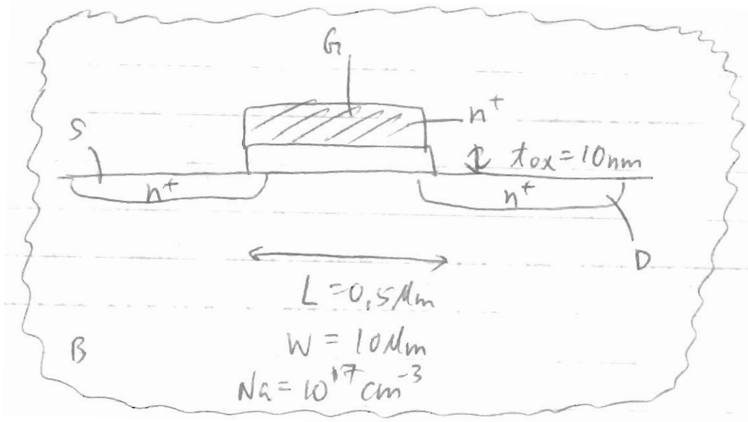
Ming Tang

HW #5

Sep 27, 2008

(1)



$V_{GS} = 2V$
$V_{DS} = 2V$
$V_{BS} = 0V$

(a) $V_{Tn} = V_{FB} - 2\phi_p - \frac{Q_{B,max}}{C_{ox}}$

$V_{FB} = \phi_p - \phi_{n^+} = -60mV \log \frac{10^{17}}{10^{10}} - (+550mV) = \underline{-970mV}$

$\phi_p = -60mV \log \frac{10^{17}}{10^{10}} = \underline{-420mV}$

$Q_{B,max} = -\sqrt{2 q \varepsilon_s N_a |2\phi_p|} = -\sqrt{2(1.6\times10^{-19}C)(11.7\times 8.85\times10^{-14} F/cm)(10^{17} cm^{-3})(2\times 420mV)}$

$= \underline{-1.67\times10^{-7} C/cm^2}$

$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9\times10^{-14}\times 8.85 \ F/cm}{1\times10^{-6} \ cm} = \underline{3.45\times10^{-7} F/cm^2}$

$V_{Tn} = -970mV + 2(420mV) + \frac{1.67\times10^{-7} C/cm^2}{3.45\times10^{-7} F/cm^2}$

$V_{Tn} = 0.35 V$

$V_{GS} > V_{Tn}$ ✓
$V_{DS} > V_{GS} - V_{Tn}$ ✓ $\Rightarrow$ **saturation**

(b) $Q_N = -C_{ox}(V_{GS} - V_{Tn})$

$Q_N = -3.45\times10^{-7} F/cm^2 \ (2V - 0.35V) = \underline{-5.69\times10^{-7} C/cm^2}$

e^- conc $= \frac{Q_N}{-q} = \frac{-5.69\times10^{-7} C/cm^2}{-1.6\times10^{-19} C}$

e^- conc $= 3.56\times10^{12} /cm^2$

(c) $V_{GS} > V_{Tn} \Rightarrow$ MOS is in inversion

$$Q_{B,max} = -qN_a X_{d,max}$$

$$X_{d,max} = \frac{Q_{B,max}}{-qN_a}$$

$$X_{d,max} = (-1.67\times10^{-7}\ C/cm^2)/[-1.6\times10^{-19}C \times 10^{17} cm^{-3}]$$

$$\boxed{X_{d,max} = 1.04\times10^{-5} cm}$$

(d) cutoff $\Rightarrow V_{GS} < V_{Tn}(V_{BS})$

$$V_{Tn} > 2V$$

$$V_{Tn} = V_{Ton} + \gamma_n\left(\sqrt{-V_{BS} - 2\phi_p} - \sqrt{-2\phi_p}\right)$$

