ESE 3190 HW2

n_i = # free e^- & holes in a unit volume (cm^3)

Garrett Kusch

1. $p = N_A$ ~ # boron atoms added

a) $p \approx N_A \approx 2.5 \cdot 10^{17}\ cm^{-3}$

$n_i = 9.65 \cdot 10^9\ cm^{-3}$

$n_i^2 = n \cdot p$

$$\boxed{n = \frac{n_i^2}{p} = \frac{(9.65 \cdot 10^9)^2}{2.5 \cdot 10^{17}} = 372.5\ cm^{-3} \qquad p = 2.5 \cdot 10^{17}\ cm^{-3}}$$

$n \cdot p = n_i^2$

$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$

$\varepsilon_{ox} = \varepsilon_r \varepsilon_0 = 3.45 \cdot 10^{-11} \frac{F}{m}$ for SiO_2

$Q_{dep} = \sqrt{4q\, \varepsilon_{si}\, |\phi_F|\, N_{sub}}$

$Q_{impl} = q \cdot N_{impl}$

$V_{TH0} = \phi_{MS} + 2\phi_F + \frac{Q_{dep}}{C_{ox}}$

$V_{TH} = V_{TH0} - \frac{Q_{impl}}{C_{ox}}$

$\phi_F = \left(\frac{kT}{q}\right) \ln\left(\frac{N_{sub}}{n_i}\right)$

$k: 1.38 \cdot 10^{-23} \frac{J}{K}$

T: temp

$q: 1.602 \cdot 10^{-19}\ C$

N_{sub}: doping density of substrate

n_i: density of electrons in un-doped si

$C_{dep} = \varepsilon_{si} WL W_{dm}$

dielectric of Si

11.68

b) $V_{TH0} = \phi_{MS} + 2\phi_F + \frac{Q_{dep}}{C_{ox}}$

$C_{ox} = \frac{3.45 \cdot 10^{-11} \frac{F}{m}}{8.5 \cdot 10^{-9}\ m} = 4.06\ \frac{mF}{m^2}$

$N_{sub} = 2.5 \cdot 10^{17}\ cm^{-3}$

$n_i = 9.65 \cdot 10^9\ cm^{-3}$

$\phi_F = \left(\frac{1.38 \cdot 10^{-23} \frac{J}{K} \cdot 300K}{1.602 \cdot 10^{-19}\ C}\right) \ln\left(\frac{2.5 \cdot 10^{17}\ cm^{-3}}{9.65 \cdot 10^9\ cm^{-3}}\right)$

$= 0.441\ V$

$Q_{dep} = \sqrt{4q\, \varepsilon_{si}\, |\phi_F|\, N_{sub}} = \left[4 \cdot 1.602 \cdot 10^{-19} C \cdot 1.03 \cdot 10^{-10} \frac{F}{m} \cdot 0.441 V \cdot \frac{2.5 \cdot 10^{17}}{cm^3} \cdot \frac{10^6 cm^3}{m^3}\right]^{\frac{1}{2}}$

$= 2.7 \cdot 10^{-3} \frac{\sqrt{CFV}}{m^2}$

$\varepsilon_{si} = 11.68 \cdot \varepsilon_0 = 1.03 \cdot 10^{-10}$

$\varepsilon_0 = 8.85 \cdot 10^{-12}$

$\frac{Q_{dep}}{C_{ox}} = \frac{2.7 \cdot 10^{-3}}{4.06 \cdot 10^{-3}} = 0.665$

$V_{TH0} = -0.7V + 2(0.441)V + 0.665\ V$

$= 0.847\ V$

c) $\frac{Q_{impl}}{C_{ox}}$ ← must be + ⇒ we need acceptors

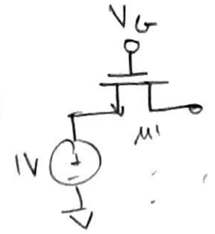
$\frac{Q_{impl}}{C_{ox}} = 0.847V - 0.62V = 0.227V$

$Q_{impl} = .227V \cdot 4.06 \frac{mF}{m^2} = 9.216 \cdot 10^{-4} \frac{C}{m^2}$

$= 9.22 \cdot 10^{-8} \frac{C}{cm^2}$

1\. c) $N_{impl} = \frac{Q_{impl}}{q} = \frac{9.22\cdot10^{-8}\ \frac{C}{cm^2}}{1.602\cdot10^{-19}\ C} = 5.753\cdot10^{11}$ $\frac{\text{charge carries}}{cm^2}$

2\. a)



