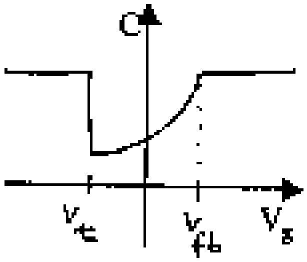
EE 130, Spring/2000
Midterm II Solutions
Professor C. Hu

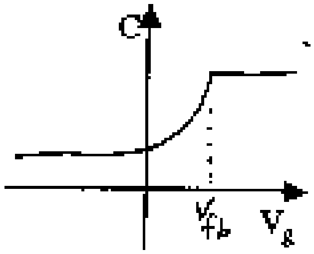
Problem #1

1. Consider a PMOSFET with a P+ poly-silicon gate and a N-type body. The body doping concentration is 2.0* 10^17cm^-3, and gate oxide thickness is 10nm. **(35 Points)**

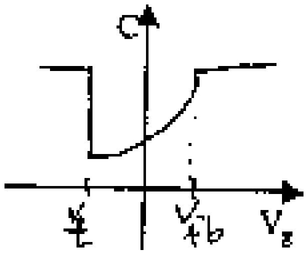
(a) Qualitatively sketch the C-V curve of MOS capacitor and MOSFET for high frequency and low frequency. (No need to calculate Vfb and Vt here) **(7 pts)**