$$\gamma_n = \frac{\sqrt{2q\varepsilon_s N_a}}{C_{ox}} = \frac{\sqrt{2(1.6\times10^{-19}C)(11.7\times8.85\times10^{-14}F/cm)(1\times10^{17}cm^{-3})}}{3.45\times10^{-7}\ F/cm^2}$$

$$= \underline{0.53\ \sqrt{V}}$$

$$V_{Tn} = 0.35V + 0.53\sqrt{V}\left(\sqrt{-V_{BS} + 0.84V} - \sqrt{0.84V}\right) > 2V$$

$$-V_{BS} > 15.4V$$

$$\boxed{V_{BS} < -15.4V}$$

(2) (a) $V_{Top} = -0.5V$

$N_d = 10^{17} cm^{-3}$

$$V_{Tp} = V_{FB} - 2\phi_n - \frac{Q_{B,max}}{C_{ox}}$$

$$V_{FB} = \phi_n - \phi_{p+} = 60mV \log\frac{10^{17}}{10^{10}} - (-550mV) = \underline{970mV}$$

$$\phi_n = 60mV \log\frac{10^{17}}{10^{10}} = \underline{420\,mV}$$

$$Q_{B,max} = \sqrt{2q\varepsilon_s N_d(2\phi_n)} = \underline{1.67 \times 10^{-7}\,C/cm^2} \quad \text{(from \#1)}$$

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

$$V_{Tp} = -0.5V = 970mV - 2(420mV) - \frac{1.67\times10^{-7}\,C/cm^2}{\varepsilon_{ox}/t_{ox}}$$

$$-0.5V = 0.97V - 0.84V - \frac{1.67\times10^{-7}\,C/cm^2 \quad t_{ox}}{25 \times 8.85\times10^{-14}\,F/cm}$$

$$\boxed{t_{ox} = 8.35\times10^{-6}\,cm} \Rightarrow C_{ox} = 2.65\times10^{-7}\,F/cm^2$$

(b) $\gamma_p = \sqrt{2q\varepsilon_s N_d}\,/\,C_{ox}$

$$\gamma_p = \frac{\sqrt{2(1.6\times10^{-19}C)(11.7\times8.85\times10^{-14}F/cm)(1\times10^{17}cm^{-3})}\ (8.35\times10^{-6}cm)}{25\times8.85\times10^{-14}\,F/cm}$$

$$\boxed{\gamma_p = 0.687\sqrt{V}}$$

(c) $V_{SG} = 1.5V,\ V_{SD} = 1.5V,\ V_{SB} = 0V$

$V_{SG} > -V_{Tp}$ ✓

$V_{SD} > V_{SG} + V_{Tp}$ ✓ $\Rightarrow$ saturation

$$-I_D = \mu_p C_{ox}\left(\frac{W}{2L}\right)(V_{SG}+V_{Tp})^2(1+\lambda_p V_{SD})$$

$$\lambda_p = \frac{0.1\,\mu m\,V^{-1}}{L}$$

$$\lambda_p = \frac{0.1\,\mu m\, V^{-1}}{L} = \frac{1\times10^{-5}\, cm/V}{1\times10^{-4}\, cm} = \underline{0.1\ V^{-1}}$$

$$-I_D = \mu_p C_{ox}\left(\frac{W}{2L}\right)(V_{SG}+V_{Tp})^2(1+\lambda_p V_{SD})$$

$$-I_D = \left(100\frac{cm^2}{V\cdot s}\right)\left(2.65\times10^{-7}\frac{F}{cm^2}\right)\left(\frac{30\,\mu m}{2\times1\,\mu m}\right)(1.5V-0.5V)^2(1+0.1\times1.5V)$$

$$\boxed{-I_D = 457\ \mu A}$$

(d) $I_{D_n} = +WQ_N(L)\,v_y(L)$ for NMOS

$-I_{D_p} = +WQ_N(L)\,v_y(L)$ for PMOS

$$V_c(y) = V_{SG}+V_{Tp} - \sqrt{(V_{SG}+V_{Tp})^2 - 2\left(V_{SG}+V_{Tp}-\frac{V_{SD}}{2}\right)V_{SD}\left(\frac{y}{L}\right)}$$

