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"Electronics from the Bottom Up"

Exercises on Quantum Transport Using nanoMOS

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Objectives:
In "Physics of Nanoscale Transistors: Lecture 6: "Quantum Transport in Nanoscale MOSFETs," we illustrated quantum transport using a carbon nanotube MOSFET as an example. The purpose of this exercise is to explore ballistic quantum transport in an ultra-thin body (UTB), double gate, silicon MOSFET. We will use the nanoMOS 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 nanoMOS to simulate a double gate UTB N-MOSFET with the follow device parameters:

Device Structure:

Film thickness:	3 nm	(the silicon body thickness)
Insulator thickness:	1.5 nm	(no oxide penetration)
Gate workfunction:	4.3075 eV	(to set I_{OFF} = 0.1 uA/um)
Gate length:	15 nm	
Source/drain length:	10 nm	
Source/drain overlap:	0 nm	
N_{SD} (source/drain doping):	10^{20} /cm^3	
N_{body}(body doping):	0	(intrinsic body assumed)
Doping profile slope (S/D):	0	(abrupt junction assumed)
R_{SD}:	0 Ω-µm	
Temperature:	300 K	
V_{DD}:	0.8 V	(bias step $\Delta V_{G,D}$ = 0.05 V)

Simulation Option:

Please choose 2 subbands for this simulation.

Exercises on Quantum Transport Using nanoMOS (cont.)

1a) Make a sketch of the device structure with all device parameters labeled.

1b) Run a nanoMOS simulation using the "quantum ballistic transport" option, and plot I_D vs. V_{GS} at low and high V_{DS}, $\log_{10} I_D$ vs. V_{GS} at low and high V_{DS}, and I_D vs. V_{DS} with gate voltage as a parameter. Use these plots to extract the following device parameters.

a) The on-current in µA/µm
b) The off-current in µA/µm
c) The subthreshold swing, S, in mV/decade
d) Estimate V_{DSAT} for $V_{GS} = 0.8$V
e) The DIBL in mV/V
f) The threshold voltages, V_T(lin) and V_T(sat), in V
g) The output resistance, R_o in Ω-µm
h) The channel resistance, R_{ch} in Ω-µm
i) The transconductance, g_m, in mS/mm at the maximum gate and drain voltage.

1c) Examine each of the following plots of internal device quantities under OFF-STATE and ON-STATE conditions. In each case, give a brief explanation of what the plot shows.

- density of states from source contact
- density of states from drain contact
- energy-resolved electron density
- energy resolved current density
- 2D electron density along the channel
- average electron velocity along the channel

2) Use the FETToy simulation tool to perform a simulation of the same UTB double gate device. Explain how you set the FETToy input parameters to produce the same subthreshold swing, DIBL, and off current as the nanoMOS simulation. Run the FETToy simulation, plot I_D vs. V_{GS} at low and high V_{DS}, $\log_{10} I_D$ vs. V_{GS} at low and high V_{DS}, and I_D vs. V_{GS} with gate voltage as a parameter, and use these plots to extract the same device parameters as in question 1b). Compare your results to the nanoMOS simulation results and discuss any significant differences.

You should run FETToy both with and without the "floating source" option and compare results.

3) Repeat the analysis of part 1) using the same input parameters, but this time, select the “classical” simulation option for nanoMOS. Compare key device parameters for the quantum ballistic and classical ballistic cases and discuss any significant differences that you observe.

4) Repeat the analysis for a device with $L_{channel}$ = 5 nm. Compare device parameters with those obtained in part 1b) and discuss the significant differences. Examine the internal plots, compare with those of part 1c) and discuss any significant differences. Use FETToy to simulate this device, compare device parameters, and discuss any significant differences.