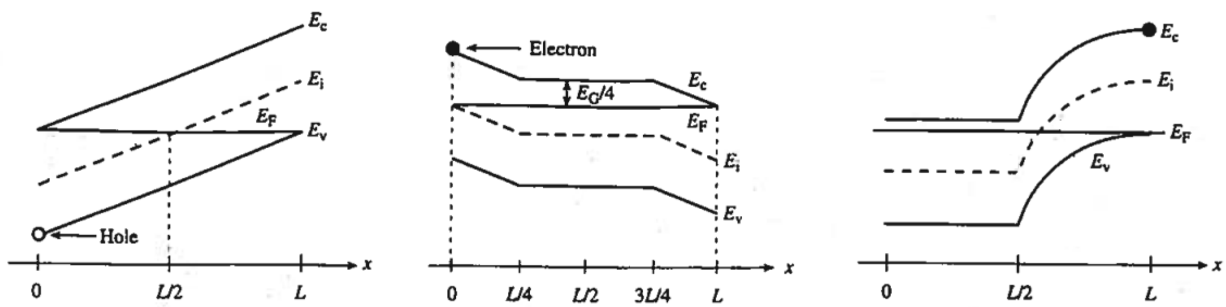
NANENG 520: Problem Set 1

1) Consider a MOS capacitor with a p-type silicon substrate doped to $N_a = 2\times10^{17}$ cm^{-3}, a silicon dioxide insulator with a thickness of $t_{ox} = 10$ nm, and an n$^+$ polysilicon gate. Assume that $Q'_{ss} = 5\times10^{10}$ electronic charges per cm^2. Calculate:
   (a) The difference $E_{Fi} - E_F$ in the bulk, φ_{fp}.
   (b) The oxide capacitance.
   (c) The maximum depletion region width.
   (d) The metal-semiconductor workfunction difference, φ_{ms}.
   (e) The flat-band voltage.
   (f) The threshold voltage.

2) Three different Si samples maintained at 300K are characterized by the energy band diagrams shown in the figure. Answer the following questions:
   (a) Do equilibrium conditions prevail? How do you know?
   (b) Sketch the electrostatic potential inside the semiconductor as a function of *x*.
   (c) Sketch the electric field inside the semiconductor as a function of *x*.
   (d) Roughly sketch *n* and *p* versus *x*.



3) A p-channel MOSFET has the following parameters: $k'_p = 0.10$ mA/V^2, W/L = 17, and $V_T = -0.5$ V. Calculate the drain current I_D for (a) $V_{SG} = 0.9$ V, $V_{SD} = 0.3$ V; and (b) $V_{SG} = 1.2$ V, $V_{SD} = 2.0$ V.

4) Consider A p-channel MOSFET has an oxide thickness of $t_{ox} = 25$ nm and a substrate doping of $N_d = 6 \times 10^{15}$ cm^{-3} . Find:
   (a) The body-effect coefficient.
   (b) The body-to-source voltage, V_{BS} , such that the shift in threshold voltage, ΔV_T is -0.22 V.

5) Consider an n-channel MOSFET with a substrate doping concentration of $N_a = 10^{16}$ cm^{-3}, a threshold voltage of $V_T = 0.5$ V. The device is biased at $V_{GS} = 1.5$ V and $V_{DS} = 3$ V.
   (a) Determine the change in channel length, ΔL, using simple change in depletion width at drain.

(b) Repeat (a), using 1D Poission's equation at pinch-off region.

(b) Determine the ratio of actual drain current compared to the ideal value if the channel length is $L = 1.2$ µm.

(c) Find the minimum channel length such that the ratio of actual drain current to the ideal drain current due to channel length modulation is no larger than 1.4 .

(e) Determine the minimum channel length so that the incremental change ΔL is no more than 10 percent of the original length L.

(f) Calculate the CLM coefficient λ, using either methods in (a) or (b)

6) An n-channel MOSFET has a substrate doped with boron with $N_A = 2\times10^{17}$ cm^{-3} , and n+ polysilicon gate, gate oxide thickness of 10 nm, Oxide charges of $+10^{10}$ electron charges/cm^{2} , the channel length is 0.5µm, the channel width is 2µm, the source/drain junction depth is 0.15µm, $V_{gs} = V_{ds} = 5V$, $V_{substrate} = 0V$. Find:

(a) The long and short channel threshold voltages

(b) The average "lateral" electric field in the inversion channel, ignoring the effect of inversion charges in the solution of 1D Poisson's equation in the inversion layer.

(c) The electron velocity in the inversion channel.

(d) The "normal" effective field in the inversion layer

(e) The mobility in the presence of effective field alone (i.e. at V_{ds} =100mV). Assume that the mobility before the onset of inversion charges is 1000 cm^{2}.V^{-1}.s^{-1} .

(f) The mobility in the presence of both effective field and lateral field. Assume the mobility at low electron velocity can be calculated from part "e".

(g) Check if the transistor is near velocity saturation

(h) Calculate the drain current using:

i. velocity saturation assumption, and

ii. The regular equation using the mobility calculated in part "f".

iii. Comment on which of the previous condition is more realistic for current calculation