10.23 An ideal MOS capacitor with an n^+ polysilicon gate has a silicon dioxide thickness of $t_{ox} = 12$ nm $= 120$ Å on a p-type silicon substrate doped at $N_a = 10^{16}$ cm^{-3}. Determine the capacitance C_{ox}, C'_{FB}, C'_{min}, and $C'(\text{inv})$ at (*a*) $f = 1$ Hz and (*b*) $f = 1$ MHz. (*c*) Determine V_{FB} and V_T.

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

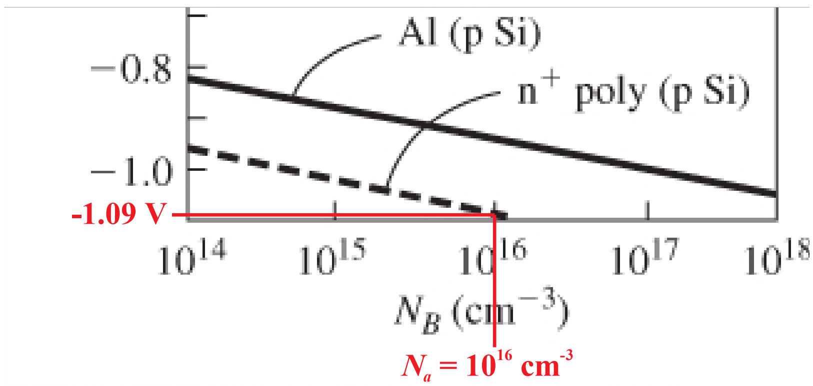

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n^- and p^- polysilicon gates. (*From Sze [17] and Werner [20].*)

Since it is not mentioned in the problem statement, assume $Q_{ss}' = 0$.

From Figure 10.16, $\phi_{ms} = -1.09$ V for n^+ poly w/ p-type silicon substrate.

From Table B.4, $n_i = 1.5 \times 10^{10}$ cm^{-3} & $\varepsilon_r = 11.7$ for silicon at 300 K.

From Table B.6, $\varepsilon_r = 3.9$ for SiO_2 at 300 K.

Per (7.10), $$V_t = \frac{k_B T}{e} = \frac{8.617333 \bullet 10^{-5}\,\text{eV/K}(300\text{ K})}{e} = 0.025852\text{ V}.$$

Per (10.4), $$\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right) = 0.025852 \ln\left(\frac{10^{16}}{1.5 \bullet 10^{10}}\right) = 0.3466765\text{ V}.$$

Per (10.6), $$x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{eN_a}\right)^{0.5} = \left(\frac{4\,(11.7)\,8.8541878 \bullet 10^{-12}\,(0.3466765)}{1.602176634 \bullet 10^{-19}\,(10^{22})}\right)^{0.5} = 2.99436 \bullet 10^{-7}\text{ m}.$$

Per (10.27), $$\begin{aligned}\left|Q'_{SD}(\max)\right| &= eN_a x_{dT} = 1.602176634 \bullet 10^{-19}(10^{22})(2.99436 \bullet 10^{-7}) \\ &= 4.797497 \bullet 10^{-4}\text{ C/m}^2 = 4.797497 \bullet 10^{-8}\text{ C/cm}^2\end{aligned}.$$

a) Per (10.35), $C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$

$$C_{ox} = \frac{3.9(8.8541878\times10^{-12})}{12\times10^{-9}}$$

$$C_{ox} = 2.8776\times10^{-3}\ F/m^2 = 2.8776\times10^{-7}\ F/cm^2$$

Per (10.40), $C'_{FB} = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right)\sqrt{\frac{k_BT}{e}\left(\frac{\epsilon_s}{eN_a}\right)}}$

$$C'_{FB} = \frac{3.9(8.8541878\times10^{-12})}{12\times10^{-9} + \left(\frac{3.9}{11.7}\right)\sqrt{0.025852\left(\frac{11.7(8.8542\times10^{-12})}{1.6022\times10^{-19}(10^{22})}\right)}}$$

$$C'_{FB} = 1.3474\times10^{-3}\ F/m^2 = 1.3474\times10^{-7}\ F/cm^2$$

Per (10.38), $C'_{min} = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right)x_{dT}}$

$$C'_{min} = \frac{3.9(8.8541878\times10^{-12})}{12\times10^{-9} + \left(\frac{3.9}{11.7}\right)2.99436\times10^{-7}}$$

$$C'_{min} = 3.08834\times10^{-4}\ F/m^2 = 3.08834\times10^{-8}\ F/cm^2$$

Per (10.39), $C'(inv) = C_{ox} = 2.8776\times10^{-7}\ F/cm^2$

b) Per section 10.2.2, @ high frequency

$C_{ox} = C_{ox} = 2.8776 \times 10^{-7}\ F/cm^2$

$C'_{FB} = C'_{FB} = 1.3474 \times 10^{-7}\ F/cm^2$

$C'_{min} = C'_{min} = 3.08834 \times 10^{-8}\ F/cm^2$

} No change

However, $C'(inv) = C'_{min} = 3.08834 \times 10^{-8}\ F/cm^2$

c) Per (10.25), $V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}}$

Here, we assumed $Q'_{ss} = 0$

$$V_{FB} = \phi_{ms} = -1.09\ V$$

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

$$V_{TN} = \frac{4.7975 \times 10^{-8}}{2.8776 \times 10^{-7}} - 1.09 + 2(0.3466765)$$

$$V_{TN} = -0.230\ V$$