10.24 Repeat Problem 10.23 for an ideal MOS capacitor with a p^+ polysilicon gate and an n-type silicon substrate doped at $N_d = 10^{16}$ 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.

- 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.

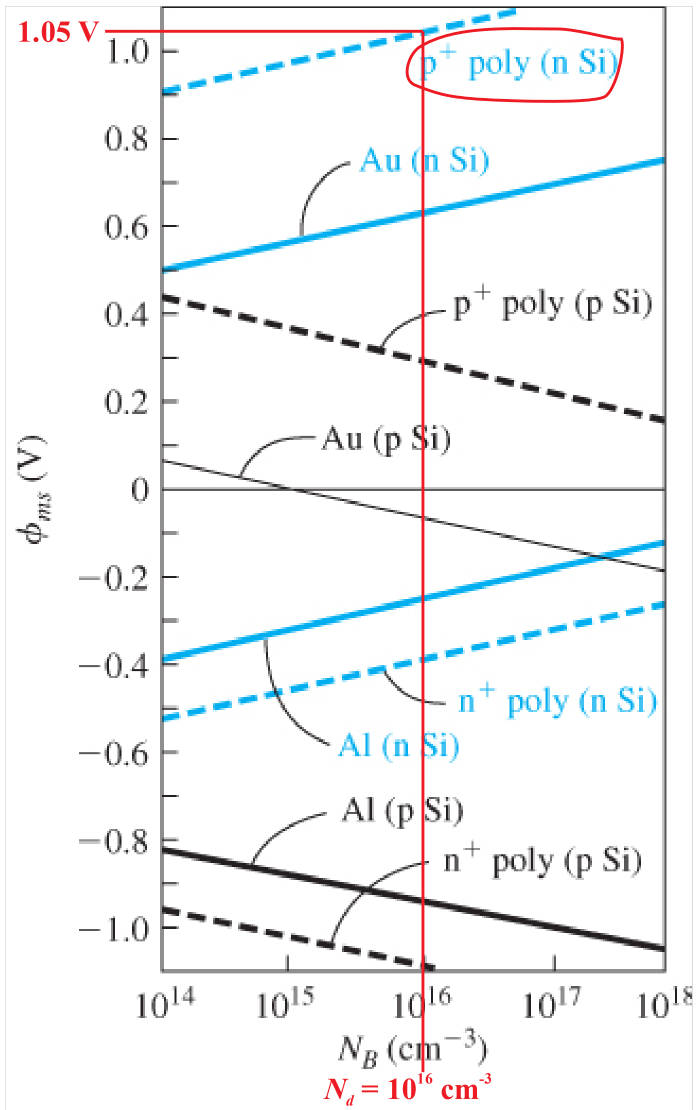

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n^- and p^- polysilicon gates. (*From Sze [17] and Werner [20].*)

From Figure 10.16, $\phi_{ms} = 1.05$ 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), $V_t = k_B T/e = 8.617333 \bullet 10^{-5}\,\text{eV/K}(300\text{ K})/e = 0.025852\text{ V}$.

Per (10.7), $\phi_{fn} = V_t \ln\left(N_d/n_i\right) = 0.025852 \ln\left(10^{16}/1.5 \bullet 10^{10}\right) = 0.346676\text{ V}$.

Per (10.8), $x_{dT} = \left(\dfrac{4\varepsilon_s \phi_{fn}}{eN_d}\right)^{0.5} = \left(\dfrac{4\,(11.7)\,8.8541878 \bullet 10^{-12}\,(0.346676)}{1.602176634 \bullet 10^{-19}\,(10^{22})}\right)^{0.5} = 2.994362 \bullet 10^{-7}\text{ m}$.

Per (10.33b), $\left|Q'_{SD}(\text{max})\right| = eN_d x_{dT} = 1.602176634 \bullet 10^{-19}(10^{22})(2.99436 \bullet 10^{-7})$
$= 4.797497 \bullet 10^{-4}\text{ C/m}^2 = 4.797497 \bullet 10^{-8}\text{ C/cm}^2$.

a) @ 1 Hz. Per (10.1), $C' = \varepsilon/d \Rightarrow C_{ox} = \varepsilon_{ox}/t_{ox} = 3.9\,(8.8541878 \times 10^{-12})/12 \times 10^{-9}$

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

Modify (10.40),

$$C'_{FB} = \frac{\varepsilon_{ox}}{t_{ox} + \left(\dfrac{\varepsilon_{ox}}{\varepsilon_s}\right)\sqrt{\left(\dfrac{k_B T}{e}\right)\left(\dfrac{\varepsilon_s}{e N_d}\right)}} = \frac{3.9\,(8.8541878 \bullet 10^{-12})}{12 \bullet 10^{-9} + \left(\dfrac{3.9}{11.7}\right)\sqrt{0.025852\left(\dfrac{11.7\,(8.8541878 \bullet 10^{-12})}{1.602176634 \bullet 10^{-19}\,(10^{22})}\right)}}$$

$\Rightarrow$ **$C'_{FB} = 1.3474 \times 10^{-3}$ C/m^2 = 1.3474×10^{-7} C/cm^2.**

Per (10.38), $C'_{\min} = \dfrac{\varepsilon_{ox}}{t_{ox} + \left(\varepsilon_{ox}/\varepsilon_s\right)x_{dT}} = \dfrac{3.9\,(8.8541878 \bullet 10^{-12})}{12 \bullet 10^{-9} + \left(3.9/11.7\right)2.994362 \bullet 10^{-7}}$

$\Rightarrow$ **$C'_{\min} = 3.08834 \times 10^{-4}$ C/m^2 = 3.08834×10^{-8} C/cm^2.**

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

C'_{FB} unchanged $\Rightarrow$ **$C'_{FB} = 1.3474 \times 10^{-3}$ C/m^2 = 1.3474×10^{-7} C/cm^2.**

$C'_{\min}$ unchanged $\Rightarrow$ **$C'_{\min} = 3.08834 \times 10^{-4}$ C/m^2 = 3.08834×10^{-8} C/cm^2.**

However, $C'(\text{inv}) = C'_{\min}$ $\Rightarrow$ **$C'(\text{inv}) = 3.08834 \times 10^{-4}$ C/m^2 = 3.08834×10^{-8} C/cm^2.**

c) Per (10.25), $V_{FB} = \phi_{ms} - Q'_{SS}/C_{ox} = 1.05\text{ V} - 0$ $\Rightarrow$ **$V_{FB} = 1.05$ V.**

Per (10.32), $V_{TP} = (-|Q'_{SD}(\text{max}) - Q'_{SS}|/C_{ox} + \phi_{ms} - 2\phi_{fn}$

$= -4.7975 \times 10^{-4}/2.8776 \times 10^{-3} + 1.05 - 2(0.346676)$ $\Rightarrow$ **$V_{TN} = 0.1899$ V.**