**10.10** Consider a MOS device with a p-type silicon substrate with $N_a = 2 \times 10^{16}$ cm$^{-3}$. The oxide thickness is $t_{ox} = 15$ nm $= 150$ Å and the equivalent oxide charge is $Q'_{ss} = 7 \times 10^{10}$ cm$^{-2}$. Calculate the threshold voltage for (*a*) an n$^+$ polysilicon gate, (*b*) a p$^+$ polysilicon gate, and (*c*) an aluminum gate.

- Change doping to $N_a = 4 \times 10^{16}$ cm$^{-3}$. Also, find $\phi_{fp}$, $x_{dT}$, $|Q_{SD}'(\max)|$, and $C_{ox}$.

Per Table B.4, $n_i = 1.5 \times 10^{10}$ cm$^{-3}$ and $\varepsilon_s = 11.7\varepsilon_0$ for silicon at 300 K.

Per Table B.6, $\varepsilon_{ox} = 3.9\varepsilon_0$ for silicon dioxide at 300 K.

$Q'_{SS} = 7 \times 10^{10}(1.602176634\times10^{-19})$ $\Rightarrow$ $\underline{Q'_{SS} = 1.121524\times10^{-8}\ \text{C/cm}^2}$.

Per (7.10), $V_t = \dfrac{8.617333\bullet10^{-7}\ \text{eV/K}\,(300\,\text{K})}{e}$ $\Rightarrow$ $\underline{V_t = 0.025852\ \text{V}}$

Per (10.4), $\phi_{fp} = V_t \ln\left(\dfrac{N_a}{n_i}\right) = 0.025852 \ln\left(\dfrac{4\times10^{17}}{1.5\times10^{10}}\right)$ $\Rightarrow$ $\underline{\boldsymbol{\phi_{fp} = 0.382515\ \text{V}}}$

Per (10.6) w/ MKS units, $x_{dT} = \sqrt{\dfrac{4\varepsilon_s\phi_{fp}}{e\,N_a}} = \sqrt{\dfrac{4(11.7)8.8541878\times10^{-12}(0.382515)}{1.602176634\times10^{-19}(4\times10^{22})}}$

$\Rightarrow$ $\underline{\boldsymbol{x_{dT} = 157.2665\ \text{nm}}}$

Per (10.27), $|Q'_{SD}(\max)| = e\,N_a\,x_{dT} = 1.602176634 \times 10^{-19}(4\times10^{22})\ 157.2665 \times 10^{-9}$

$\Rightarrow$ $\underline{\boldsymbol{|Q'_{SD}(\max)| = 1.007875 \times 10^{-3}\ \text{C/m}^2 = 1.007875 \times 10^{-7}\ \text{C/cm}^2}}$

Per (10.1), $C' = \varepsilon / d \Rightarrow C_{ox} = \varepsilon_{ox} / t_{ox} = 3.9\,(8.8541878 \times 10^{-12})/15\times10^{-9}$

$\Rightarrow$ $\underline{\boldsymbol{C_{ox} = 2.30209 \times 10^{-3}\ \text{F/m}^2 = 2.30209 \times 10^{-7}\ \text{F/cm}^2}}$

From Semiconductor Physics and Devices: Basic Principles (4th Edition), Donald A. Neamen, McGraw Hill, 2012, ISBN 978-0-07-352958-5.

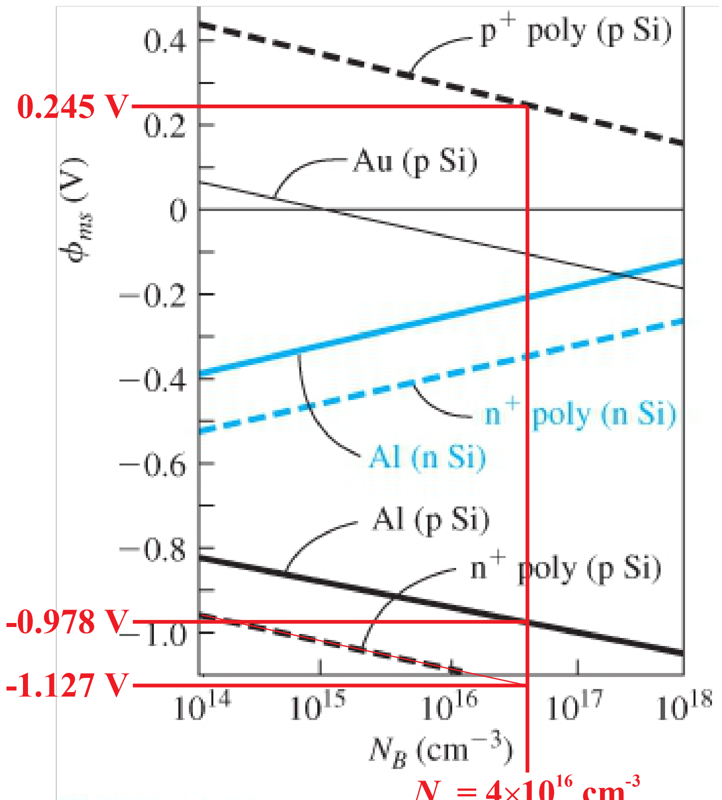

**Figure 10.16** | Metal–semiconductor work function difference versus doping

Per (10.31), $V_{TN} = \dfrac{|Q'_{SD}(\max)|}{C_{ox}} - \dfrac{|Q'_{SS}|}{C_{ox}} + \phi_{ms} + 2\phi_{fp}$.

a) Per Figure 10.16, $\phi_{ms}$ = -1.127 V for n$^+$ polysilicon.

$$V_{TN} = \frac{1.007875\times10^{-7}}{2.30209\times10^{-7}} - \frac{1.121524\times10^{-8}}{2.30209\times10^{-7}} - 1.127 + 2(0.382515)$$

$$V_{TN} = 0.437809 - 0.048717 - 1.127 + 2(0.382515) \quad \Rightarrow \underline{\mathbf{V_{TN} = 0.0271\ V}}.$$

b) Per Figure 10.16, $\phi_{ms}$ = 0.245 V for p$^+$ polysilicon.

$$V_{TN} = 0.437809 - 0.048717 + 0.245 + 2(0.382515) \quad \Rightarrow \underline{\mathbf{V_{TN} = 1.399\ V}}.$$

c) Per Figure 10.16, $\phi_{ms}$ = -0.978 V for aluminum.

$$V_{TN} = 0.437809 - 0.048717 - 0.978 + 2(0.382515) \quad \Rightarrow \underline{\mathbf{V_{TN} = 0.176\ V}}.$$