$$V_c\left(\frac{L}{2}\right) = 1.5+(-0.5) - \sqrt{(1V)^2 - 2\left(1V-\frac{1.5V}{2}\right)(1.5V)\left(\frac{L/2}{L}\right)}$$

$$V_c\left(\frac{L}{2}\right) = \underline{0.209V}$$

$$Q_N\left(y=\frac{L}{2}\right) = -C_{ox}(V_{GB}-V_{Tp}) = -C_{ox}(V_G - V_{channel} - V_{Tp})$$

$$= C_{ox}(V_{SG} - V_{S\,channel} + V_{Tp})$$

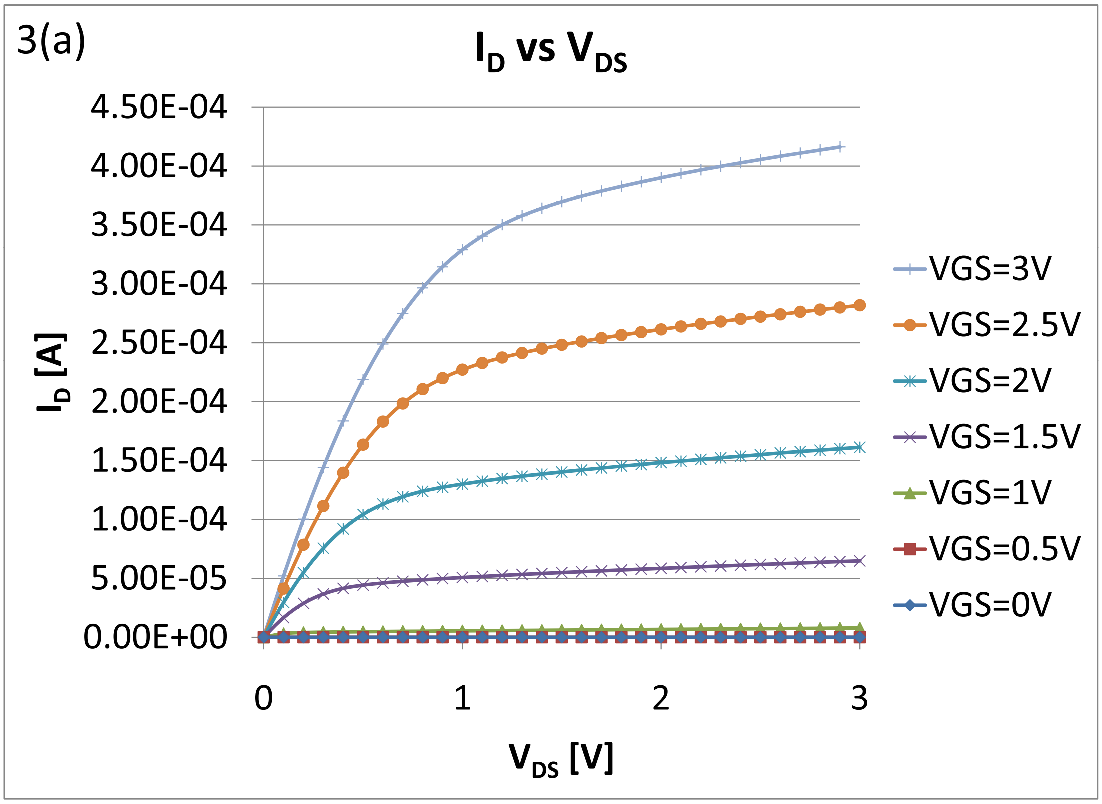
$$= (2.65\times10^{-7}\ F/cm^2)(1.5V - 0.209V - 0.5V)$$

