Home Work # 7 Solutions:

1) $N_d = 10^{17}\,cm^{-3}$

$t_{ox} = 10 \times 10^{-7}\,cm = 10^{-6}\,cm \qquad \frac{\rho_{ox}}{q} = 2 \times 10^{16}\,cm^{-3}$

$\frac{Q_{ss}'}{q} = 5 \times 10^{10}\,cm^{-2}$

(PolySilicon Gate $E_F = E_V$)

a) $C_{ox}' = \frac{K_{ox}\epsilon_0}{t_{ox}} = \frac{(3.9)(8.85 \times 10^{-14}\,F\,cm^{-1})}{10^{-6}\,cm} = \underline{3.45 \times 10^{-7}\,F\,cm^{-2}}$

$\varphi_s = \chi_s + (E_c - E_f) = \chi_s + \frac{kT}{q}\ln\left(\frac{N_c}{N_d}\right)$

$= 4.05 + 0.0256\ln\left(\frac{2.8 \times 10^{19}\,cm^{-3}}{10^{17}\,cm^{-3}}\right) = \underline{4.19\,V}$

$\varphi_{ms} = \varphi_m - \varphi_s = \chi_s + E_g - 4.19\,V = \underline{0.98\,V}$

Oxide and Interface charges exist $\Rightarrow V_{FB} \neq \varphi_{ms}$

$V_{FB} = \varphi_{ms} - \frac{Q_{ss}'}{C_{ox}'} - \frac{Q_{ox}'}{C_{ox}'} = \varphi_{ms} - \frac{Q_{ss}'}{C_{ox}'} - \frac{1}{C_{ox}'}\int_0^{t_{ox}} \frac{x}{t_{ox}}\rho(x)\,dx$

$= \varphi_{ms} - \frac{1}{C_{ox}'}\left[Q_{ss}' + \frac{\rho_{ox} t_{ox}}{2}\right]$

$= 0.98 - \frac{1.6 \times 10^{-19}\,C}{3.45 \times 10^{-7}\,F\,cm^{-2}}\left[5 \times 10^{10}\,cm^{-2} + \frac{10^{-6}\,cm}{2} \times 2 \times 10^{16}\,cm^{-3}\right]$

$= \underline{0.95\,V}$

$V_{th} = V_{FB} - 2\varphi_F - \frac{Q_B'}{C_{ox}'}$

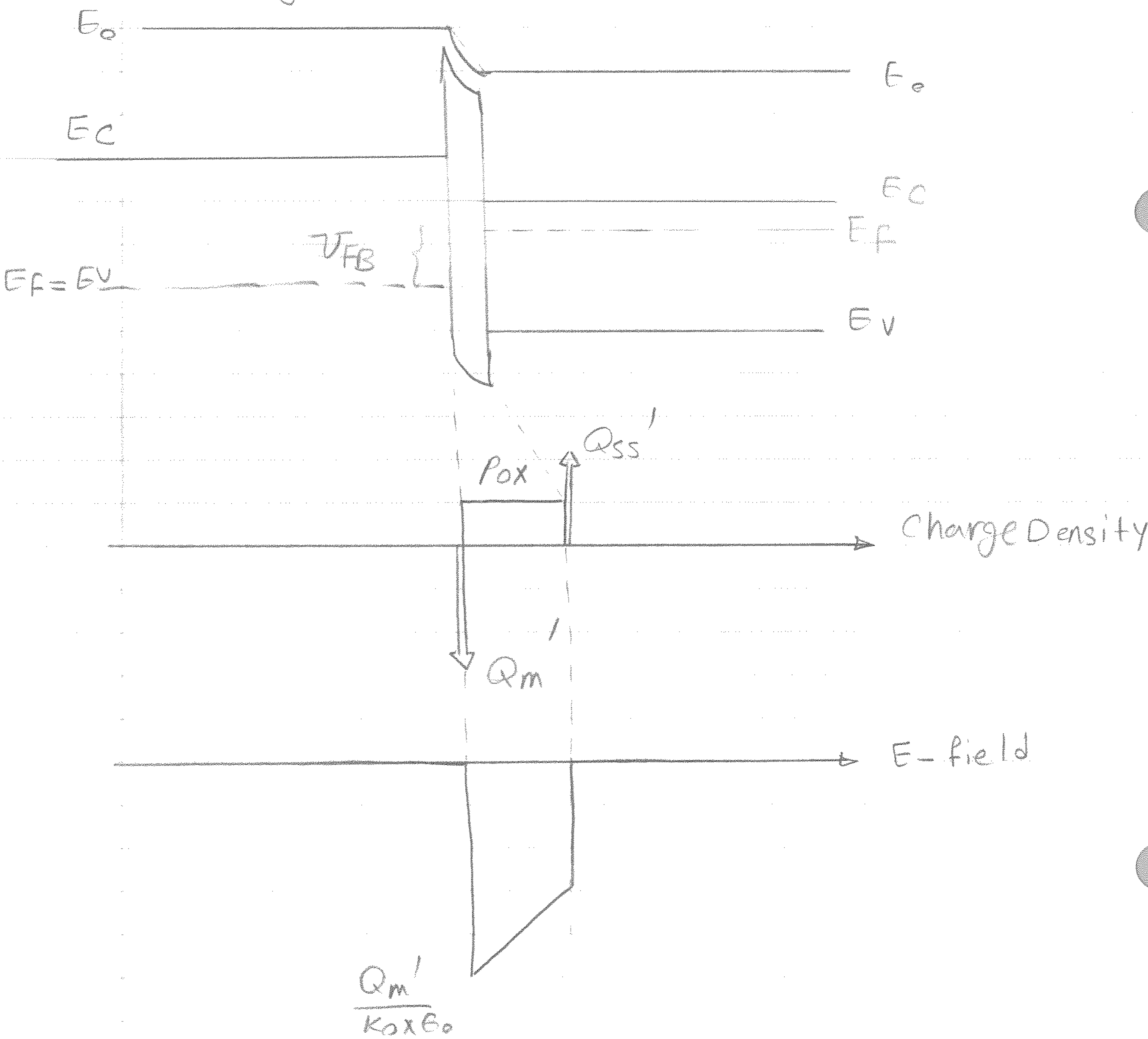
$$\phi_F = \frac{kT}{q} \ln\left(\frac{N_d}{n_i}\right) = 0.0256 \ln\left(\frac{10^{17}}{10^{10}}\right) = 0.41v$$

