COURSE NAME: VLSI DESIGN

SOLUTION TUTORIAL-1

Answer.1

(a)

$$V_{T0} = \Phi_{GC} - 2\phi_F - \frac{Q_{B0}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$$

$$\phi_F = \frac{kT}{q} ln\frac{n_i}{N_A} = 0.026 ln\frac{1.45\times10^{10}}{2\times10^{15}} = -0.308 \text{ V}$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.97\times8.854\times10^{-14}}{200\times10^{-8}} = 1.758\times10^{-7} \text{ F/cm}^2$$

$$\begin{aligned} Q_{B0} &= -\sqrt{2qN_A\varepsilon_{si}|-2\phi_F|} \\ &= -\sqrt{2\cdot1.6\times10^{-19}\cdot2\times10^{15}\cdot11.7\times8.854\times10^{-14}\cdot|-2\times0.308|} \\ &= -2.01\times10^{-8} \end{aligned}$$

$$V_{T0} = -0.85 + 0.615 + \frac{2\times10^{-8}}{1.758\times10^{-7}} - \frac{1.6\times10^{-19}\cdot2\times10^{11}}{1.758\times10^{-7}} = -0.303 \text{ V}$$

(b) p-type implanted needed in the amount of:

$$\Delta V = 0.8 - V_{T0} = 0.8 + 0.303 = 1.303 = \frac{qN_I}{C_{ox}}$$

$$N_I = \frac{1.303C_{ox}}{q} = \frac{1.303\cdot1.758\times10^{-7}}{1.6\times10^{-19}} = 1.21\times10^{12} \text{ cm}^{-2}$$

Answer.2

$$\phi_F(substrate) = \frac{kT}{q} ln\frac{N_{D,sub}}{n_i} = 0.026 ln\frac{1\times10^{16}}{1.45\times10^{10}} = 0.348[V]$$

$$\phi_F(gate) = \frac{kT}{q} ln\frac{N_{D,poly}}{n_i} = 0.026 ln\frac{1\times10^{20}}{1.45\times10^{10}} = 0.587[V]$$

$$\Phi_{GC} = \phi_F(substrate) - \phi_F(gate) = 0.348 - 0.587 = -0.239[V]$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9\times8.85\times10^{-14}}{0.1\times10^{-4}} = 3.45\times10^{-8}[F/cm^2]$$

$$Q_{B0} = \sqrt{2qN_{D,sub}\varepsilon_{si}|2\phi_F|}$$
$$= \sqrt{2\times1.6\times10^{-19}\times10^{16}\times11.7\times8.85\times10^{-14}\times2\times0.348}$$
$$= 4.8\times10^{-8}[C/cm^2]$$

$$V_{T0} = \Phi_{GC} - 2\phi_F - \frac{Q_{B0}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$$
$$= -0.239 - 2\times0.348 - \frac{4.8\times10^{-8}}{3.45\times10^{-8}} - \frac{4\times10^{10}\times1.6\times10^{-19}}{3.45\times10^{-8}}$$
$$= -2.51[V]$$

Answer.3.

(a) For unimplanted transistor,

$$\phi_F(substrate) = \frac{kT}{q}\ln\frac{n_i}{N_A} = 0.026\ln\frac{1.45\times10^{10}}{1.0\times10^{16}} = -0.35[V]$$

$$\phi_F(gate) = \frac{kT}{q}\ln\frac{N_{D,poly}}{n_i} = 0.026\ln\frac{1\times10^{20}}{1.45\times10^{10}} = 0.59[V]$$

$$\Phi_{GC} = \phi_F(substrate) - \phi_F(gate) = -0.35 - 0.59 = -0.94[V]$$

$$Q_{B0} = \sqrt{2qN_{A,sub}\varepsilon_{si}|2\phi_F|}$$
$$= \sqrt{2\times1.6\times10^{-19}\times10^{16}\times11.7\times8.85\times10^{-14}\times2\times0.35}$$
$$= -4.82\times10^{-8}[C/cm^2]$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9\times8.85\times10^{-14}}{500\times10^{-8}} = 6.9\times10^{-8}[F/cm^2]$$

$$V_{T0} = \Phi_{GC} - 2\phi_F - \frac{Q_{B0}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$$
$$= -0.94 - 2\times(-0.35) - \frac{(-4.82\times10^{-8})}{6.9\times10^{-8}} - \frac{2\times10^{10}\times1.6\times10^{-19}}{6.9\times10^{-8}}$$
$$= 0.41[V]$$

(b) For $V_T = 2V$:

$$V_T = 2 = V_{T0} - \frac{Q_{II}}{C_{ox}} = 0.412 - \frac{Q_{II}}{C_{ox}}$$

Negative charges needed in this case, so it must be p-type implant in the amount of $Q_{II} = qN_I = (V_T - V_{T0})C_{ox}$

$$N_I = (2-0.41)\times\frac{6.9\times10^{-8}}{1.6\times10^{-19}} = 6.85\times10^{11}[cm^{-3}]$$

