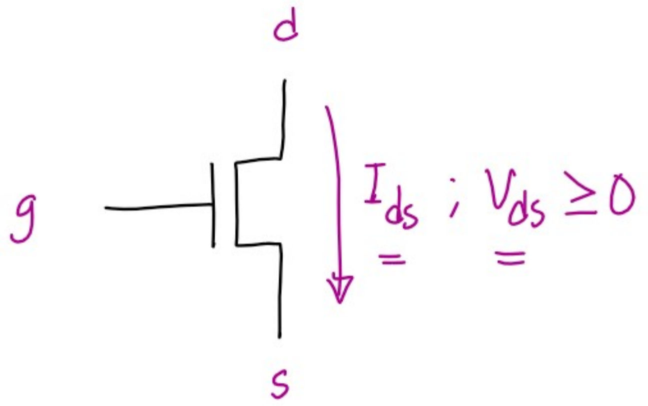
MOSFET I-V Summary & Examples

Tuesday, July 27, 2021 1:11 AM

I-V characteristics of MOSFET devices: Current & Voltage

1. nMOS



V_t : Threshold voltage $V_t > 0$

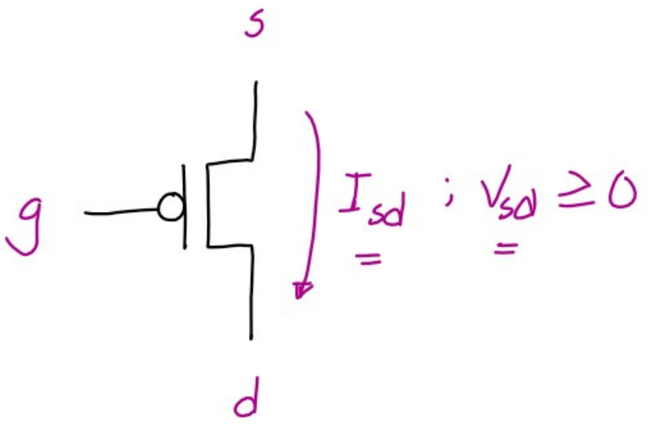
$$\beta = \mu_n \frac{\varepsilon_{ox}}{t_{ox}} \left(\frac{W}{L}\right)_n$$

$$V_{ds(sat)} = V_{gs} - V_t$$

nMOS operating modes

- ON ($V_{gs} \geq V_t$)
  - linear: $V_{ds} < V_{ds(sat)}$
    $$I_{ds} = \beta\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)V_{ds}$$
  - saturation: $V_{ds} \geq V_{ds(sat)}$
    $$I_{ds} = \frac{\beta}{2}\left(V_{gs} - V_t\right)^2$$
- OFF ($V_{gs} < V_t$)
  $I_{ds} = 0$

2. pMOS



V_{tp} : Threshold voltage $V_{tp} < 0$

$$\beta_p = \mu_p \frac{\varepsilon_{ox}}{t_{ox}} \left(\frac{W}{L}\right)_p$$

$$V_{sd(sat)} = V_{sg} - |V_{tp}|$$

pMOS operating modes

- ON ($V_{sg} \geq |V_{tp}|$)
  - Linear: $V_{sd} < V_{sd(sat)}$
    $$I_{sd} = \beta_p\left(V_{sg} - |V_{tp}| - \frac{V_{sd}}{2}\right)V_{sd}$$
  - saturation: $V_{sd} \geq V_{sd(sat)}$
    $$I_{ds} = \frac{\beta_p}{2}\left(V_{sg} - |V_{tp}|\right)^2$$
- Off ($V_{sg} < |V_{tp}|$)
  $I_{sd} = 0$