$$Q_B' = \sqrt{2 K_s \epsilon_0 q N_d |2\phi_F|} = 1.66 \times 10^{-7}\ C\,cm^{-2}$$

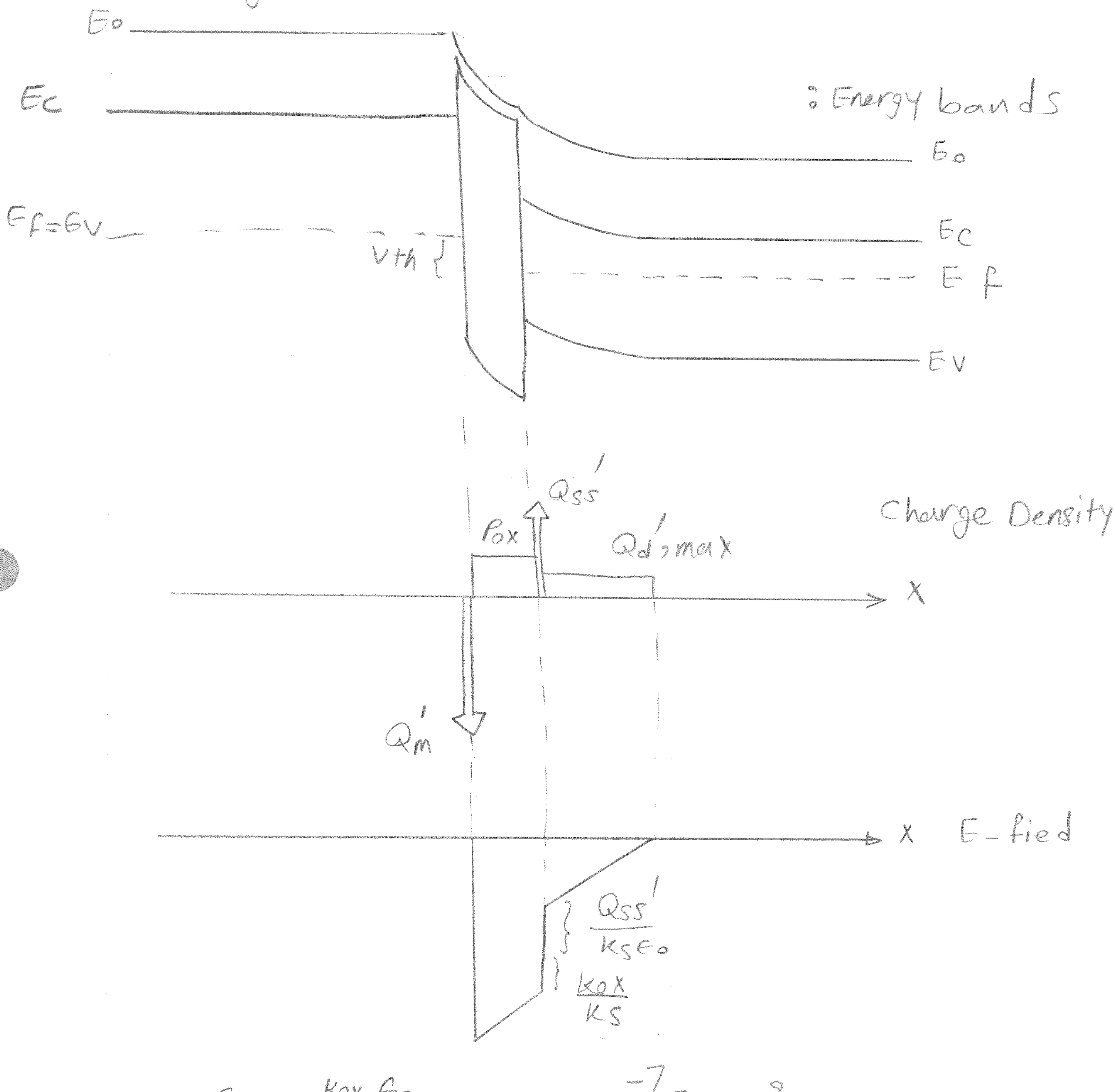
$$\Rightarrow V_{th} = 0.95v - 2(0.41) - \frac{1.66 \times 10^{-7}\ C\,cm^{-2}}{3.45 \times 10^{-7}\ F\,cm^{-2}}$$

