s model

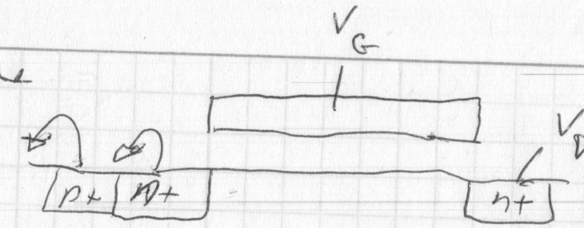
Intr. gain

g_m vs $V_{GS}-V_{TH}$

sub-thresh cond.

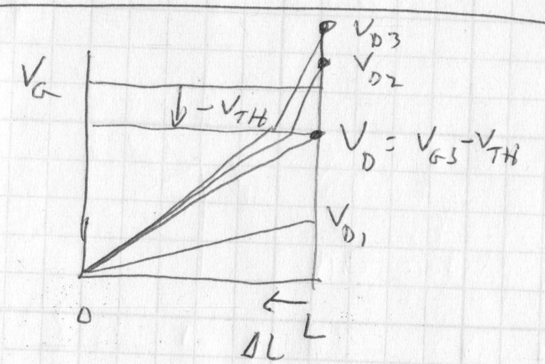
velocity scattering limit

Last time



$$I_D = [\text{avg. charge density per length}][\text{velocity}]$$

$$= \begin{cases} 0 & V_{GS} \le V_{TH} \\ \left[C_{ox}(V_{GS}-V_{TH}-\tfrac{1}{2}V_{DS})W\right]\left[\mu \frac{V_{DS}}{L}\right] & V_{GS} > V_{TH},\ V_{DS} < V_{GS}-V_{TH} \\ \left[C_{ox}\left(\frac{V_{GS}-V_{TH}}{2}\right)(W)\right]\left[\mu \frac{V_{GS}-V_{TH}}{L-\Delta L}\right] & \end{cases}$$



λ for mosfets worse than V_A

$\frac{1}{\lambda} = 10V \to 1V$ or less

$V_A = 10-100V$ typ.

$$I_D = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS}-V_{TH})^2(1+\lambda V_{DS}) \qquad (2.27)$$

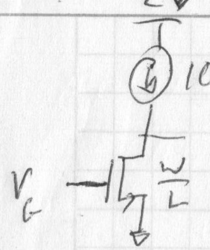
$$g_m = \frac{\partial I_D}{\partial V_{GS}} = \frac{2 I_D}{V_{GS}-V_{TH}}$$

$$g_o = \frac{\lambda I_D}{1+\lambda V_{DS}} \qquad r_o = \frac{1+\lambda V_{DS}}{\lambda I_D} \approx \frac{1}{\lambda I_D} ?$$

intrinsic gain

$$A_v = -g_m r_o = \left(\frac{2 I_D}{V_{GS}-V_{TH}}\right)\left(\frac{1+\lambda V_{DS}}{\lambda I_D}\right)$$

$$= \frac{2(1+\lambda V_{DS})}{(V_{GS}-V_{TH})\lambda}$$

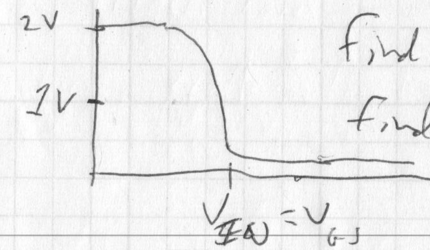


$V_{TH} = 0.5V$

$\mu_n C_{ox} = 200\frac{\mu A}{V^2}$ $\lambda = 0.2$

$\frac{W}{L} = \frac{1\mu m}{0.2\mu m}$ find V_{GS}

st. device is in saturation



find output swing

find intrinsic gain

$100\mu A = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS}-V_{TH})^2(1+\lambda V_{DS})$

