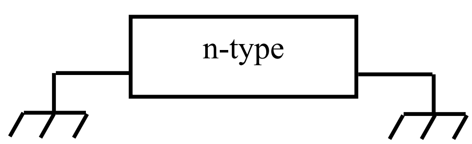
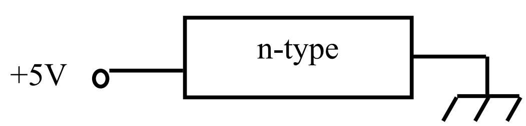
MS Exam ECE103 Fall 2014

1. Answer the following questions concisely.
   a. For a Si sample doped with N_A=10^{16} cm^{-3} Boron atoms, (i) sketch qualitatively the energy band-edge diagram as function of temperature for $0 \leq T \leq 800$ K, and (ii) indicate the location of Fermi energy as a function of temperature for $0 \leq T \leq 800$ K.
   b. For a p-n diode under thermal equilibrium, the Fermi energy is constant throughout the whole diode. For a p-n diode under external voltage bias, quasi-Fermi levels were introduced. Sketch the quasi-Fermi levels across a forward biased p-n diode and justify your plot.
   c. For a well designed n^+-p-n BJT transistor, is the built-in potential in the base-emitter junction higher, lower or the same as that in the base-collector junction? Explain the variation or similarity by comparing important design requirements at the base-emitter and the base-collector junctions.
   d. For a BJT in common-emitter configuration, the collector current has a slight slope when plotted as function of collector-emitter voltage (i.e. keeps on increasing) beyond saturation in the active operating regime. (i) What is the name of this phenomenon? (ii) Describe its physical origin.

2. The n-type Silicon sample shown below is maintained at 300 K with N_D=5x$10^{16}$$cm^{-3}$ and N_A=0 such that μ_n=1000 cm^2/V·s, μ_p=110 cm^2/V·s and τ_n=τ_p=10^{-7}s. The sample has a length of 0.1 cm and a cross-sectional area of 10^{-4} cm^{-2}.



   a. What are the majority and minority carrier concentrations in the sample?
   b. A voltage of 5V is applied across the sample as indicated below.



      i. Calculate the electric field created across the sample.
      ii. Draw an energy band diagram indicating the direction and the magnitude of band-bending upon application of the 5V.
      iii. Calculate the drift current across the sample at a temperature of 300 K and at a temperature of 0 K.

c. With the 5V still applied, the Si sample has been illuminated with light for $t < 0$ producing a uniform generation rate G_L=5x10^{21} cm^{-3}/s across the entire sample. At t=0, the light is turned off.

   i. For $t < 0$, assume steady state conditions. What is the expression for excess minority carrier concentration? Do you expect the current to be smaller, larger or equal to that of part (b-iii)? Justify you answer.
   ii. For $t \geq 0$, derive an expression for the excess minority carrier concentration.

3. Consider a Si PMOS capacitor with gold metal gate ($q\varphi_m$=5.3 eV) and N_A=5x10^{16}cm^{-3}. The oxide thickness x_0 is 5 nm and the device is operated at 300K. Assume $q\chi_s$=4.05 eV for Si.

   a. Determine the flat band voltage and draw the energy band-edge diagram for the MOS structure at zero gate bias.

   b. Assuming that there are no oxide charges, calculate the threshold voltage of the PMOS capacitor and its high frequency capacitance at V_T.

   c. If the Si-SiO_2 interface has a trap density Q_{it}/q=10^{13} cm^{-2}, (i) calculate the flat band voltage, and (ii) the threshold voltage.

   d. Is the PMOS capacitor in accumulation, depletion or strong inversion condition at V_G=0V with the Q_{it} of part (c) present at the Si-SiO_2 interface. Deduce the effects of large interface trap density on n-channel MOSFET operation.