For $V_T = -2V$, positive charges need, must be n-type implant,

$$N_I = (2+0.41)\times\frac{6.9\times10^{-8}}{1.6\times10^{-19}} = 1.04\times10^{12}[cm^{-3}]$$

Answer-4

(a) For enhancement transistor and $V_{T0} > 0$, it must be nMOS.

$$V_T(V_{SB}) = V_{T0} + \gamma\left(\sqrt{|2\phi_F| + V_{SB}} - \sqrt{|2\phi_F|}\right)$$
$$= 0.8 + 0.2\cdot\left(\sqrt{0.58+1} - \sqrt{0.58}\right) = 0.899[V]$$

$$\because V_{DS} = 4 > V_{GS} - V_T = 1.8 - 0.899 = 0.901$$

nMOS transistor is in saturation region.

$$\because I_D(sat) = \frac{k'}{2}\frac{W}{L}(V_{GS} - V_T)^2(1+\lambda V_{DS})$$
$$\therefore \frac{W}{L} = \frac{2\cdot I_D(sat)}{k'\cdot(V_{GS} - V_T)^2(1+\lambda V_{DS})}$$
$$= \frac{2\cdot 0.24\times 10^{-3}}{20\times 10^{-6}(1.8-0.899)^2(1+0.05\times 4)} = 24.64$$

(b)

$$V_T(V_{SB}) = V_{T0} + \gamma\left(\sqrt{|2\phi_F| + V_{SB}} - \sqrt{|2\phi_F|}\right)$$
$$= 0.8 + 0.2\cdot\left(\sqrt{0.58+2} - \sqrt{0.58}\right) = 0.969[V]$$

$$\because V_{DS} = 2 < V_{GS} - V_T = 3 - 0.969 = 2.031$$

nMOS transistor is in linear region.

$$I_D(lin) = \frac{k'}{2}\frac{W}{L}\left[2(V_{GS} - V_T)V_{DS} - V_{DS}^2\right]\left[1+\lambda V_{DS}\right]$$
$$= 10\times 10^{-6}\times 24.64\left[2\times(3-0.969)\times 2 - 4\right]\left[1+0.05\times 2\right]$$
$$= 1.12[mA]$$

(c)

$$C_{ox} = \frac{k'}{\mu_n} = \frac{20\times 10^{-6}}{500} = 4\times 10^{-8}\left[F/cm^2\right]$$

Answer. 5:

	Const E - field	Const. V_{DD}
W, L, t_{ox}	$1/S$	$1/S$
V_{DD}	$1/S$	1
C_{ox}	S	S
$C = C_{ox}WL$	$1/S$	$1/S$
k_n, k_p	S	S
I_{DD}	$1/S$	S
$t_{delay} = \dfrac{C\Delta V}{I_{DD}}$	$1/S$	$1/S^2$
$Power = I_{DD}V_{DD}$	$1/S^2$	S
Power density $\left(\dfrac{Power}{Area}\right)$	1	S^3

Answer. 6

(a) Find V_{TO}
For both case 1 (Row1) and case 2(Row2), the transistor operates in saturation region, using equation (3.62)

$$I_D(sat) = \frac{k_n}{2}(V_{GS} - V_{TO})^2$$

$$\frac{I_D(Row1)}{I_D(Row2)} = \frac{(4 - V_{TO})^2}{(5 - V_{TO})^2} = \frac{256}{441}.$$

$$\frac{4 - V_{TO}}{5 - V_{TO}} = \pm\frac{16}{21}$$

The correct solution is:

$$V_{TO} = 0.8[V]$$

(b) Find mobility

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9 \times 8.85 \times 10^{-14}}{345 \times 10^{-8}} = 1.0 \times 10^{-7}[F/cm]$$

$$256 \times 10^{-6} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(4 - V_{TO})^2$$

$$\mu_n = \frac{2 \times 256 \times 10^{-6}}{1.0 \times 10^{-7} \times 1.0 \times 3.2^2} = 500[cm^2/V \cdot s]$$

(c) Find body effect coefficient γ
Using either Row 3 or Row4 data and equation (3.62), first find V_T

$$144 \times 10^{-6} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(4 - V_T)^2$$

$$V_T = 1.6[V]$$

from equation (3.64)

$$\gamma = \frac{V_T(V_{SB}) - V_{T0}}{\sqrt{|2\phi_F| + V_{SB}} - \sqrt{|2\phi_F|}} = \frac{1.6 - 0.8}{\sqrt{0.64 + 2.6} - \sqrt{0.64}} = 0.8\left[V^{1/2}\right]$$
