10.11 Repeat Problem 10.10 for an n-type silicon substrate with a doping of $N_d = 3 \times 10^{15}$ cm^{-3}.

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10.10 Consider a MOS device with a p-type silicon substrate with $N_a = 2 \times 10^{16}$ cm^{-3}. The oxide thickness is $t_{ox} = 15$ nm $= 150$ Å and the equivalent oxide charge is $Q'_{ss} = 7 \times 10^{10}$ cm^{-2}. Calculate the threshold voltage for (*a*) an n$^+$ polysilicon gate, (*b*) a p$^+$ polysilicon gate, and (*c*) an aluminum gate.

➢ Also, find ϕ_{fn}, x_{dT}, $|Q_{SD}'(\max)|$, and C_{ox}.

$Q'_{SS} = 1.602176634 \times 10^{-19} (7 \times 10^{16}) = 1.121524 \times 10^{-4}$ C/m^2

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

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

Per (7.10), $V_t = \dfrac{8.617333 \cdot 10^{-7}\ \text{eV/K}\,(300\,\text{K})}{e} \quad \Rightarrow \quad V_t = 0.025852$ V

Per (10.7), $\phi_{fn} = V_t \ln\left(\dfrac{N_d}{n_i}\right) = 0.025852 \ln\left(\dfrac{3\times10^{15}}{1.5\times10^{10}}\right) \quad \Rightarrow \quad \underline{\boldsymbol{\phi_{fn} = 0.31555\ \text{V}}}$

Per (10.8), $x_{dT} = \sqrt{\dfrac{4\varepsilon_s \phi_{fn}}{e\, N_d}} = \sqrt{\dfrac{4(11.7)\,8.8541878\times10^{-12}\,(0.31555)}{1.602176634\times10^{-19}\,(3\times10^{21})}}$

$\Rightarrow \quad \underline{\boldsymbol{x_{dT} = 521.575\ \text{nm}}}$

Per (10.33), $|Q'_{SD}(\max)| = e\, N_d\, x_{dT} = 1.602176634 \times 10^{-19} (3 \times 10^{21})\ 521.575 \times 10^{-9}$

$\Rightarrow \quad \underline{\boldsymbol{|Q'_{SD}(\max)| = 2.50696 \times 10^{-4}\ \text{C/m}^2 = 2.50696 \times 10^{-8}\ \text{C/cm}^2}}$

Per (10.1), $C' = \varepsilon/d \Rightarrow C_{ox} = \varepsilon_{ox}/t_{ox} = 3.9\ (8.8541878 \times 10^{-12})/15 \times 10^{-9}$

$\Rightarrow \quad \underline{\boldsymbol{C_{ox} = 2.30209 \times 10^{-3}\ \text{C/m}^2 = 2.30209 \times 10^{-7}\ \text{C/cm}^2}}$

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

$= (-|Q'_{SD}(\max)| - Q'_{SS})/C_{ox} - 2\phi_{fn} + \phi_{ms}$

$= (-2.50696 \times 10^{-4} - 1.121524 \times 10^{-4})/2.30209 \times 10^{-3} - 2(0.31555) + \phi_{ms}$

$= -0.78872 + \phi_{ms}$

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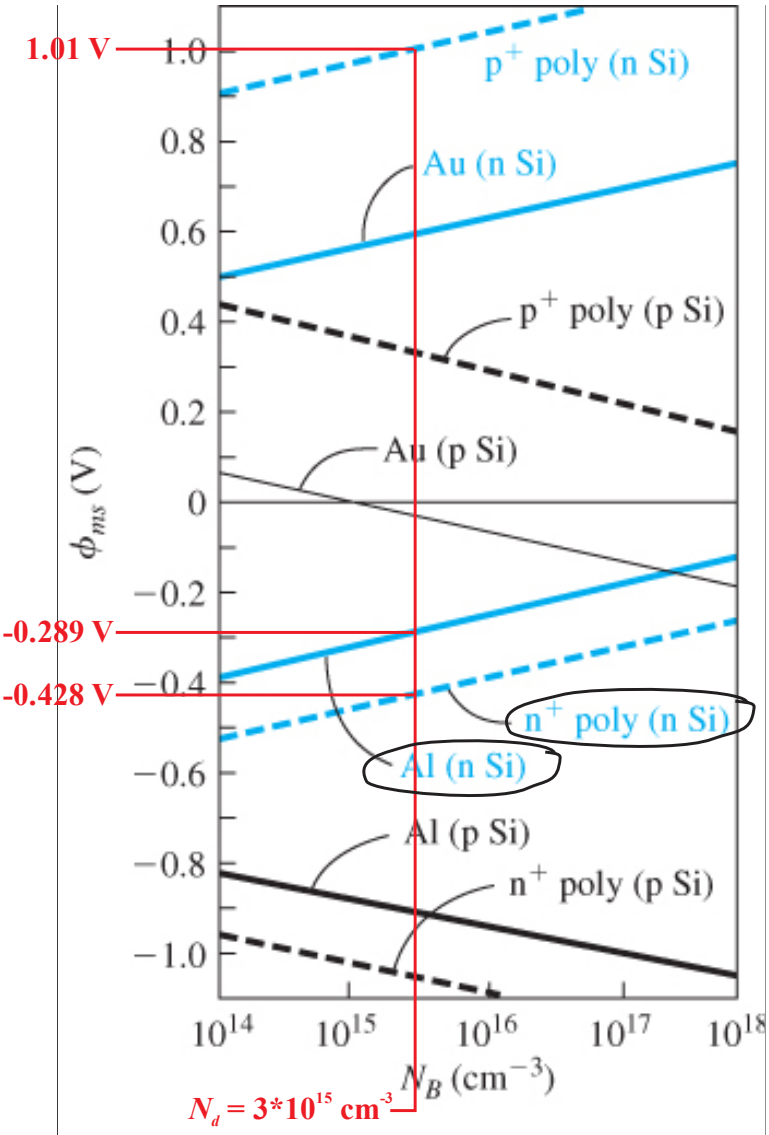

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n^- and p^- polysilicon gates. (*From Sze [17] and Werner [20].*)

a) From Figure 10.16, ϕ_{ms} = -0.428 V for n^+ polysilicon

V_{TP} = -0.78872 – 0.428 ⇒ **V_{TP} = -1.217 V**

b) From Figure 10.16, ϕ_{ms} = 1.01 V for p^+ polysilicon

V_{TP} = -0.78872 + 1.01 ⇒ **V_{TP} = 0.221 V**

c) From Figure 10.16, ϕ_{ms} = -0.289 V for aluminum

V_{TP} = -0.78872 – 0.289 ⇒ **V_{TP} = -1.087 V**