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"Electronics from the Bottom Up: Physics of Nanoscale Transistors"

Exercises on State-of-the-Art MOSFETs Using nanoCMOS on nanoHU.org

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A few key parameters are used to characterize the electrical performance of modern MOSFETs. Examples are on-current, off-current, subthreshold swing, DIBL, etc. For these exercises, you will run the nano-CMOS simulation tool on nanoHUB.org. To run a simulation tool, you will first have to apply for an account, which you can do with the Register link at the upper left of the nanoHUB main page. As soon as you have an account, you can proceed with the exercises below.

1) Use the simulation tool, nano-CMOS to examine the IV characteristics of "45nm" N-channel CMOS technology. Select "NMOS 45nm," and use the default values. Push the "Simulate" button, and then answer the following questions.

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You should clearly describe how you obtain each parameter. You can download images from the nanoHUB and insert them in a Word file to document your work. Note that you are able to change the minimum and maximum axes scales and to select either linear or logarithmic scales.

a) Determine the on-current in μA/μm
b) Determine the off-current in μA/μm
c) Determine the subthreshold swing, S, in mV/decade
d) Estimate V_{DSAT} for V_{GS} = 1.0V. (Do not simply "eyeball" the answer; develop a simple methodology so that another person who follows it would get the same answer.
e) Estimate the DIBL in mV/V
f) Estimate V_T(lin) and V_T(sat) in V
g) Estimate the output resistance, R_o in Ω-μm
h) Estimate the channel resistance, R_{ch} in Ω-μm
i) Estimate the transconductance, g_m, in mS/mm at the maximum gate voltage.
j) The "self-gain," $A = g_m R_o$ is often used as a metric for analog applications (it is roughly the maximum small signal gain that could be achieved in an amplifier circuit with this transistor). Estimate the self-gain for this transistor.

2) Repeat problem 1) for a p-channel MOSFET by selecting "PMOS 45nm," and pushing the "Simulate" button. You should use the default values. Estimate all of the device parameters from problem 1) for the PMOS transistor. Discuss the main difference that you see.

3) It is interesting to see how device parameters scale from one technology generation to another. Select "NMOS 130nm" and run a simulation. You should use the default values. Estimate all of the device parameters and compare them to the 45 nm device. Discuss the main differences you see between present-day device parameters and the parameters of a device from an older technology generation.

4) To get a feel for how key parameters affect the performance of a device, answer the following questions for the 45 nm NMOS device. In each case, one parameter will be varied. Run simulations for both parameters, and compare the results (the nanoCMOS tool allows you to view both results at the same time). Identify the one, two, or three most important changes in the device characteristics. Based on your knowledge of MOSFETs, try to explain these changes.

   a) Increase T_{ox} from 1.1 nm to 1.8 nm.

   b) Return to the original 45nm NMOS parameters. Increase V_T from 0.25 V to 0.4 V.

   c) Return to the original 45nm NMOS parameters. Increase R_{SD} from 150 Ω-μm to 220 Ω-μm.

   d) Return to the original 45nm NMOS parameters. Increase T from 300K to 425 K.

   e) Return to the original 45nm NMOS parameters. Increase L_{eff} from 35 nm to 45 nm.