Example- Find the flat band voltage and threshold voltage for a MOS capacitor at 300 K with a gold metal gate. It has a silicon dioxide for the oxide layer of thickness 21 nm with an equivalent trapped charge density of 2×10^{11} cm^{-2} and a p-type silicon substrate where $N_a = 10^{17}$ cm^{-3}.

From Table B.4, $n_i = 1.5 \times 10^{10}$ cm^{-3}, $\varepsilon_{s,\mathrm{Si}} = 11.7\varepsilon_0$, and $\varepsilon_{s,\mathrm{SiO2}} = 3.9\varepsilon_0$ at 300 K.

Oxide capacitance per unit area is (10.1) $C' = \varepsilon / d \;\Rightarrow\; C_{ox} = \varepsilon_{ox} / t_{ox}$

$$C_{ox} = 3.9(8.8541878 \times 10^{-12}\ \mathrm{F/m})/21 \times 10^{-9}\ \mathrm{m}$$

$$\Rightarrow \underline{\mathbf{C_{ox} = 1.64435 \times 10^{-3}\ F/m^2 = 1.64435 \times 10^{-7}\ F/cm^2}}.$$

Equivalent trapped charge density is

$$Q'_{ss} = 1.6021766 \times 10^{-19}\ \mathrm{C}\ (2 \times 10^{11}\ \mathrm{cm^{-2}}) \;\Rightarrow\; \underline{\mathbf{Q'_{ss} = 3.204353 \times 10^{-8}\ C/cm^2}}.$$

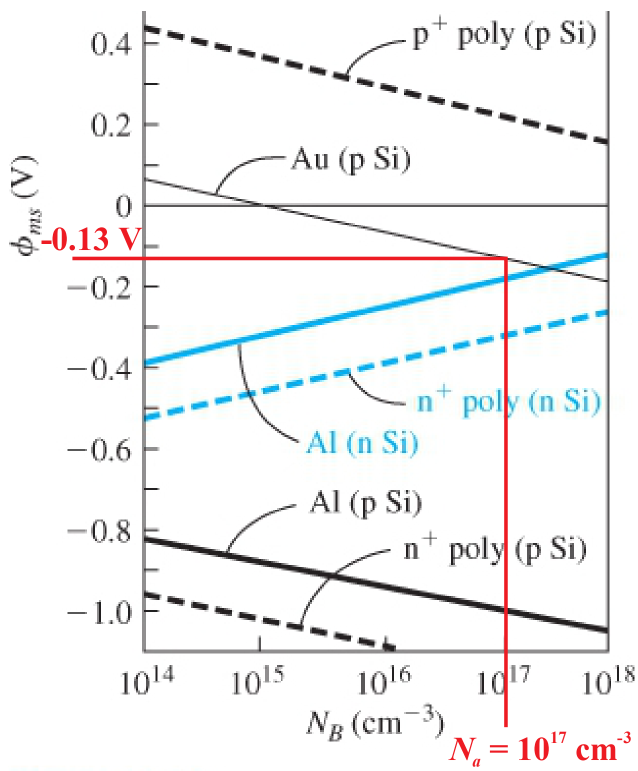

Figure 10.16 | Metal–semiconductor work function difference versus doping

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

From Figure 10.16, the metal-semiconductor work function for gold to p-type silicon semiconductor substrate is $\Rightarrow$ $\underline{\boldsymbol{\phi_{ms} = -0.13\ \mathrm{V}}}$.

Per (10.25), the flat-band voltage is-

$$V_{FB} = \phi_{ms} - \frac{Q_{ss}'}{C_{ox}} = -0.13 - \frac{3.20435 \bullet 10^{-8}}{1.64435 \bullet 10^{-7}} = -0.13 - 0.19487 \Rightarrow \underline{\boldsymbol{V_{FB} = -0.32487\ \mathrm{V}}}$$

Per (10.4), the potential difference between E_{Fi} and E_F in the substrate is

$$\phi_{fp} = V_t \ln\left(\frac{N_a}{n_i}\right) = 0.025852 \ln\left(\frac{10^{17}}{1.5 \bullet 10^{10}}\right) \quad \Rightarrow \quad \underline{\boldsymbol{\phi_{fp} = 0.406203\ \mathrm{V}}}.$$

Per (10.6), the maximum depletion layer width (use MKS units) is

$$x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{eN_a}\right)^{1/2} = \sqrt{\frac{4(11.7)8.85419 \bullet 10^{-12}(0.406203)}{(1.602176634 \bullet 10^{-19})10^{23}}} \Rightarrow \underline{\boldsymbol{x_{dT} = 1.024976 \times 10^{-7}\ \mathrm{m}}}.$$

Per (10.27), the maximum depletion layer charge density (use MKS units) is

$$|Q_{SD}'(\max)| = eN_a x_{dT} = (1.602176634 \bullet 10^{-19})10^{23}(1.024976 \bullet 10^{-7})$$

$$\Rightarrow \underline{\boldsymbol{|Q_{SD}'(\max)| = 1.64435 \times 10^{-3}\ \mathrm{C/m^2} = 1.64435 \times 10^{-7}\ \mathrm{C/cm^2}}}.$$

Per (10.31c), the threshold voltage (use MKS units) is

$$V_{TN} = \frac{|Q_{SD}'(\max)|}{C_{ox}} + V_{FB} + 2\phi_{fp} = \frac{1.64435 \bullet 10^{-3}}{1.64435 \bullet 10^{-3}} + (-0.32487) + 2(0.406203)$$

$$\Rightarrow \quad \underline{\boldsymbol{V_{TN} = 1.48622\ \mathrm{V}}}.$$