Chapter 11

Exercise Solutions

E11.1

(a) $\phi_{fp} = (0.0259)\ln\left(\frac{3x10^{16}}{1.5x10^{10}}\right) = 0.376\ V$

$$x_{dT} = \left\{\frac{4(11.7)(8.85x10^{-14})(0.376)}{(1.6x10^{-19})(3x10^{16})}\right\}^{1/2}$$

or

$$\underline{x_{dT} = 0.180\ \mu m}$$

(b) $\phi_{fp} = (0.0259)\ln\left(\frac{10^{15}}{1.5x10^{10}}\right) = 0.288\ V$

$$x_{dT} = \left\{\frac{4(11.7)(8.85x10^{-14})(0.288)}{(1.6x10^{-19})(10^{15})}\right\}^{1/2}$$

or

$$\underline{x_{dT} = 0.863\ \mu m}$$

E11.2

$$\phi_{fn} = (0.0259)\ln\left(\frac{8x10^{15}}{1.5x10^{10}}\right) = 0.342\ V$$

$$x_{dT} = \left\{\frac{4(11.7)(8.85x10^{-14})(0.342)}{(1.6x10^{-19})(8x10^{15})}\right\}^{1/2}$$

or

$$\underline{x_{dT} = 0.333\ \mu m}$$

E11.3

$$\phi_{fp} = (0.0259)\ln\left(\frac{3x10^{16}}{1.5x10^{10}}\right) = 0.376\ V$$

$$\phi_{ms} = \phi'_m - \left(\chi' + \frac{E_g}{2e} + \phi_{fp}\right)$$

$$= 3.20 - (3.25 + 0.555 + 0.376)$$

or

$$\underline{\phi_{ms} = -0.981\ V}$$

E11.4

$$\phi_{fp} = 0.376\ V$$

$$\phi_{ms} = -(0.555 + 0.376) \Rightarrow \underline{\phi_{ms} = -0.931\ V}$$

E11.5

$$\phi_{fp} = 0.376\ V$$

$$\phi_{ms} = (0.555 - 0.376) \Rightarrow \quad \phi_{ms} = +0.179\ V$$

E11.6

From E11.3, $\phi_{ms} = -0.981\ V$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{(3.9)(8.85x10^{-14})}{200x10^{-8}} = 1.73x10^{-7}\ F/cm^2$$

Then

$$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}} = -0.981 - \frac{(1.6x10^{-19})(8x10^{10})}{1.73x10^{-7}}$$

or

$$\underline{V_{FB} = -1.06\ V}$$

E11.7

From E11.4, $\phi_{ms} = -0.931\ V$

$$V_{FB} = -0.931 - \frac{(1.6x10^{-19})(8x10^{10})}{1.73x10^{-7}}$$

or

$$\underline{V_{FB} = -1.01\ V}$$

E11.8

From E11.5, $\phi_{ms} = +0.179\ V$

$$V_{FB} = +0.179 - \frac{(1.6x10^{-19})(8x10^{10})}{1.73x10^{-7}}$$

or

$$\underline{V_{FB} = +0.105\ V}$$

E11.9

From E11.3, $\phi_{ms} = -0.981$ V and $\phi_{fp} = 0.376\ V$

$$x_{dT} = \left\{\frac{4(11.7)(8.85x10^{-14})(0.376)}{(1.6x10^{-19})(3x10^{16})}\right\} = 0.18\ \mu m$$

Now

$$|Q'_{SD}(\max)| = (1.6x10^{-19})(3x10^{16})(0.18x10^{-4})$$

or

$$|Q'_{SD}(\max)| = 8.64x10^{-8}\ C/cm^2$$

From Equation [11.27b]

$$V_{TN} = \left[8.64x10^{-8} - \left(10^{11}\right)\left(1.6x10^{-19}\right)\right] \times \left(\frac{250x10^{-8}}{(3.9)\left(8.85x10^{-14}\right)}\right) - 0.981 + 2(0.376)$$

or

$$V_{TN} = +0.281\ V$$

E11.10

From Figure 11.15, $\phi_{ms} = +0.97\ V$

$$\phi_{fn} = (0.0259)\ln\left(\frac{10^{15}}{1.5x10^{10}}\right) = 0.288\ V$$

$$x_{dT} = \left\{\frac{4(11.7)\left(8.85x10^{-14}\right)(0.288)}{\left(1.6x10^{-19}\right)\left(10^{15}\right)}\right\}^{1/2} = 0.863\ \mu m$$