$$= \underline{\underline{-0.35v}}$$

1b) Diagrams @ $v_{GB} = v_{FB}$



1b) Diagrams @ $V_{GB} = V_{th}$



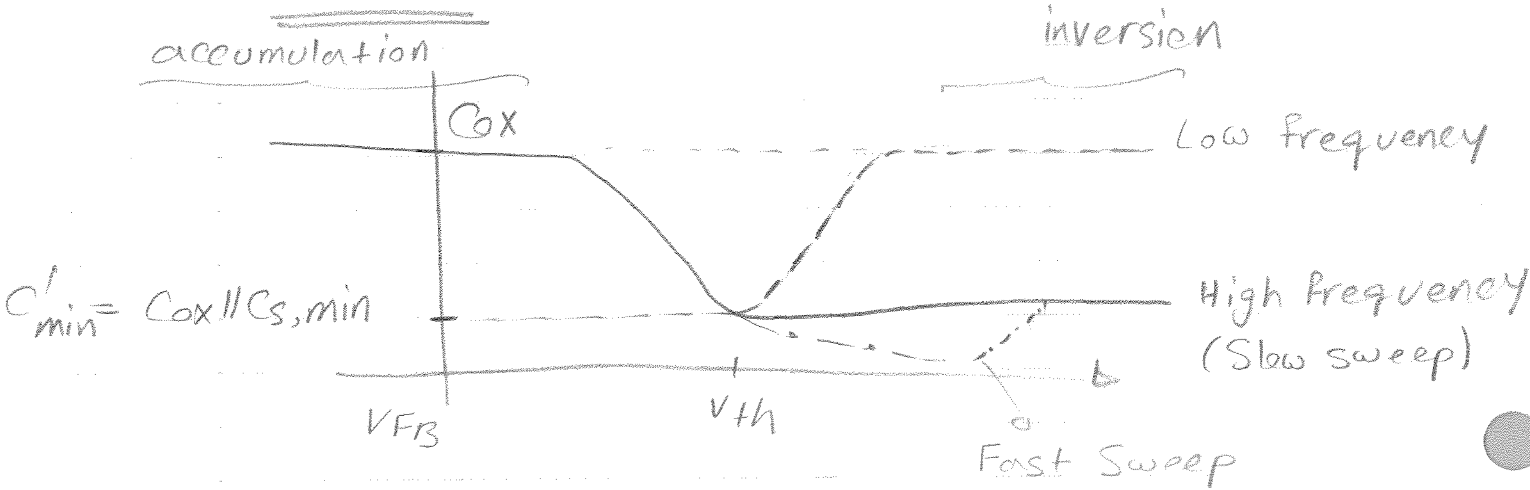
1c) $C_{ox} = \frac{k_{ox} \epsilon_0}{t_{ox}} = 3.45 \times 10^{-7} \, F cm^{-2}$

