E151 Lecture 14 – MOSFETs

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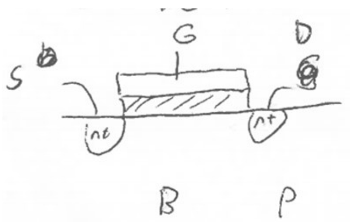
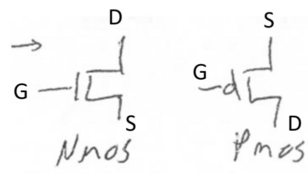
Disclaimer

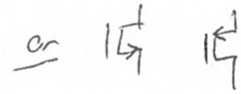
These are notes for Prof. Spencer to give the lecture, they were not intended as a reference for students. Students asked for them anyway, so I’m putting them up as a courtesy. Remember that they are not intended as a substitute for attending lecture.

Introduction to MOS Physics

- 4 terminals, 2 types NMOS and PMOS
- METAL OXIDE SEMICONDUCTOR FIELD EFFECT TRANSISTOR
- Unlike BJT: no I_G <u>AND</u> symmetric, D&S switch if voltage does
- NMOS S and B →GND whereas PMOS S and B → VDD (Latchup!)

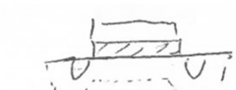






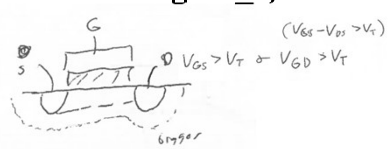
Channel, Inversion, Regions of Operation

- Ground D&S for now and apply +ve voltage on gate
- +ve charge on gate drives away holes (field lines terminate on -ve P-)
- Depletion and then inversion and formation of a channel
- Happens at threshold voltage V_T, Note that V_SB makes V_T bigger



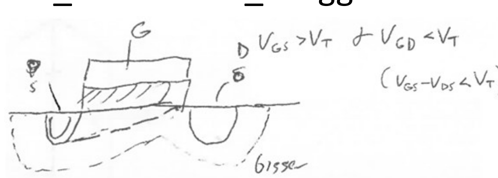
Cutoff, no inversion

- $V_{GS} < V_T$



- Triode/Linear
- Channel all the way across
- Like a weird resistor

V_{GS} big & V_{DS} small



- saturation
- voltage @ edge of channel < V_T
  (b/c V_c varies linearly from S→D)
- Horz field max @ $V_{GS}-V_T$

How Much Drain Current?

- Apply Vds to make current move
- Do current continuity at every spot y in the channel
- Conduction product of charge density (Cox helps) & speed (mu helps)

$$dQ(y) = WC_{ox}\big(V_{GS} - V_T - V(y)\big)dy$$

$$I_D = \frac{dQ(y)}{dt} = \frac{dQ(y)}{dy}v(y)$$

$$v(y) = \mu_n E(y) = \mu_n \frac{dV}{dy}$$

$$I_D = \mu_n WC_{ox}\big(V_{GS} - V_T - V(y)\big)dV/dy$$

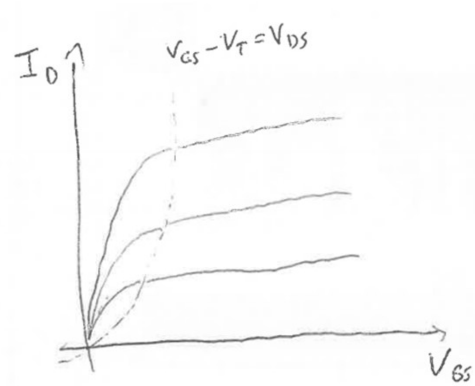
$$\int_0^L I_D dy = \mu_n WC_{ox}\int_0^{V_{DS}}\big(V_{GS} - V_T - V(y)\big)dV$$

Assume linear region

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

Large Signal Model

- If we assume sat instead



$$\int_0^{L-\Delta L} I_D dy = \mu_n WC_{ox}\int_0^{V_{GS}-V_T}\big(V_{GS} - V_T - V(y)\big)dV$$

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

λ From $\Delta L/L$, like $1/V_A$

$$I_D = \begin{cases} 0 & \\ \mu_n C_{ox}\frac{W}{L}\left((V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right) & V_{GS} > V_T \text{ \& } V_{GD} > V_T \quad (V_{GS} - V_{DS} > V_T) \\ \mu_n C_{ox}\frac{W}{L}\frac{(V_{GS}-V_T)^2}{2}(1+\lambda V_{DS}) & V_{GS} > V_T \text{ \& } V_{GD} < V_T \quad (V_{GS} - V_{DS} < V_T) \end{cases}$$

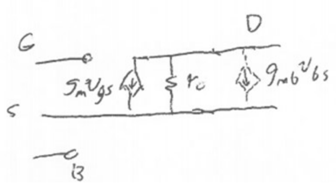
Small Signal Model

- Take derivatives to linearize as before

$$\frac{\partial i_D}{\partial v_{GS}} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)(1 + \lambda V_{DS})$$

$$\approx \sqrt{\mu_n C_{ox} \frac{W}{L} I_D} \quad \text{if } \lambda V_{DS} \ll 1$$

$$\equiv g_m$$



$$\frac{\partial i_D}{\partial v_{DS}} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 \cdot \lambda$$

$$\approx \lambda I_D$$

$$\equiv 1/r_o$$

Practical Calculations for gm

- Often don't have μ_n and C_{ox} for discrete devices

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

$$g_m = \frac{\partial i_D}{\partial v_{gs}} = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)$$

$$V_{ov} = V_{GS} - V_T = \sqrt{\frac{2 I_D}{\mu_n C_{ox} \frac{W}{L}}}$$

$$g_m = \sqrt{\frac{2 I_D}{\mu_n C_{ox} \frac{W}{L}}} \mu_n C_{ox} \frac{W}{L}$$

$$\boxed{g_m V_{ov} = 2 I_D}$$

Can get Vsw and av from a large signal xfer fn.

- Slope in linear region is av
- Leaving linear region defines bounds of swing