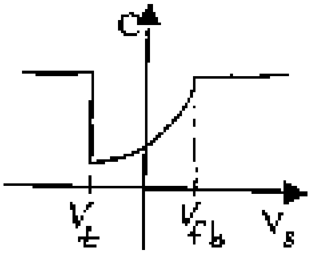
MOS Cap. LF



MOS Cap. HF

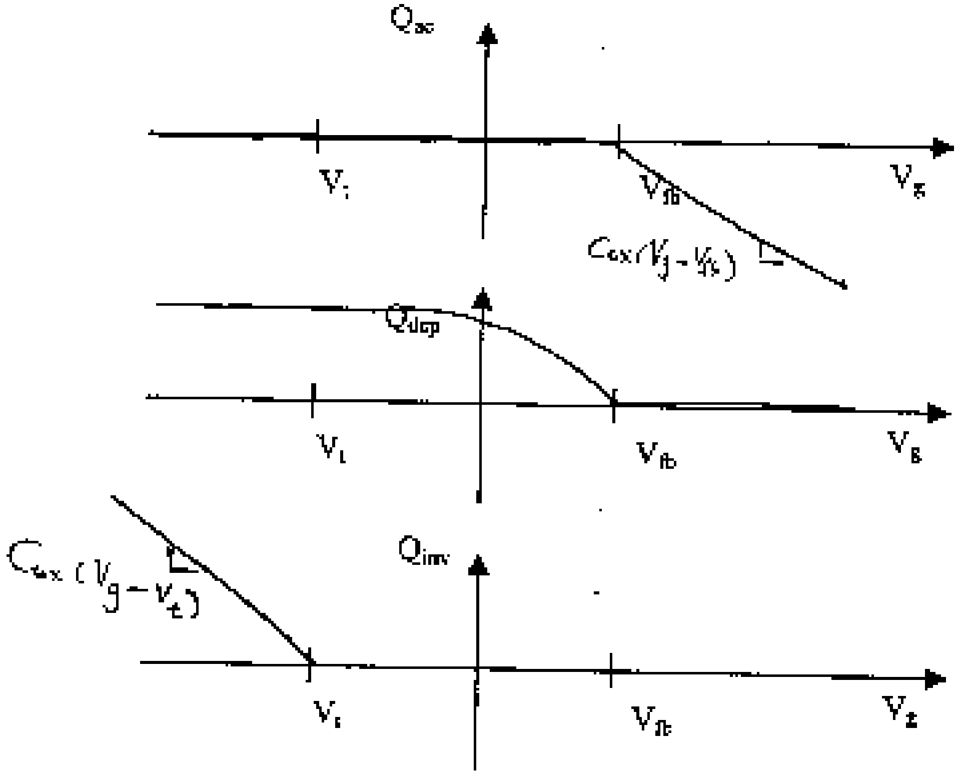


MOSFET LF

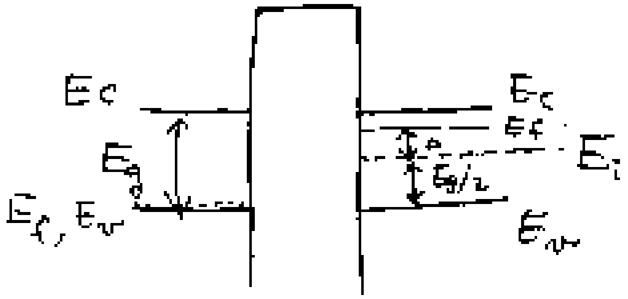


MOSFET HF

(b) Draw charge vs gate voltage of PMOSFET qualitatively. **(7 pts)**



(c) Calculate the flat band voltage. **(7 pts)**

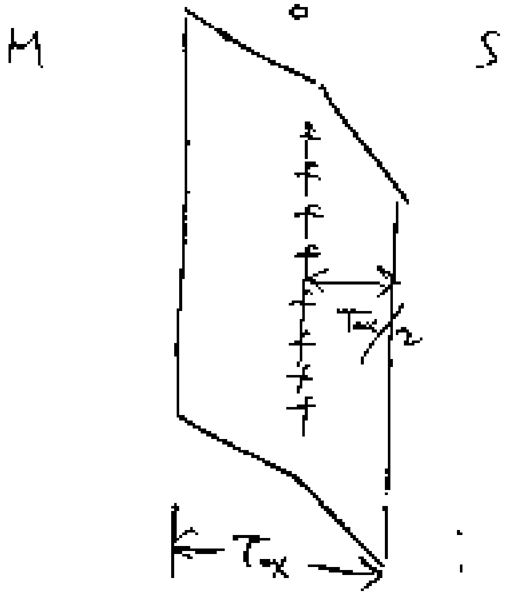


Vfb = Eg/2 + DELTA = Eg/2+K*T/q * ln(Nsub/Ni) = 0.55+0.026*ln(2.0*10^17/(1.0*10^10)) = 0.55 +0.44 = 0.99V

(d) Calculate the threshold voltage. **(7 pts)**

Vt = Vfb - 2*PHIb - (2*EPSILONs*q*Nsub*2*PHIb)^.5/Cox
PHIb = K*T/q * ln(Nsub/N1) = 0.44 (= DELTA in (d))
Cox = EPSILONox/Tox = 3.9*8.85*10^-14/10^-6 = 3.45*10^-7 (F/cm^2)
Vt = 0.99-2*0.44-2.41*10^-7)/(3.45*10^7) = -0.59V

(e) A sheet of electrons (6.9*10^-8C/cm^2) is trapped at the center of the gate oxide. How much is the threshold voltage changed? **(7 pts)**

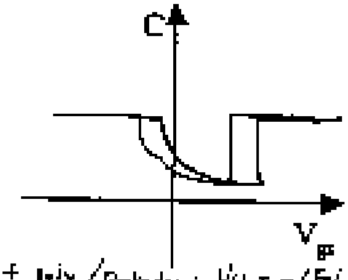


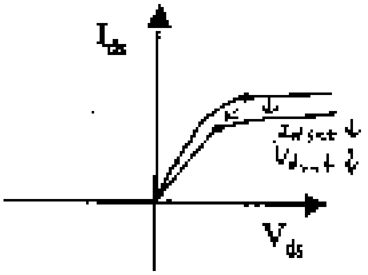
DELTA Vt = -Q/Coxe = -Q/(EPSILONox/(Tox/2)) = -Q/(2*Cox) = -(-6.9*10^-8)/(2*3.45*10^-7) = 0.1V

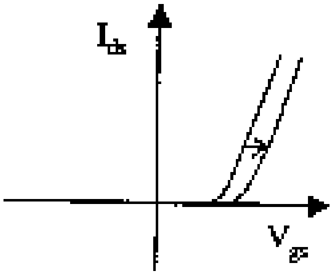
Problem #2

Qualitatively sketch the C-V, Id-Vg, and Id-Vd curves for an NMOSFET to indicate how the curves would differ in response to the changes given below. Assume the **mobility is fixed for (a) and (b)**. **(30 pts)**