$C_{s,min} = \frac{k_s \epsilon_0}{x_{dmax}}$

$$X_{dmax} = \sqrt{\frac{2\kappa_s \epsilon_0 \, |2\varphi_F|}{qN_d}} = \sqrt{\frac{2(11.7)(8.85\times10^{-14})(0.82)}{(1.6\times10^{-19})\,10^{17}}}\ \text{cm}$$

$$= \underline{1.03\times10^{-5}\ \text{cm}} \Longrightarrow C_{S,min} = \frac{11.7\times 8.85\times10^{-14}\ \text{Fcm}^{-1}}{1.03\times10^{-5}\ \text{cm}^{-1}} =$$

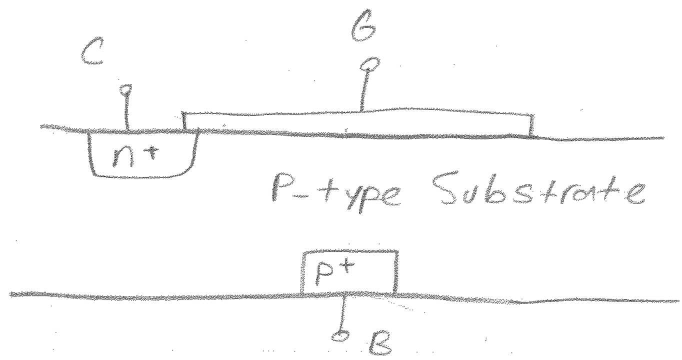
$$\underline{\simeq 10^{-7}\ \text{Fcm}^{-2}}$$



2 a)

$N_a = 10^{18}\ cm^{-3}$

$t_{ox} = 2\times10^{-7}\ cm$



$$|Q_d| = \sqrt{2K_s\epsilon_0 q N_a V_s} = 5.76\times10^{-7}\sqrt{V_s}\ \ Ccm^{-2}$$

$$|Q_i| \cong q\, n_s\, x_i = q\, x_i \frac{n_i^2}{N_a} \exp\left(q\frac{(V_s - V_{CB})}{KT}\right)$$

Assume that channel thickness is 0.5nm

$$= (1.6\times10^{-19}\,C)(0.5\times10^{-7}\,cm)\left(\frac{10^{20}}{10^{18}}\right)cm^{-3}\exp\left(q\frac{(V_s - V_{CB})}{KT}\right)$$

$$= 8\times10^{-25}\,C\,cm^{-2}\exp\left(\frac{V_s - V_{CB}}{0.0256V}\right)$$

b) $$V_{ox} = \frac{Q_i' + Q_d'}{C_{ox}'}$$

$$C_{ox}' = \frac{K_{ox}\epsilon_0}{t_{ox}} = 1.73\times10^{-6}\ Fcm^{-2}$$

$$V_{ox} = \frac{1}{1.73\times10^{-6}\,Fcm^{-2}}\left[-8\times10^{-25}\,Ccm^{-2}\exp\left(\frac{V_s - V_{CB}}{0.0256}\right) - 5.76\times10^{-7}\sqrt{V_s}\right]$$

$$V_{GC} = V_{GB} - V_{CB}$$

$$V_{GB} - \phi_{ms} = V_{ox} + V_s$$

$$\Rightarrow V_{GC} = +V_{ox} + V_S + \varphi_{mS} - V_{CB}$$

$$\varphi_{mS} = \varphi_m - \varphi_S = \chi_S - (\chi_S + E_g - (E_F - E_V))$$

$$= -E_g + \frac{KT}{q} \ln\left(\frac{N_V}{N_a}\right) = -1.12 + 0.0256\,V \ln\left(\frac{2.5\times10^{19}}{10^{18}}\right)$$

$$= -1.04\,V$$

$$\Rightarrow \underline{V_{GC} = V_{OX} + V_S - V_{CB} - 1.04\,V}$$

9c) $V_{th} = \varphi_{mS} - 2\varphi_F - \frac{Q'_{dmax}}{C_{ox}'} = V_{GC}$ ϵ_{oSI}

$$\varphi_F = -\frac{KT}{q} \ln\left(\frac{N_a}{n_i}\right) = -0.0256 \ln\left(\frac{10^{18}}{10^{10}}\right) = \underline{-0.471V}$$

