ECE 321, Electronics I

Quiz 3 (Fall 2015), MOS-Cap

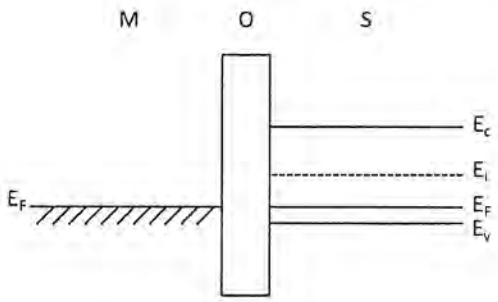
Name Solution

Section _____

1. (25 points) The MOS-Cap energy band for V_G=0 V is given below. Sketch the energy band diagram for the remaining cases of V_G and circle the resulting condition.

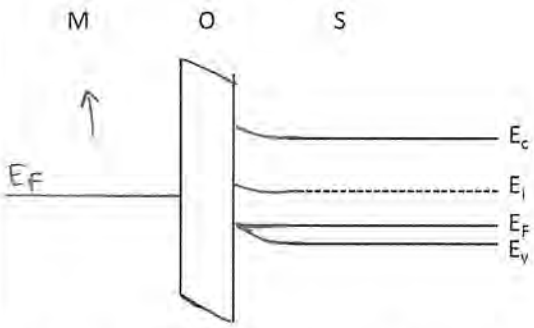
Carefully detail the band bending at the oxide interface and relative positioning of E_F to E_i.

V_G=0 V



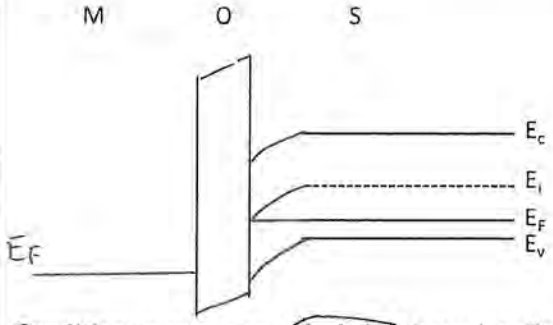
Condition: flat band

$V_G < 0$ V



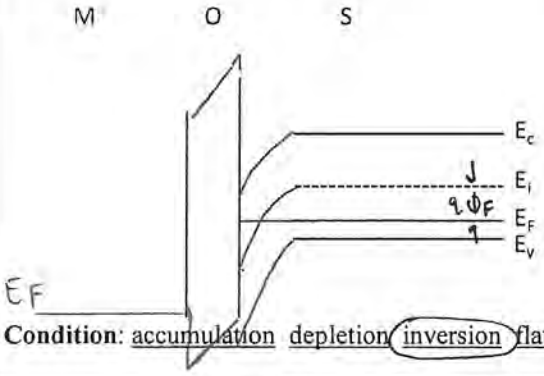
Condition: (accumulation) depletion inversion flat band