$R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{GS}-V_{TH})} = \frac{1}{50\frac{\mu A}{V^2}(5V)\,W} = \frac{4000}{W}\,\Omega$

$V_g = 6.7V \rightarrow V_{GS} = 5.7V$

$L = 1$

$W: 0 \rightarrow 10$

$V_{ov} = V_{GS} - V_{TH} = \underline{5V}$

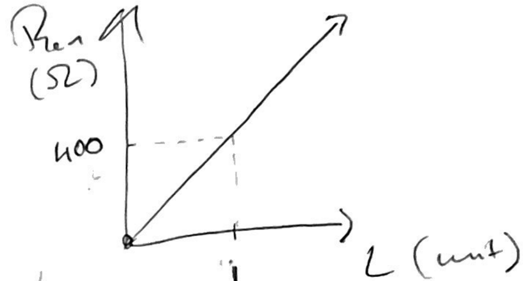
*digital plot attached

b) $\mu_n C_{ox} = 50\frac{\mu A}{V^2}$

$V_G = 6.7V$

$W = 10$

$\rightarrow R_{on} = \frac{1}{50\frac{\mu A}{V^2}(5V)\frac{10}{L}} = 400L$



it's just linear → no digital plot

assume:
$\mu C_{ox} = 50\frac{\mu A}{V^2}$
$V_G = 6.7\ V$
$L = 1$

3\. $V_{TH} = 0.62V$

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

a) $\frac{350\ cm^2}{V\cdot s}$ = channel mobility

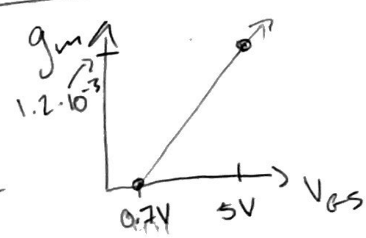
$k' = 0.035\frac{m^2}{V\cdot s}\cdot\frac{4.06mF}{m^2}$

$C_{ox} = 4.06\frac{mF}{m^2}$

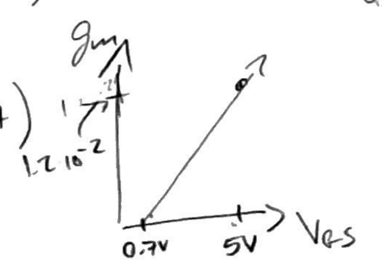
$\frac{350\ cm^2}{V\cdot s}\cdot\frac{4.06\cdot10^{-3}F}{m^2}\cdot\frac{m^2}{10^4\ cm^2} = \boxed{1.42\cdot10^{-4}\ \frac{A}{V^2} = k'}$

b) $g_m = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{TH})$

$\frac{W}{L} = 2$: $g_m = 2.84\cdot10^{-4}(V_{GS}-0.7V)$ ← linear

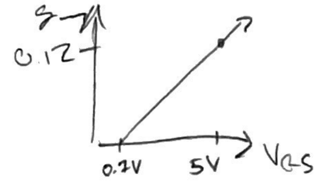


$\frac{W}{L} = 20$: $g_m = 2.84\cdot10^{-3}(V_{GS}-0.7)$



ESE 3190 HW 2

3. b) $\frac{W}{L} = 200$: $g_m = 2.84 \cdot 10^{-2} (V_{GS} - 0.7V)$



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

square root relationship

*all plots attached

$\frac{W}{L} = 2$: $g_m = 0.0238 \sqrt{I_D}$

$\frac{W}{L} = 20$: $g_m = 0.0754 \sqrt{I_D}$

$\frac{W}{L} = 200$: $g_m = 0.238 \sqrt{I_D}$

$I_D = \frac{1}{2} k' \frac{W}{L} (V_{GS} - V_{TH})^2$

d) Keeping I_D constant, you could increase g_m ~~either~~ by increasing ~~the~~ $\frac{W}{L}$ ratio ~~(taking up more space)~~ or increasing the transconductance parameter (probably costing more money), but that's a process specific parameter.

$g_m = k' \frac{W}{L} V_{ov} = \sqrt{2k' \frac{W}{L} I_D} = \sqrt{2k' \frac{W}{L} \cdot \frac{k'}{2} \frac{W}{L} V_{ov}^2}$

To keep I_D constant while increasing $\frac{W}{L}$, you'd have to decrease V_{ov} at a rate of $\sqrt{\Delta \frac{W}{L}}$. This plays into our hands since g_m would be increasing at a rate of n due to the increase in $\frac{W}{L}$, and decrease at a rate of $\sqrt{n}$ due to the decrease in V_{ov}.

This may also help save power by lowering V_{ov}, thereby decreasing the voltage input requirement.