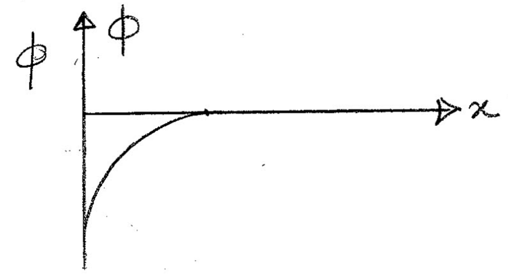
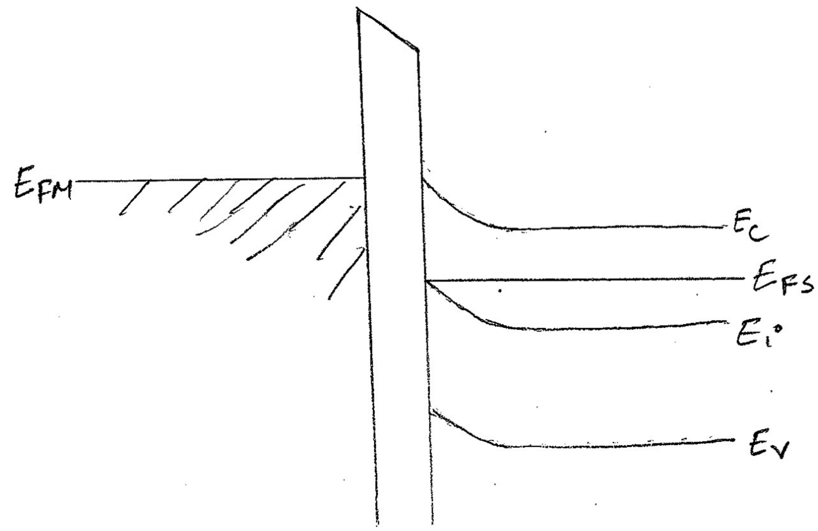
HW #6 SOLUTIONS

(1.)

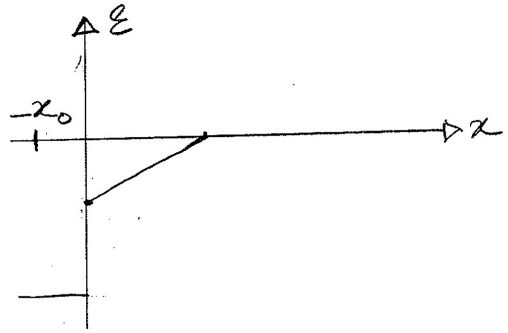
Prob # 16.7.

ⓐ $\phi(x) = \frac{1}{q}\left[E_i(\text{bulk}) - E_i(x)\right]$



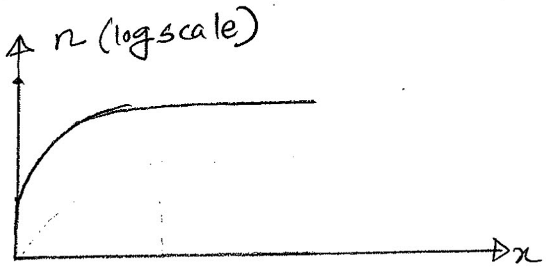


ⓑ



ⓒ Yes, Inside the semiconductor E_F, is position independent.

ⓓ



ⓔ $n_{\text{Si-SiO}_2\text{ interface}} = n_i\, e^{\frac{(E_F - E_i)_{\text{Si-SiO}_2\text{ interface}}}{KT}}$

$= n_i e^0 = n_i$ ← (intrinsic).

