Exam #2 — EE 531

Winter 2014

This is a take-home exam. You are welcome to use any notes and/or books. However, you are not permitted to have the assistance of any other person on the exam. If you have any questions regarding interpretation of the questions, you should submit your question to class GoPost web site.

Your exam papers are due back in my office (EE 218) by 9am on Wednesday, March 19. Please do not spend more than 12 hours actively working on the exam. In completing these questions, feel free to make reasonable assumptions, but be sure to state them clearly and check them when possible. Assume $T = 300\text{K}$ unless otherwise specified.

1. Consider an fully-depleted SOI nMOSFET with 10 nm silicon body doped with $N_a = 2\times10^{19}\text{cm}^{-3}$, a metal gate, and high-κ front gate dielectric of thickness 3nm and average dielectric constant of $\kappa = 15$. The buried oxide has thickness of 30 nm and the substrate is p-type Si doped with $N_a = 5 \times 10^{19}\text{cm}^{-3}$.

   (a) What metal workfunction would be required to make the threshold voltage equal to 0.3 V if the substrate is grounded?

   (b) Using this front gate workfunction, over what range can the substrate voltage modulate the frontside threshold voltage?

   (c) What is the subthreshold slope factor m?

2. A retrograde Si pNMOS transistor has donor doping of $10^{18}\,\text{cm}^{-3}$ up to a depth a, and then doping of $N_d = 5\times10^{19}\,\text{cm}^{-3}$ below that. The transistor has a metal gate with work function $\phi_m = 5.1\,\text{eV}$ and a two-layer high-κ gate dielectric. The top layer has thickness 2 nm and dielectric constant of 25, while the lower layer (near Si) has dielectric constant of 6 and thickness 0.3 nm. $V_{SB} = 0\,\text{V}$.

   (a) Determine the value of a required to give a long-channel threshold voltage of -0.2 V.

   (b) What is the minimum value of L such that off current ($V_{GS} = 0\,\text{V}$) is less than $10^{-4}\,\text{A/cm}$ for $V_{DS} = -1\,\text{V}$. Assume that SCE can be calculated as for uniformly-doped MOSFET with the same depletion region width.

3. Consider a silicon MOSFET channel with a nearly uniform lateral electric field of $\mathcal{E} = 2\times10^5 V/\text{cm}$. Assume that for energies below $\langle E\rangle = 0.063\,\text{eV}$, scattering is primarily elastic, with $\langle\tau_m\rangle = 0.2\,\text{ps}$ and $\langle\tau_E\rangle = 5\,\text{ps}$, while for higher energies, the scattering is very strongly inelastic and $\langle\tau_m\rangle = 0.1\,\text{ps}$ and $\langle\tau_E\rangle = 0.5\,\text{ps}$.

   (a) Calculate the time and associated distance required for the average energy to reach $\langle E\rangle = 0.063\,\text{eV}$.

   (b) Estimate the average transit time for $L = 15\,\text{nm}$.