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Problem Set #4

Due Wednesday, September 23, 1998

EEC105 **FALL, 1998**

1. Due to a processing error, the n^+ polysilicon gate of a MOS capacitor is merely n-type with a doping concentration $N_d=10^{17}$ cm^{-3}. The gate oxide thickness, t_{ox}, is 200 Angstroms and the substrate doping concentration is $N_a=10^{17}$ cm^{-3}. See figure 1.
   (a) In thermal equilibrium under V_{GB} = 0V, assume the depletion width in the p-type substrate is $X_{do}{}^p$, and the depletion width in the n-type gate is $X_{do}{}^n$. Plot the charge density. Assume the thickness of the n-type gate is not a constraint for $X_{do}{}^n$. (Hint: note that the "0" of the x-axis is set in the middle of the oxide layer to underscore the "symmetry" of this capacitor).
   (b) Write an expression of the electric field for each region in terms of $X_{do}{}^p$ and $X_{do}{}^n$ and plot it. Use symbols and do not plug in the values. What is the relationship between $X_{do}{}^p$ and $X_{do}{}^n$?
   (c) Write an expression for the potential for each region in terms of $X_{do}{}^p$ and $X_{do}{}^n$ and plot it. Use the continuity condition for the potential at the boundaries of regions to solve for $X_{do}{}^p$ and $X_{do}{}^n$. What are their numerical values?
   (d) What is the flatband voltage V_{FB}? What is the threshold voltage V_{Tn}? What is the capacitance ($fF/\mu m^2$)? For V_{GB} = 2V, what are the widths of the depletion regions.
   (e) Sketch the normalized C-V curve for this capacitor.

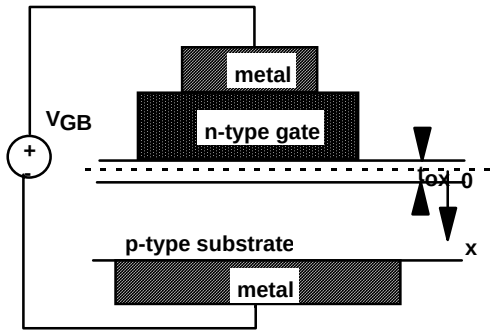

Figure 1

2. Consider a different MOS capacitor with n^+ polysilicon gate and p-type substrate. The gate oxide thickness is 250 Angstroms. Due to a mistake during substrate doping, however the substrate doping is $N_a = 10^{16}$ cm^{-3} rather than the desirable value of $5x10^{16}$ cm^{-3}. One might try to remedy the problem by doing an additional boron implant.
   (a) What is the minimum dose and depth of the implant required to obtain the desired threshold voltage? (i.e., the V_{Tn} you would have when $N_a = 5x10^{16}$ cm^{-3}).
   (b) Even though the threshold voltage could be corrected by the additional implant, the device has changed in other aspects. Sketch the normalized C-V curve before and after the corrective implant.

(over)

(c) A Stanford-educated engineer suggests that instead of changing the doping concentration, they should change the oxide thickness to achieve the desired threshold voltage. He claims that the capacitance will remain the same. Do you agree with him? While he is busy trying to prove it analytically, can you give the physical reason to your answer? In general, describe the effect on an MOS capacitor if oxide thickness or doping concentration is increased. Extend the results to MOS transistor thresholds.

3. Consider an n-channel MOS transistor with (W/L) = 25 μm/2.5 μm, $\mu_n C_{ox}$ = 50 μA/V^2, and V_{TOn} = 1V.
   (a) Plot the drain current I_D vs. V_{GS} for V_{DS} = 250 mV and V_{BS} = 0V. Label the portions of the curve that corresponds to cutoff, triode and saturation. You can assume $V_{Tn} = V_{TOn}$ for this question. (But keep in mind that in practice such a curve is obtained through measurement, and one can extract V_{Tn} from the triode region.)
   (b) Plot the square root of drain current $(I_D)^{1/2}$ vs. V_{GS} for V_{DS} = 5V and V_{BS} = 0V. (In practice, the threshold voltage can also be extracted from this plot. Due to second-order effects, the measurement will differ somewhat from the threshold found in the triode region in part (a).)

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Please return your homework in 558 Cory Hall, to Cheryl Craigwell (cmc@eecs, 642-1237, fax 642-2739), or in class by 11:10am of the due date. Late homeworks will not be graded.