10.24 Repeat Problem 10.23 for an ideal MOS capacitor with a p^+ polysilicon gate and an n-type silicon substrate doped at $N_d = 5 \times 10^{14}$ cm^{-3}.

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.

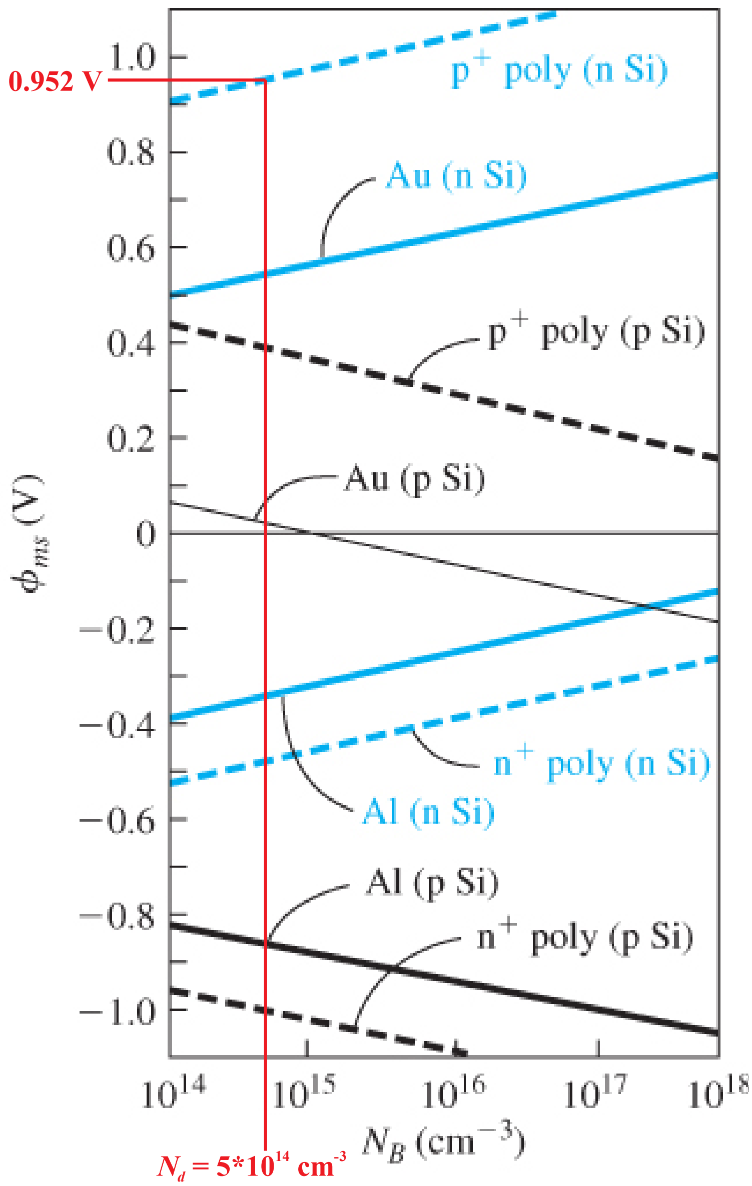

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n^- and p^- polysilicon gates. (*From Sze [17] and Werner [20].*)

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

From Figure 10.16, $\phi_{ms} = 0.952$ V for p^+ poly w/ n-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), $V_t = \dfrac{k_B T}{e} = \dfrac{8.617333 \bullet 10^{-5}\,\text{eV/K}(300\text{ K})}{e} = 0.025852\text{ V}$.

Per (10.7), $\phi_{fn} = V_t \ln\left(\dfrac{N_d}{n_i}\right) = 0.025852 \ln\left(\dfrac{5 \bullet 10^{14}}{1.5 \bullet 10^{10}}\right) = 0.2692308\text{ V}$.

Per (10.8), $x_{dT} = \left(\dfrac{4\varepsilon_s \phi_{fn}}{eN_d}\right)^{0.5} = \left(\dfrac{4\,(11.7)\,8.8541878 \bullet 10^{-12}\,(0.269231)}{1.602176634 \bullet 10^{-19}\,(5 \bullet 10^{20})}\right)^{0.5} = 1.180102 \bullet 10^{-6}\text{ m}$.

Per (10.33b), $\left|Q'_{SD}(\max)\right| = eN_d x_{dT} = 1.602176634 \bullet 10^{-19}(5 \bullet 10^{20})(1.1801 \bullet 10^{-6})$
$= 9.453658 \bullet 10^{-5}\text{ C/m}^2 = 9.453658 \bullet 10^{-9}\text{ C/cm}^2$.

a) Per (10.35), $C_{ox} = \dfrac{\epsilon_{ox}}{t_{ox}} = \dfrac{3.9(8.8541878 \times 10^{-12})}{12 \times 10^{-9}}$

$$\underline{\underline{C_{ox} = 2.8776 \times 10^{-3}\text{ F/m}^2 = 2.8776 \times 10^{-7}\text{ F/cm}^2}}$$

Per (10.40) w/ N_d for N_a

$$C'_{FB} = \frac{\epsilon_{ox}}{t_{ox} + \left(\frac{\epsilon_{ox}}{\epsilon_s}\right)\sqrt{\frac{k_B T}{e}\left(\frac{\epsilon_s}{eN_d}\right)}}$$

$$= \frac{3.9(8.8541878 \times 10^{-12})}{12 \times 10^{-9} + \left(\frac{3.9}{11.7}\right)\sqrt{0.025852\left(\frac{11.7(8.8541878 \times 10^{-12})}{1.6022 \times 10^{-19}(5 \times 10^{20})}\right)}}$$

$$\underline{\underline{C'_{FB} = 4.73375 \times 10^{-4}\text{ F/m}^2 = 4.73375 \times 10^{-8}\text{ F/cm}^2}}$$

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

$$C'_{min} = \frac{3.9(8.8541878 \times 10^{-12})}{12 \times 10^{-9} + \left(\frac{3.9}{11.7}\right) 1.1801 \times 10^{-6}}$$

$$\underline{\underline{C'_{min} = 8.51853 \times 10^{-5}\ F/m^2 = 8.51853 \times 10^{-9}\ F/cm^2}}$$

Per (10.39), $\underline{\underline{C'(inv) = C_{ox} = 2.8776 \times 10^{-7}\ F/cm^2}}$

b) @ high freqs per section 10.2.2

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

$$\underline{\underline{C'_{FB} = 4.73375 \times 10^{-8}\ F/cm^2}}$$

$$\underline{\underline{C'_{min} = 8.5185 \times 10^{-9}\ F/cm^2}}$$

No change

However, $\underline{\underline{C'(inv) = C'_{min} = 8.5185 \times 10^{-9}\ F/cm^2}}$

c) Per (10.25), $V_{FB} = \phi_{ms} - \dfrac{Q'_{ss}}{C_{ox}} \xrightarrow{Q'_{ss} \to 0} \Rightarrow \underline{\underline{V_{FB} = 0.952\ V}}$

Per (10.32), $V_{TP} = \dfrac{-|Q'_{SD}(max)| - Q'_{ss}}{C_{ox}} + \phi_{ms} - 2\phi_{fn}$, with $Q'_{ss} \to 0$

$$V_{TP} = \frac{-9.45366 \times 10^{-9} - 0}{2.8776 \times 10^{-7}} + 0.952 - 2(0.26923)$$

$$\underline{\underline{V_{TP} = 0.38069\ V}}$$