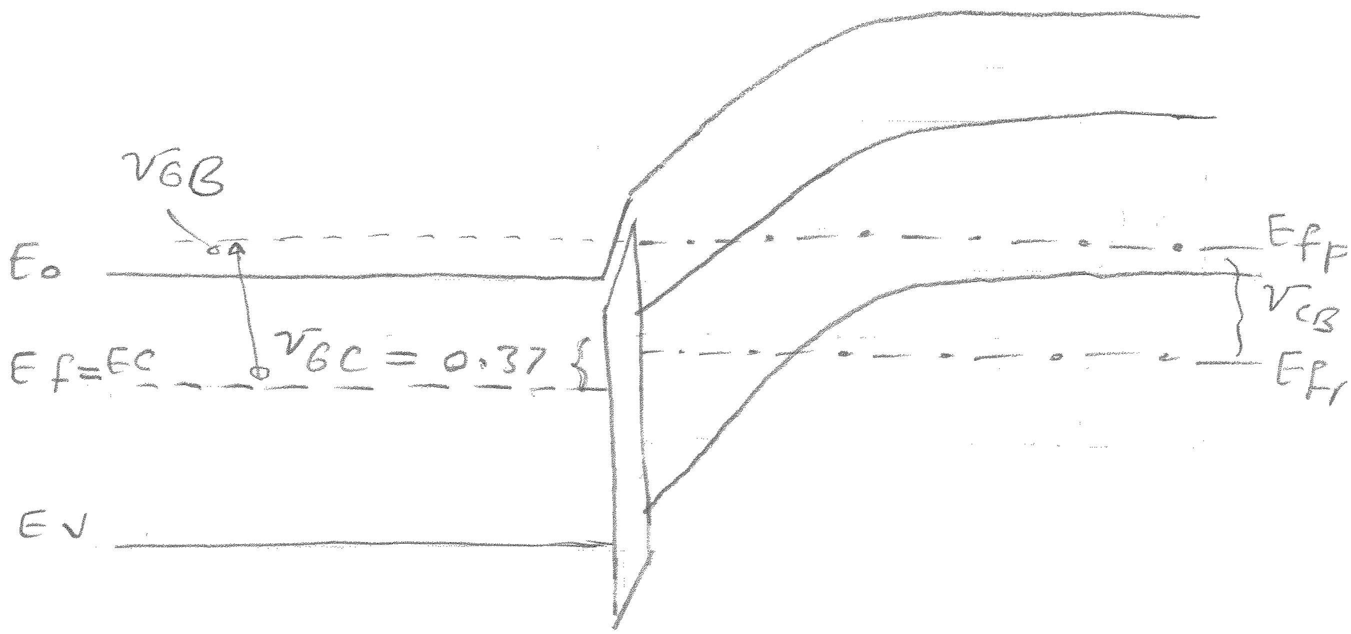
$$Q'_{d,max} = -\left[2k_S\epsilon_0 q N_a (V_{CB} - 2\varphi_F)\right]^{\frac{1}{2}} =$$

$$= -0.58\times10^{-6}\,C\,cm^{-2}\,(V_{CB} + 0.942)^{\frac{1}{2}}$$

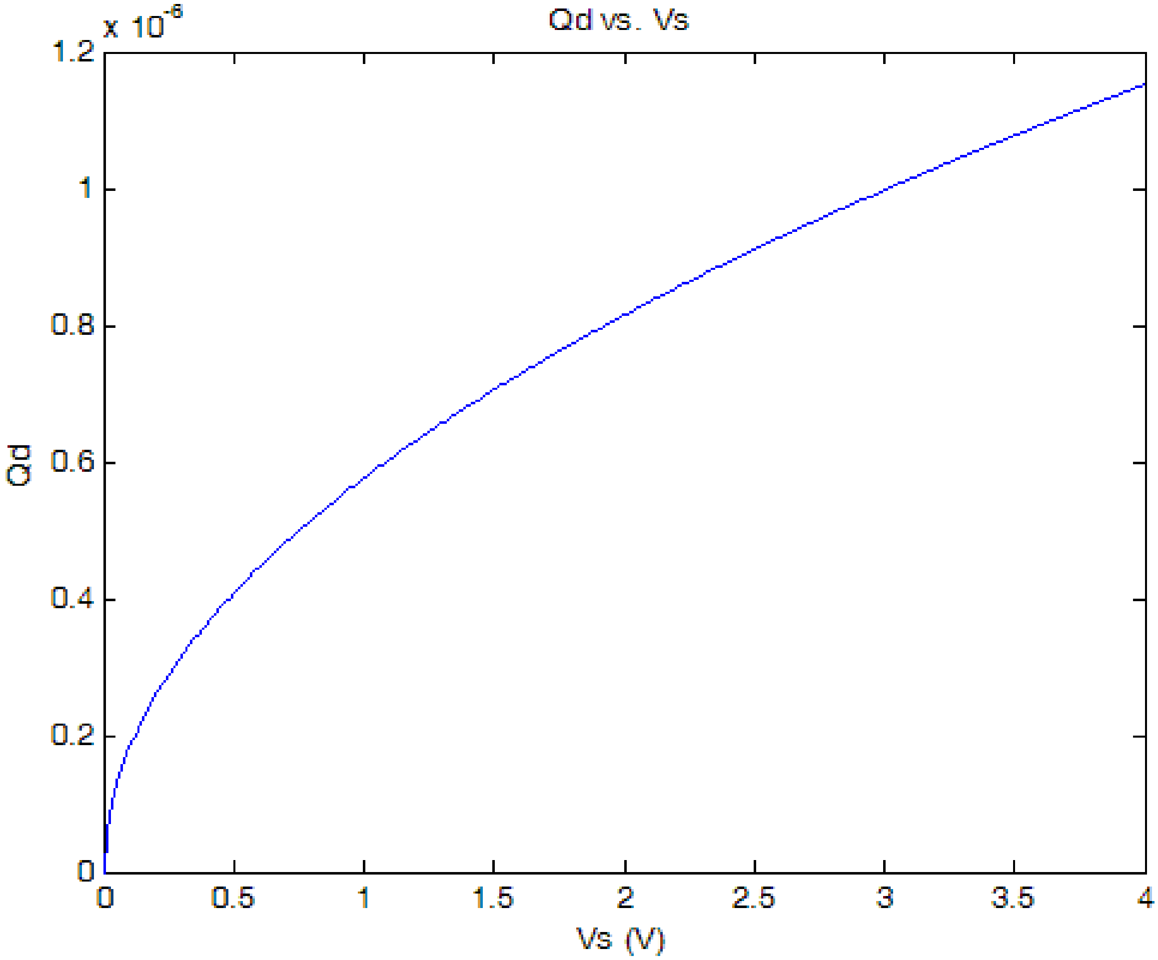
$$= \begin{cases} -0.56\times10^{-6}\,C\,cm^{-2} & V_{CB}=0 \\ -0.81\times10^{-6}\,C\,cm^{-2} & V_{CB}=1 \end{cases}$$

