approx N_D(x)) \) and equilibrium conditions and compute the position of the Fermi level with respect to the bottom of the conduction band at \( x = 0 \) and as \( x \rightarrow \infty \).

1b) Using the above information, sketch \( E_C(x) \) vs. \( x \). Be sure to include the Fermi level.

1c) Sketch the electrostatic potential vs. position.

1d) Sketch the electric field vs. portion.

1e) Derive an expression for the position dependent electric field, \( E(x) \), in terms of the position-dependent doping density, \( N_D(x) \). HINT: Use the electron current equation and assume equilibrium conditions.
HW Week 8 Continued

2) A silicon diode is symmetrically doped at $N_D = N_A = 10^{15} \text{ cm}^{-3}$. Answer the following questions assuming room temperature, equilibrium conditions, and the depletion approximation.

2a) Compute $V_{bi}$.
2b) Compute $x_n, x_p$ and $W$.
2c) Compute $V(x = 0)$ and $E(x = 0)$.
2d) Sketch $\rho(x)$ vs. $x$.

3) Your textbook (Pierret, SDF) presents the “classic” expressions for PN junction electrostatics. Simplify these expressions for a “one-sided” P+N junction for which $N_A \gg N_D$. Present simplified expressions (when possible) for:

3a) The built-in potential, $V_{bi}$, from Pierret, Eqn. (5.10).
3b) The total depletion layer depth, $W$, from Pierret, Eqn. (5.31).
3c) The peak electric field, $E(0)$, from Pierret, Eqn. (5.19) or (5.21).
3d) The electrostatic potential, $V(x)$ from Pierret, Eqn. (5.28)

4) A silicon diode is asymmetrically doped at $N_A = 10^{19} \text{ cm}^{-3}$ and $N_D = 10^{15} \text{ cm}^{-3}$ Answer the following questions assuming room temperature, equilibrium conditions, and the depletion approximation.

2a) Compute $V_{bi}$.
2b) Compute $x_n, x_p$ and $W$.
2c) Compute $V(x = 0)$ and $E(x = 0)$.
2d) Sketch $\rho(x)$ vs. $x$.

5) Repeat problem 4) using the “exact” solution to PN junction electrostatics.
6) Semiconductor devices often contain “high-low” junctions for which the doping density changes magnitude, but not sign. The example below shows a high-low step junction. Answer the questions below.

\[ \text{log}_{10} N_D(x) \]
\[ N_{D1} = 10^{18} \]
\[ N_{D2} = 10^{15} \]
\[ x = 0 \rightarrow x \]

6a) Sketch an energy band diagram for this junction.
6b) Sketch \( V(x) \)
6c) Sketch \( E(x) \)
6d) Sketch \( \rho(x) \) vs. \( x \).
6e) Name the charged entities responsible for \( \rho(x) \) in 6d).
6f) Explain why the depletion approximation cannot be used for this problem.
6g) Calculate \( V_{bi} \) for this high-low junction assuming silicon at room temperature.

7) Consider an \( N^+P \) diode with the length of the quasi-neutral P-region being, \( W_P \). Answer the following questions assuming that recombination in the space-charge region can be neglected.

7a) Derive a general expression for \( I_D(V_A) \) valid for a P region of any length, \( W_P \).
7b) Simplify the expression derived in 7a) for a “long diode”. Explain what “long” means (i.e. \( W_P \) is long compared to what?)
7c) Simplify the expression derived in 7a0 for a “short diode”. Explain what “short” means.
8) Consider a P+N diode that is illuminated with light that produces a uniform generation, $G_L$, of electron-holes pairs per cm$^3$ per second. You may assume that the N-region is long compared to a diffusion length.

8a) Consider first a uniform, infinitely long N-type semiconductor with a uniform generation rate and solve for the steady-state excess minority carrier density, $\Delta p$.

8b) Now consider the illuminated P+N diode. What are the boundary conditions at $\Delta p_n(x_n)$ and $\Delta p_n(x \to \infty)$?

8c) Use the boundary conditions developed in 8b), neglect recombination-generation in the SCR and in the P+ layer, and solve for $I_D(V_A)$ for this illuminated diode.

8d) Sketch $I_D(V_A)$ for $G_L = 0$, $G_L = G_0$ and $G_L = 2G_0$. 