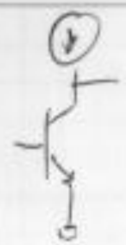
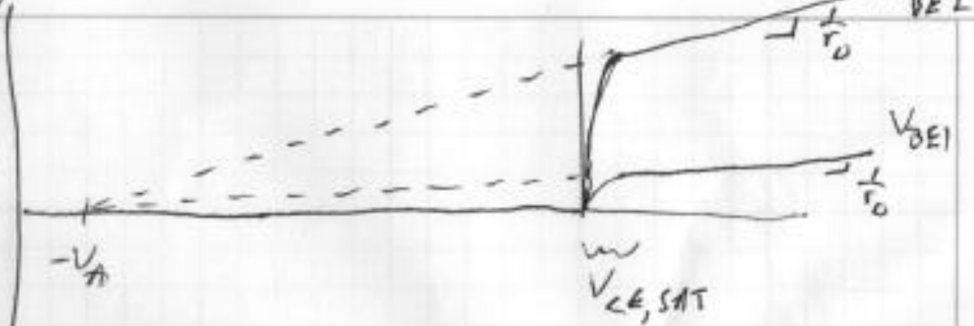


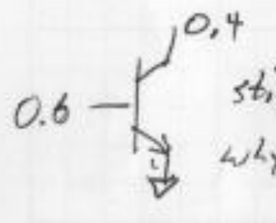
$A_V = -g_m r_o = -\frac{I_C}{V_{TH}} \frac{V_A}{I_C} = \frac{-V_A}{V_{TH}}$ ← 10–100V

$V_{TH} \approx 25mV$

$\approx$ 400–4000

$\beta \approx$ 10–400



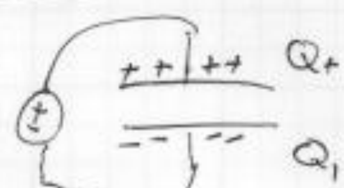


still ok?

why? V_{CB} is fwd biased?!

MOS

parallel plate cap

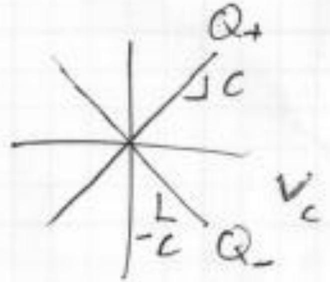


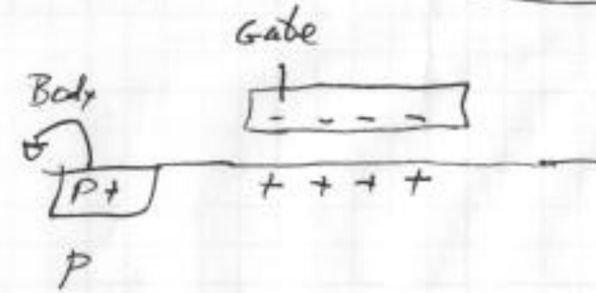
$Q = CV$

Q_+

$Q_+ = -Q_-$

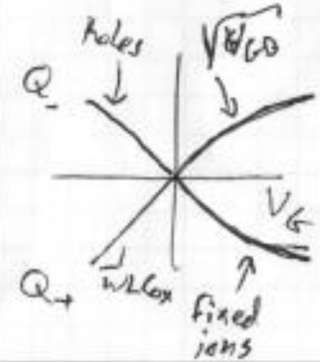
$C = \epsilon_r \epsilon_0 \frac{A}{d}$

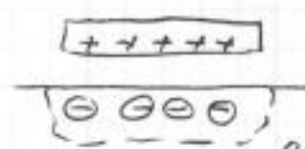




$V_G < 0$

(technically V_{FB})





