

# Chapter 5: MOSFET

3 terminal semiconductor devices: (2 types)

- 1) MOSFET
- 2) BJT

Enhancement type MOSFET

4 terminals

- 1) gate terminal G
  - 2) source terminal S
  - 3) drain terminal D
  - 4) body terminal B  $\rightarrow$  body has no effect
- Three Terminal Device (G, S, D)

- Voltage applied to gate controls current flow between source and drain. "Channel Region"

$V_T$  = Threshold Voltage

(S.1)

$V_{GS} - V_T = V_{OV}$  : effective Voltage or Overdrive Voltage  
- quantity that determines change in the channel

(S.2)

$$Q = C_{ox}(W L) V_{OV}$$

$C_{ox}$  = Oxide Capacitance

Voltage  $V_{DS}$  causes current  $I_D$  to flow through induced n channel.

$\mu_n$  = mobility of electrons

(S.4) :  $\frac{Q}{L} = C_{ox} V_{OV}$  (Charge per unit channel length)

(S.5) :  $|E| = \frac{V_{DS}}{L}$  (Electric Field)

(S.6) : Electron drift velocity =  $\mu_n |E| = \mu_n \frac{V_{DS}}{L}$

$I_D$  is found by multiplying Charge per unit length (S.4) by electron drift velocity (S.6)

$$I_D = [C_{ox}(W L) V_{OV}] \mu_n \frac{V_{DS}}{L} \quad (S.7)$$

$$\text{S.I. if } V_{DS} = \text{Small}$$

$$\text{or } i_D = [\mu_n C_{ox} \left(\frac{W}{L}\right) (V_{GS} - V_t)] V_{DS}$$

process trans conductance : product  $\mu_n C_{ox}$   
Oxide Capacitance  $\times$  mobility of electrons

$$k'_n = \mu_n C_{ox} \quad (\text{S.II})$$

(subscript  $n$  = n channel)

dimensions :  $A/V^2$

$W/L$  = transistor aspect ratio

\* channel conductance proportional to channel width ( $W$ )  
and inversely proportional to channel Length ( $L$ )

trans conductance parameter  $k'_n$

- product of process transconductance  $k'_n$
- and aspect ratio  $W/L$

$$k_n = k'_n (W/L) = (\mu_n C_{ox}) (W/L) \quad (\text{S.II.2})$$

Units:  
( $A/V^2$ )

$g_{DS}$  = channel conductance

$V_{DS}$  small MOSFET behaves as resistor  $r_{DS}$   
controlled by gate voltage  $V_{GS}$

$$r_{DS} = 1/g_{DS} = \frac{1}{(\mu_n C_{ox}) (W/L) (V_{GS} - V_t)} = \frac{1}{(\mu_n C_{ox}) (W/L) (V_{GS} - V_t)} \quad (\text{S.I.3 a-b})$$

$V_{GS} > V_t$  "enhances channel."  
thus enhancement type.

Ex 5.11

Given:  $t_{ox} = 4\text{nm}$

$\mu_n = 450\text{ cm}^2/\text{V}\cdot\text{s}$

$V_t = 0.5\text{V}$

$r_{DS} = 1000\Omega$

$V_{DS} = 1\text{V}$

Find:  $k_n$  &  $W$

$L = 0.18 \times 10^{-6}$

Overdrive Voltage:

$V_{OV} = V_{GS} - V_t = 1 - 0.5 = 0.5\text{V}$

Permittivity of  $\text{SiO}_2$ :

$\epsilon_{ox} = 3.45 \times 10^{-11}\text{ F/m}$

Oxide Capacitance:

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.45 \times 10^{-11}}{4 \times 10^{-9}} = 0.8625 \times 10^{-2}\text{ F/m}^2$

Transconductance:

$k_n' = \mu_n C_{ox} = (450 \times 10^{-4}) (0.8625 \times 10^{-2}) = 386 \times 10^{-5}\text{ A/V}^2$

Linear resistance

$r_{DS} = 1 / (k_n' C_{ox}) \left( \frac{W}{L} \right) (V_{OV} - V_t)$   
 $1000 = 1 / (450 \times 10^{-4}) (0.8625 \times 10^{-2}) \left( \frac{W}{0.18 \times 10^{-6}} \right) (1 - 0.5)$   
 $W = 1 / (450 \times 10^{-4}) (0.8625 \times 10^{-2}) \left( \frac{1000}{0.18 \times 10^{-6}} \right) (0.5)$

$W = 9.28 \times 10^{-7}\text{ m}$

5.1.5  $V_{DS}$  Increased

$V_{DS}$  increase channel becomes tapered.

