Homework #3 - EE 531

due 1/13/17

1. Use Sentaurus Device to simulate the diode analyzed in Homework 1. Compare the SDevice results to your analytic results and comment on the similarities and/or differences.

2. Consider a contact between aluminum ($\Phi_M = 4.1$V) and silicon ($\chi_S = 4.05$V) doped with $N_d = 10^{18}$ cm^{-3}. Assume that the silicon surface states have a neutrality level of $E_v + 0.5$eV. Determine the barrier (if any) for electrons from the semiconductor to the metal if there are:

   (a) No surface states.

   (b) An infinite density of surface states.

   (c) A large (but not infinite density) of surface states equal to $N_{ss}(E) = 7\times10^{14}$ cm^{-2}eV^{-1}. Assume that the surface states are located an average distance of 0.1nm into the silicon and the electrons in the aluminum located an average distance of 0.1nm into the metal. Use the silicon dielectric constant for all materials. (Hint: As for pn junction, assume a value for the depletion region width and determine expression for voltage drop across junction which equals built-in voltage.)

3. Calculate the lowest two bound energy levels ($E < V_o$) for an electron in a finite 1D potential well with $V(x) = V_i = -2$eV for $|x| < 0.25$nm and $V(x) = V_o = 2$eV elsewhere. Compare these to the lowest bound energies for the infinite potential well ($V_o \Rightarrow \infty$). For each state, what is the probability that the electron is outside the well?

   Some potentially useful constants/conversions are: $q = 1.60\times10^{-19}$ C, $h = 6.625\times10^{-34}$ Js, $m_0 = 9.11\times10^{-31}$ kg, 1 J = 1 kg m^2/s^2, 1 eV = 1.6×10^{-19} J. Remember, $\hbar = h/2\pi$. You will likely have to do iteration or a graphical solution to solve transcendental equation(s) for the allowed energies.

4. Calculate the transmission (tunneling) probability for a free electron ($V = 0$) with energy E incident upon a rectangular potential with height $V_b > E$ and width x_b. Note that you will have to match boundary conditions at two interfaces.

5. (a) Use the effective mass tensor to show that the overall average acceleration of electrons in the conduction band of silicon is in the direction of the electric field as long as the carrier concentrations in the respective k-space minima are all equal.

   (b) If due to lattice strain the minima in the $\pm z$ directions ((001) and (00$\bar{1}$)) are reduced in energy by 0.05 eV below the minima in the $\pm x$ and $\pm y$ directions:

      i What would be the effective mass for electric fields in the x direction? How does this compare to the effective mass in unstrained silicon?

      ii What would be the direction of average electron acceleration for a field in the (111) direction?

   iii For what field directions would the acceleration be parallel to the field?