EE 536a Notes 8/30/24

NMOS current eq: weak inversion/subthreshold

$V_{GS} < V_{TH} \Rightarrow$ cutoff $\quad I_{DS} \approx 0$

$\begin{cases} V_{GS} \geq V_{TH} \\ V_{DS} > V_{GS} - V_{TH} \end{cases} \Rightarrow$ triode $\quad I_{DS} = k_n \dfrac{2(V_{gs}-V_{TH})V_{DS} - V_{DS}^2}{1+\frac{V_{DS}}{E_c L}}$

$\begin{cases} V_{gs} > V_{TH} \\ V_{DS} > V_{gs} - V_{TH} \end{cases} \Rightarrow$ sat. $\quad I_{DS} = k_n \dfrac{(V_{gs}-V_{TH})^2}{1+\frac{V_{gs}-V_{TH}}{E_c L}}(1+\lambda V_{DS})$

↳ $V_{gs} - V_{TH} \ll E_c L \Rightarrow I_{DS} = k_n (V_{gs}-V_{TH})^2 (1+\lambda V_{DS})$

$V_{gs} - V_{TH} \gg E_c L \Rightarrow I_{DS} = \dfrac{\mu_n C_{ox}}{2} E_c W (V_{gs} - V_{TH})(1+\lambda V_{DS})$

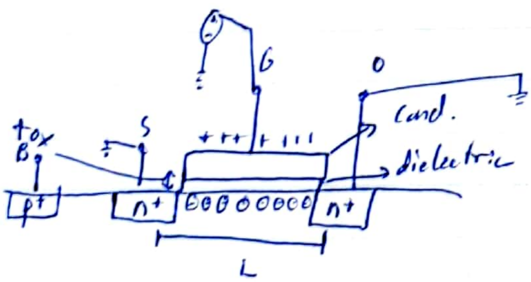
vel. sat.

Example

$E_c \approx 10^6$ V/m

old tech: $E_c L = 0.5$ V $\quad (L = 0.5\,\mu m)$

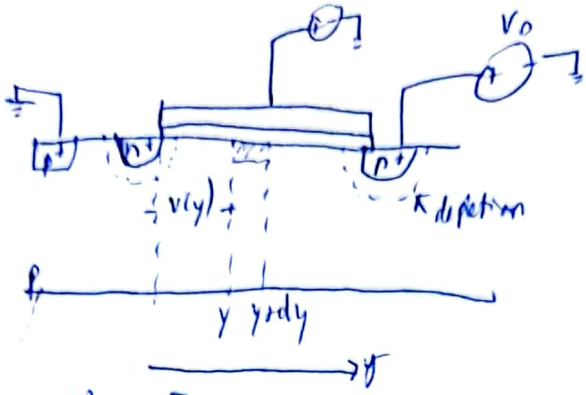
new tech: $E_c L = 5$ mV $\quad (L = 5$ nm$)$



old tech transistor

ρ

$V_{TH} = V_{T0} + \gamma\left(\sqrt{|2\phi_F + V_{SB}|} - \sqrt{|2\phi_F|}\right)$

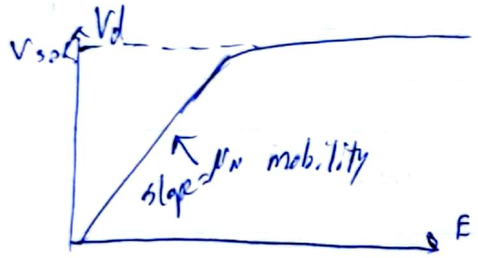


$$Q_I(y) = [V_{gs} - V(y) - V_{TH}]\, C_{ox}$$

Induced charge density / unit area

$$I_{ds} = W\, Q_I(y) \cdot v(y)$$

drift velocity



semiconductor

$$V_d(y) = \frac{\mu_N E(y)}{1 + \frac{E(y)}{E_C}}$$

$E(y) \ll E_c \Rightarrow V_d \approx \mu_N E(y)$

$E(y) \gg E_c \Rightarrow V_d \approx \mu_N E_C$

$$E(y) = \frac{d}{dy}(V(y))$$

$$I_{DS} = W C_{ox}[V_{gs} - V(y) - V_{TH}]\, \frac{\mu_N E(y)}{1 + \frac{E(y)}{E_C}}$$

$$\Rightarrow I_{DS}\left[1 + \frac{1}{E_C}\frac{dV(y)}{dy}\right] = W C_{ox}[V_{gs} - V(y) - V_{TH}]\, \mu_N \frac{dV(y)}{dy}$$

$$\int_0^L I_{DS}\, dy + \int_0^{V_{DS}} \frac{I_{DS}}{E_C}\, dV(y) = \int_0^{V_{DS}} W \mu_N C_{ox}[V_{gs} - V(y) - V_{TH}]\, dV(y)$$

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