$100\mu A = 100\frac{\mu A}{V^2}(5)(V_{GS}-V_{TH})^2(1+0.2(2V))$ ← pick

$\frac{100\mu A}{(100\frac{\mu A}{V^2})(5)(1.2)} = (V_{GS}-V_{TH})^2$

$\frac{1}{6}V^2 = (V_{GS}-V_{TH})^2$

$V_{GS}-V_{TH} \approx 0.4V$

$V_{GS} \approx 0.9V$

$g_m = \frac{200\mu A}{0.4V} = 0.5mS$

$r_o \approx \frac{1}{(0.2\frac{1}{V})(100\mu A)} \approx 50K\Omega$

} $A_V \approx -25$, swing $\approx 0.4-2$

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what if $\frac{W}{L} = \frac{100\mu m}{0.2\mu m}$? $V_{GS} = 40mV + V_{TH}$

I_D, r_o same

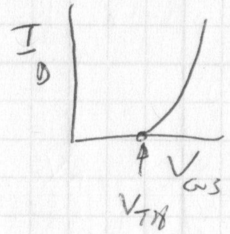
$g_m = \frac{200\mu A}{40mV} = 5mS$ $A_V = -250$

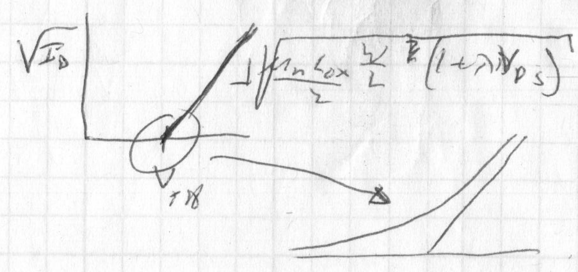
what if $\frac{W}{L} = \frac{10,000\mu m}{0.2\mu m}$? $V_{GS}-V_{TH} = 4mV$

$g_m = \frac{200\mu A}{4mV} = 50mS$ $A_v = -2,500!$

.. does it end?

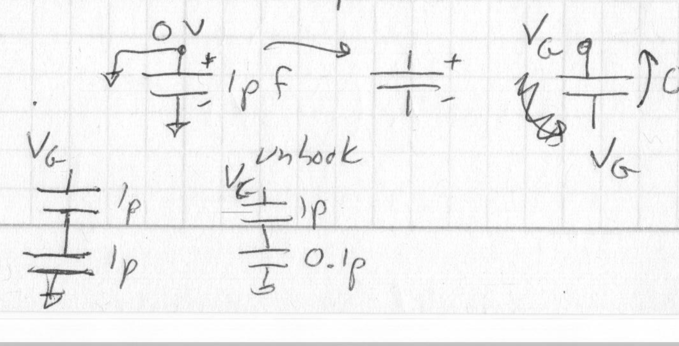
subthreshold conduction

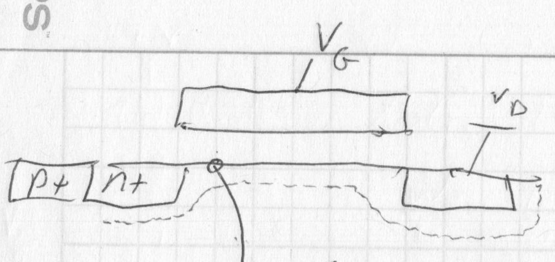




Why?

Consider a capacitor





surface potential $\varphi_s \approx V_{GS} \frac{C_{ox}}{C_{ox}+C_{dep}}$

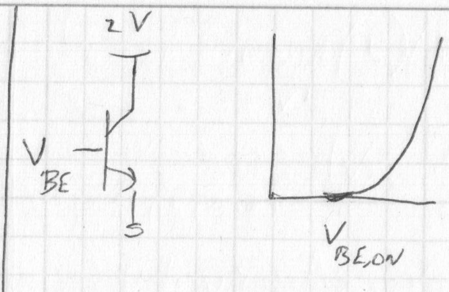
V_{GS} increasing

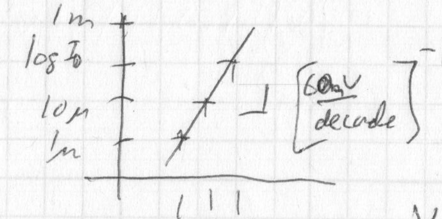
$\Rightarrow \varphi_s$ increasing (slower)

