Solve the following questions for Week 9.

There are 10 questions, for a total of 20 marks.

1. (2 marks) For an ideal p-type Depletion MOSFET, choose the correct statement.

   A. A hole inversion layer is created for an applied bias greater than threshold voltage.

   B. An electron inversion layer is created for an applied bias greater than threshold voltage.

   C. A hole inversion layer exists for zero applied bias.

   D. A hole inversion layer is created for an applied bias less than threshold voltage

   E. An electron inversion layer exists for zero applied bias.

   F. An electron inversion layer is created for an applied bias less than threshold voltage

2. (2 marks) Consider an n-channel MOSFET with the following parameters: $\kappa = 1\ mA/V^2$, $W/L = 8$, and $V_T = 0.4\ V$. The drain current I_D for $V_{GS} = 0.9\ V$ and $V_{DS} = 1\ V$ is ______ (*Hint: You are given* κ *(not* κ'*!)*)

   Here $V_{GS} - V_T \Rightarrow 0.9 - 0.4 = 0.5 < V_{DS}$
   So MOSFET operates in saturation regime
   $I_{Dsat} = \frac{K}{2}(V_{GS} - V_T)^2$
   $= \frac{1}{2}(0.5)^2$
   $= 0.125\ mA$

   A. $1\ mA$

   B. $1\ \mu A$

   C. $0\ mA$

   D. $0.125\ \mu A$

   E. $0.125\ mA$

   F. $1.125\ mA$

3. (2 marks) Consider an ideal long channel n-MOSFET with the following parameters: $\mu_n C_{ox} = 0.18\,mA\,V^{-2}$, $W/L = 8,\ and\ V_T = 0.4\ V$. The drain current I_D for $V_{GS} = 0.8\ V$ and $V_{DS} = 0.1\ V$ is ______.

   Here, $V_{GS} - V_T \Rightarrow 0.8 - 0.4 = 0.4 < V_{DS}$
   So MOSFET is operating in linear regime
   $I_D = \frac{\mu_n C_{ox} W}{2L}\left[2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right]$
   $= \frac{0.18 \times 8}{2}\left[2(0.8 - 0.4)0.1 - 0.1^2\right]$
   $= 0.0504\ mA$

   A. $3.2\ mA$

   B. $0.0504\ mA$

   C. $0.1152\ \mu A$

   D. $86.4\ mA$

   E. $0.0576\ mA$

   (For Q3-Q4) Answer the following with regards to the subthreshold swing of a MOSFET:

4. (2 marks) The subthreshold swing is defined as:

A. The increase in gate voltage necessary to increase the drain current by a factor of 2.

B. The increase in source voltage necessary to increase the drain current by a factor of 2.

C. The increase in drain voltage necessary to increase the drain current by a factor of 10.

D. The increase in drain voltage necessary to increase the drain current by a factor of 2.

E. The increase in gate voltage necessary to increase the drain current by a factor of 10.

5. (2 marks) What is the minimum subthreshold swing of a classical MOSFET (in $mV\ decade^{-1}$) at $T = 300K$?

A. 30

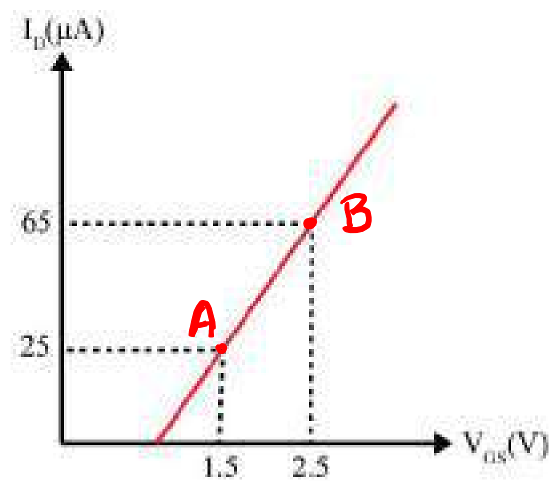
B. 60

C. 120

D. 26

E. 150

(For Q6-Q7) The $I_D\ vs\ V_{GS}$ characteristics determined experimentally for an n-channel MOSFET are given below. The width and length of this device is $10\ \mu m$ and $1\ \mu m$ respectively. Assuming the drain voltage $V_{DS} = 0.1\ V$, and oxide capacitance $C_{ox} = 8 \times 10^{-8}\ Fcm^{-2}$,



6. (2 marks) the mobility of carriers in the inversion region is ______ $cm^2\ (V-s)^{-1}$ (rounded off to the nearest integer)

A. 250

B. 500

C. 5000

D. 1450

E. 450

F. 8000

MOSFET is in linear regime.

