Columbia University
Department of Electrical Engineering
Solid State Devices and Materials
ELEN E3106/4106
Homework #4

Due: Friday, October 10th by 5pm
Goal: Gain familiarity with p-n junction electrostatics in equilibrium and with external bias. Practice calculating/sketching band and electrostatic diagrams. Practice finding important parameters like the built-in potential, depletion width, capacitance, and current.
Instructions: Show your work and include units in answers for full credit. Unless stated otherwise, make the assumptions we have been taking in class (the sample is at 300 K). Circle or box your final answer.
Points: 110 pts for 3106. 130 pts for 4106.

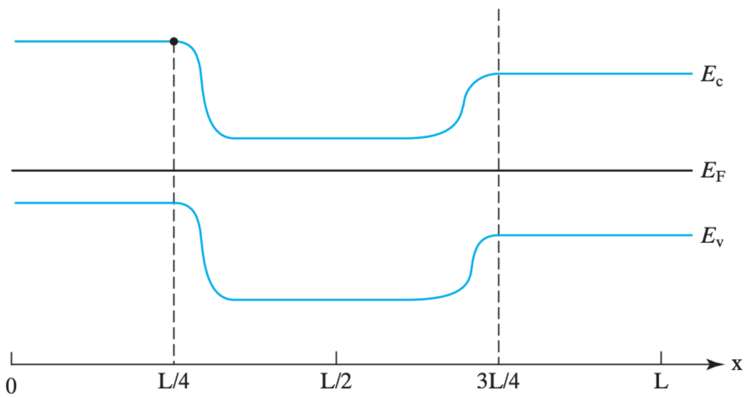
- **Problem 1 (36 pts)** p-n junction in equilibrium.

An abrupt Si junction (area = $0.0001\ cm^2$) has the following parameters:

n-side	p-side
$N_d = 3 \times 10^{18}\ cm^{-3}$	$N_a = 6 \times 10^{17}\ cm^{-3}$

(a) Calculate the difference between the Fermi level and the intrinsic Fermi level on both sides.
(b) Draw and label the band diagram.
(c) Calculate the built-in potential at the junction in equilibrium.
(d) Calculate the depletion width in equilibrium.
(e) Calculate the depletion width on the p-side.
(f) Calculation the depletion width on the n-side.
(g) Calculate the peak electric field.
(h) What is the total number of exposed acceptors in the depletion region? (Hint: to find the total # of exposed acceptors, first find the charge present in the p-side depletion region, then divide by the charge of an acceptor. Recall each ionized acceptor has accepted one electron – so we know its charge.)
(i) Sketch "the big three": $E(x),\ \rho(x),\ V(x)$ to scale. See Fig. 5.12 and Fig. 5.13 in textbook.

- **Problem 2 (20 pts)** Electrostatics of p-n junctions.
  A silicon sample maintained at 300 K is characterized by the energy band diagram below:



(a) Does the equilibrium condition prevail? How do you know?
(b) Roughly sketch n, p, and n_i versus x. The y-axis should be log scale. Label the regions as p- or n-type.
(c) Sketch the electrostatic potential (denoted as V or ϕ) as a function of x.
(d) Assume that the carrier pictured on the band diagram by the dot may move without changing its total energy. Sketch the kinetic and potential energies of the carrier as a function of its position x. (Hint: Recall the potential energy, $PE = E_c - E_F$, and the kinetic energy, $KE = E - E_c$).

- **Problem 3 (16 pts)** p-n diode capacitance.

In a p+n diode reverse biased at 6 V, the generated capacitance is 20 pF.
(a) If the doping of the p side is doubled and the bias is changed to 24 V, what will be the change in capacitance?
(b) If now the bias is changed to 100 V, then what will be the change?

- **Problem 4 (28 pts)** p-n diode currents.

Consider a p^+-n Si diode with $N_a = 10^{18}\ cm^{-3}$ and $N_d = 10^{16}\ cm^{-3}$. The hole diffusion coefficient in the n-side is 15 cm^2/s and $\tau_p = 10^{-7}\ s$. The device area is $10^{-4}\ cm^2$. If the forward bias is 0.7 V at 300 K,
(a) Calculate the reverse saturation current.
(b) Calculate the forward current.
(c) With the ideality factor n = 1.75, recalculate the forward current.

- **Problem 5 (20 pts) (Required for 4106 students ONLY, 11 pts)** p-i-n diode.
It is possible to create diodes that have an intrinsic region in the center. These are known as p-i-n diodes (where the i is the intrinsic region). Because there are no dopants, there are no ionized dopant centers, so $\rho = 0$ in that region. Using the depletion approximation:
(a) If we have a symmetrical diode with semi-infinite p and n regions, $N_a = 1 \times 10^{16}\ cm^{-3}$ and $N_d = 1 \times 10^{17}\ cm^{-3}$, and a 1 micron thick i region, sketch the charge potential $\rho(x)$, electric field $E(x)$, and the potential $V(x)$ (no numbers needed, but show the shapes).

(b) What is the width of the depletion region on each side?
(c) What is the electric field in the i-region?
(d) What is the potential drop in the i-region?