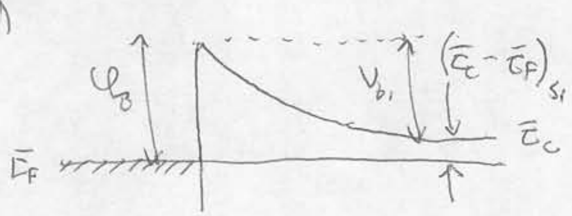
8.16 | For Si MESFET w/ $\varphi_B = .8V$, $N_D = \frac{5\cdot 10^{16}}{cm^3}$, $L = 1.5\,\mu m$, $h = .25\,\mu m$, $Z = 25\,\mu m$. Assume $N_c = \frac{2.8\cdot 10^{19}}{cm^3}$

1/1

a)



$$(\bar{E}_c - \bar{E}_F)_{Si} = -kT \ln\left(\frac{n_{no}}{N_c}\right)$$
$$= .0259\,V \ln\left(\frac{5\cdot 10^{16}}{2.8\cdot 10^{19}}\right)$$
$$= .16\,eV$$

$$V_{bi} = \frac{1}{q}\left(\varphi_B - (\bar{E}_c - \bar{E}_F)_{Si}\right) = .8\,V - .16\,V = .64\,V$$

Intrinsic pinch-off voltage is defined as $V_P = \frac{qN_Dh^2}{2\varepsilon} = 2.37V$

Threshold voltage applied to the gate is: $V_T = V_{bi} - V_P$

$$V_T = .64V - 2.37V = \boxed{-1.73V}$$

b) Drain saturation voltage is $V_{DS}^{sat} = V_T + V_{GS}$

For $V_{GS} = 0$, $V_{DS}^{sat} = V_T = \boxed{-1.73V}$

$$g_m^{sat} = \left.\frac{\partial I_D}{\partial V_{GS}}\right|_{V_{DS} = V_{DS}^{sat}} = \frac{q\mu_n N_D Z h}{L}\left[1 - \left(\frac{V_{bi} - V_{GS}}{V_P}\right)^{\frac{1}{2}}\right]$$

$$g_m^{sat} = \boxed{\frac{1.60\cdot 10^{-3}A}{V}}$$

c) $V_T = V_{bi} - V_P = \varphi_B - \frac{kT}{q}\ln\left(\frac{N_D}{N_c}\right) - \frac{qN_Dh^2}{2\varepsilon}$

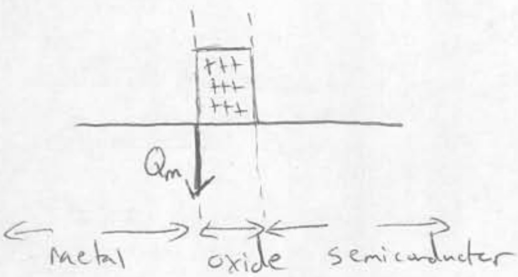
For $V_T' = 2V$, get $2.8V + .0259V \ln\left(\frac{N_D'}{2.8\cdot 10^{19}}\right) - 4.747\cdot 10^{17}\,cm^3 V \cdot N_D'$

Solve numerically, get $\boxed{N_D' = \frac{5.56\cdot 10^{16}}{cm^3}}$

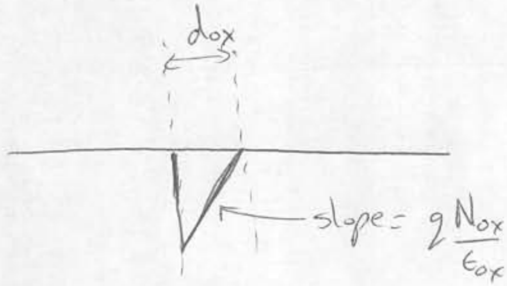
9.4

1/2

(a) At flat band, the charge profile looks like this:



The corresponding $\mathcal{E}$-field will be:



$$N_{ox} = \frac{3\times10^{11}}{d_{ox}} = \frac{3\times10^{11}\ cm^{-2}}{100\times10^{-8}\ cm} = 3\times10^{17}\ cm^{-3}$$

So the additional negative voltage needed to create flat bands (ΔV_{FB}) is

$$\frac{1}{2}q\frac{N_{ox}}{\epsilon_{ox}}d_{ox}^2 = \frac{1\,(1.6\times10^{-19})(3\times10^{17})(100\times10^{-8})^2}{2\,(3.9)(8.85\times10^{-14})}$$

$$\boxed{\Delta V_{FB} = .07\,eV}$$

ϕ_{ms} for this Al-gate/p-Si system is $\underline{\sim -.93\,eV}$ from the chart in the book on page 439.

