# Homework #7 - EE 531

due 6/5/09

1. (Second chance) You are told by your process engineers that they can control doping concentration within $\pm 5\%$ and channel dimensions within $\pm 0.02\mu$m.

   (a) Given these process variations, design an NMOS transistor with an $n^+$ poly gate ($\phi_{poly} \cong \chi_s$), 4nm thick oxide, deep source/drains, a very shallow threshold-shifting implant, and otherwise constant substrate doping to minimize the worst-case switching time under the constraint that the worst-case off-state leakage current is less than 1nA/$\mu$m (with $V_{GS} = 0$V and including DIBL). Assume that the power supply voltage is 2V (set to limit gate field to 5MV/cm) and that the switching speed can be approximated by

   $$W\left[4LC'_{ox} + (0.5\mu\text{m})C'_j\right]V_{dd}/I_{DS},$$

   ($C'_j$ is junction capacitance for S and D) where $I_{DS}$ is calculated from Eq. 3.76 for $V_{GS} = V_{DS} = 2V$ and $V_{SB} = 0$. You have control over the substrate doping, implant dose (to shift $V_T$, ignore effect on mobility), and channel dimensions $L$ and $W$. Use Eq. 3.66 in the text for short channel effects and DIBL and the model for channel length modulation from Eq. 3.97 (use $\mathcal{E}_{sat} = 2\mathcal{E}_c$, $v_{sat} = 8 \times 10^6$ cm/s). Use value of effective mobility calculated at the source.

   (b) Test your design using Sentaurus Device (remember to use worst-case analysis). You can modify the example used in previous homework. Suggest possible reasons for significant discrepancies. Test the switching speed first by just determining $I_{DS}$. Then use an output load consisting of a capacitor equal to $4WLC'_{ox}$ (fan-out of 4 equivalent transistors) in a transient simulation. Initialize the capacitor with a voltage equal to 2V and determine the time to discharge down to 0.5 V (roughly $V_T$).

      i. Plot the mobility as limited by ionized impurity scattering versus temperature for doping of $10^{16}$cm$^{-3}$ and $10^{18}$cm$^{-3}$ in silicon. Rather than integrating over all possible $k$ values, you can instead use an average value of $k$ for the given temperature ($KE = 3k_BT/2$). Assume the scattering is within a single minima which can be approximated to be spherically symmetric with a single effective mass $(m_l m_t^2)^{1/3}$. What is the approximate power law dependence?

      ii. Plot the mobility versus doping at room temperature. Comment on your results.

2. Problem 4.10 in Taur and Ning.

3. Problem 5.4 in Taur and Ning.