Homework #6 - EE482

due 11/16/00

1. Copper (work function 4.4eV) is in contact with silicon (electron affinity 4.05eV) doped with 10^{18}cm^{-3} of arsenic at room temperature.

   (a) Ignoring surface states, calculate the work function of the silicon ϕ_s, the metal-semiconductor barrier height ϕ_B for both holes and electrons, and the built-in voltage ϕ_i.

   (b) Draw the theoretical equilibrium energy-band diagram.

   (c) Would this contact be blocking or ohmic? Explain.

2. Assuming that basic Schottky theory applies (no surface states), sketch the energy-band diagrams for:

   (a) an ohmic contact between p-type silicon and a metal (i) at equilibrium, and (ii) with a positive voltage applied to the metal relative to the semiconductor,

   (b) a blocking contact between p-type silicon and a metal (i) at equilibrium, (ii) under 0.1V forward bias, and (iii) under 3V reverse bias.

3. Aluminum (work function 4.1eV) is in contact with silicon (electron affinity 4.05eV) doped with 10^{17}cm^{-3} of phosphorus at room temperature.

   (a) Ignoring surface states, calculate the work function of the silicon ϕ_s, the metal-semiconductor barrier height ϕ_B and the built-in voltage ϕ_i and draw the theoretical equilibrium energy-band diagram.

   (b) Repeat (a) assuming that a very large number of surface states (both donors and acceptors) exist centered 0.35eV above the valence band. Assume that the interface layer is thin enough to allow easy tunnelling and can be ignored in calculating the barriers.

   (c) Briefly compare the electrical behavior of the metal-semiconductor systems described in (a) and (b) (i.e. blocking or ohmic and why?).

4. When gold is deposited on n-type silicon a Schottky barrier diode with $\phi_B = 0.8\,\mathrm{V}$ is formed.

   (a) What fraction of the available electrons in the metal would have enough energy to surmount that barrier and spill over into the silicon?

   (b) If the doping in the silicon is 10^{17}cm^{-3}, what is the barrier presented to electrons in the silicon?

   (c) If in reverse bias at 300K, this contact passes 10^{-8} A, how should the metal be biased for the contact to pass 0.1 mA with the semiconductor grounded (ignore changes in Schottky barrier lowering)?

   (d) Assuming the barrier height is unchanged as the doping is increased, calculate the doping concentration necessary to reduce the depletion region width to 4nm in equilibrium (narrow enough to allow tunnelling).

5. A MOS capacitor is made with a silicon substrate doped with $N_a = 5 \times 10^{17}$cm^{-3} of boron, 50 Å of silicon dioxide, and an n^+ polysilicon gate doped such that $E_f - E_c = 0.05\,\mathrm{eV}$. Assume there are no significant oxide charges. Determine the charge on the gate, the voltage dropped across the oxide and the voltage dropped across the silicon with the following voltages applied between the gate and the substrate:
   (a) $V_{gb} = -1\,\mathrm{V}$; (b) $V_{gb} = 0.0\,\mathrm{V}$; (c) $V_{gb} = 2\,\mathrm{V}$
   Sketch the charge densities, electric fields and energy band diagrams in each case. What are the capacitances at low and high frequencies in each of the above cases?

6. An MOS capacitor is made on n-type silicon with an oxide thickness of 50 Å, a positive interface charge of $Q'_{ss}/q = 5 \times 10^{10}\,\mathrm{cm}^{-2}$ and a uniform positive oxide charge density of $\rho_{ox}/q = 2 \times 10^{16}\,\mathrm{cm}^{-3}$ throughout the oxide. The substrate is doped with $N_d = 10^{17}\,\mathrm{cm}^{-3}$ and the gate is polysilicon doped with boron just to the edge of degeneracy (p^+ poly, $E_f = E_v$).

   (a) Calculate the flat-band voltage V_{FB} and the threshold voltage V_T.

   (b) Sketch the charge density, electric field and energy-band diagram at flat-band and at the edge of strong inversion.