	Vgs < Vt	Vgs ≥ Vt
Vds < Vds(sat)	Cutoff	Linear
Vds ≥ Vds(sat)	Cutoff	Saturation

	Vsg < |Vtp|	Vsg ≥ |Vtp|
Vsd < Vsd(sat)	Cutoff	Linear
Vsd ≥ Vsd(sat)	Cutoff	Saturation

$$I_{ds} = \begin{cases} 0 & \rightarrow \text{cutoff} \\ \beta\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)V_{ds} & \rightarrow \text{linear} \\ \frac{\beta}{2}\left(V_{gs} - V_t\right)^2 & \rightarrow \text{saturation} \end{cases}$$

$$I_{sd} = \begin{cases} 0 & \rightarrow \text{cutoff} \\ \beta_p\left(V_{sg} - |V_{tp}| - \frac{V_{sd}}{2}\right)V_{sd} & \rightarrow \text{linear} \\ \frac{\beta_p}{2}\left(V_{sg} - |V_{tp}|\right)^2 & \rightarrow \text{saturation} \end{cases}$$

Problem 1

→ nMOS.

Consider an n-channel MOSFET with the following parameters:
V_t = 0.4 V, W = 20 μm, L = 0.8 μm, μ_n = 650 cm^2/V–s, t_{ox} = 200 Å, and **ε_{ox} = (3.9)(8.85 × 10^{-14}) F/cm**.
Calculate **β**. Then determine the operating mode and the current through the transistor (I_{ds}) for the following cases:

(a) **Vgs = 0.8 V** & **Vds = 0.2 V**

(b) **Vgs = 1.6 V** & **Vds = 2.0 V**

$$I = C\frac{dV}{dt} \Rightarrow A = F\cdot\frac{V}{s}$$

$$F = \frac{A\cdot s}{V}$$

$$\beta = \mu_n \frac{\varepsilon_{ox}}{t_{ox}} \frac{W}{L} = 650 \times \frac{3.9 \times 8.854 \times 10^{-14}}{200 \times 10^{-8}} \times \frac{20}{0.8} \qquad \frac{\cancel{cm^2}}{V\cdot\cancel{s}} \times \frac{F}{\cancel{cm}} \cdot \frac{1}{\cancel{cm}} \times \frac{\cancel{\mu m}}{\cancel{\mu m}}$$

$$F \rightarrow \frac{A\cdot\cancel{s}}{V}$$

$$= 0.0027105 \ \frac{A}{V^2} = 2.7105 \ \frac{mA}{V^2} \qquad t_{ox} = 200\text{Å} \qquad 1\text{Å} = 10^{-10}m = 10^{-8}cm$$

(a) $V_{gs} = 0.8V \quad V_t = 0.4V \quad V_{gs} > V_t \Rightarrow$ ON ✓

$V_{ds(sat)} = V_{gs} - V_t = (0.8 - 0.4)V = 0.4V \qquad V_{ds} = 0.2 < V_{ds(sat)} = 0.4 \Rightarrow$ linear

$$I_{ds} = \beta\left(V_{gs} - V_t - \frac{V_{ds}}{2}\right)V_{ds} = 0.0027105 \times \left(0.8 - 0.4 - \frac{0.2}{2}\right) \times 0.2 \quad \frac{A}{\cancel{V^2}}\cdot\cancel{V^2}$$

$$= 0.00016263 \ A = 0.16263 \ mA. \ ■$$

(b) $V_{gs} = 1.6V \quad V_t = 0.4V \quad V_{gs} > V_t \Rightarrow$ ON ✓

$V_{ds(sat)} = V_{gs} - V_t = (1.6 - 0.4)V = 1.2V \qquad V_{ds} = 2V \qquad V_{ds} > V_{ds(sat)} \Rightarrow$ saturation

$$I_{ds} = \frac{\beta}{2}\left(V_{gs} - V_t\right)^2 = \frac{0.0027105}{2} \times (1.6 - 0.4)^2 \quad \frac{A}{\cancel{V^2}}\cdot\cancel{V^2}$$

$$= 0.001952 \ A = 1.952 \ mA \ ■$$

This value was wrongly calculated in box!