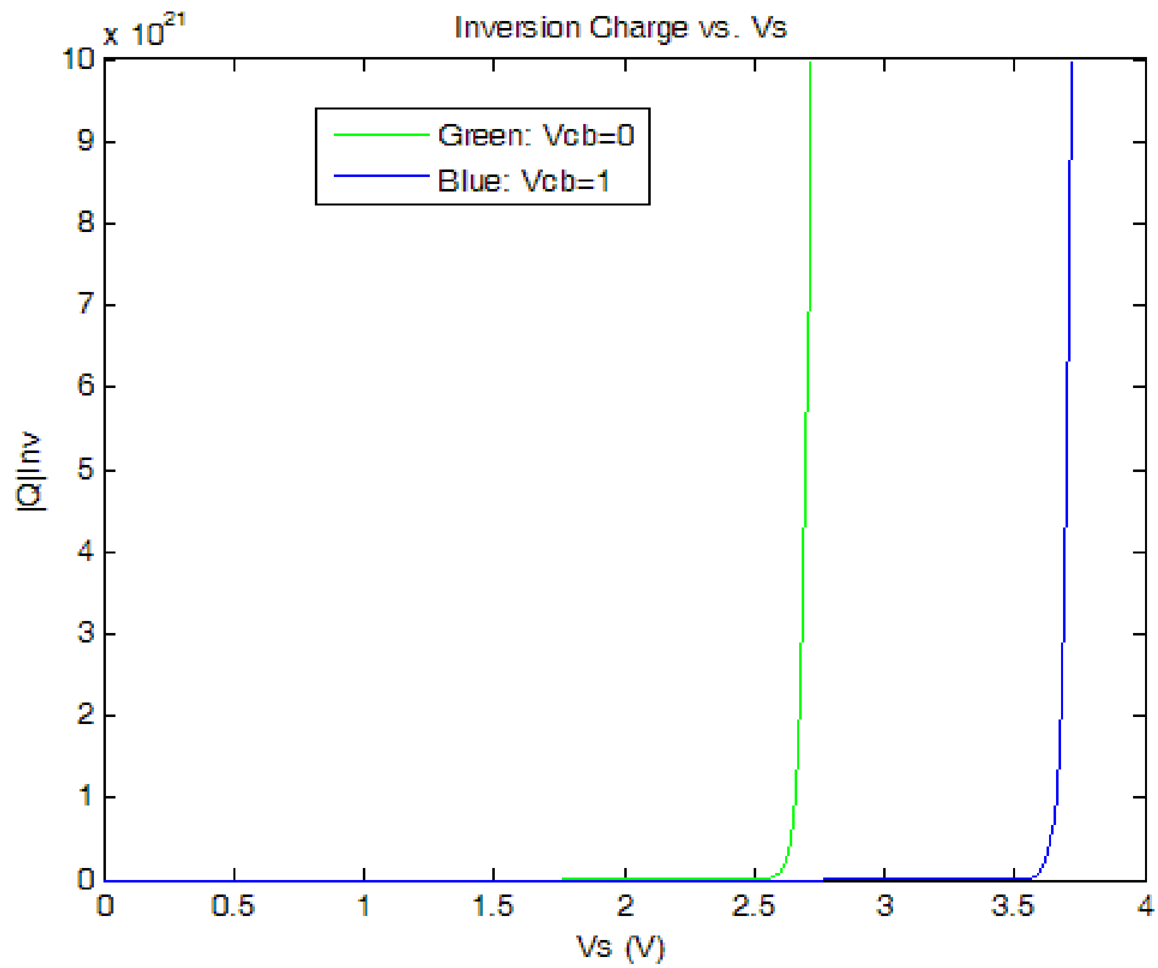
$$\Rightarrow V_{th} = -1.04\,V + 0.942 - \frac{Q'_{d,max}}{C_{ox}'}$$