ⓕ $N_D = n_i\, e^{\frac{q(E_F - E_i)_{\text{bulk}}}{KT}} = n_i\, e^{\frac{0.29}{KT}} = 7.45\times10^{14}\ \text{cm}^{-3}$ ←

ⓖ $\phi_s = \frac{1}{q}\left[E_i(\text{bulk}) - E_i(\text{surface})\right] = -0.29\ \text{V}$ ←

ⓗ $-V_G = \phi_s + \frac{K_S}{K_O} x_o \sqrt{\frac{2q N_D}{K_S \epsilon_0}\phi_s} \Rightarrow V_G = -0.79\ \text{V}$ ←

$K_o = 3.9,\ K_S = 11.8$

16.7 continued

(i) $\Delta\phi_{ox} = V_G - \phi_s = -0.5\ V \leftarrow$

(j) $$\frac{C}{C_o} = \frac{1}{1+\frac{K_o W}{K_s x_o}} \quad ; \quad W = \left[\frac{2K_s\epsilon_o}{qN_D}\phi_s\right]^{1/2} = 7.12\times10^{-5}$$

$= 0.46$.

Prob #2.:- (a) $C_o = 1.92\times10^{-7}\ \frac{F}{cm^2} = \frac{K_o\epsilon_o}{x_o}$.

$$\Rightarrow x_o = \frac{K_o\epsilon_o}{C_o} = \frac{3.9\times8.85\times10^{-14}}{1.92\times10^{-7}} = 1.8\times10^{-6}\ cm \leftarrow$$

(b) $V_T = 1.25\ V \leftarrow$

(c) $$\frac{C_T}{C_o} = \frac{1}{1+\frac{K_o W_T}{K_s x_o}} \Rightarrow 1+\frac{K_o W_T}{K_s x_o} = \frac{C_o}{C_T} = \frac{1.92\times10^{-7}}{4.43\times10^{-8}}$$

$$\Rightarrow 1+\frac{K_o W_T}{K_s x_o} = 4.334 \Rightarrow \frac{K_o W_T}{K_s x_o} = 3.334$$

$$\Rightarrow W_T = 1.81\times10^{-5}\ cm \leftarrow$$

(d) $$V_T = 2\phi_F + \frac{K_s x_o}{K_o}\mathcal{E}_{ST} = 2\phi_F + \frac{K_s x_o}{K_o}\times\frac{4\phi_F}{W_T}$$

$$\Rightarrow V_T = 2\phi_F\left(1+2\frac{K_s x_o}{K_o W_T}\right) = 2\phi_F\left(1+2\frac{11.8\times1.8\times10^{-6}}{3.9\times1.81\times10^{-5}}\right)$$

