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 $N_a = 10^{15}$ cm^{-3}. Determine the capacitance C_{ox}, C'_{FB}, C'_{min}, and C'(inv) at (*a*) f = 1 Hz and (*b*) f = 1 MHz. (*c*) Determine V_{FB} and V_T.

- Assume $Q'_{SS} = 0$.

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

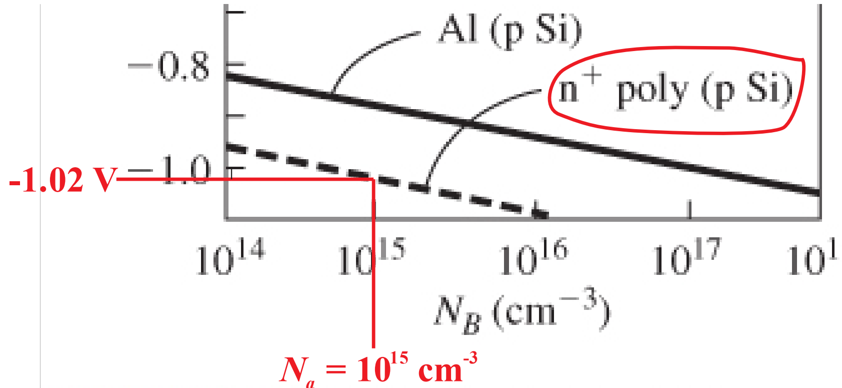

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n^- and p^- polysilicon gates. (*From Sze [17] and Werner [20].*)

From Figure 10.16, ϕ_{ms} = -1.02 V for n^+ poly w/ p-type silicon substrate.

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

From Table B.6, ε_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), $$\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right) = 0.025852 \ln\left(\frac{10^{15}}{1.5 \bullet 10^{10}}\right) = 0.28715\text{ V}.$$

Per (10.6), $$x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{eN_a}\right)^{0.5} = \left(\frac{4\,(11.7)\,8.8541878 \bullet 10^{-12}\,(0.28715)}{1.602176634 \bullet 10^{-19}\,(10^{21})}\right)^{0.5} = 8.617803 \bullet 10^{-7}\text{ m}.$$

Per (10.27), $$\begin{aligned}|Q'_{SD}(\max)| &= eN_a x_{dT} = 1.602176634 \bullet 10^{-19}(10^{21})(8.6178 \bullet 10^{-7}) \\ &= 1.380724 \bullet 10^{-4}\text{ C/m}^2 = 1.380724 \bullet 10^{-8}\text{ C/cm}^2\end{aligned}.$$

a) @ 1 Hz

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

$\Rightarrow$ **C_{ox} = 2.8776 × 10^{-3} C/m^2 = 2.8776 × 10^{-7} C/cm^2**.

Per (10.40),

$$C'_{FB} = \frac{\varepsilon_{ox}}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right)\sqrt{\left(\frac{k_B T}{e}\right)\left(\frac{\varepsilon_s}{eN_a}\right)}} = \frac{3.9\,(8.8541878 \bullet 10^{-12})}{12 \bullet 10^{-9} + \left(\frac{3.9}{11.7}\right)\sqrt{0.025852\left(\frac{11.7\,(8.8541878 \bullet 10^{-12})}{1.602176634 \bullet 10^{-19}\,(10^{21})}\right)}}$$

$\Rightarrow$ **C'_{FB} = 6.2675 × 10^{-4} C/m^2 = 6.2675 × 10^{-8} C/cm^2**.

Per (10.38), $$C'_{\min} = \frac{\varepsilon_{ox}}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right)x_{dT}} = \frac{3.9\,(8.8541878 \bullet 10^{-12})}{12 \bullet 10^{-9} + \left(\frac{3.9}{11.7}\right)8.6178 \bullet 10^{-7}}$$

$\Rightarrow$ **$C'_{\min}$ = 1.1539 × 10^{-4} C/m^2 = 1.1539 × 10^{-8} C/cm^2**.

Per (10.39), $C'(\text{inv}) = C_{ox} \Rightarrow$ **$C'(\text{inv})$ = 2.8776 × 10^{-3} C/m^2 = 2.8776 × 10^{-7} C/cm^2**.

b) @ 1 MHz, per section 10.2.2 of text at high frequency-

C_{ox} unchanged $\Rightarrow$ **C_{ox} = 2.8776 × 10^{-3} C/m^2 = 2.8776 × 10^{-7} C/cm^2**.

C'_{FB} unchanged $\Rightarrow$ **C'_{FB} = 6.2675 × 10^{-4} C/m^2 = 6.2675 × 10^{-8} C/cm^2**.

$C'_{\min}$ unchanged $\Rightarrow$ **$C'_{\min}$ = 1.1539 × 10^{-4} C/m^2 = 1.1539 × 10^{-8} C/cm^2**.

However, $C'(\text{inv}) = C'_{\min}$ $\Rightarrow$ **$C'(\text{inv})$ = 1.1539 × 10^{-4} C/m^2 = 1.1539 × 10^{-8} C/cm^2**.

c)

Per (10.25), $V_{FB} = \phi_{ms} - Q'_{SS}/C_{ox}$ = -1.02 V – 0 $\Rightarrow$ **V_{FB} = -1.02 V**.

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

= 1.38072×10^{-4}/2.8776×10^{-3} - 1.02 + 2(0.28715) $\Rightarrow$ **V_{TN} = -0.3977 V**.