Problem 2

This value was wrongly calculated in box!

#Problem 2

For a 0.8-µm process technology, t_{ox} = 15 nm, µ = 275 cm²/V.s, ε_{ox} = (3.9)(8.85 × 10^{-14}) F/cm and V_t = - 0.7 V.

(a) Judging from the value of V_t and µ, comment on whether the MOSFET is NMOS or PMOS
(b) Calculate C_{ox}
(c) For a MOSFET with W/L = 20 calculate the values of β, V_{sg} and $V_{sd(min)}$ needed to operate the transistor in the saturation region with a dc current of I_d = 0.1 mA

(a) since $V_t = -0.7$ V ; $V_t < 0 \Rightarrow$ pMOS. $\mu = 275$

(b) $C_{ox} = \dfrac{\varepsilon_{ox}}{t_{ox}} = \dfrac{3.9 \times 8.854 \times 10^{-14}}{15 \times 10^{-8}} \dfrac{F/cm}{cm} = 0.000002302$ F $= 2.302 \times 10^{-6}$ F

we know

$V_{sd(min)} = V_{sg} - |V_t|$

in sat^n region,

$I_d = \dfrac{\beta}{2}\left(V_{sg} - |V_t|\right)^2$

(c) $\beta = \mu \dfrac{\varepsilon_{ox}}{t_{ox}} \dfrac{W}{L} = 275 \times 2.302 \times 10^{-6} \times 20 \ \dfrac{A}{V^2} = 0.012661 \ A/V^2$

$\Rightarrow V_{sg} = \sqrt{\dfrac{2I_d}{\beta}} + |V_t|$

saturation region condition for pMOS : $\boxed{V_{sd} \geq V_{sd(sat)}}$ $(= V_{gs} - |V_t|)$

$V_{sg} = \sqrt{\dfrac{2 \times 0.1 \times 10^{-3}}{0.012661}} + 0.7$

$= 0.82568$ V

$V_{sd(min)} = V_{sg} - |V_t| = 0.82568 - 0.7$ V $= 0.1278$ V

$V_{sg} = 0.8256$ V

#Problem 3

$V_t = 0.3$V

Consider an nMOS transistor in a 65 nm process with a minimum drawn channel length of 50 nm (λ = 25 nm). Let $W/L = 4/2\ \lambda$ (i.e., 0.1/0.05 μm). In this process, the gate oxide thickness is 10.5 Å. Estimate the high-field mobility of electrons to be 80 cm²/V·s at 70 °C. The threshold voltage is 0.3 V. Plot I_{ds} vs. V_{ds} for V_{gs} = 0, 0.2, 0.4, 0.6, 0.8, and 1.0 V using the long-channel model.

$\beta = 80 \times \dfrac{3.9 \times 8.854 \times 10^{-14}}{10.5 \times 10^{-8}} \times \dfrac{4}{2} \ \dfrac{A}{V^2}$

$= 526 \ \dfrac{\mu A}{V^2}$

$V_{gs} = 0 \rightarrow V_{gs} < V_t \rightarrow$ Cutoff $\rightarrow I_{ds} = 0$

$V_{gs} = 0.2V \rightarrow V_{gs} < V_t \rightarrow$ Cutoff $\rightarrow I_{ds} = 0$