$i_D = k_n' \left( \frac{W}{L} \right) (V_{OV} V_{DS} - \frac{1}{2} V_{DS}^2) = (5.115)$

$i_D = k_n' \left( \frac{W}{L} \right) (V_{OV} - \frac{1}{2} V_{DS}) V_{DS} = (5.14)$

$i_D = k_n' \left( \frac{W}{L} \right) [V_{GS} - V_t] V_{DS} - \frac{1}{2} V_{DS}^2 = (5.16)$

5.1.16  $V_{DS} \geq V_{OV}$

Channel Pinch/Current Saturation

Here  $V_{GS} > V_T$

$$V_{DS} = V_{OV} = \text{Saturation}$$

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{OV}^2 \quad (5.17)$$

Saturation Region

Example 5.1

Given:  $L_{min} = 0.18 \mu m$

$t_{ox} = 4 nm$

$\mu_n = 450 cm^2/V \cdot s$

$V_T = 0.5 V$

a) find  $C_{ox}$  &  $k_n'$

b) if  $W/L = 1.8 \mu m / 0.18 \mu m$

find  $V_{OV}$ ,  $V_{DS}$ ,  $V_{DSmin}$  @  $I_D = 100 \mu A$

c) find  $V_{OV}$  &  $V_{GS}$  to achieve  $r_{DS} = 1000 \Omega$   
assume very small  $V_{DS}$

$$a) C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.45 \times 10^{-14}}{4 \times 10^{-9}} = \boxed{8.63 \times 10^{-3} F/m^2}$$

$$k_n' = \mu_n C_{ox} = (450 \times 10^{-4}) (8.63 \times 10^{-3}) = \boxed{3.88 \times 10^{-6} A/V^2}$$

b) Operation in saturation region

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{OV}^2$$
$$100 \times 10^{-6} = \frac{1}{2} (3.88 \times 10^{-6}) \left(\frac{1.8 \times 10^{-4}}{0.18 \times 10^{-4}}\right) V_{OV}^2$$
$$\boxed{V_{OV} = 0.227 V}$$

$$V_{DS} = V_{OV} + V_T = 0.227 + 0.5 = \boxed{0.727 V}$$

$$\boxed{V_{DSmin} = V_{OV} = 0.227 V}$$

$$c) r_{DS} = 1 / k_n' \left(\frac{W}{L}\right) V_{OV}$$
$$1000 = 1 / (3.88 \times 10^{-6}) (10) V_{OV}$$
$$\boxed{V_{OV} = 0.257 V}$$

$$V_{GS} = V_{OV} + 0.5 = \boxed{0.757 V}$$

Ex 5.21

Find  $C_{ox}$ ,  $k_n'$ ,  $V_{ov}$ ,  $V_{gs}$ ,  $V_{ds\min}$

$$\begin{aligned} t_{ox} &= 1.4 \text{ nm} \\ \epsilon_{ox} &= 6.5 \times 10^{-4} \\ \mu_n &= 216 \text{ cm}^2/\text{V}\cdot\text{s} \\ V_t &= 0.35 \text{ V} \\ W/L &= 10 \\ I_D &= 50 \times 10^{-6} \end{aligned}$$

$$C_{ox} = \epsilon_{ox} / t_{ox} = 3.45 \times 10^{-11} / 1.4 \times 10^{-9} =$$

$$C_{ox} = 0.0246$$

$$k_n' = \mu_n C_{ox} = (216 \times 10^{-4}) (0.0246) = 532 \times 10^{-4}$$

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{ov}^2$$

$$50 \times 10^{-6} = \frac{1}{2} (532 \times 10^{-4}) (10) V_{ov}^2$$

$$V_{ov} = 0.137 \text{ V}$$

$$V_{gs} = 0.137 + 0.35 = 0.487 \text{ V}$$

$$V_{ds\min} = 0.137 \text{ V}$$

5.1.7 p channel MOSFET

- substrate is n type
- channel regions are p type
- polarity reversed.

To induce current (-) voltage is applied.

$$V_{gs} \leq V_t$$

$$|V_{gs}| \geq |V_{tp}|$$

$P_{mos}$  originally dominated b/c  $N_{mos}$  was hard to make as  $N_{mos}$  tech difficulties solved  $N_{mos}$  began to dominate the market.

$N_{mos} >$  gains & operation speeds

$$\mu_n > \mu_p$$

now both dominate: both  $N_{mos}$  &  $P_{mos}$