(a) Change the poly-silicon gate from N+ to P+ type: **(10 pts)**



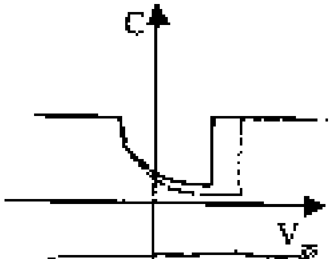


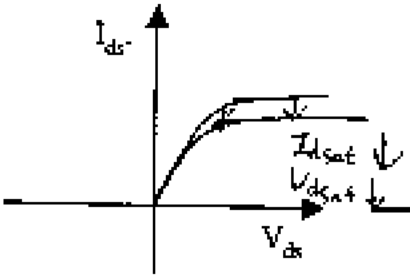


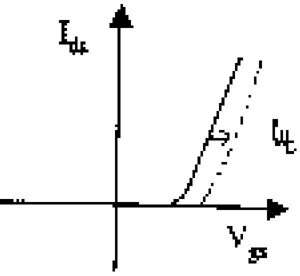
C, μn is assumed to be independent of V_t) ⇒ same slope

N+ poly / p-body : $V_{fb} = -(E_g/2 + \psi_B)$
P+ poly / p body . $V_{fb} = (E_g/2 - \psi_B)$
$V_{fb} > 0$
$V_{t_{new}} > V_{t_{old}}$

(b) Reverse back bias is applied to the body. **(10 pts)**





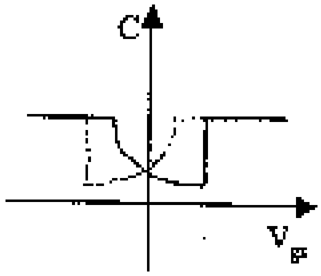


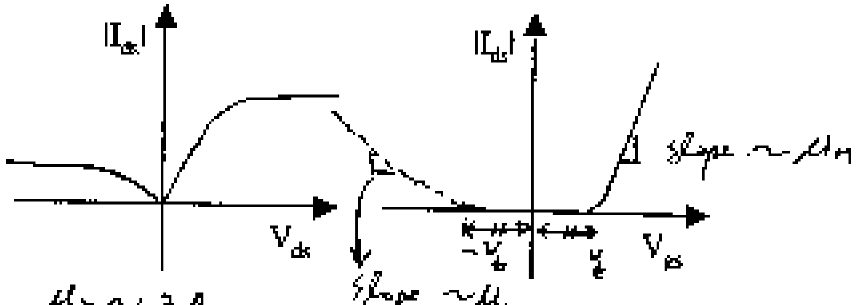
V_t increased

$$V_t \propto \frac{\sqrt{2\epsilon_s q N_{sub}(2\psi_B + |V_{bs}|)}}{C_{ox}}$$

$V_{bs}\uparrow \Rightarrow V_t\uparrow$, $W_{dmax}\uparrow \rightarrow C_{dep}\downarrow \Rightarrow C_{tot}\downarrow$

(c) Reverse the doping types of the source/drain, body, and gate, i.e. change from NMOSFET to PMOSFET. Select the proper quadrant. Source and body are tied to ground (0V). Consider MUn != MUp. **(10 pts)**



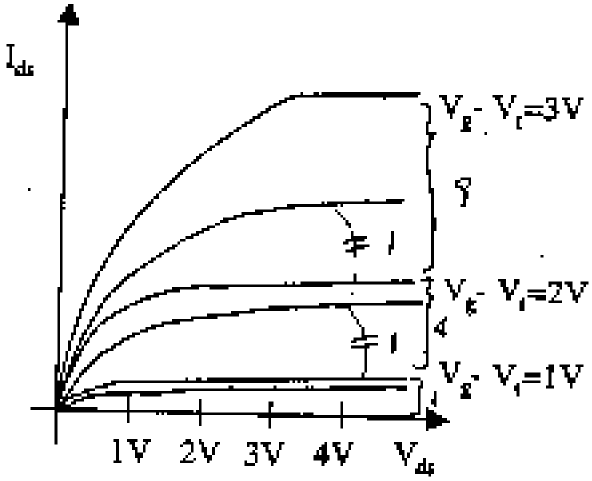


$\mu_n \sim 3\mu_p$

Problem #3

The printed curves in each of the figures are drawn for a MOSFET without consideration for velocity saturation. Draw new curves in each figure to indicate the effect of velocity saturation. **(15 pts: 5 pts each)**

(a)