$$= 2\phi_F(1+0.6) \Rightarrow \phi_F = \frac{V_T}{2\times1.6} = 0.39$$

$$N_A = n_i e^{q\phi_F/kT} = 3.6\times10^{16}\ cm^{-3}$$

② continued

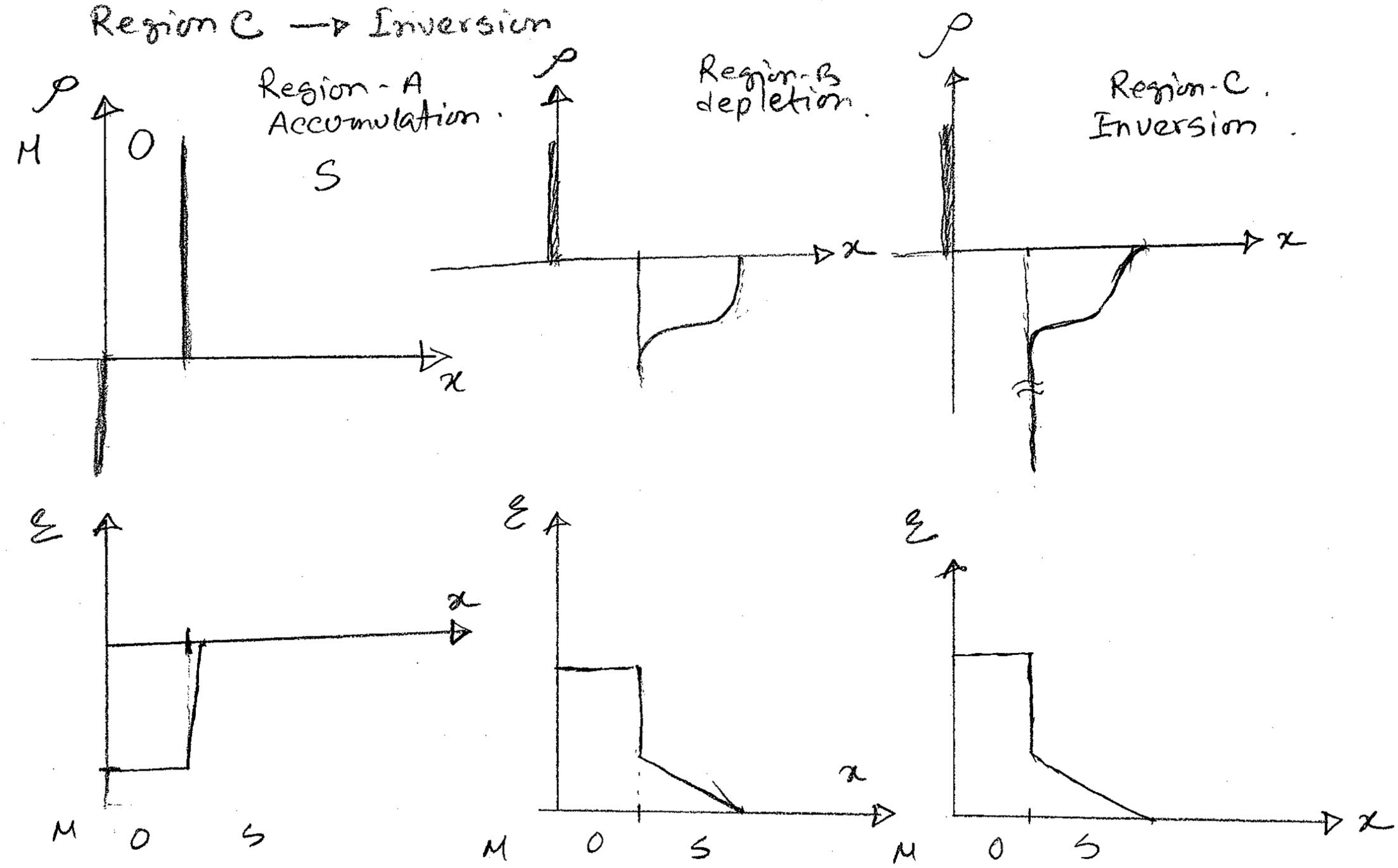
ⓔ $f = 100$ kHz, → high frequency -

for MOS transistor high frequency & low frequency curve is same -

→ CV curve for MOS transistor.

ⓕ Region A → Accumulation; Region B → depletion

Region C → Inversion



Prob #3:- MOS Cap. $N_A = 5\times10^{16}$; $x_o = 300\times10^{-8}$ cm $= 3\times10^{-6}$ cm.

$$C_o = \frac{K_o \varepsilon_o}{x_o} = 1.15\times10^{-7} \text{ F/cm.}$$

$$\phi_F = \frac{kT}{q}\ln\frac{N_A}{n_i} = 0.4$$

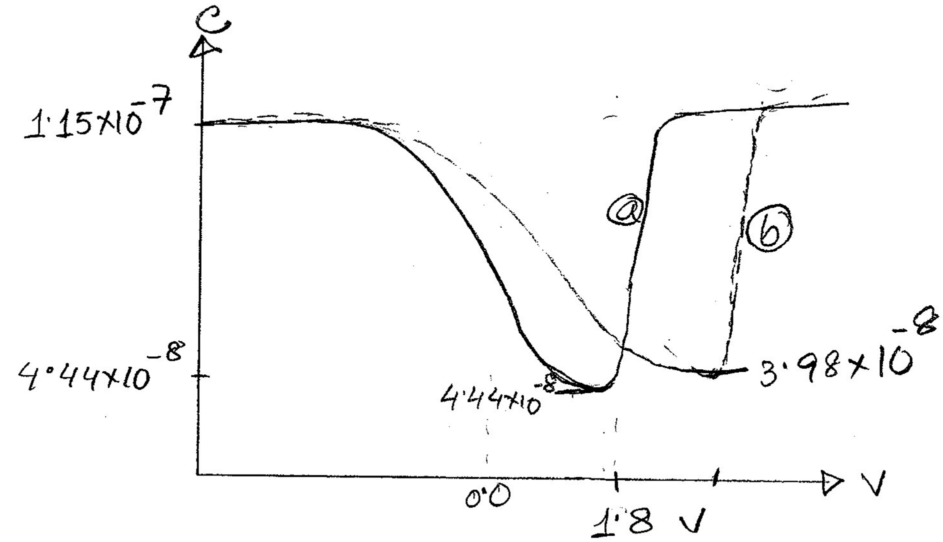
$$C_{inv} = \frac{C_o}{1+\frac{K_o W_T}{K_s x_o}} = 4.44\times10^{-8} \text{ F/cm.}$$