Then

$$\left|Q'_{SD}(\max)\right| = \left(1.6x10^{-19}\right)\left(10^{15}\right)\left(0.863x10^{-4}\right)$$

or

$$\left|Q'_{SD}(\max)\right| = 1.38x10^{-8}\ C/cm^2$$

Also

$$Q'_{ss} = \left(8x10^{10}\right)\left(1.6x10^{-19}\right) = 1.28x10^{-8}\ C/cm^2$$

Now, from Equation [11.28]

$$V_{TP} = \left(-1.38x10^{-8} - 1.28x10^{-8}\right) \times \left(\frac{220x10^{-8}}{(3.9)\left(8.85x10^{-14}\right)}\right) + 0.97 - 2(0.288)$$

or

$$V_{TP} = +0.224\ V$$

E11.11

By trial and error, let $N_d = 4x10^{16}\ cm^{-3}$, then

$\phi_{fn} = 0.383$, $\phi_{ms} \cong 1.07$,

$\left|Q'_{SD}(\max)\right| = 1x10^{-7}$ and

$V_{TP} = -0.405\ V$ which is between the limits specified.

E11.12

$$\frac{C'_{\min}}{C_{ox}} = \frac{\dfrac{\in_{ox}}{t_{ox} + (\in_{ox}/\in_s)x_{dT}}}{\dfrac{\in_{ox}}{t_{ox}}} = \frac{t_{ox}}{t_{ox} + \left(\dfrac{\in_{ox}}{\in_s}\right)x_{dT}}$$

or

$$\frac{C'_{\min}}{C_{ox}} = \frac{1}{1 + \left(\dfrac{\in_{ox}}{\in_s}\right)\left(\dfrac{x_{dT}}{t_{ox}}\right)}$$

From E11.9, $x_{dT} = 0.18\ \mu m$

Then

$$\frac{C'_{\min}}{C_{ox}} = \frac{1}{1 + \left(\dfrac{3.9}{11.7}\right)\left(\dfrac{0.18x10^{-4}}{250x10^{-8}}\right)} \Rightarrow$$

$$\frac{C'_{\min}}{C_{ox}} = 0.294$$

Also

$$\frac{C'_{FB}}{C_{ox}} = \frac{1}{1 + \left(\dfrac{\in_{ox}}{\in_s}\right)\left(\dfrac{1}{t_{ox}}\right)\sqrt{\left(\dfrac{kT}{e}\right)\left(\dfrac{\in_s}{eN_a}\right)}}$$

$$= \frac{1}{1 + \left(\dfrac{3.9}{11.7}\right)\left(\dfrac{1}{220x10^{-8}}\right)\sqrt{\dfrac{(0.0259)(11.7)\left(8.85x10^{-14}\right)}{\left(1.6x10^{-19}\right)\left(3x10^{16}\right)}}}$$

or

$$\frac{C'_{FB}}{C_{ox}} = 0.736$$

E11.13

$$C_{ox} = \frac{\in_{ox}}{t_{ox}} = \frac{(3.9)\left(8.85x10^{-14}\right)}{200x10^{-8}} \Rightarrow$$

$$C_{ox} = 1.73x10^{-7}\ F/cm^2$$

Now

$$I_D = \frac{1}{2}\left(\frac{W}{L}\right)\mu_n C_{ox}\left(V_{GS} - V_{TN}\right)^2$$

$$= \left(\frac{50}{2}\right)(650)\left(1.73x10^{-7}\right)\left(V_{GS} - 0.4\right)^2$$

or

$$I_D = \left(2.81x10^{-3}\right)\left(V_{GS} - 0.4\right)^2$$

Then

$V_{GS} = 1\ V \Rightarrow I_D = 1.01\ mA$

$V_{GS} = 2\ V \Rightarrow I_D = 7.19\ mA$

$V_{GS} = 3\ V \Rightarrow I_D = 19\ mA$

E11.14

$$I_D = \frac{1}{2}\left(\frac{W}{L}\right)\mu_n C_{ox}\left(V_{GS} - V_{TN}\right)^2$$