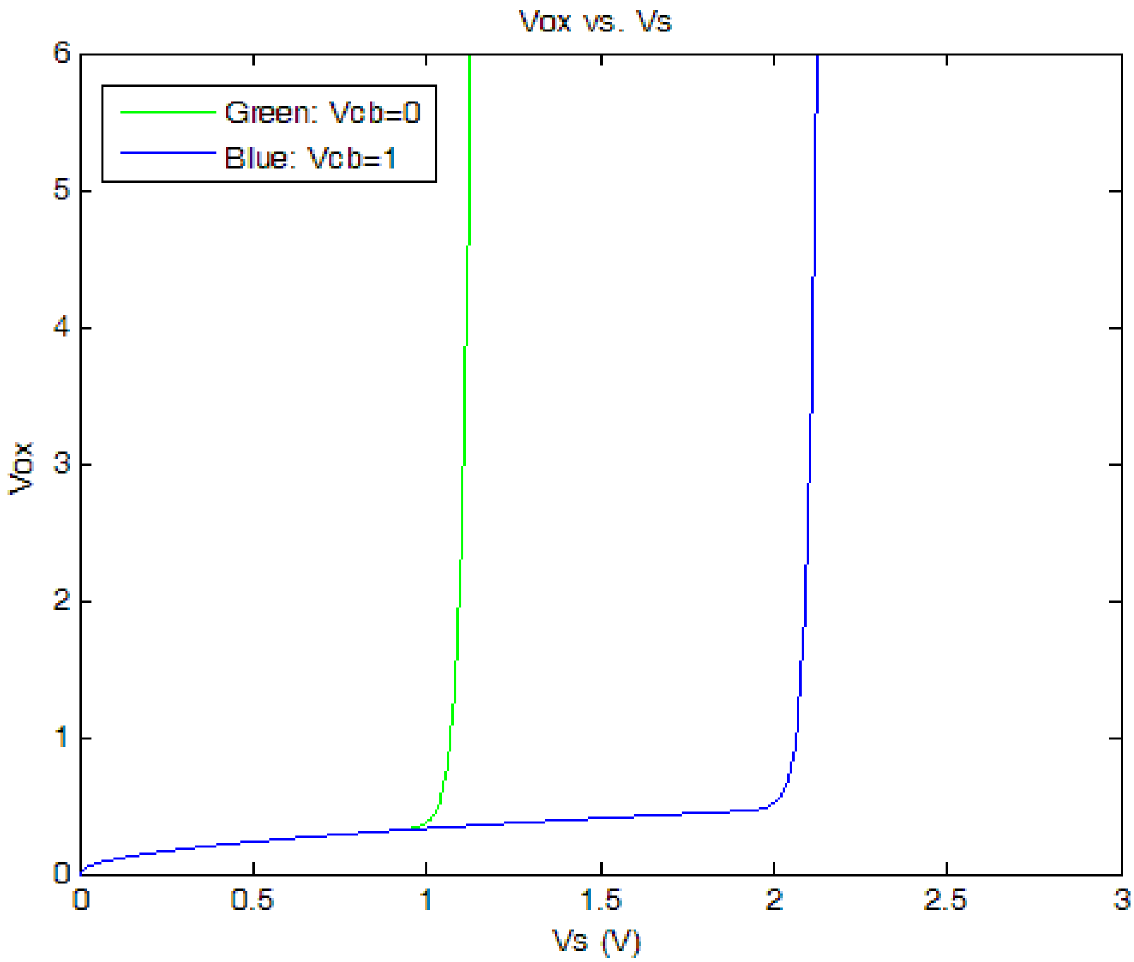
$$= \begin{cases} 0.23\,V & V_{CB}=0 \\ 0.37\,V & V_{CB}=1 \end{cases}$$

