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# EE566 Solid State Devices

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Dept of Electrical Engineering

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## Assignment 4

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**Reading:** Chapter 4 of the Textbook (Muller/Kamins/Chan: MKC). For material constants & parameters, Table 1.3 page 52 of MKC should work. For materials not listed in this table, go to - <http://www.ioffe.rssi.ru/SVA/NSM/>.

### Problem 1\* (Practice problem for p-n junctions)

Consider a p-n junction made of GaAs at  $T=300\text{K}$ . (Doping densities:  $N_A=10^{17}/\text{cm}^3$  and  $N_D=10^{16}/\text{cm}^3$ ).

a) Sketch the charge-field-band diagrams under the depletion approximation. Label it with the *calculated* values of all important quantities such as  $x_n$ ,  $x_p$ ,  $W$ ,  $F_{max}$ ,  $V_{bi}$ , etc. Use natural units like *nm* for lengths, *V/cm* for fields, and *Volts* for potential. Your sketch should be roughly *to scale*. Which side is the depletion region large? Remember this property of the ratio of depletion region thickness in p-n junctions. How does the maximum electric field in the depletion region compare with the breakdown voltage of GaAs? What is the capacitance of the depletion region?

b) Use 1-D Poisson to simulate the junction, and *plot* the charge-field-band diagram *neatly*. Compare the values you calculated from part a) and explain the critical differences invoking the Gummel correction.

### Problem 2 (Another practice problem)

Problem 4.5, MKC.

### Problem 3 (Real-life p-n junction issues in IC Fab)

Problem 4.10, MKC.

### Problem 4 (Exact solution for a homojunction)

Consider a  $n^- - n^+$  homojunction made of GaAs. Let the doping densities on the two sides of the junction be  $N_{D1}=10^{15}/\text{cm}^3$  and  $N_{D2}=10^{17}/\text{cm}^3$ , and the two sides to be long ( $>2000\text{nm}$ ). Note that this is NOT a p-n junction, and you are asked here to solve the problem *exactly*, without the depletion approximation.

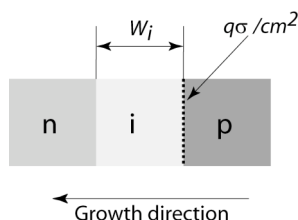
a) Find the potential barrier to electron flow across the junction. Is the junction ohmic or rectifying?

b) Sketch (qualitatively) the charge-field-band diagram for the junction. Denote the variation of the bands across the junction (parabolic, exponential, flat), and relate them to the Debye lengths on the two sides.

c) Calculate the maximum electric field at the junction *exactly*. (Do not neglect Gummel corrections!).

d) Simulate this band diagram using 1D Poisson. Compare the simulated maximum electric field with your calculated *exact* value in part c), and the smearing length of the free charge densities on the two sides with your calculation of Debye lengths in part b). Are they consistent?

### Problem 5



Here is a real-life problem in dealing with junctions, especially if you are a great device engineer at the hands of a not-so-great crystal grower (they are known to be a strange lot!). Suppose you asked the grower to grow you a GaAs *p-i-n* junction. Since the grower was paranoid that zinc, the acceptor dopant, might diffuse into the *i*-layer, he dropped the temperature after the *p*-layer, and waited for all the excess zinc to be pumped away before going on to

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\* Remember to use proper units and label every figure/plot. Turn in your answers worked out neatly. Please attach this question sheet to your solution when you turn it in.

grow the  $i$ -layer (thickness  $W_i$ ), followed by the  $n$ -layer. When he gave the sample to you, you performed a  $C$ - $V$  measurement and found that the depletion capacitance is the same as the normal p-n junction, i.e., as if there was NO  $i$ -layer at all! The reason is that while he was waiting for the zinc to be pumped away, oxygen, a donor, incorporated in the crystal and formed a sheet of density  $q\sigma/cm^2$  at the  $p$ - $i$  interface (see Figure).

**a)** Derive an algebraic relation between the doping densities  $N_D$ ,  $N_A$ ,  $q\sigma$ , and  $W_i$  which will explain the capacitance. To do this, you *have* to sketch the charge, field, and band diagram. Assume  $N_D=N_A$  for simplicity. Neglect Gummel correction.

**b)** Next, calculate a numerical value of  $W_i$ . Assume  $N_D=N_A=10^{17}/cm^3$ , and  $q\sigma=5\times 10^{11}/cm^2$ .

In general, make sure you are comfortable with the chapter-end problems of MKC Chapter 4. Read the sections on Heterojunctions (4.2), Capacitance (4.3), and Breakdown (4.4) critically.