$$I_D = \frac{\mu_n C_{ox} W}{2L}\left[2(V_{GS}-V_T)V_{DS} - V_{DS}^2\right]$$

At point A, $I_D = 25\mu A$ & $V_{GS} = 1.5V$

$$25\times10^{-6} = \frac{\mu_n \times 8\times10^{-8}\times10}{2}\left[2(1.5-V_T)0.1 - 0.1^2\right]$$

$$25\times10^{-6} = \mu_n \times 4\times10^{-7}\left[0.3 - 0.2V_T - 0.01\right]$$

$$\frac{250}{4\mu_n} = 0.29 - 0.2V_T \quad \text{——— (A)}$$

At point B, $I_D = 65\mu A$ & $V_{GS} = 2.5V$

$$65\times10^{-6} = \frac{\mu_n\, 8\times10^{-8}\times10}{2}\left[2(2.5-V_T)0.1 - 0.1^2\right]$$

$$65\times10^{-6} = \mu_n \times 4\times10^{-7}\left[0.5 - 0.2V_T - 0.01\right]$$

$$\frac{650}{4\mu_n} = 0.49 - 0.2V_T \quad \text{——— (B)}$$

Subtracting (B) from (A)

$$\frac{650}{4\mu_n} = 0.49 - \cancel{0.2V_T}$$

$$-\ \frac{250}{4\mu_n} = -0.29 + \cancel{0.2V_T}$$

$$\frac{400}{4\mu_n} = 0.2$$

$$\therefore \mu_n = \frac{100}{0.2} = \frac{1000}{2}$$

$$\boxed{\mu_n = 500\ cm^2/V{\cdot}S}$$

7. (2 marks) The threshold voltage for the MOSFET is ______ V. (*Hint:* Ignore $\frac{V_{DS}^2}{2}$ term for calculating V_T)

   A. 0.8

   B. 0.875

   C. 0.75

   D. 0.32

   E. 0.625

   F. 0.08

Ignoring $\frac{V_{DS}^2}{2}$ term, current is given as

$$I_D = \frac{\mu_n C_{ox} W}{L}\left[(V_{GS}-V_T)V_{DS}\right]$$

$$25\times10^{-6} = 500\times8\times10^{-8}\times10\left[(1.5-V_T)0.1\right]$$

$$\frac{25\times10^{-6}}{4\times10^{-4}} = 0.15-0.1V_T$$

$$0.1V_T = 0.15-\frac{0.25}{4}$$

$$0.1V_T = 0.0875$$

$$\boxed{V_T = 0.875\text{ V}}$$

8. (2 marks) Given below are two statements regarding I_D in conventional PMOS and NMOS devices.

   $S1$: Drain current for a PMOS device $(I_{D,PMOS})$ $<$ Drain current for a NMOS device $(I_{D,NMOS})$ for a particular V_{GS}

   $S2$: Mobility of a PMOS device (μ_P) $<$ Mobility of an NMOS device (μ_N) at the interface

   A. Statement $S1$ is true and $S2$ is false

   B. Statement $S1$ is false and $S2$ is true

   C. Statement $S1$ is true and $S2$ is true and $S2$ is the correct explanation of $S1$

   D. Statement $S1$ is true and $S2$ is true and $S2$ is not the correct explanation of $S1$

   E. Statement $S1$ and $S2$ are false

9. (2 marks) Given below are two statements regarding substrate bias in PMOSFET.

   $S1$: Source-to-body bias V_{SB} must always be lesser than or equal to zero for a PMOSFET.

   $S2$: The source-to-substrate pn junction must be either grounded or reverse biased for normal transistor action.

   A. Statement $S1$ is true and $S2$ is false

   B. Statement $S1$ is false and $S2$ is true

   C. Statement $S1$ is true and $S2$ is true and $S2$ is not the correct explanation of $S1$

   D. Statement $S1$ and $S2$ are false

   E. Statement $S1$ is true and $S2$ is true and $S2$ is the correct explanation of $S1$

Gate Previous Year Question

10. (2 marks) **(EC-GATE 2014)** The slope of the I_D vs V_{GS} curve of an n–channel MOSFET in linear region is $0.02\ \Omega^{-1}$ at $V_{DS} = 0.1\ V$. For the same device, neglecting channel length modulation, the slope of the $\sqrt{I_D}$ vs V_{GS} curve $(in\ \sqrt{A}/V)$ under saturation is approximately ______ (rounded off to one decimal place)

Ans: 0.316

Range: $0.3 - 0.4$

Current in linear regime is -

$$I_{DS} = K_n \left[(V_{GS} - V_T) V_{DS} \right], \quad \text{where } K_n = \frac{\mu C_{ox} W}{L}$$

$$\therefore \frac{\partial I_{DS}}{\partial V_{GS}} = K_n V_{DS}$$

Given is $\frac{\partial I_{DS}}{\partial V_{GS}} = 0.02$ @ $V_{DS} = 0.1V$

$$\therefore 0.02 = K_n \, 0.1$$

$$\boxed{\therefore K_n = 0.2}$$

Now, current in saturation is given as

$$I_{DS} = \frac{K_n}{2} \left[V_{GS} - V_T \right]^2$$

$$\sqrt{I_{DS}} = \sqrt{\frac{K_n}{2}} (V_{GS} - V_T)$$

$$\frac{\partial \sqrt{I_{DS}}}{\partial V_{GS}} = \sqrt{\frac{K_n}{2}}$$

$$= \sqrt{\frac{0.2}{2}}$$

$$= \sqrt{0.1}$$

$$\boxed{\frac{\partial \sqrt{I_{DS}}}{\partial V_{GS}} = 0.316}$$