UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE 130/230A — Prof. Liu
Fall 2013

<u>Homework Assignment #12</u>

Due at the beginning of class on Thursday, 11/21/13

<u>Problem 1</u>: Velocity Saturation

The saturation velocity for electrons in Si is $v_{sat} = 8\times10^6$ cm/sec. Consider an n-channel MOSFET with T_{oxe} = 3 nm, V_T = 0.3 V and W_T = 35 nm, with gate bias V_{GS} = 1.0 V:

(a) Find V_{Dsat} for
- **(i)** L = 1 μm. Is this a "long-channel" device or a "short-channel" device?
- **(ii)** L = 0.05 μm. Is this a "long-channel" device or a "short-channel" device?

(b) Explain how V_{Dsat} would change if
- **(i)** the equivalent oxide thickness (T_{oxe}) were to be decreased
- **(ii)** the channel length (L) were to be decreased

<u>Problem 2</u>: MOSFET Short-Channel Effect

(a) Explain qualitatively why the short-channel effect (reduction in the magnitude of the threshold voltage V_T with decreasing channel length L) occurs.

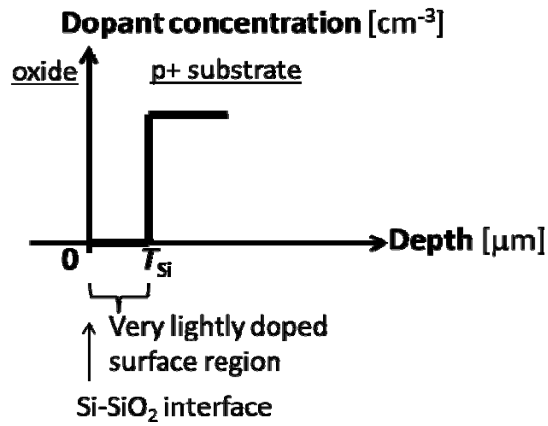
(b) Note that the equation for ΔV_T given in Slide 19 of Lecture 22 is valid for small values of V_{DS} only, since it assumes that the depletion depth equals W_T at all points beneath the central portion gate. Consider an n-channel MOSFET with channel doping concentration $N_A = 1\times10^{17}/cm^3$, electrical gate-oxide thickness T_{oxe} = 3 nm, source/drain junction depth r_j = 0.05 μm.

i. What is ΔV_T for L = 1 μm when V_{DS} = 0.1V?

ii. What is ΔV_T for L = 0.1 μm when V_{DS} = 0.1V?

iii. Suppose V_{DS} is increased to 1 V. How will ΔV_T change, qualitatively? Explain briefly.

<u>Problem 3</u>: MOSFET with Retrograde Channel Doping
As mentioned in Lecture 22 Slide 21, retrograde channel doping can be used to mitigate drain-to-source punchthrough in a MOSFET. A retrograde profile comprises a lightly doped surface region of thickness T_{Si} and a heavily doped region beneath it, idealized as shown below:



(a) Draw the MOS equilibrium energy band diagram (in the depth direction) corresponding to the threshold condition (when the Si surface is heavily n-type), for an n-channel MOSFET (with an n+ poly-Si gate electrode) with the idealized retrograde channel doping profile as shown above. Assume that the depletion charge density in the surface region is essentially zero so that the change in electric field strength within this region is zero according to Poisson's equation.
<u>Note</u>: At the threshold condition, the lightly doped surface region will be completely depleted whereas the heavily doped sub-surface region will be barely depleted, so that the depletion width $W_T \cong T_{Si}$.

(b) What is the electric field strength at the silicon surface, under strong inversion?

(c) Use the result obtained in part (b) to derive an expression for the voltage drop across the oxide (V_{ox}) in terms of T_{Si}, ϕ_F, and ε_{Si}. Assume that there are no oxide charges.

(d) Using the result obtained in part (c), obtain an expression for the threshold voltage, V_T. Compare this with the expression for V_T for a MOSFET with uniform channel/body doping N_A. Which one is expected to be smaller when all other transistor parameters are the same?

<u>Problem 4</u>. MOSFET Source/Drain Structure

(a) Discuss the design trade-offs involved for
  i) the source/drain extension junction depth, r_j;
  ii) the source/drain extension doping concentration, $N_{S/D}$.

(b) Why are the source/drain junctions typically deeper, far away (approximately one gate length away) from the edges of the gate electrode?