$$W_T = \left[\frac{2K_s\varepsilon_o}{qN_A}\cdot 2\phi_F\right]^{1/2} = 1.44\times10^{-5} \text{ cm.}$$

$$V_T = 2\phi_F + \frac{K_s x_o}{K_o}\sqrt{\frac{4qN_A}{K_s\varepsilon_o}\phi_F} = 1.8 \text{ V} \longleftarrow$$

Prob #3. continued

(a) MOS- C-V Curve



(b) For GaAs, $K_S = 13.1$.

$$\therefore C_{inv} = \frac{C_0}{1 + \frac{K_0 W_T}{K_S x_0}} = 3.98 \times 10^{-8} \text{ F/cm}$$

$$\phi_F = \frac{KT}{q} \ln \frac{N_A}{n_i} = 0.62 \text{ V}$$

$$W_T = \left[\frac{2 K_S \epsilon_0}{q N_A} \cdot 2\phi_F\right] = 1.9 \times 10^{-5} \text{ cm}$$

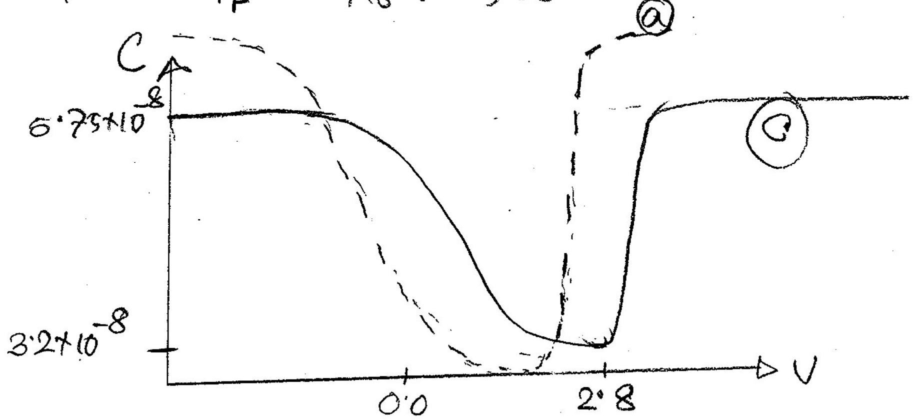
$$V_T = 2\phi_F + \frac{K_S x_0}{K_0} \sqrt{\frac{4 q N_A}{K_S \epsilon_0} \phi_F} = 2.56 \text{ V}$$

(c) $x_0 = 6 \times 10^{-6}$ cm. (Si), $\phi_F = 0.4$, $W_T = 1.44 \times 10^{-5}$ cm.

$C_0 = 5.75 \times 10^{-8}$

$$C_{inv} = \frac{C_0}{1 + \frac{K_0 W_T}{K_S x_0}} = 3.2 \times 10^{-8} \text{ F/cm}.$$

$$V_T = 2\phi_F + \frac{K_S x_0}{K_0} \sqrt{\frac{4 q N_A}{K_S \epsilon_0} \phi_F} = 2.8 \text{ V}$$



