Serie 10 - Solution

Given constants

$\epsilon_0 = 8.85 \cdot 10^{-14} \, [F/cm]$
$\epsilon_{ox} = 3.9 \cdot \epsilon_0$

Exercise 01

Consider a MOS transistor polarized as in Figure 1. We know: $V_{th} = 0.7 \ [V]$, $W = 10 \ [\mu m]$, $L = 0.5 \ [\mu m]$, $t_{ox} = 20 \ [nm]$. When the circuit is polarized with $V_{DD} = 3.3 \ [V]$, the current flowing through the channel of the transistor is $I_D = 0.5 \ [mA]$.
The value of electron mobility, μ_n, in the inversion channel of the MOS transistor is:

a) $\sim 250 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$

b) $\sim 500 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$

c) $\sim 750 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$

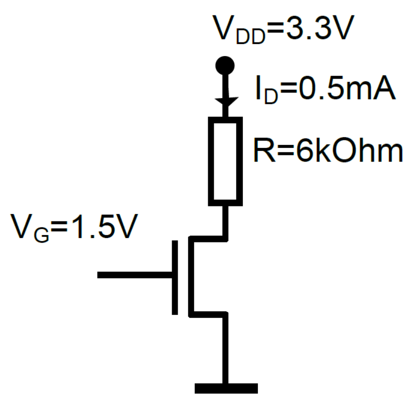

Figure 1: MOS transistor circuit.

We begin by calculating the voltage drop across the resistor and across the transistor:

$$V_R = R \cdot I_D = 0.5 \cdot 10^{-3} \cdot 6 \cdot 10^3 = 3 \ [V] \tag{1}$$

$$V_{DS} = V_{DD} - V_R = 0.3 \ [V] \tag{2}$$

Since we have:

- $V_{GS} - V_{th} = 0.8\ [V] \quad \Rightarrow \quad V_{GS} > V_{th}$
- $V_{DS} < V_{GS} - V_{th} \quad \Rightarrow \quad V_{GD} > V_{th}$

the transistor is in the **linear region**. Thus, the drain current is expressed as:

$$I_D = \frac{W}{L}\mu_n C_{ox}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS} \tag{3}$$

We first need to compute the oxide capacitance:

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.9 \cdot 8.85 \cdot 10^{-14}}{20 \cdot 10^{-7}} = 1.7 \cdot 10^{-7}\ \left[F/cm^2\right] \tag{4}$$

Finally, we can calculate the mobility:

$$\begin{aligned} \mu_n &= \frac{I_D}{\frac{W}{L}C_{ox}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right)V_{DS}} \\ &= \frac{0.5 \cdot 10^{-3}}{\frac{10}{0.5} \cdot 1.7 \cdot 10^{-7}\,(1.5 - 0.7 - 0.15) \cdot 0.3} = 754\ \left[cm^2\ V^{-1}\ s^{-1}\right] \end{aligned} \tag{5}$$

The correct answer, then, is answer c.

Exercise 02

Consider a n-MOSFET on a p-type Si substrate. We know: $W = 10\ [\mu m]$, $L = 1\ [\mu m]$, $t_{ox} = 5\ [nm]$. The measured transistor characteristics are shown in Figure 2. For Fig. 2a, $g_m = 1.4 \cdot 10^{-4}\ [A/V]$; for Fig. 2b, we don't know the scale of the axes.

Q1. By looking at the $I_D - V_G$ characteristics, we can conclude that at $V_G = 0.8\ [V]$ the MOSFET is in:

- **a)** Saturation region.
- **b)** Linear region.
- **c)** Cut-off region.

Sol: **b)** Linear region, since $V_{GS} > V_{th}$ and $V_{DS} < V_{GS} - V_{th}$.