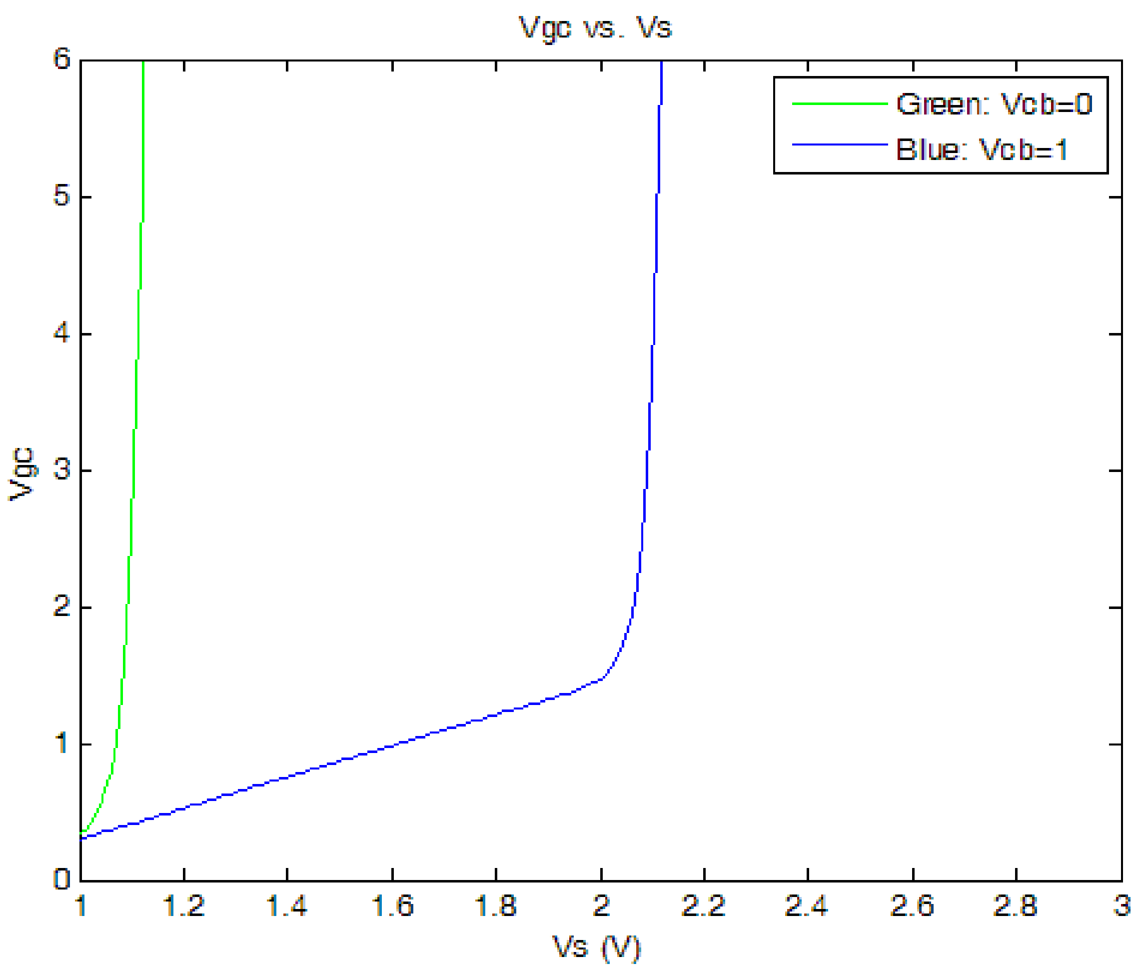


If V_{CB} is held constant, above V_{th}, as V_{GC} increases, Q_i increases linearly


Qd vs. Vs
x 10^-6
1.2
1
0.8
0.6
0.4
0.2
0
Qd
0
0.5
1
1.5
2
2.5
3
3.5
4
Vs (V)


Inversion Charge vs. Vs
x 10^21
10
9
8
7
6
5
4
3
2
1
0
|Q|inv
Green: Vcb=0
Blue: Vcb=1
0
0.5
1
1.5
2
2.5
3
3.5
4
Vs (V)


Vox vs. Vs
Green: Vcb=0
Blue: Vcb=1
Vox
Vs (V)
0
1
2
3
4
5
6
0.5
1.5
2.5


Vgc vs. Vs
Green: Vcb=0
Blue: Vcb=1
Vgc
Vs (V)
0
1
2
3
4
5
6
1.2
1.4
1.6
1.8
2.2
2.4
2.6
2.8