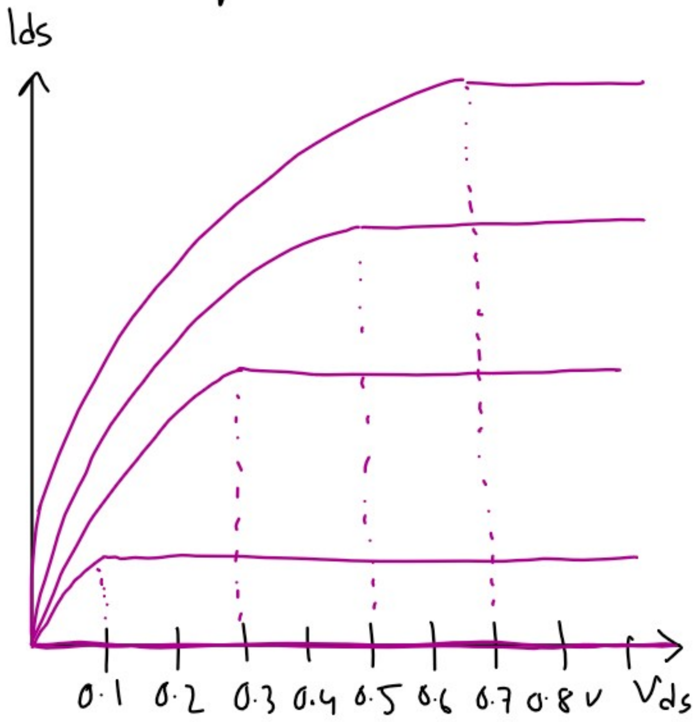
$V_{gs} = 0.4V \rightarrow V_{gs} > V_t \rightarrow$ ON w/ $I_{ds} \neq 0$: $V_{ds(sat)} = V_{gs} - V_t = 0.1V$

$V_{ds} < 0.1$ $\quad I_{ds} = \beta\left(V_{gs} - V_t - \dfrac{V_{ds}}{2}\right)V_{ds}$

$V_{ds} \geq 0.1$ $\quad I_{ds} = \dfrac{\beta}{2}\left(V_{gs} - V_t\right)^2$

$V_{gs} = 0.6 \rightarrow V_{gs} > V_t \rightarrow$ ON $\longrightarrow V_{ds(sat)} = 0.6 - 0.3 = 0.3$

$V_{gs} = 0.8 \rightarrow V_{ds(sat)} = 0.8 - 0.3 \rightarrow 0.5V$ $\quad V_{gs} = 1V$; $V_{ds(sat)} = 1 - 0.3 = 0.7V$



Homework: try for pMOS

#Problem 4

Concept: polysilicon crossing diffusion creates transistors

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Using the figure given below, answer the following questions:

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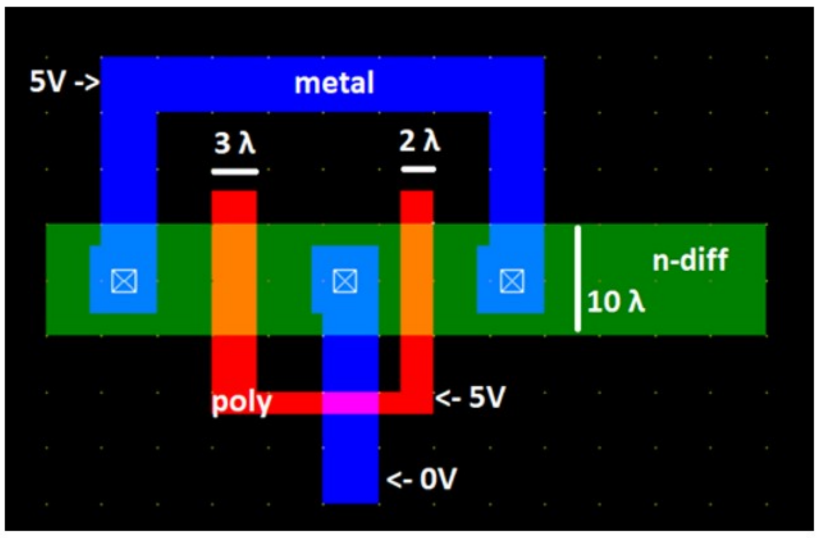
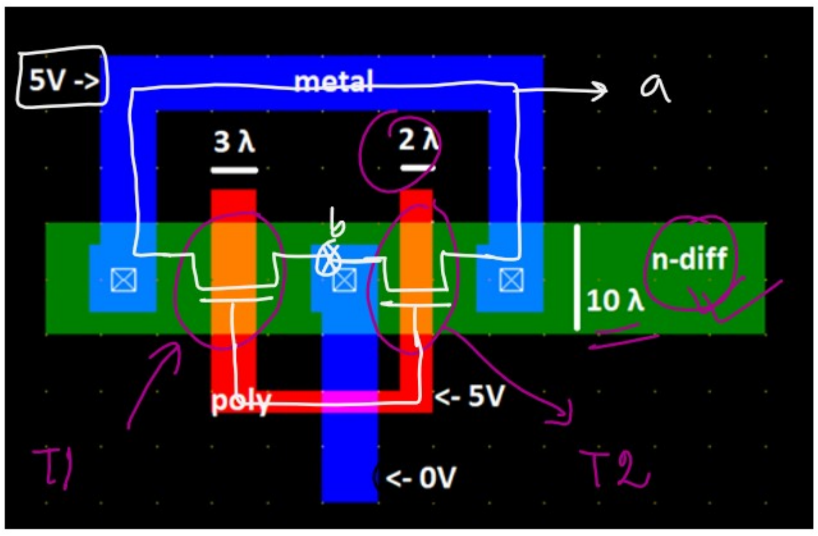
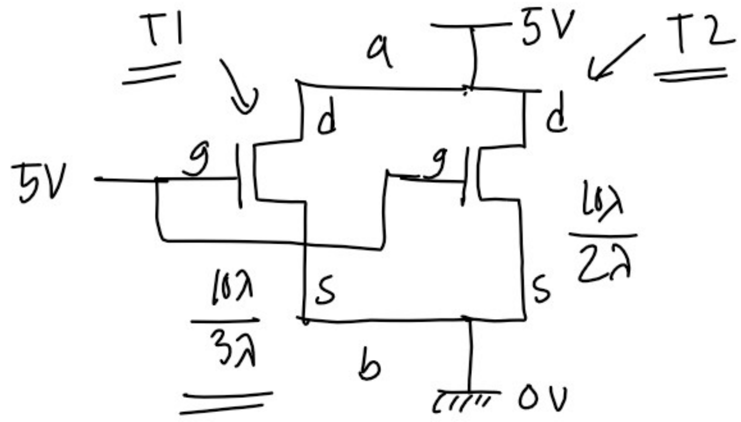


transistors





a. Draw the schematic diagram of the circuit (that results in this layout) and then clearly mark the length and width of each of the transistors.

b. Find the current flowing through each of the transistors, if $\mu_n C_{ox}$ = 120 μA/V², V_t = 1 V

(b)

T1 $\quad V_t = 1V \quad \mu_n C_{ox} = \cancel{10}\,120\,\mu A/V^2$

$V_{gs} = 5V - 0V = 5V > V_t$ ON

$V_{ds(sat)} = V_{gs} - V_t = 5 - 1V = 4V$

$V_{ds} = 5 - 0V = 5V > V_{ds(sat)} \Rightarrow$ Saturation

$I_{ds} = \frac{\beta}{2}(V_{gs} - V_t)^2$

$= \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{gs} - V_t)^2$

$= \frac{1}{2} \times 120 \times \frac{10}{3} (5-1)^2$

$= 60 \times \frac{10}{3} \times 16$

$= 3200\ \mu A$

$= 3.2\ mA$

T2:

$I_{ds} = \frac{\beta}{2}(V_{gs} - V_t)^2$

$= \frac{1}{2} \times 120 \times \frac{W}{L} \times (V_{gs} - V_t)^2$

$= \frac{1}{2} \times 120 \times \frac{10}{2} \times 16\ \mu A$

$= 4800\ \mu A = 4.8\ mA.$