$0 < V_G < V_t$



Condition: accumulation (depletion) inversion flat band

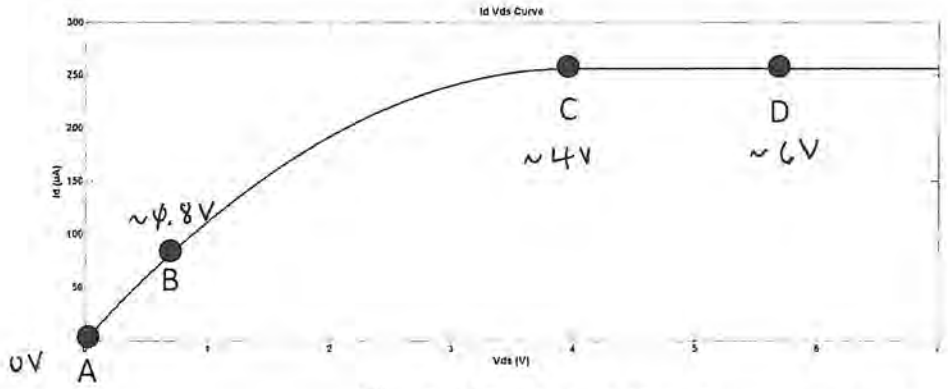
$V_G = V_t$



Condition: accumulation depletion (inversion) flat band

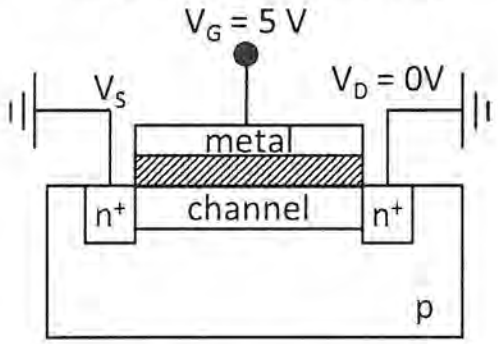
$E_{is} - E_{ibulk} = 2(E_F - E_{ibulk})$

2. (25 points) Suppose an nMOS transistor (V_t=1 V) is biased with V_G =5 V with the resulting I_D vs V_{DS} curve below. Sketch the cross section of the conducting channel at the four points given. Circle the resulting mode of operation. Point A is already sketched for you!



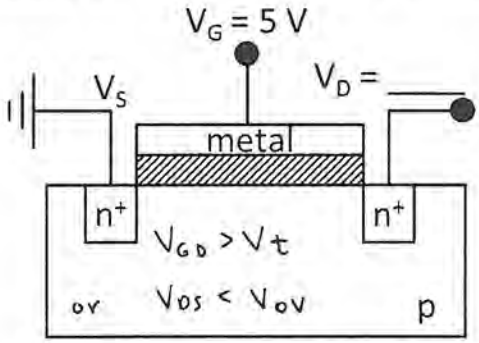
$V_{OV} = V_{GS} - V_t = 4V$ for all cases

Point A: V_{GS}=5V, V_{GD}=5V, V_{DS}=0V



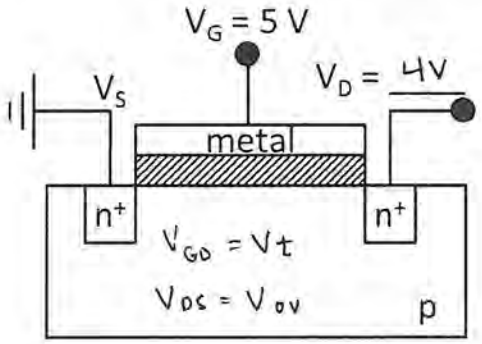
Mode: Cutoff

Point B: V_{GS}= 5V V_{GD}= 4.2V V_{DS}= 0.8V



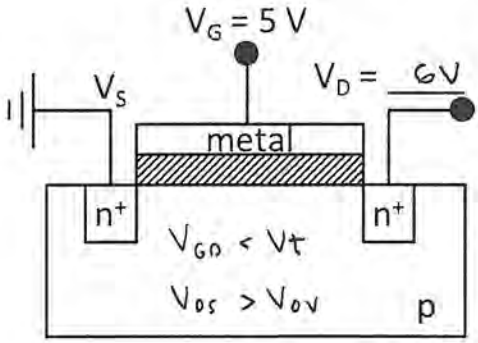
Mode: Cutoff (Triode) Saturation Forward

Point C: V_{GS}= 5V V_{GD}= 1V V_{DS}= 4V



Mode: Cutoff Triode (Saturation) Forward

Point D: V_{GS}= 5V V_{GD}= -1V V_{DS}= 6V

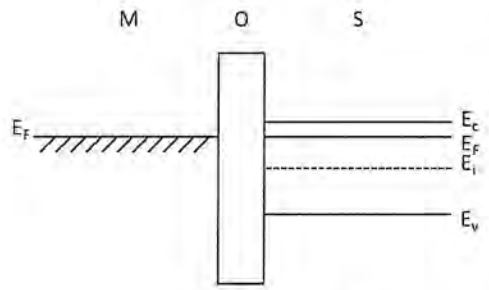


Mode: Cutoff Triode (Saturation) Forward

3. (25 points) The MOS-Cap energy band for V_G=0 V is given below. Sketch the energy band diagram for the remaining cases of V_G and circle the resulting condition.

