MIT6.012/SMA5111 COMPOUND SEMICONDUCTOR DEVICES

Problem Set No. 1

Issued: February 10, 2003 **Due:** February 24, 2003

Problem 1 - Consider a metal-semiconductor junction formed between a metal with a work function of 4.0 eV, and a hypothetical semiconductor with an energy gap, E_g, of 1.4 eV, an electron affinity of 3.5 eV, and a conduction band effective density of states of 10^{19} cm^{-3}, that is doped n-type with 10^{16} cm^{-3} donor atoms (which you may assume are all ionized at room temperature).

   a) What is the work function of this semiconductor sample? NOTE: For convenience you may assume that kT ln 10 = 0.06 eV at room temperature.

   b) What is the barrier height in this Schottky diode, and what is the depletion region width in thermal equilibrium, i.e., with zero bias?

Now consider that the semiconductor also has 10^{13} cm^{-2} surface states that are located 0.3 E_g above the edge of the valence band. Assume that these surface states are neutral when they are empty.

   c) What is the condition of a <u>bare</u> surface of this semiconductor because of the presense of these surface states, that is, is it depleted, accumulated, or unchanged? If it is depleted, what is the depletion region width and what fraction of the surface states are occupied in thermal equilibrium?

Next return to the metal-semiconductor junction, now with the surface states present. Assume that the centroids of the charge layer at the metal surface and of the charge in the surface states are separated by 20 nm.

   d) What is the barrier height in this Schottky diode when there are surface states present, and what is the depletion region width in thermal equilibrium? Also, what fraction of the surface states are occupied in thermal equilibrium?

Problem 2 - Develop a simple approximate expression for the reduction in the barrier height of a metal-semiconductor junction caused by image force lowering. Discuss the functional dependance of the decrease on the doping level, N_d, and the barrier height without lowering, i.e. ϕ_{Bo}.

Problem 3 - Compare the saturation current, I_S, of a metal-semiconductor diode on n-type silicon, $N_d = 10^{17}$ cm^{-3}, with that of a p-n junction diode made on the same n-type Si using p-type silicon with (a) $N_a = 10^{18}$ cm^{-3} and (b) $N_a = 10^{16}$ cm^{-3}. Assume infinite minority carrier lifetime, n- and p-region lengths of 1 μm each (you may neglect the depletion region widths in your calculations), a low-field electron mobility, μ_e, of 1600

cm^2/V-s, a low-field hole mobility, μ_h, of 600 cm^2/V-s, an intrinsic carrier concentraion, n_i, of 10^{10} cm^{-3}, and a barrier height, $q\phi_B$, of 0.7 eV for the metal-semiconductor barrier. Use the thermoinic emission model for the Schottky diode current.

Problem 4 -   Reading is FUNdamental:
   a) Look up the following reference: Applied Physics Letters, Vol. 80 (27 May 2002), pp. 3967-3969.
      i)   What new do they report?
      ii) What measurements did they use to reach their conclusions?
      iii) Why should anyone care?

   b) Consider the ternary compound GaN$_x$As$_{1-x}$. For x small it crystallizes in the zinc blende lattice, just like GaAs.
      i) Based on our discussion in Lecture 1, how would you expect the energy gap of this material to vary with x, for x small (i.e., near GaAs)?
      ii) Look in the literature and find out how the energy gap of this material varies with x, for small x. You might find it easier to also look for information on Ga$_{1-y}$In$_y$N$_x$As$_{1-x}$, which is very similar for y small. State what reference(s) you use.

   c) Find a text that explains velocity saturation in semiconductors and give a 25 to 50 word synopsis of the arguement. Include your source.