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.

- Change doping to $N_a = 10^{17}$ cm^{-3}. 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.

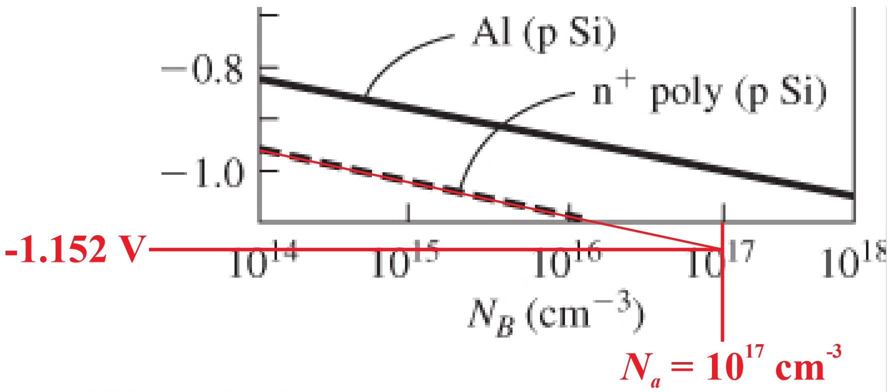

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n⁻ and p⁻ polysilicon gates. (*From Sze [17] and Werner [20].*)

From Figure 10.16, ϕ_{ms} = -1.152 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), $$V_t = \frac{k_B T}{e} = \frac{8.617333 \bullet 10^{-5}\,\text{eV/K(300 K)}}{e} = 0.025852\ \text{V}.$$

Per (10.4), $$\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right) = 0.025852 \ln\left(\frac{10^{17}}{1.5\times10^{10}}\right) = 0.406203\ \text{V}.$$

Per (10.6), $$x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{e N_a}\right)^{0.5} = \left(\frac{4(11.7)8.8541878\times10^{-12}(0.406203)}{1.602176634\times10^{-19}\,(10^{23})}\right)^{0.5} = 1.024976\times10^{-7}\ \text{m}.$$

Per (10.27), $$\begin{aligned}\left|Q'_{SD}(\max)\right| &= eN_a x_{dT} = 1.602176634\times10^{-19}(10^{23})(1.024976\times10^{-7}) \\ &= 1.642192\times10^{-3}\ \text{C/m}^2 = 1.642192\times10^{-7}\ \text{C/cm}^2\end{aligned}.$$

a) @ 1 Hz

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

$\Rightarrow$ **$C_{ox} = 2.87761 \times 10^{-3}$ C/m^2 = 2.87761×10^{-7} C/cm^2**.

Per (10.40),

$$C'_{FB} = \frac{\varepsilon_{ox}}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right)\sqrt{\left(\frac{k_B T}{e}\right)\left(\frac{\varepsilon_s}{e N_a}\right)}} = \frac{3.9\,(8.8541878 \bullet 10^{-12})}{12 \bullet 10^{-9} + \left(\frac{3.9}{11.7}\right)\sqrt{0.025852\left(\frac{11.7\,(8.8541878 \bullet 10^{-12})}{1.602176634 \bullet 10^{-19}\,(10^{23})}\right)}}$$

$\Rightarrow$ **$C'_{FB} = 2.11724 \times 10^{-3}$ C/m^2 = 2.11724×10^{-7} C/cm^2**.

Per (10.38), $$C'_{min} = \frac{\varepsilon_{ox}}{t_{ox} + \left(\frac{\varepsilon_{ox}}{\varepsilon_s}\right) x_{dT}} = \frac{3.9\,(8.8541878 \times 10^{-12})}{12 \times 10^{-9} + \left(\frac{3.9}{11.7}\right) 1.024976 \times 10^{-7}}$$

$\Rightarrow$ **$C'_{min} = 7.479842 \times 10^{-4}$ C/m^2 = 7.479842×10^{-8} C/cm^2**.

Per (10.39), $C'(\text{inv}) = C_{ox} \Rightarrow$ **$C'(\text{inv}) = 2.87761 \times 10^{-3}$ C/m^2 = 2.87761×10^{-7} C/cm^2**.

c)

Per (10.25), $V_{FB} = \phi_{ms} - Q'_{SS} / C_{ox} = -1.152\text{ V} - 0$ $\Rightarrow$ **$V_{FB} = -1.152$ V**.

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

$= 1.642192 \times 10^{-4} / 2.8776 \times 10^{-3} - 1.152 + 2(0.406203)$ $\Rightarrow$ **$V_{TN} = 0.2311$ V**.