Example- Let's revisit our earlier example where we found the flat band voltage and threshold voltage for a MOS capacitor at 300 K with a gold metal gate. Now, let's assume it is used to make an n-channel MOSFET where we apply $V_{SB} = 1$ V and see how things change. It has a silicon dioxide for the oxide layer of thickness 21 nm with an equivalent trapped charge density of 2×10^{11} cm^{-2} and a p-type silicon substrate where $N_a = 10^{17}$ cm^{-3}.

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From prior example (assumed $V_{SB} = 0$ V)-

From Table B.4, $n_i = 1.5 \times 10^{10}$ cm^{-3}, $\varepsilon_{s,\text{Si}} = 11.7\varepsilon_0$, and $\varepsilon_{s,\text{SiO2}} = 3.9\varepsilon_0$ at 300 K.

$C_{ox} = \varepsilon_{ox}/t_{ox}$ ⇒ $\underline{\mathbf{C_{ox} = 1.64435 \times 10^{-3}\ F/m^2 = 1.64435 \times 10^{-7}\ F/cm^2}}$.

Equivalent trapped charge density is ⇒ $\underline{\mathbf{Q'_{ss} = 3.204353 \times 10^{-8}\ C/cm^2}}$.

From Fig. 10.16, the metal-semiconductor work function is ⇒ $\underline{\mathbf{\phi_{ms} = -0.13\ V}}$.

Per (10.25), the flat-band voltage is ⇒ $\underline{\mathbf{V_{FB} = -0.32487\ V}}$

Per (10.4), $\phi_{fp} = V_t \ln\left(\dfrac{N_a}{n_i}\right) = 0.025852 \ln\left(\dfrac{10^{17}}{2.4 \bullet 10^{10}}\right)$ ⇒ $\underline{\mathbf{\phi_{fp} = 0.406203\ V}}$.

Per (10.6), the maximum depletion layer width is ⇒ $\underline{\mathbf{x_{dT} = 1.024976 \times 10^{-7}\ m}}$.

Per (10.27), ⇒ $\underline{\mathbf{|Q_{SD}'(max)| = 1.64435 \times 10^{-3}\ C/m^2 = 1.64435 \times 10^{-7}\ C/cm^2}}$.

Per (10.31c), the threshold voltage is ⇒ $\underline{\mathbf{V_{TN} = 1.48622\ V}}$.

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$V_{SB} = 1$ V

Using (10.79), calculate the space charge density to now be

$$Q'_{SD} = -eN_a x_d = -\sqrt{2 e \varepsilon_s N_a \left(2\phi_{fp} + V_{SB}\right)}$$

$$= -\sqrt{2\left(1.6022 \bullet 10^{-19}\right) 11.7 \left(8.8542 \bullet 10^{-12}\right) 10^{23} \left(2(0.406203) + 1\right)}$$

⇒ $\underline{\mathbf{Q_{SD}' = -2.45282 \times 10^{-3}\ C/m^2 = -2.45282 \times 10^{-7}\ C/cm^2}}$.

Using (10.80), the change in the space-charge density is

$$\Delta Q_{SD} = -\sqrt{2e\varepsilon_s N_a}\left[\sqrt{2\phi_{fp}+V_{SB}}-\sqrt{2\phi_{fp}}\right]$$

$$= -\sqrt{2\left(1.6022\bullet10^{-19}\right)11.7\left(8.8542\bullet10^{-12}\right)10^{23}}\left[\sqrt{2(0.4062)+1}-\sqrt{2(0.4062)}\right]$$

$\Rightarrow$ **ΔQ_{SD} = -8.10625 × 10^{-4} C/m^2 = -8.10625 × 10^{-8} C/cm^2.**

Calculate the body-effect coefficient using (10.82),

$$\gamma = \frac{\sqrt{2e\varepsilon_s N_a}}{C_{ox}} = \frac{\sqrt{2\left(1.6022\bullet10^{-19}\right)11.7\left(8.8542\bullet10^{-12}\right)10^{23}}}{1.64435\bullet10^{-3}}$$

$\Rightarrow$ **γ = 1.108009 V$^{1/2}$.**

Calculate the change in threshold voltage using (10.83),

$$\Delta V_T = \gamma\left[\sqrt{2\phi_{fp}+V_{SB}}-\sqrt{2\phi_{fp}}\right] = 1.108009\left[\sqrt{2(0.4062)+1}-\sqrt{2(0.4062)}\right]$$

$\Rightarrow$ **ΔV_T = 0.492976 V.**

Calculate the new threshold voltage-

$$V_T = V_{T0} + \Delta V_T = 1.48622 + 0.492976 \qquad \Rightarrow \qquad V_T = 1.9792\ \text{V}.$$