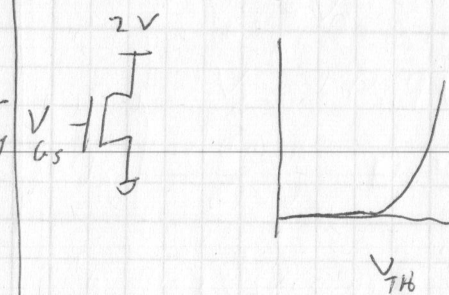
$\Rightarrow$ barrier to <u>source</u> majority carriers decreasing

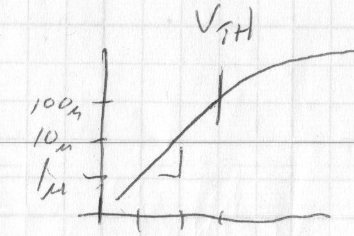
$\Rightarrow$ current $\sim e^{\varphi_s/V_T} = e^{V_{GS}/nV_T}$

$n = \frac{C_{ox}+C_{dep}}{C_{ox}} \approx 1 - 2$ 1.5 common





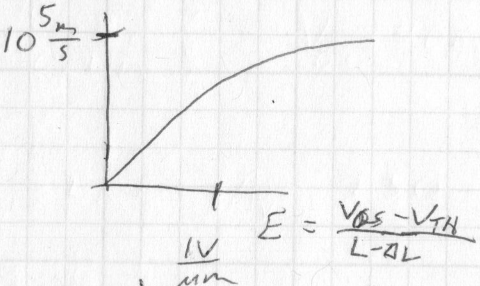




→ ← $n \ln 10 V_T$ $\approx 90 mV$

velocity saturation

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

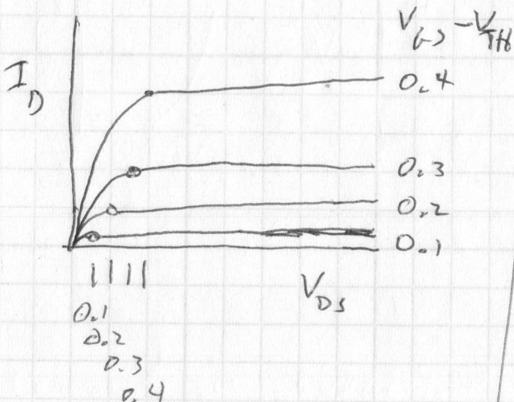


$I_D = (\text{avg charge den})(\text{velocity})$

$\sim (V_{GS}-V_{TH}) \sim (V_{GS}-V_{TH})$ quadratic

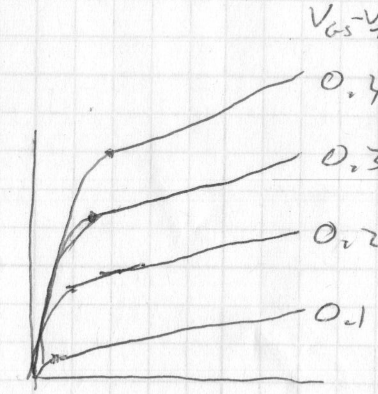
$\sim (V_{GS}-V_{TH})$ v_{sat} velocity sat.

$I_D = WC_{ox}(V_{GS}-V_{TH}) v_{sat}$



quadratic
- relatively flat
- ≈ quadratic $(V_{GS}-V_{TH})$ dependence

- Steep
- evenly spaced



scattering