Now

$$100x10^{-6} = \left(\frac{W}{L}\right)\frac{(650)\left(1.73x10^{-7}\right)}{2}(1.75 - 0.4)^2$$

which yields

$$\underline{\left(\frac{W}{L}\right) = 0.976}$$

E11.15

$$C_{ox} = \frac{\in_{ox}}{t_{ox}} = \frac{(3.9)\left(8.85x10^{-14}\right)}{220x10^{-8}} = 1.57x10^{-7}\ F/cm^2$$

$$I_D = \left(\frac{60}{2}\right)(310)\left(1.57x10^{-7}\right)\left(V_{SG} - 0.4\right)^2$$

or

$$I_D = 1.46x10^{-3}\left(V_{SG} - 0.4\right)^2$$

Then

$$\underline{V_{SG} = 1\ V \Rightarrow I_D = 0.526\ mA}$$

$$\underline{V_{SG} = 1.5\ V \Rightarrow I_D = 1.77\ mA}$$

$$\underline{V_{SG} = 2\ V \Rightarrow I_D = 3.74\ mA}$$

E11.16

$$200x10^{-6} = \left(\frac{W}{L}\right)\left(\frac{310}{2}\right)\left(1.57x10^{-7}\right)(1.25 - 0.4)^2$$

which yields

$$\underline{\left(\frac{W}{L}\right) = 11.4}$$

E11.17

(a)

$$C_{ox} = \frac{\in_{ox}}{t_{ox}} = \frac{(3.9)\left(8.85x10^{-14}\right)}{200x10^{-8}} = 1.73x10^{-7}\ F/cm^2$$

Now

$$\gamma = \frac{\sqrt{2e\in_s N_a}}{C_{ox}}$$

$$= \frac{\left[2\left(1.6x10^{-19}\right)(11.7)\left(8.85x10^{-14}\right)\left(10^{16}\right)\right]^{1/2}}{1.73x10^{-7}}$$

or

$$\underline{\gamma = 0.333\ V^{1/2}}$$

(b) $\phi_{fp} = (0.0259)\ln\left(\frac{10^{16}}{1.5x10^{10}}\right) = 0.347\ V$

(i)

$$\Delta V = (0.333)\left[\sqrt{(2)(0.347)+1} - \sqrt{2(0.347)}\right]$$

or

$$\underline{\Delta V = 0.156\ V}$$

(ii)

$$\Delta V = (0.333)\left[\sqrt{2(0.347)+2} - \sqrt{2(0.347)}\right]$$

or

$$\underline{\Delta V = 0.269\ V}$$

E11.18

$$C_{ox} = 1.73x10^{-7}\ V/cm^2$$

(a)

$$\gamma = \frac{\left[2\left(1.6x10^{-19}\right)(11.7)\left(8.85x10^{-14}\right)\left(10^{15}\right)\right]^{1/2}}{1.73x10^{-7}}$$

or

$$\underline{\gamma = 0.105\ V^{1/2}}$$

(b) $\phi_{fp} = (0.0259)\ln\left(\frac{10^{15}}{1.5x10^{10}}\right) = 0.288\ V$

(i)

$$\Delta V = (0.105)\left[\sqrt{2(0.288)+1} - \sqrt{2(0.288)}\right]$$

or

$$\underline{\Delta V = 0.052\ V}$$

(ii)

$$\Delta V = (0.105)\left[\sqrt{2(0.288)+2} - \sqrt{2(0.288)}\right]$$

or

$$\underline{\Delta V = 0.0888\ V}$$

E11.19

$$C_{ox} = 1.73x10^{-7}\ V/cm^2$$

$$g_m = \left(\frac{W}{L}\right)\mu_n C_{ox}\left(V_{GS} - V_T\right)$$

$$= (20)(400)\left(1.73x10^{-7}\right)(2.5 - 0.4)$$

or

$$g_m = 2.91\ mA/V$$

Now

$$\frac{C_M}{C_{gdT}} = 1 + g_m R_L = 1 + (2.91)(100)$$

or

$$\frac{C_M}{C_{gdT}} = 292$$

E11.20

$$f_T = \frac{\mu_n (V_{GS} - V_T)}{2\pi L^2}$$

$$= \frac{(400)(2.5 - 0.4)}{2\pi (0.5x10^{-4})^2}$$

or

$$f_T = 53.5\ GHz$$
