Problem 1: Describe how MOSFET works, including 4 regions talked in the class.

Main point: list 4 regions (Cutoff, Subthreshold, Triode, Saturation), and give the working conditions for those 4 region and explain it in relative detail, follow the lecture notes.

Note: There is a subtle difference from what we talked Accumulation, Depletion, Weak/Strong Inversion in the MOS cap. Don’t mixed those two models up, although they do have strong relationships.

Problem 5.2

Ans: From Eq (5.8), the number of acceptor atoms in the substrate
\[ N_A = n_i \exp\left(\frac{\phi_F}{q} \right) = 8.354 \times 10^{14} \text{ atoms/cm}^3 \]

Use Eq (5.20),
\[ C'_{ox} = (2 q \varepsilon_{ox} N_A)^{0.5} / \lambda = 369.72 \text{ aF/\mu m}^2 \]
The KP of this n-channel MOSFET is
\[ KP = \mu_n \times C'_{ox} = 550 \text{ cm}^2 / \text{V} \times 369.72 \text{ aF/\mu m}^2 = 20.33 \mu \text{A/V}^2 \]

From Eq. (5.36), \[ \beta = KP \times W/L = 20.33 \times 10/2 = 101.56 \]
From Eq. (5.21), \[ V_{THN} = 0.8V + 0.45 \times (5.7+1)^{0.5} - (5.7)^{0.5} = 1.024V \]

Since \( V_{DS} > V_{GS} - V_{THN} \) and \( V_{GS} > V_{THN} \), the MOSFET is operated in saturation region.
With \( \lambda = 0 \), use Eq (5.39),
\[ I_D = \beta (V_{GS} - V_{THN})^2 / 2 \approx 48.4 \mu \text{A} \]

If use CN20 process, the \( C'_{ox} = 800 \text{ aF/\mu m}^2 \), and \( KP = 44 \mu \text{A/V}^2 \), \( I_D = 104.78 \mu \text{A} \)

For Vsb=0V
Clearly, \( V_{thn} = V_{thn} = 0.8V \), and \( V_{gs} - V_{thn} = 2 - 0.8 = 1.1V \), \( V_{ds} = 1.1V \), so \( V_{ds} < V_{gs} - V_{thn} \), it works in Triode region, so we need to use the equation of \( I_D \) in Triode region to calculate \( I_D \), and the result is \( I_D = 72.7 \mu \text{A} \).

Problem 5.5

\[ C'_{ox} = \varepsilon_{ox} / TOX = (8.85 \times 3.97 \text{ aF/\mu m}) / (400 \times 10^{-10} \text{ m}) = 878.4 \text{ aF/\mu m}^2 \]

Problem 5.8

The electrostatic potential of the oxide semiconductor interface when \( V_{GS} = V_{VTH} \) is:
\[ \phi_S = \phi_F = \frac{kT}{q} \ln \left( \frac{N_A}{N_i} \right) \]

Where \( N_A \) is the number of acceptor atoms in the substrate, \( N_i \) is the intrinsic carrier concentration of silicon.
Problem 5.13

Since every MOSFET shown in Figure P5.13 has the same $V_{DS}$, $V_{GS}$, $K_P$, $L$ and $V_{THN}$, the current flowing through every MOSFET is

$$I_{Dn} = (K_P \times W \times I/L) \times [(V_{GS} - V_{THN})V_{DS} - V_{DS}^2/2]$$

(neglect the body effect and for both triode and saturation region, this equation is effective.)

Therefore, the total current from drain to source is

$$I_D = [K_P \times (W_1 + W_2 + \ldots + W_N)/L] \times [(V_{GS} - V_{THN})V_{DS} - V_{DS}^2/2]$$

This I-V characteristic is the same as one single MOSFET with a width equal to the sum of each individual MOSFET’s width.

Problem 5.15

From Figure P5.14, we assume that both MOSFET are in the triode region. Neglecting the body effects,

1) $I_D \times L = (V_{G1} - V_{THN})V_{DS1} - V_{DS1}^2/2 = (V_g - V_{THN})V_1 - V_1^2/2$

2) $I_D \times L = (V_{G2} - V_{THN})V_{DS2} - V_{DS2}^2/2$

$= (V_g - V_{THN} - V_1)(V_d - V_1) - (V_d - V_1)^2/2$

1)+2)

$I_D \times (L_1 + L_2)(K_P \times W) = V_gV_d - V_{THN}V_d - V_d^2/2 = (V_g - V_{THN})V_d - V_d^2/2$

Re-arranging this equation,

$$I_D = [K_P \times W/(L_1 + L_2)] \times [(V_{GS} - V_{THN})V_{DS} - V_{DS}^2/2]$$

From this equation, Figure P5.14 does behave as a single MOSFET with the length equal to the sum of the individual MOSFET’s length.

Problem 5.19

For the Fig. P5.19, the layout of an n-channel MOSFET is equal to 5 MOSFETs, each with $W/L = 4/25$, connected serially. Therefore, the device’s width is 4 $\mu$m and length is $5 \times 25 = 125 \mu$m.

You could relate problem 5.15 with Problem 5.19, just like you could relate the layout example on the book Page 103 with the problem 5.13.