$V_G > 0$

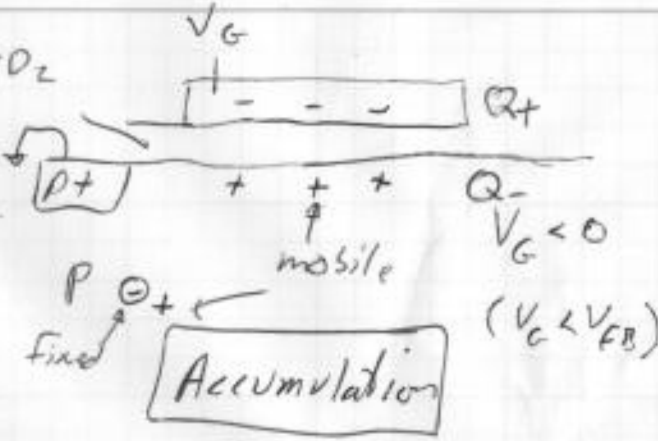
depl region

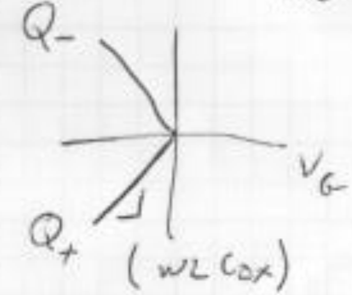
$\sim \sqrt{V_{GB}}$

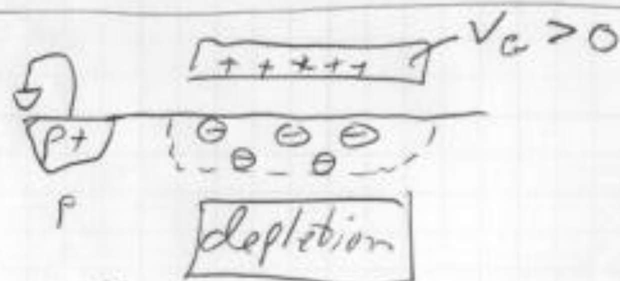
$C = \varepsilon_r \varepsilon_0 \frac{A}{t_{ox}}$

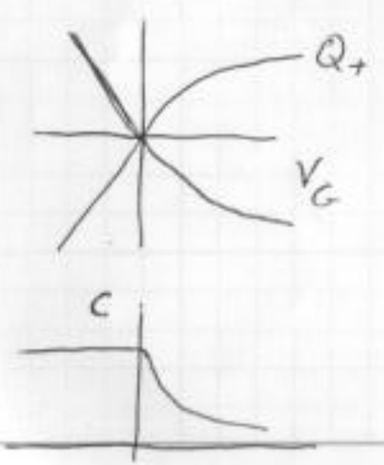
$= WL \frac{\varepsilon_r \varepsilon_0}{t_{ox}}$

