(50 pts)

1. For an ideal MOS structure shown below in Figure 1, answer the following questions;
   (a) (10 pts) Sketch the energy band diagram for the ideal MOS structure assuming the silicon is N-type, when V = 0 volts.
   (b) (10 pts) Draw the high and low frequency C-V characteristics for this device, assuming the silicon is N-type, and highlight any important regions of operation of the device. Note V is shown in Figure 1.
   (c) (10 pts) Qualitatively draw the band diagram and the location and type of charges in the structure, assuming the silicon is N-type, when the magnitude of the voltage is large enough to cause inversion in the silicon
   (d) (10 pts) Now assume that the metal layer is replaced by a silicon layer, to form an Silicon-Oxide-Silicon (SOS) structure, such that both silicon layers are N-type. Sketch the high and low frequency C-V characteristics for this device, and highlight any important regions of operation of the device.
   (e) (10 pts) For the SOS structure from part d, write an expression for the capacitance at high frequencies, when V is large and positive.

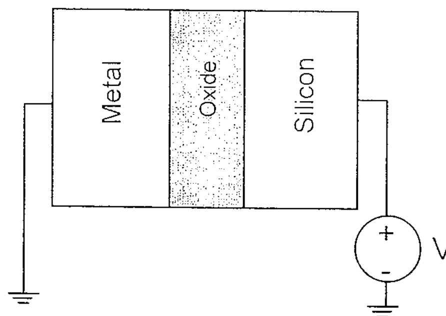

Figure 1

(50 pts)

2. Considering a P Channel silicon enhancement mode MOSFET with $|V_T| = 1$, answer the following questions below:

(a) (8 pts) Sketch a cross-section of the device and indicate all parts appropriately. Show the channel and the depletion layers assuming the device is turned on, and $|V_{DS}| > |V_{GS} - V_T|$. Indicate the pinch off region and the change in the effective channel length.

(b) (8 pts) Assuming the square-law current voltage relationship and that the body is shorted to the source, draw the approximate I_{DS}-V_{DS} curves as a function of V_{GS} for the p-channel MOSFET, noting the correct sign of the voltages required.

(c) (8 pts) How would the curves from part b change if positive fixed charges were added in the oxide close to the oxide/semiconductor interface?

(d) (12 pts) Qualitatively explain how you would derive the ideal Square-Law Equation for a MOSFET in saturation region.

(e) (10 pts) If the effective channel is reduced by ΔL and assuming that the ΔL can be modeled as the depletion width of a one-sided junction, develop an expression for ΔL in terms of V_{DS} and $V_{DS(sat)}$.

(f) (4 pts) For the three models of the MOSFETs (Square-Law theory, Bulk-Charge theory, and the Charge-Sheet theory), which one explains the sub-threshold currents?