# Numerical on Threshold Voltage :



26/1/2020

1. Consider a MOS system with the following parameters:

$t_{ox} = 200°A$ , $\phi_{GC} = -0.85V$ , $N_A = 2\times10^{15}/cm^3$

$Q_{ox} = q \times 2\times10^{11} C/cm^2$

a) Determine the threshold voltage $V_{TO}$ under zero-bias at room temperature ($T = 300K$)
(Use $\epsilon_{ox} = 3.97\epsilon_0$ and $\epsilon_s = 11.7\epsilon_0$)

b) Determine the type (p-type or n-type) and amount of channel implant ($N_I/cm^2$) required to change the threshold voltage to 0.8V

$$\boxed{\phi_{GC} \approx \phi_{ms}}$$

Solution:

a) $$V_{TO} = \phi_{ms} - 2\phi_F - \frac{Q_{BO}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$$

$$\phi_{Fsub} = \phi_{Fp} = \frac{KT}{q}\ln\left[\frac{n_i}{N_A}\right] = 26\times10^{-3}\ln\left[\frac{1.45\times10^{10}}{2\times10^{15}}\right]$$

$$\phi_{Fsub} = -0.308\ V$$

$$Q_{BO} = -\sqrt{2qN_A\epsilon_s|-2\phi_F|}$$

$$= -\sqrt{2\times1.6\times10^{-19}\times2\times10^{15}\times11.7\times8.854\times10^{-14}\times2\times0.308}$$

$$Q_{BO} = -20.21\times10^{-9}\ C/cm^2$$

$$Q_{ox} = 1.6\times10^{-19}\times2\times10^{11} = 32\times10^{-9}\ C/cm^2$$

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$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.97 \times 8.854 \times 10^{-14}}{200 \times 10^{-8}} = 175.75 \times 10^{-9} \ F/cm^2$$ 02

$$V_{TO} = \phi_{ms} - 2\phi_F - \frac{Q_{BO}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$$

$$= -0.85 + 2 \times 0.308 + \frac{20.21}{175.75} - \frac{32}{175.75}$$

$$= -0.85 + 0.616 + 0.115 - 0.182$$

$$\boxed{V_{TO} = -0.301 \ V}$$

b) $V_{TOold} = -0.301 V$

$V_{TOnew} = 0.8 V$

$\because V_{TOnew} > V_{TOold}$

We implant p-type impurity,

$$V_{TOnew} = V_{TOold} + \frac{qN_I}{C_{ox}}$$

$$\frac{qN_I}{C_{ox}} = (V_{TOnew} - V_{TOold}) \rightarrow N_I = [0.8 - (-0.301)] \times \frac{C_{ox}}{q}$$

$$N_I = (0.8 + 0.301) \times \frac{175.75 \times 10^{-9}}{1.6 \times 10^{-19}}$$

$$\boxed{N_I = 1.21 \times 10^{12} \ /cm^2}$$

↳ Amount of channel implant

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2. A pMOS transistor was fabricated on a n-type substrate with a bulk doping density of $10^{16}/cm^3$, gate doping density (n-type poly) of $10^{20}/cm^3$, $Q_{ox}/q = 4\times10^{10}/cm^2$ and gate oxide thickness of $0.1\,\mu m$. Calculate the threshold voltage at room temperature for $V_{SB} = 0$ (Use $\epsilon_s = 11.7\,\epsilon_0$) 03

**Solution:**

Given: $N_D = 10^{16}/cm^3$ (Sub), $N_D = 10^{20}/cm^3$ (poly gate)

$\frac{Q_{ox}}{q} = 4\times10^{10}/cm^2$, $t_{ox} = 0.1\,\mu m = 0.1\times10^{-6}\,m$

$t_{ox} = 0.1\times10^{-4}\,cm$

To find: $V_{TO} = ?$

$$\rightarrow V_{TO} = \phi_{ms} - 2\phi_{Fsub} - \frac{Q_{BO}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$$

$$\phi_{Fsub} = \frac{KT}{q}\ln\left[\frac{N_A}{n_i}\right] = 26\times10^{-3}\ln\left[\frac{10^{16}}{1.45\times10^{10}}\right]$$

$$\phi_{FN} = \underline{0.349\ V}$$

$$\phi_{Fgate} = \frac{KT}{q}\ln\left[\frac{N_D}{n_i}\right] = 26\times10^{-3}\ln\left[\frac{10^{20}}{1.45\times10^{10}}\right]$$

$$= \underline{0.589\ V}$$

$$\phi_{ms} = \phi_{Fsub} - \phi_{Fgate} = 0.349 - 0.589$$

$$= \underline{-0.24\ V}$$

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$$Q_{BO} = +\sqrt{2q N_0 \epsilon_s |-2\phi_F|}$$

$$= \sqrt{2 \times 1.6 \times 10^{-19} \times 10^{16} \times 11.7 \times 8.854 \times 10^{-14} \times 2 \times 0.349}$$

$$Q_{BO} = +\ 48.1 \times 10^{-9}\ C/cm^2$$

$$\frac{Q_{ox}}{q} = 4 \times 10^{10}$$

$$\rightarrow Q_{ox} = 1.6 \times 10^{-19} \times 4 \times 10^{10} = 6.4 \times 10^{-9}\ C/cm^2$$

$$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.97 \times 8.854 \times 10^{-14}}{0.1 \times 10^{-4}}$$

$$\boxed{C_{ox} = 35.15 \times 10^{-9}\ F/cm^2}$$

$$\therefore V_{TO} = \phi_{ms} - 2\phi_{Fsub} - \frac{Q_{BO}}{C_{ox}} - \frac{Q_{ox}}{C_{ox}}$$

$$= -0.24 - 2 \times 0.349 - \frac{48.1}{35.15} - \frac{6.4}{35.15}$$

$$= -0.24 - 0.698 - 1.368 - 0.182$$

$$\boxed{V_{TO} = -2.488\ V}$$

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**3.12** The following parameters are given for an nMOS process.

- $t_{ox} = 500Å$
- substrate doping $N_A = 1 \cdot 10^{16} cm^{-3}$
- polysilicon gate doping $N_D = 1 \cdot 10^{20} cm^{-3}$
- oxide-interface fixed-charge density $N_{ox} = 2 \cdot 10^{10} cm^{-3}$

(a) Calculate $V_T$ for an unimplanted transistor.

(b) What type and what concentration of impurities must be implanted to achieve $V_T$ = +2V and $V_T$ = -2V?

**SOLUTION:**

(a) For unimplanted transistor,

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

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

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

$$\begin{aligned} Q_{B0} &= \sqrt{2qN_{A,sub}\varepsilon_{si}|2\phi_F|} \\ &= \sqrt{2 \times 1.6 \times 10^{-19} \times 10^{16} \times 11.7 \times 8.85 \times 10^{-14} \times 2 \times 0.35} \\ &= -4.82 \times 10^{-8}[C/cm^2] \end{aligned}$$

$$C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.9 \times 8.85 \times 10^{-14}}{500 \times 10^{-8}} = 6.9 \times 10^{-8}[F/cm^2]$$

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

$$= -0.94 - 2\times(-0.35) - \frac{\left(-4.82\times10^{-8}\right)}{6.9\times10^{-8}} - \frac{2\times10^{10}\times1.6\times10^{-19}}{6.9\times10^{-8}}$$

$$= 0.41[V]$$

(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 $Q_{II} = qN_I = (V_T - V_{T0})C_{ox}$

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

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

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

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