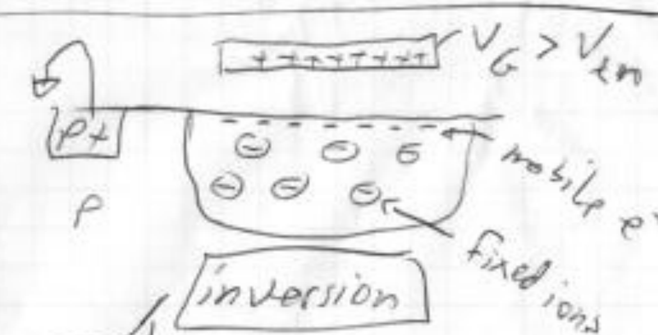
$= WL C_{ox}$

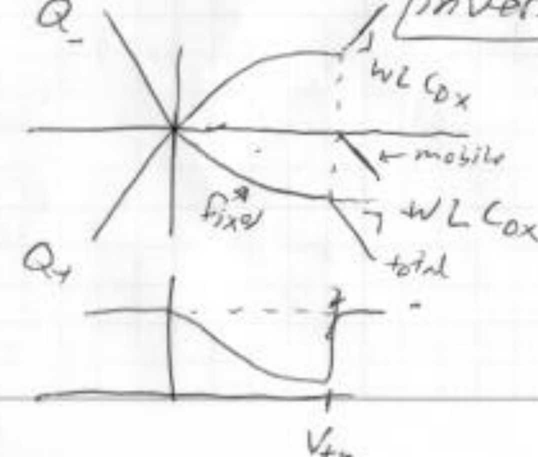


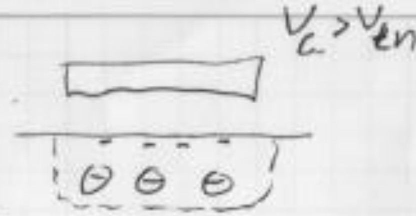


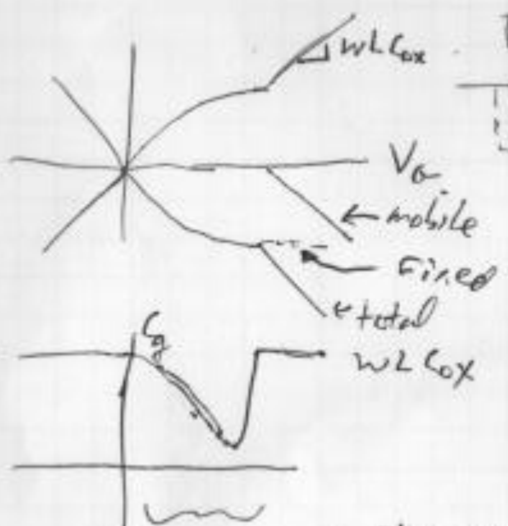




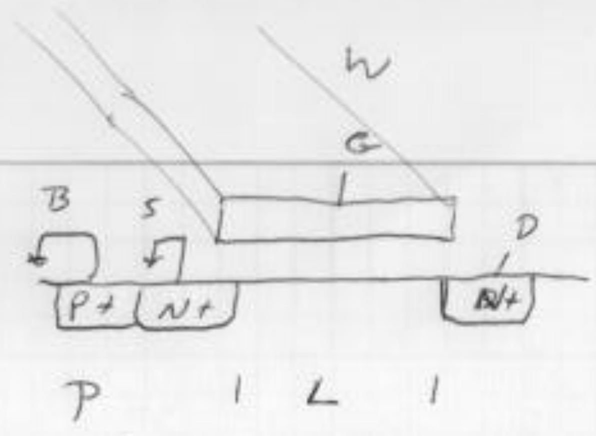






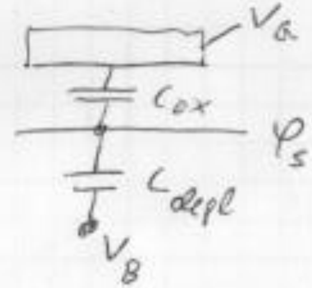


MOS capacitor varactors common



$V_D = V_S = 0$

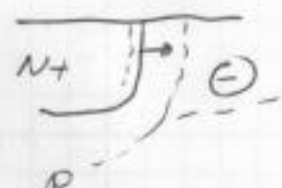
$V_D = 100\,mV$



$\varphi_s = \dfrac{C_{ox}}{C_{ox}+C_{depl}} \cancel{V}_G$

$= \frac{1}{n} V_G \quad n > 1$

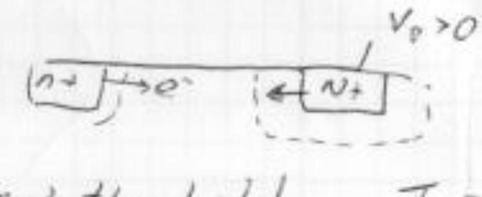
$\boxed{+V_{G+}}$



Very thin fwd biased diode!

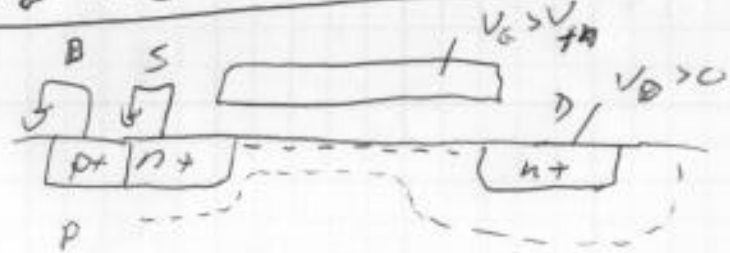
$I_D = I_s e^{\varphi_s / V_{TH}}$

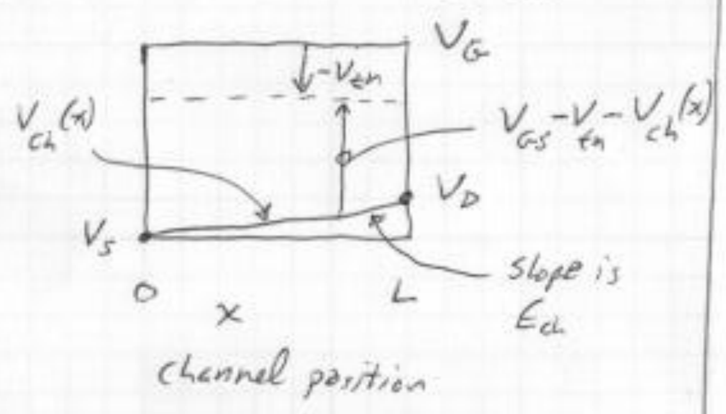
$= I_s e^{V_{GS}/nV_{TH}}$



looks like a BGT

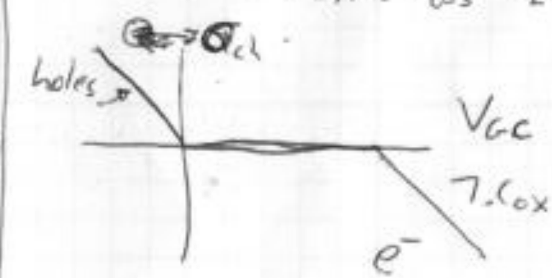
sub-threshold $\quad I_D = I_s e^{V_{GS}/nV_{TH}}$