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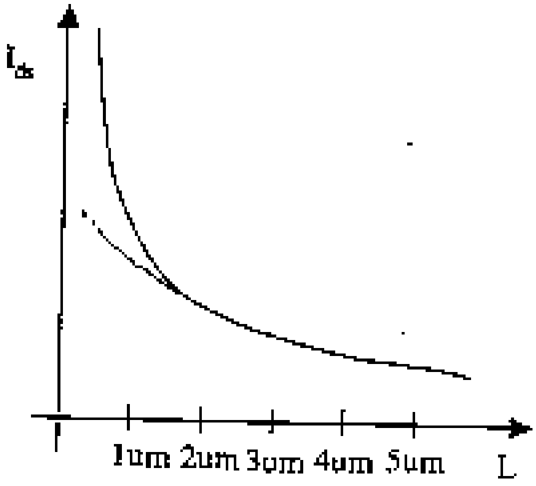
(b)



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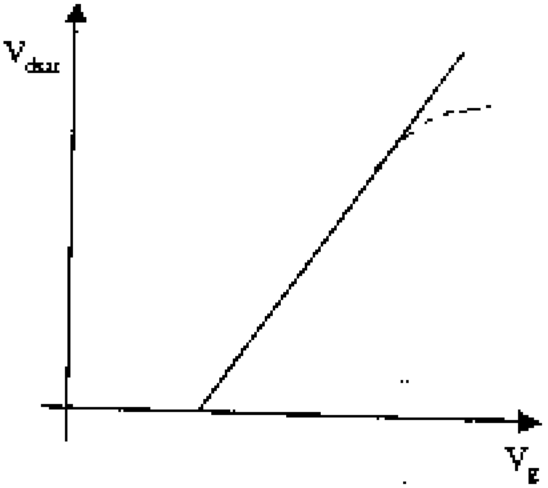
(c)



$$V_{dsat} = \frac{(V_g - V_t)\cdot \mathcal{E}_{sat}\cdot L}{V_g - V_t + \mathcal{E}_{sat}\cdot L}$$

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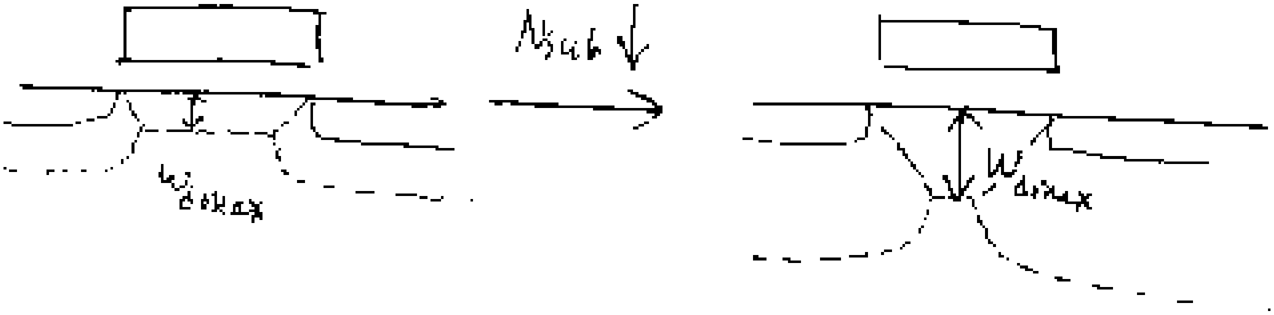
Vdsat = (Vs-Vt)*Esat*L/(Vg-Vt+Esat*L)

Problem #4

Indicate in the table below the consequences of decreasing the body doping concentration, Nsub, in and NMOSFET by checking two appropriate boxes (Increase/Decrease and Desirable/Undesirable) for each line. **(20 pts)**

	Increases	Decreases	Desirable	Undesirable	Points
Transconductance, Gmsat	X		X		5 pts
Subthreshold swing, S		X	X		5 pts
Vt roll-off (Short channel effect)	X			X	5 pts
Body effect coefficient, ALPHA		X	X		5 pts

i)Gmsat = dIdsat/dVgs = MU*W*Cox/L * (Vg-Vt)   Nsub down implies Vt down implies Gmsat up desirable
ii) S = 60mV*(1+Cdep/Cox)   Nsub down implies Wdmax up implies Cdep down implies S down desirable
iii)



Vt roll-off increases implies undesirable

iv) ALPHA = Cdep/Cox ; Nsub down ; Cdep down ; ALPHA down

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