So the new $V_{FB} = -.93\,eV - .07\,eV = \boxed{-1\,eV.}$

(b) $$\phi_F = \frac{\cancel{kT}}{q}\ln\left(\frac{N_A}{n_i}\right) = .026\ln\left(\frac{5\times10^{15}}{1.5\times10^{10}}\right) = .33\,eV$$

$$V_T = V_{FB} + 2\phi_F + \frac{Q_s}{C_{ox}}$$

$$Q_s = \sqrt{4q\epsilon_s N_A|\phi_F|} = \sqrt{4(1.6\times10^{-19})(11.9)(8.85\times10^{-14})(5\times10^{15})(.33)}$$

$$= 3.33\times10^{-8}\ C/cm^2$$

9.4

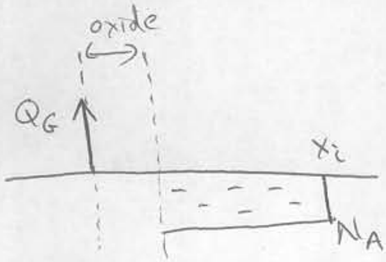
2/2 $V_T = -1 + 2(.33) + (3.33 \times 10^{-8})\left(\dfrac{100 \times 10^{-8}}{(3.9)8.85 \times 10^{-14}}\right)$

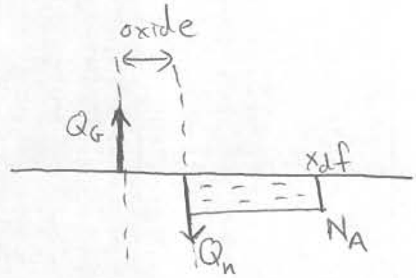
9.4

2/2 $V_T = -1 + 2(.33) + (3.33 \times 10^{-8})\left(\dfrac{100 \times 10^{-8}}{(3.9)8.85 \times 10^{-14}}\right)$

9.22 $\boxed{t=0}$ $\boxed{t=\infty}$

1/2





$Q_G = qN_A x_i$ $\qquad\qquad$ $Q_G = Q_n + qN_A x_{df}$

(a) Using charge neutrality at any instant of time we must have

$$\star\ Q_G = Q_n(t) + qN_A(x_d(t))$$

But we know $\dfrac{dQ_n}{dt} = \dfrac{-qn_i(x_d - x_{df})}{2\tau_0}$. Solving for x_d:

$$x_d = -\frac{2\tau_0}{qn_i}\frac{dQ_n}{dt} + x_{df}$$

Substituting back into the charge neutrality equation:

$$\boxed{Q_G - qN_A x_{df} = Q_n - \frac{2\tau_0 N_A}{n_i}\frac{dQ_n}{dt}}$$

(b) Rewriting the equation above

$$-Q_n + Q_G - qN_A x_{df} = -\frac{2\tau_0 N_A}{n_i}\frac{dQ_n}{dt} \rightarrow Q_n - Q_G + qN_A x_{df} = \frac{2\tau_0 N_A}{n_i}\frac{dQ_n}{dt}$$

$$\int_{t=0}^{t=\tau} dt\left(\frac{-n_i}{2\tau_0 N_A}\right) = \int_{Q_n(t=0)}^{Q_n(t=\tau)} \frac{dQ_n}{-Q_n + Q_G - qN_A x_{df}}$$

$$-\frac{n_i\tau}{2\tau_0 N_A} = \ln\left|-Q_n + Q_G - qN_A x_{df}\right|\Big|_{Q_n(t=0)}^{Q_n(t=\tau)}$$

$$-\frac{n_i\tau}{2\tau_0 N_A} = \ln\left(\frac{|-Q_n(\tau) + Q_G - qN_A x_{df}|}{|+Q_G - qN_A x_{df}|}\right)$$

9.22

2/2

$$e^{-\frac{n_i}{2\tau_0 N_A}\tau} = \frac{|-Q_n(t) + Q_G - qN_A x_{df}|}{|Q_G - qN_A x_{df}|}$$

$$(Q_G - qN_A x_{df}) e^{-\frac{n_i}{2\tau_0 N_A}\tau} = -Q_n(t) + Q_G - qN_A x_{df}$$

$$Q_n(t) = +(Q_G - qN_A x_{df}) - (Q_G - qN_A x_{df}) e^{-\frac{n_i}{2\tau_0 N_A}\tau}$$

$$\boxed{Q_n(t) = (Q_G - qN_A x_{df})\left(1 - e^{-\frac{n_i}{2\tau_0 N_A}\tau}\right)}$$