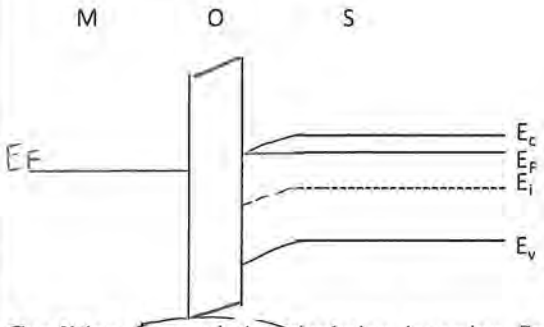
Carefully detail the band bending at the oxide interface and relative positioning of E_F to E_i.

V_G=0 V



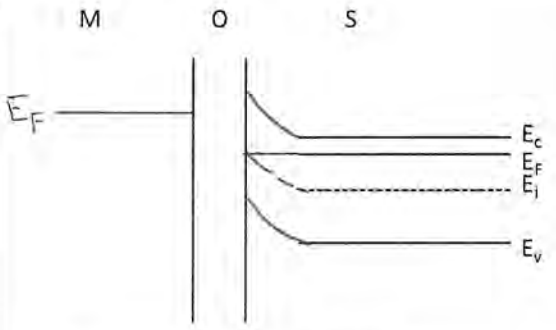
Condition: flat band

$V_G > 0$ V



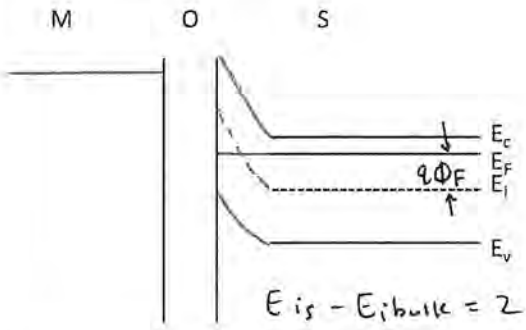
Condition: accumulation depletion inversion flat band

$V_t < V_G < 0$



Condition: accumulation depletion inversion flat band

$V_G = V_t$



$E_{is} - E_{ibulk} = 2(E_F - E_{ibulk})$

Condition: accumulation depletion inversion flat band

4. (25 points) Suppose the n-type Si of the MOS in part 3 is doped at 10^{15} cm^{-3}. Calculate threshold voltage V_t. Use an oxide thickness x_o of 8 nm. For Si, K_S=11.7. For SiO_2, K_o=3.9.

$$V_t = 2\Phi_F - \frac{K_S x_o}{K_o}\sqrt{\frac{4qN_D}{K_S\varepsilon_o}(-\Phi_F)} \text{ where } \Phi_F = \frac{1}{q}(E_{ibulk} - E_F)$$

$\Phi_F = (E_{ibulk} - E_F)/q$ need to calculate $E_F = E_i - kT\ln\left(\frac{N_d}{n_i}\right)$

$= \left(\frac{1.12}{2} - \phi.8478\right)/q$ $= \frac{1.12}{2} + \phi.025\ln\left(10^{15}/10^{10}\right)$

$= -\phi.2878$ V $= \phi.8478$ eV

$$V_t = 2(-\phi.2878) - \frac{11.7(8\cdot10^{-9}\text{m})}{3.9}\left[\left(\frac{4(1.6\cdot10^{-19}\text{C})(10^{15}\text{cm}^{-3}\times(100)^3)}{11.7(8.85\cdot10^{-12}\text{F/m}}\right)(\phi.2878)\right]^{1/2}$$

$V_t = -\phi.6077$ V