Exam#2—EE531

Spring 2017

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 9 am on Tuesday, June 6. 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 = 300K unless otherwise specified.

1. Consider a bulk NMOS transistor with a tungsten gate, effective $t_{ox} = 1.5nm$ and uniform channel doping. Assuming that long-channel V_T is to be held to 0.4V.

   (a) Determine the minimum channel length and associated substrate doping to keep $I_{off}/W < 10^{-4}$ A/μm with V_{GS} = 0 V and V_{DS} = 1.0 V. Use the simple expression for short channel effects on threshold voltage given in Taur and Ning.

   (b) At the minimum channel length determined in (a), calculate the drain current for $V_{GS} = V_{DS}$ = 1 V. Include effect of velocity saturation using n = 1 model. At what fraction of the ballistic limit is this transistor operating?

2. Consider a symmetric dual gate Si pMOSFET with undoped 4 nm silicon body thickness, a metal gate, and high-κ gate dielectric of thickness 3nm and average dielectric constant of κ = 16. To make the analysis easier, assume that the electron potential in the silicon ($\psi_{si} = (E_F - E_i)/q$) can be considered uniform with value equal to average over body thickness and that the valence bands are spherically symmetric.

   (a) Calculate the inversion charge as function of gate voltage and gate work function. Include the effects of quantum confinement.

   (b) If the threshold voltage is defined as point at which $dV_g/d\psi_{Si} = 2$, what is the value of ψ_{si} at the edge of strong inversion? What gate work function would give a threshold voltage of 0.2V?

   (c) What would actually be the variation of potential over the Si body and how would this change your answers above (e.g., higher, lower, or little change). Explain.

3. Consider a population of electrons in a bulk material. Assume that for energies below E = 0.05 eV, scattering is totally elastic and $\langle\tau_m\rangle$ = 2 ps, while for higher energies, the scattering is strongly inelastic and $\langle\tau_E\rangle = \langle\tau_m\rangle$ = 1 ps. Calculate and sketch the electron velocity in this material as a function of time if a uniform electric field of strength 10^5 V/cm is turned on at time t = 0 and $m_e^* = 0.2\ m_0$.