$\sigma_{ch}(x)$ = mobile charge per unit area

$= C_{ox}\left(V_{GS} - V_{tn} - V_{ch}(x)\right)$



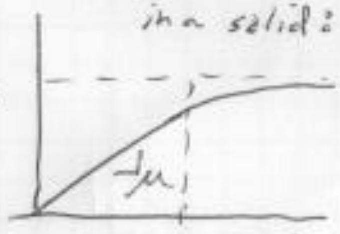
$$\text{current} = \underbrace{\left(\text{average } \frac{\#\text{ mobile charges}}{\text{length}}\right)}_{\bar{\sigma}_{ch} W} \underbrace{(\text{velocity})}_{?}$$

mobility

Free electron: $m\ddot{x} = qE$ accel.

in a solid: $\dot{x} = \mu E$ velocity

$\frac{m}{s}$ $\frac{cm}{s}$



$v_{sat} \approx 10^5 \frac{m}{s}$

compare to $c = 3\times10^8 \frac{m}{s}$

$\approx \frac{1V}{\mu m}$ $\frac{V}{cm}$ $\frac{V}{m}$

$v = \mu_n E \qquad E = \frac{V_{DS}}{L}$

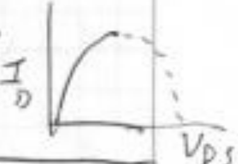
$$I_D = \bar{\sigma}_{ch} W \mu_n \frac{V_{DS}}{L}$$

$$= C_{ox}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) W \mu_n \frac{V_{DS}}{L}$$

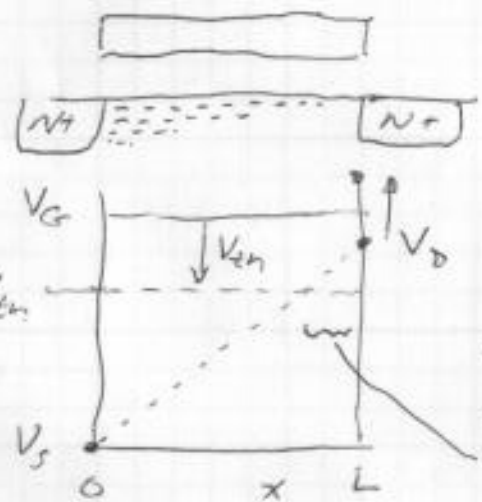
$$= \mu_n C_{ox} \frac{W}{L}\left(V_{GS} - V_{th} - \frac{V_{DS}}{2}\right) V_{DS}$$

"linear" region $0 < V_{DS} < V_{GS} - V_{th}$

$V_{GS} > V_{th}$



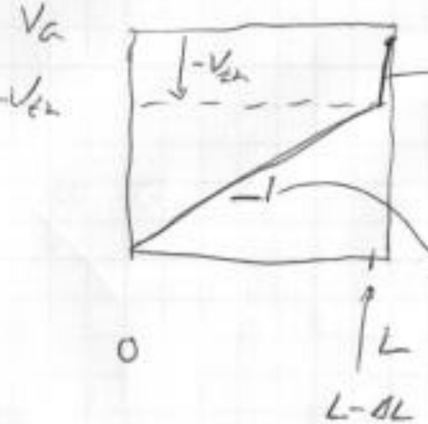
what if $V_{GS} > V_{th}$, $V_{DS} > V_{GS} - V_{th}$ (saturation)



what happens?

what if linear V_{ch}?

No conduction here



$E_{BD} \approx 30 \frac{V}{\mu m}$

$30 \frac{mV}{nm}$

$\Delta L \approx \left[V_{DS} - (V_{GS} - V_{th})\right] / E_{BD}$

$\frac{V_{GS} - V_{th}}{L - \Delta L}$

$$I_D = \left(\text{avg } \frac{\text{charge}}{\text{length}}\right)(\text{velocity})$$

$$= W C_{ox}\left(\frac{V_{GS} - V_{th} - 0}{2}\right)\left(\mu_n \frac{V_{GS} - V_{th}}{L\left(1 - \frac{\Delta L}{L}\right)}\right)$$

$$= \mu_n C_{ox} \frac{W}{L} \frac{(V_{GS} - V_{th})^2}{2}(1 + \lambda V_{DS}) \quad \text{saturation}$$

So what if $E_{ch} = \frac{V_{GS}-V_{th}}{L-\Delta L} > \frac{1V}{\mu m}$?

