10.16 An n^+ polysilicon gate–silicon dioxide–silicon MOS capacitor has an oxide thickness of $t_{ox} = 18$ nm $= 180$ Å and a doping of $N_a = 10^{15}$ cm^{-3}. The oxide charge density is $Q'_{ss} = 6 \times 10^{10}$ cm^{-2}. Calculate the (*a*) flat-band voltage and (*b*) threshold voltage.

- Change the oxide thickness to 24 nm and doping to $N_a = 6 \times 10^{15}$ cm^{-3}.

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.

$Q'_{SS} = 6 \times 10^{10}(1.602176634 \times 10^{-19})$ $\Rightarrow$ $\underline{Q'_{SS} = 9.61306 \times 10^{-9}\ \text{C/cm}^2}$.

Per (7.10), $V_t = \dfrac{8.617333 \bullet 10^{-7}\ \text{eV/K}\,(300\,\text{K})}{e}$ $\Rightarrow$ $\underline{V_t = 0.025852\ \text{V}}$.

Per (10.4), $\phi_{fp} = V_t \ln\left(\dfrac{N_a}{n_i}\right) = 0.025852 \ln\left(\dfrac{6 \times 10^{15}}{1.5 \times 10^{10}}\right)$ $\Rightarrow$ $\underline{\phi_{fp} = 0.33347063\ \text{V}}$.

Per (10.6) w/ MKS units, $x_{dT} = \sqrt{\dfrac{4\varepsilon_s \phi_{fp}}{e N_a}} = \sqrt{\dfrac{4(11.7)8.8541878 \times 10^{-12}(0.33347)}{1.602176634 \times 10^{-19}(6 \times 10^{21})}}$

$\Rightarrow$ $\underline{x_{dT} = 379.1362\ \text{nm}}$.

Per (10.27), $|Q'_{SD}(\text{max})| = e N_a x_{dT} = 1.602176634 \times 10^{-19}(6 \times 10^{21})\ 379.1362 \times 10^{-9}$

$\Rightarrow$ $\underline{|Q'_{SD}(\text{max})| = 3.64466 \times 10^{-4}\ \text{C/m}^2 = 3.64466 \times 10^{-8}\ \text{C/cm}^2}$.

Per (10.1), $C' = \varepsilon / d \Rightarrow C_{ox} = \varepsilon_{ox} / t_{ox} = 3.9\ (8.8541878 \times 10^{-12}) / 24 \times 10^{-9}$

$\Rightarrow$ $\underline{C_{ox} = 1.4388055 \times 10^{-3}\ \text{F/m}^2 = 1.4388055 \times 10^{-7}\ \text{F/cm}^2}$.

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

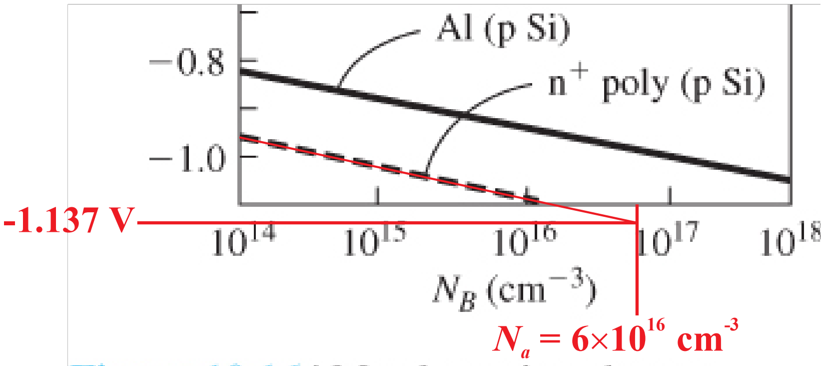

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n^- and p^- polysilicon gates. (*From Sze [17] and Werner [20].*)

a) From Figure 10.16, , ϕ_{ms} = -1.137 V for n$^+$ polysilicon.

$$\text{Per (10.25), } V_{FB} = \phi_{ms} - \frac{Q'_{SS}}{C_{\text{ox}}} = -1.137 - \frac{9.61306 \times 10^{-9}}{1.4388055 \times 10^{-7}}$$

V_{FB} = -1.137 - 0.066813 ⇒ **$\underline{V_{FB} = -1.204 \text{ V}}$.**

b) Per (10.31c), $V_{TN} = \dfrac{|Q'_{SD}(\max)|}{C_{\text{ox}}} + V_{FB} + 2\phi_{fp}$.

$$V_{TN} = \frac{3.64466 \times 10^{-8}}{1.4388055 \times 10^{-7}} - 1.204 + 2(0.33347063)$$

V_{TN} = 0.2533115 - 1.204 + 0.6694126 ⇒ **$\underline{V_{TN} = -0.281 \text{ V}}$.**