ECE 336: Semiconductor Devices
Sheet 3

Chapter 5:

1. **True of false**
    a. The step junction is an idealized doping profile used to model p^+-n and n^+-p junctions.
    b. The ρ that appears in Poisson's equation is the charge density and has units of couls/cm^3.
    c. The space charge region about the metallurgical junction is due to a pile-up of electrons on the p-side of the holes on the n-side.
    d. The built-in potential is typically less than the band energy converted to volts.
    e. Invoking the depletion approximation makes the charge density inside the region directly proportional to the doping concentration.
    f. Ohmic contacts reduce the built-in voltage drop across a junction.
    g. In solutions based on the depletion approximation, the magnitude of the electric field reaches a maximum right at the metallurgical boundary.
    h. If one has p^+-n step junction, a junction where N_A (p-side) $\gg N_D$ (n-side), then it follows that $x_p \ll x_n$.
    i. The potential hill between the n-side and the p-side of a junction increases with forward biasing.
    j. The depletion width in a linearly graded junction varies as $(V_{bi} - V_A)^{1/3}$.

2. A silicon step junction maintained at room temperature is doped such that $E_F = E_v - 2KT$ on the p-side and $E_F = E_c - E_G/4$ on the n-side.
    a. Draw the equilibrium energy band diagram for this junction.
    b. Determine the built-in voltage (V_{bi}) giving both a symbolic and a numerical result.

3. Consider the p1-p2 "isotype" step junction shown in the figure.

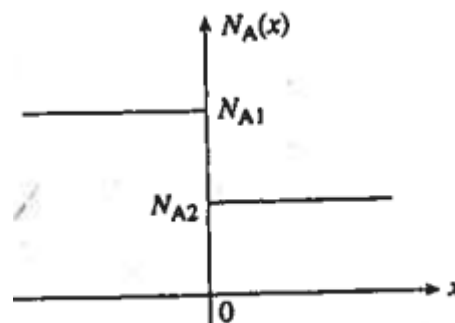**Figure P5.3**

    a. Draw the equilibrium energy band diagram for the junction, taking doping to be nondegenerate and $N_{A1} > N_{A2}$.
    b. Derive an expression for the built-in voltage (V_{bi}) that exists across the junction under equilibrium conditions.

c. Make rouch sketches of the potential, electric field, and charge density inside the junction.

d. Briefly describe the depletion approximation.

e. Can the depletion approximation be invoked in solving fot the electrostatic variables inside the pictured p1-p2 junction? Explain.

4. A Si step junction maintained at room temperature under equilibrium conditions has a p-side doping of $N_A = 2 \times 10^{15}/cm^3$ and n-side doping of $N_D = 10^{15}/cm^3$. Compute:

   a. V_{bi}.

   b. x_p, x_n and W.

   c. E at x = 0.

   d. V at x = 0.

   e. Make sketches that are roughly to scale of the charge density, electric field and electrostatic potential as function of position.

5. The doping around a metallurgical hunction of a special diode is shown in the figure. Sketch the expected chage density, electric field, electrostatic potential inside the diode based on the depletion approximation. Properly scale and label relevant lengthes. Include few words of explanation as necessary to forestall a misinterpretation of your sketches.
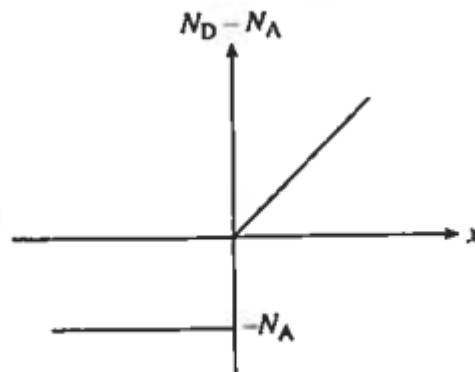

Figure P5.8

6. A pn junction diode has the doping profile sketched in the figure. Mathematically $N_D - N_A = N_0(1-e^{-\alpha x})$, where N_0 and α are constants.
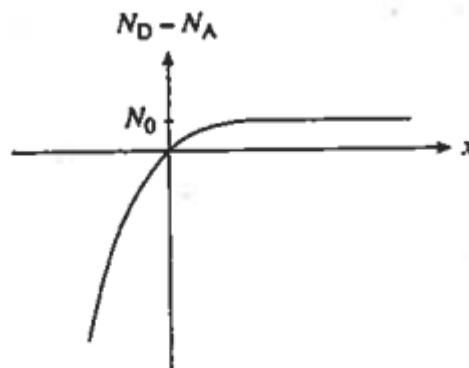

Figure P5.9

   a. Give a concise statement of the depletion approximation.

   b. Invoking the depletion approximation, make a sketch of the charge density inside the diode.

c. Establish an expression for the electric field E(x) inside the depletion region.

7. A pn junction diode has the doping profile sketched in the following figure. Make assumption that $x_n > x_0$ for all applied biases of interest.
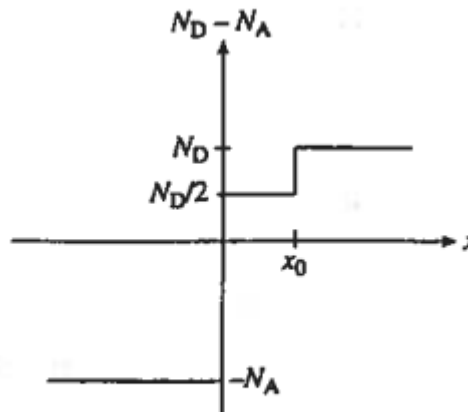

Figure P5.10

a. What is the built in potential across the junction? Justify your answer.
b. Invoking the depletion approximation, sketch the charge density ρ versus x inside the diode.
c. Obtain an analytical solution for the electric field E(x) inside the depletion region.

8. The p-i-n diode shown schematically in the figure is a three region device with a middle region that is intrinsic (actually lightly doped) and relatively narrow. Assuming the p- and n- regions to be uniformly doped and $N_D - N_A = 0$ in the i-region:
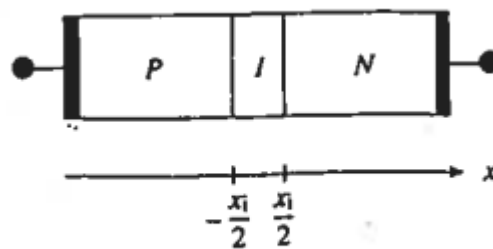

Figure P5.11

a. Roughly sketch the expected charge density, electric field and electrostatic potential inside the device. Also draw the energy band diagram under equilibrium condtions.
b. What is the built-in voltage drop between p- and n-regions? Justify your answer.
c. Establish quantitative relationships for the charge density, electric field, electrostatic potential and the n- and p-region depletion widths.

9. The electrostatic potential in the depletion region of a pn junction diode under equilibrium conditions is determined to be

$$V(x) = \frac{V_{bi}}{2}\left[1 + \sin\left(\frac{\pi x}{W}\right)\right] \quad \ldots \quad -W/2 \le x \le W/2$$

a. Establish an expressiown for the electric field as a function of position in the depletion region (-W/2 < x < W/2) and sketch E(x).
b. Establish an expression for the charge density as a function of position in the depletion region and sketch $\rho(x)$.
c. Invoking depletion approximation, determine and sketch N_D-N_A versus x in the depletion region.