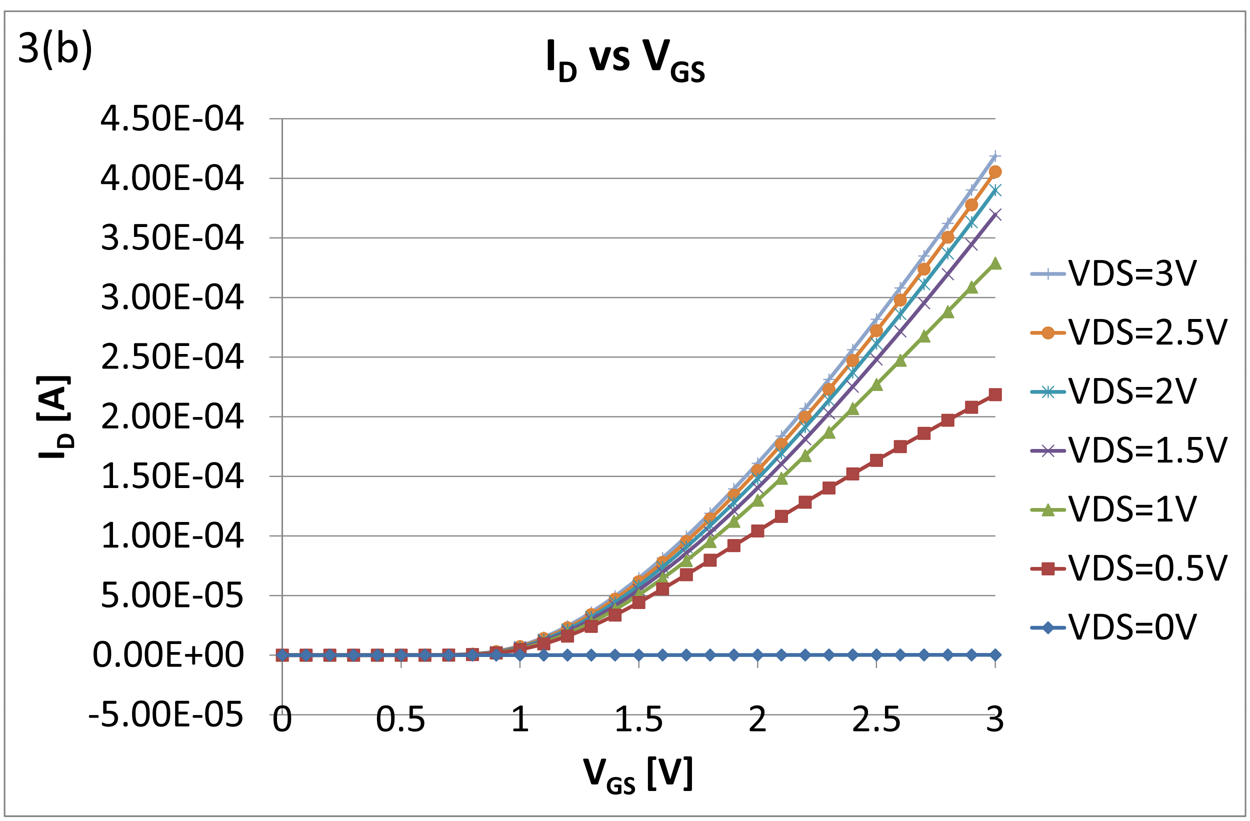
$$= \underline{2.096\times10^{-7}\ C/cm^2}$$