$I_D = \left(\text{avg } \frac{\text{charge}}{\text{length}}\right)(\text{velocity})$

$W C_{ox} \left(\frac{V_{GS}-V_{th}}{2}\right) v_{sat}$

when $L = 14nm$, $1V/\mu m$ gives $14mV$

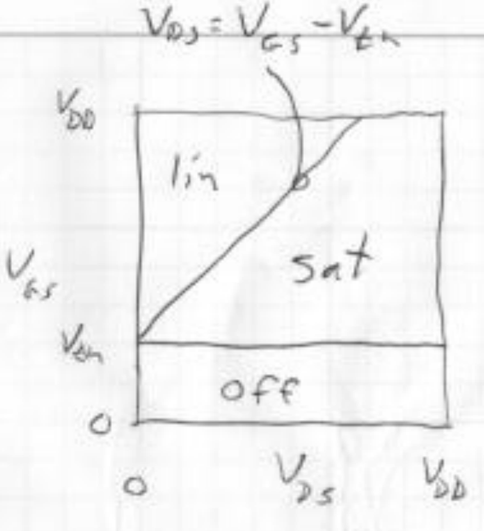
$L = 0.18\mu m$ $180mV$

Regions of operation

1st pass

if $V_{GS} > V_{th}$

linear: $V_{DS} < V_{GS} - V_{th}$



Add svs-V_t:

if $V_{GS} < V_{th}$, but ~~more than~~ within $\approx 200mV$

Add vel.

if $E_{ch} > E_{crit}$

saturation: $E_{ch} = \frac{V_{GS}-V_t}{L-\Delta L}$ $V_{GS} - V_{th} > (L-\Delta L)E_{crit}$

linear $E_{ch} \approx \frac{V_{DS}}{L}$ $V_{DS} > L E_{crit}$

Are you kidding me?!? Deep breath!

1 nonlinear solution

+

g_m, r_o

quadratic $I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{tn})^2 (1 + \lambda V_{DS})$

$g_m = \frac{\partial I_d}{\partial V_{gs}} = \frac{2 I_D}{V_{GS} - V_{tn}}$

$g_o = \frac{\partial I_d}{\partial V_{ds}} = \frac{\lambda I_D}{(1+\lambda V_{DS})}$ $\quad r_o = \frac{1+\lambda V_{DS}}{\lambda I_D} \approx \frac{1}{\lambda I_D}$?

sub-V_t $I_d = I_s e^{\frac{V_{GS}}{n V_{TH}}} \underbrace{(1 + \lambda V_{DS})}_{\text{huh?}}$

$g_m = \frac{I_D}{n V_{TH}}$

$n = 1.0\times$ — $2+$

FinFETs old

$r_o =$ ____

scl $I_d = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{gs} - V_t)(1 + \lambda V_{DS})$

$g_m = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (1 + \lambda V_{DS})$

indep of V_{GS}!

prob 10

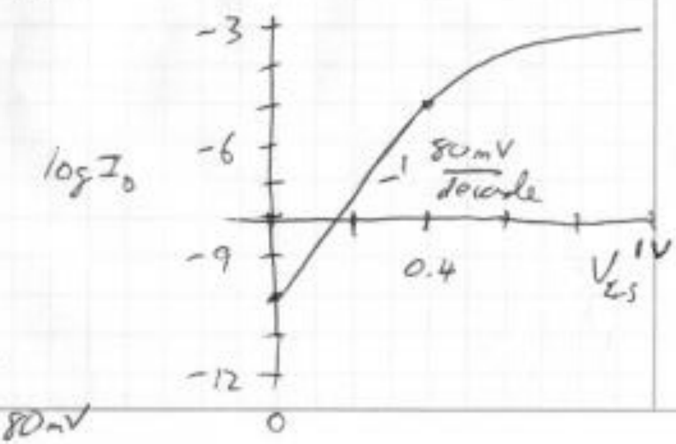
Let's look at "off" again

in sub-V_t $I_d = I_s e^{\frac{V_{GS}}{n V_{TH}}} (\quad)$

there is no "off"

~~$\log_{10} I_D$~~

often in $\frac{mA}{\mu m}$



pick $V_{th} = 0.4$

say $nV_{TH} = \cancel{60}\ 80mV$