17.2

(a)

$$\phi_F = \frac{kT}{q}\ln(N_A/n_i) = 0.0259\ln(10^{15}/10^{10}) = 0.298\text{V}$$

$$V_T = 2\phi_F + \frac{K_S x_o}{K_O}\sqrt{\frac{4qN_A}{K_S\varepsilon_0}\phi_F} \qquad ...(17.1a)$$

$$= (2)(0.298) + \frac{(11.8)(5\times10^{-6})}{(3.9)}\left[\frac{(4)(1.6\times10^{-19})(10^{15})(0.298)}{(11.8)(8.85\times10^{-14})}\right]^{1/2}$$

$$\mathbf{V_T = 0.800\ V}$$

(b) In the square-law theory

$$I_{Dsat} = \frac{Z\bar{\mu}_n C_o}{2L}(V_G - V_T)^2 \qquad ...(17.22)$$

$$C_o = \frac{K_O\varepsilon_0}{x_o} = \frac{(3.9)(8.85\times10^{-14})}{(5\times10^{-6})} = 6.90\times10^{-8}\ \text{F/cm}^2$$

$$I_{Dsat} = \frac{(5\times10^{-3})(800)(6.9\times10^{-8})(2-0.8)^2}{(2)(5\times10^{-4})} = \mathbf{0.397mA}$$

(c) In the bulk-charge theory we must first determine V_{Dsat} using Eq.(17.29). We know ϕ_F and V_T from part (a), but must compute V_W before substituting into the V_{Dsat} expression.

$$W_T = \left[\frac{2K_S\varepsilon_0}{qN_A}(2\phi_F)\right]^{1/2} = \left[\frac{(2)(11.8)(8.85\times10^{-14})(2)(0.298)}{(1.6\times10^{-19})(10^{15})}\right]^{1/2} = 0.882\mu\text{m}$$

$$V_W \equiv \frac{qN_A W_T}{C_o} = \frac{(1.6\times10^{-19})(10^{15})(8.82\times10^{-5})}{(6.90\times10^{-8})} = 0.205\text{V}$$

Noting that $V_G - V_T = 1.20$V, substituting into Eq.(17.29) then gives

$$V_{Dsat} = 1.20 - 0.205\left\{\left[\frac{(1.20)}{(2)(0.298)} + \left(1 + \frac{(0.205)}{(4)(0.298)}\right)^2\right]^{1/2} - \left[1 + \frac{(0.205)}{(4)(0.298)}\right]\right\}$$

or

$$V_{Dsat} = 1.06\text{V} \quad \text{...smaller than } V_{Dsat} \text{ of square-law theory as expected}$$

Now

$$\frac{Z\bar{\mu}_n C_o}{L} = \frac{(5\times10^{-3})(800)(6.90\times10^{-8})}{(5\times10^{-4})} = 5.52\times10^{-4}\ \text{amps/V}^2$$

Finally, substituting into Eq.(17.28) gives I_{Dsat} if $V_D = V_{Dsat}$. Thus

$$I_{Dsat} = (5.52\times10^{-4})\left\{(1.20)(1.06) - \frac{(1.06)^2}{2} - \frac{4}{3}(0.205)(0.298)\left[\left(1+\frac{(1.06)}{(2)(0.298)}\right)^{3/2} - \left(1+\frac{(3)(1.06)}{(4)(0.298)}\right)\right]\right\}$$

I_{Dsat} = 0.349mA ⇐bulk charge result (smaller than the square-law result as expected)

(d) Clearly here the device is biased below pinch-off. From Table 17.1 we note that both the square-law and bulk-charge theories reduce to the same result if $V_D = 0$.

$$g_d = \frac{Z\bar{\mu}_n C_o}{L}(V_G - V_T) = (5.52\times10^{-4})(2-0.8) = \mathbf{0.662mS}$$

(e) In the square-law theory, $V_{Dsat} = V_G - V_T$. Thus $V_{Dsat} = 1.20\text{V}$ and $V_D = 2\text{V}$. Since $V_D > V_{Dsat}$, the device is saturation (above-pinch-off) biased, and from Table 17.1

$$g_m = \frac{Z\bar{\mu}_n C_o}{L}(V_G - V_T) = \mathbf{0.662mS} \quad \text{...same as } g_d \text{ of part (d)}$$

(f) In part (c) we calculated the bulk-charge $V_{Dsat} = 1.06\text{V}$. Since $V_D > V_{Dsat}$, the device is above-pinch-off biased, and from Table 17.1

$$g_m = \frac{Z\bar{\mu}_n C_o}{L}V_{Dsat} = (5.52\times10^{-4})(1.06) = \mathbf{0.585mS}$$