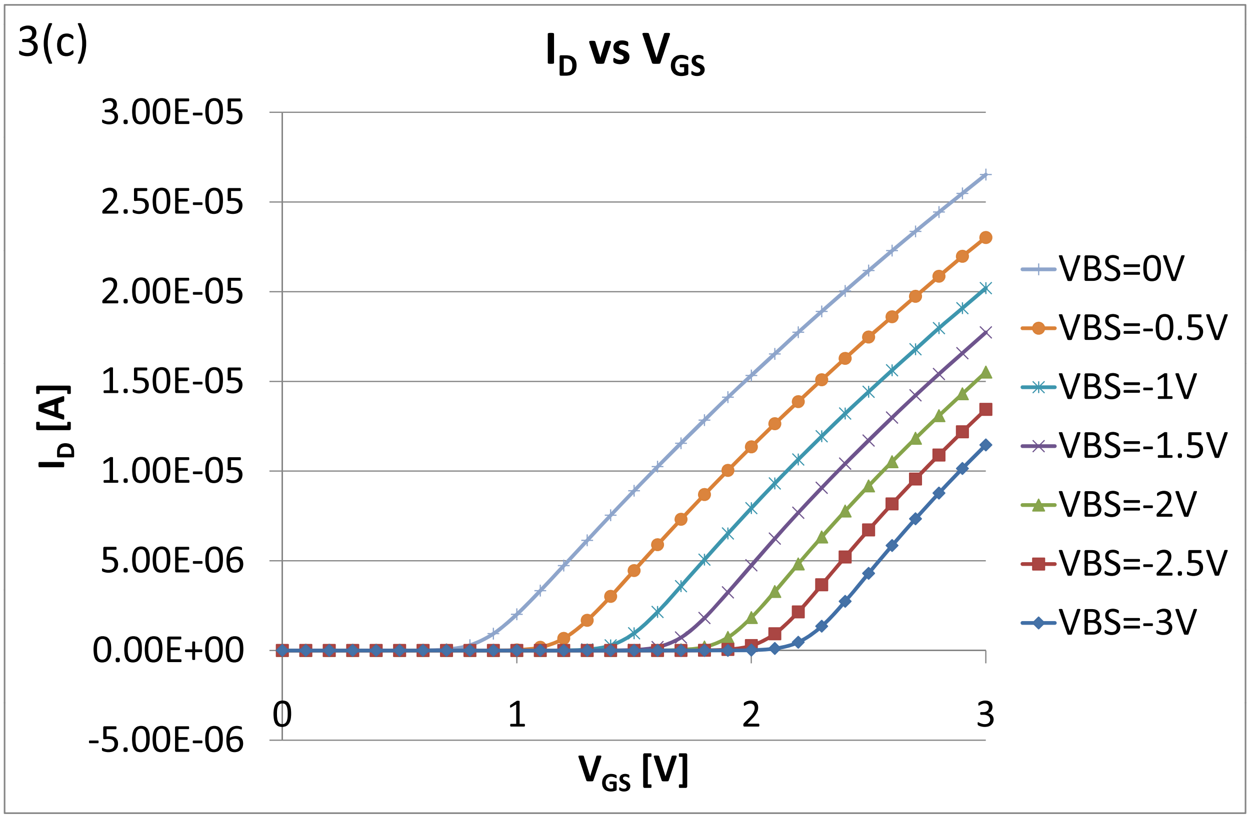
$$457\,\mu A = W\,Q_N\left(y=\frac{L}{2}\right)v_y\left(\frac{L}{2}\right)$$