Q2. The threshold voltage V_{th} of the MOSFET is:

- **a)** $V_{th} = 0.1\ [V]$
- **b)** $V_{th} = 0.2\ [V]$
- **c)** $V_{th} = 0.4\ [V]$
- **d)** $V_{th} = 1\ [V]$

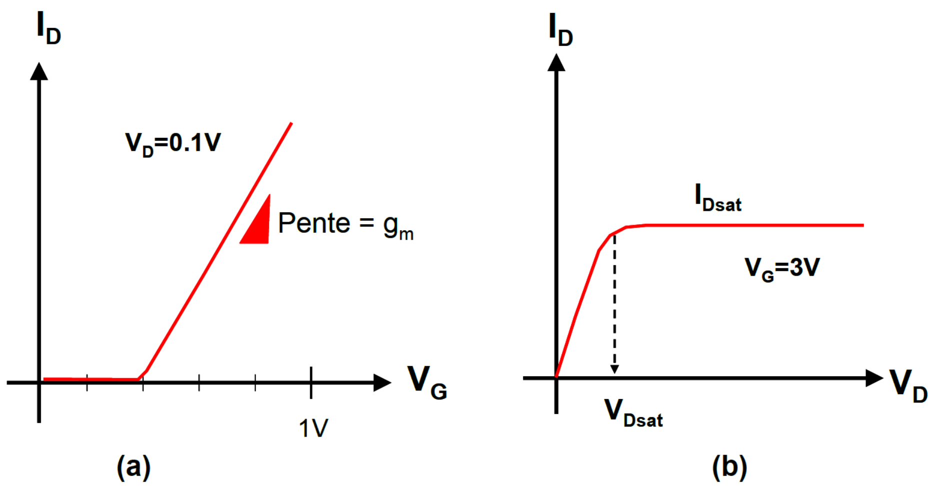

Figure 2: MOSFET characteristics.

Sol: c) By looking at the x-axis marks of Fig. 2a.

Q3. The mobility μ_n of the electrons in the n-channel is:

- **a)** $\sim 200 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$
- **b)** $\sim 300 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$
- **c)** $\sim 400 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$
- **d)** $\sim 500 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$
- **e)** $\sim 600 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$

Sol: a) In the linear region, $I_D = \frac{W}{L}\mu_n C_{ox} V_{DS}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right)$, where $g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{W}{L}\mu_n C_{ox} V_{DS}$. Upon calculation, we obtain $\mu_n = 203 \ \left[cm^2 \ V^{-1} \ s^{-1}\right]$.

Q4. For $V_G = 3 \ [V]$, the saturation voltage V_{Dsat} is:

- **a)** $V_{Dsat} = 2.9 \ [V]$
- **b)** $V_{Dsat} = 2.8 \ [V]$
- **c)** $V_{Dsat} = 2.6 \ [V]$
- **d)** $V_{Dsat} = 2 \ [V]$

Sol: c) V_{Dsat} is defined as $V_{GS} - V_{th} = 2.6 \ [V]$.

Q5. The saturation current I_{Dsat} is:

a) $I_{Dsat} = 2.1\ [mA]$

b) $I_{Dsat} = 4.7\ [mA]$

c) $I_{Dsat} = 6.8\ [mA]$

Sol: **b)** In the saturation region ($V_{GS} > V_{th},\ V_{DS} > V_{GS} - V_{th} = V_{Dsat}$), the current is expressed as $I_D = \frac{W}{2L}\mu_n C_{ox}\left(V_{GS} - V_{th}\right)^2$. Upon calculation, we obtain $I_{Dsat} = 4.74\ [mA]$.

Q6. The trend of the $I_D - V_D$ characteristics allows us to conclude that:

a) This n-MOSFET has a long channel.

b) This n-MOSFET shows short-channel effects.

c) We need the $I_D - V_G$ characteristics below threshold, in *log* scale, to determine if there are short-channel effects.

Sol: **a)** In Fig. 2b, the saturation current is constant, meaning that the transistor is not affected by channel length modulation. Therefore, the transistor is likely to be a long-channel MOSFET.

Exercise 03

Choose the correct statements regarding MOS transistors on fully-depleted silicon-on-insulator (FD-SOI) substrates:

A) The depth of the depletion region controlled by the gate is thinner than the thickness of the Si film of the SOI.

B) The junction leakage currents in FD-SOI are smaller than for MOS transistor on bulk Si, for the same technological node (channel length).

C) A kink effect in the $I_D - V_D$ characteristics exists, where the drain current shows an unusual increase before the breakdown.

D) The FD-SOI shows a better resistance to ionizing radiations, with respect to partially-depleted SOI.

E) FD-SOI transistors show stronger short-channel effects than their counterparts in bulk Si.

F) The FD-SOI has inherent self-heating effects, because of the buried oxide, which increases the thermal resistance.

G) For the same channel length, transistors on FD-SOI can operate at higher frequency with respect to those on bulk Si.

Solution: the correct statements are **B**, **D**, **F**, and **G**.