EECS277A Fall 2010 **Midterm Exam #2** Name:__________________________

10/13/2010 1 pm to 2:20 pm ID no.:__________________________

Professor Peter Burke

PROBLEM TWO(20 points):

(NO PARTIAL CREDIT)

Consider 10^9 MOSFET devices, all in the off state. Assume $V_{ds} = 2$ V. Approximate the sub-threshold current by equation 3.40 from the text. Assume m=2, $\mu_{eff} = 600$ cm^2/V-s, and W/L=10. It is desired that the total power dissipated be less than 1 W on the off state. What is the lowest value of V_t that can be used in this case?

$$I_{ds} = \underbrace{\mu C \frac{W}{L}\left(\frac{kT}{q}\right)^2}_{= 467nA} e^{(V_{gs}-V_t)/2kT}$$

$$P = I_{ds} V_{ds} \times 10^9 < 1 \text{ W}$$

$$\Rightarrow I_{ds} < 0.5 \text{ nA}$$

$$\Rightarrow e^{q(V_{gs}-V_t)/2kT} < \frac{0.5nA}{467nA}$$

$$\Rightarrow \boxed{V_t > 0.35 \text{ V}}$$

$(V_{gs} = 0)$

PROBLEM ONE: (50 points)

NO PARTIAL CREDIT

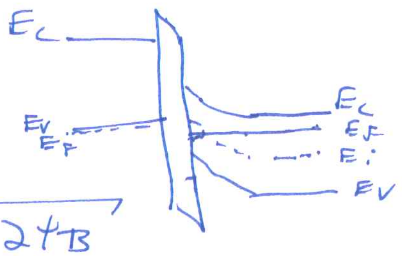
Consider a p-channel MOSFET with 30 nm thick gate oxide and uniform n-type substrate doping of 10^{16} cm^{-3}. The gate work function is that of p$^+$ Si.

A) What is the threshold voltage? Sketch the diagram at threshold condition, $\psi_s=2\psi_B$.

$$V_{Fb} = \frac{1}{2} E_g/q + \psi_B$$

$$\psi_B = \frac{kT}{q} \ln \frac{N_d}{n_i} = 0.36V$$

$$V_{Fb} = 0.92 V$$



$$V_t = V_{Fb} - 2\psi_B - \frac{\sqrt{2\epsilon_{si} q N_d 2\psi_B}}{C_{ox}} =$$

$$0.92V - 0.36V - 0.42 V = \boxed{-0.22 V}$$

B) What is the threshold voltage if a reverse bias of – 1 V is applied to the substrate?

$$V_t = V_{Fb} - 2\psi_B - \frac{\sqrt{2\epsilon_{si} q N_d (2\psi_B + 1V)}}{C_{ox}}$$

$$= 0.92V - 0.72V - 0.65V = \boxed{-0.45V}$$

C) What is the length scale of this device and how short can the channel length be reduced to before severe short-channel effect takes place?

$$W_{dm} = \sqrt{\frac{2\epsilon_{si} 2\psi_B}{qN_d}} = 0.3\mu m$$

$$\lambda = W_{dm} + 3t_{ox} = 0.39\mu m$$

$$L_{min} = 2\lambda = \boxed{0.78\mu m}$$

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PROBLEM THREE (30 points):

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The cutoff frequency f_T can be expressed as $g_m/(2\pi C)$, where $C=C_{ox}$ W L. Find an expression for the cutoff frequency in terms of the mobility μ, saturation velocity v_{sat}, $(V_{gs} - V_t)$, and the length L and width W in A) Long channel limit B) Short channel limit. Sketch the dependence on a log-log plot of f_T vs. L.

A) 10 pts

$$F_T = \frac{g_m}{2\pi C} = \boxed{\frac{g_m}{2\pi C_{ox} W L} = F_T}$$

$$g_m = \mu C_{ox} \frac{W}{L}(V_{gs}-V_t)$$

$$\Rightarrow F_T = \frac{\mu \cancel{C_{ox}} \frac{W}{L}(V_{gs}-V_t)}{\cancel{\mu C_{ox}}\, 2\pi \cancel{C_{ox}} \cancel{W} L} = \boxed{\frac{\mu}{2\pi}\frac{1}{L^2}(V_{gs}-V_t) = F_T}$$

B) 10 pts

$$g_m = C_{ox} W v_{sat}$$

$$\Rightarrow F_T = \frac{\cancel{C_{ox}} \cancel{W} v_{sat}}{2\pi \cancel{C_{ox}} \cancel{W} L} = \boxed{\frac{v_{sat}}{2\pi L} = F_T}$$

Graph 10 pts