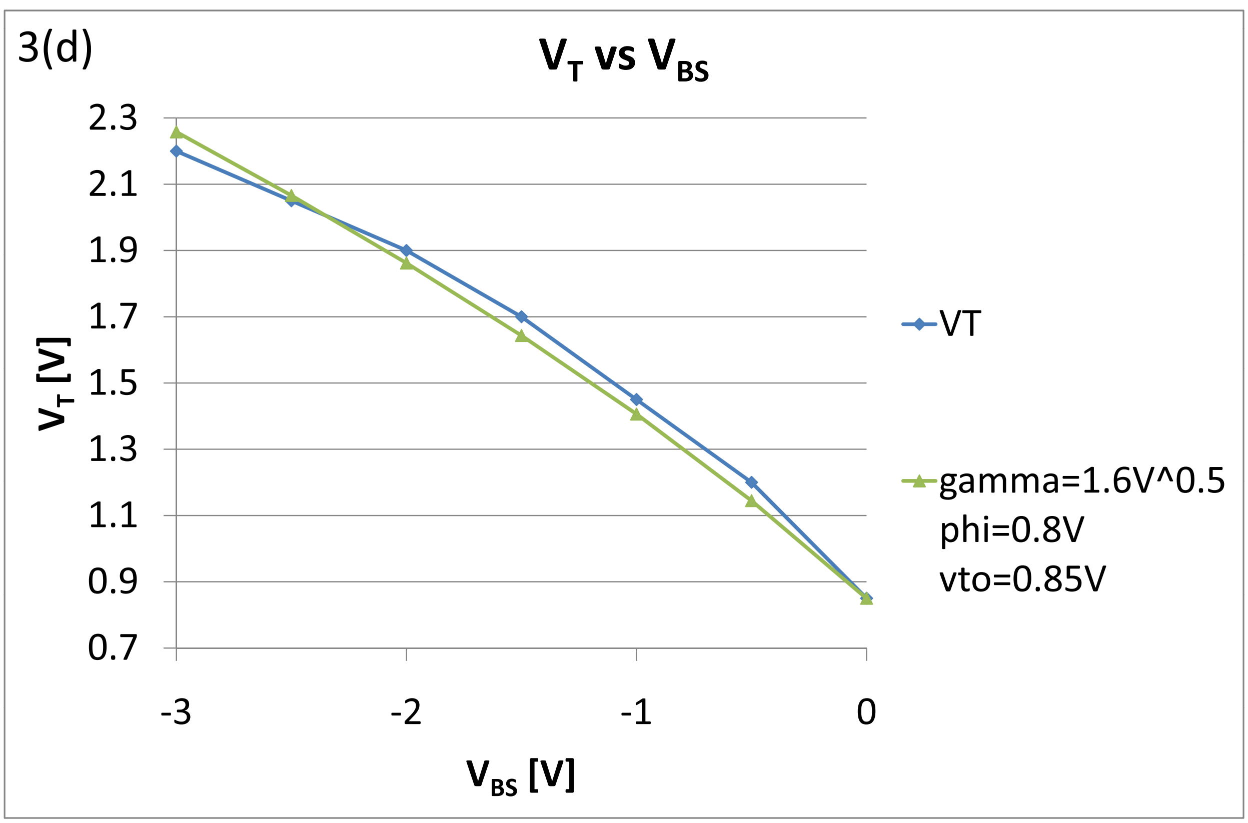
$$457\,\mu A = (3\times10^{-3}\,cm)(2.096\times10^{-7}\ C/cm^2)\,v_y\left(\frac{L}{2}\right)$$

$$\boxed{v_y\left(\frac{L}{2}\right) = 7.27\times10^{5}\ cm/s}$$


3(a)
ID vs VDS
4.50E-04
4.00E-04
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
ID [A]
0
1
2
3
VDS [V]
VGS=3V
VGS=2.5V
VGS=2V
VGS=1.5V
VGS=1V
VGS=0.5V
VGS=0V


3(b)
ID vs VGS
4.50E-04
4.00E-04
3.50E-04
3.00E-04
2.50E-04
2.00E-04
1.50E-04
1.00E-04
5.00E-05
0.00E+00
-5.00E-05
ID [A]
0
0.5
1
1.5
2
2.5
3
VGS [V]
VDS=3V
VDS=2.5V
VDS=2V
VDS=1.5V
VDS=1V
VDS=0.5V
VDS=0V


3(c)
ID vs VGS
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
-5.00E-06
ID [A]
0
1
2
3
VGS [V]
VBS=0V
VBS=-0.5V
VBS=-1V
VBS=-1.5V
VBS=-2V
VBS=-2.5V
VBS=-3V


3(d)
VT vs VBS
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
VT [V]
-3
-2
-1
0
VBS [V]
VT
gamma=1.6V^0.5
phi=0.8V
vto=0.85V