VE320 Intro to Semiconductor Devices
Summer 2022 — Problem Set 9

July 28, 2022

Exercise 9.1

Assume that the subthreshold current of a MOSFET is given by

$$I_D = 10^{-15} \exp\left(\frac{V_{GS}}{(2.1)V_t}\right)$$

over the range $0 \leq V_{GS} \leq 1$ volt and where the factor 2.1 takes into account the effect of interface states. Assume that 10^6 identical transistors on a chip are all biased at the same V_{GS} and at $V_{DD} = 5$ V.

(a) Calculate the total current that must be supplied to the chip at $V_{GS} = 0.5, 0.7$, and 0.9 V.

(b) Calculate the total power dissipated in the chip for the same V_{GS} values.

Exercise 9.2

A silicon MOSFET has parameters $N_a = 4 \times 10^{16}$ cm^{-3}, $t_{ox} = 12$ nm $= 120\mathring{A}$, $Q'_{ss} = 4 \times 10^{10}$ cm^{-2}, and $\phi_{ms} = -0.5$ V. The transistor is biased at $V_{GS} = 1.25$ V and $V_{SB} = 0$.

(a) Calculate ΔL for (i) $\Delta V_{DS} = 1$ V, (ii) $\Delta V_{DS} = 2$ V, and (iii) $\Delta V_{DS} = 4$ V.

(b) Determine the minimum channel length L such that $\Delta L/L = 0.12$ for $V_{GS} = 1.25$ V and $\Delta V_{DS} = 4$ V.

Exercise 9.3

Consider an n-channel silicon MOSFET. The parameters are $k'_n = 75\mu$A/V^2, $W/L = 10$, and $V_T = 0.35$ V. The applied drain-to-source voltage is $V_{DS} = 1.5$ V.

(a) For $V_{GS} = 0.8$ V, find (i) the ideal drain current, (ii) the drain current if $\lambda = 0.02$ V^{-1}, and (iii) the output resistance for $\lambda = 0.02$ V^{-1}.

(b) Repeat part (a) for $V_{GS} = 1.25$ V.

Exercise 9.4

(a) What is subthreshold conduction? Sketch a drain current versus gate voltage plot that shows the subthreshold current for the transistor biased in the saturation region.

(b) What is channel length modulation? Sketch an I–V curve that shows the channel length modulation effect.

(c) What is velocity saturation and what is its effect on the I–V relation of a MOSFET?

(d) Sketch the space charge region in the channel of a short-channel MOSFET and show the charge-sharing effect. Why does the threshold voltage decrease in a short-channel NMOS device?

Exercise 9.5

For a uniformly doped $n^{++}p^{+}n$ bipolar transistor in thermal equilibrium,
(a) sketch the energy-band diagram
(b) sketch the electric field through the device
(c) repeat parts (a) and (b) for the transistor biased in the forward-active region.

Exercise 9.6

What is Early effect? How to minimize it?

Exercise 9.7

(a) From fabrication point of view, why is Si the most commonly used material in semiconductor industry nowadays?
(b) After this course, what did you learn about semiconductors?

Reference

1. Neamen, Donald A. Semiconductor physics and devices: basic principles. McGraw-hill, 2003.