EE 362 Electronic, Magnetic, & Optical Properties of Materials
Quiz 8 (Spring 2024)

Name KEY A

Instructions: Open book & notes. Place answers in indicated spaces. Show **all** work. Use 4-5 significant figures.

At 300 K, a MOS capacitor with a silicon substrate uniformly doped with acceptor atoms (7.9×10^{15} #/cm^3). It has a 22 nm thick silicon dioxide layer with an equivalent trapped charge density of 2×10^{11} #/cm^2. The gate is made with p^+ polysilicon. Find the oxide capacitance C_{ox} (F/m^2), maximum depletion layer thickness (m), maximum space charge density magnitude (C/m^2), ϕ_{fp} (V), metal-semiconductor work function (V), and threshold voltage V_T (V).

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.

From Figure 10.16, $\underline{\boldsymbol{\phi_{ms} = 0.3}\ \mathbf{V}}$.

Per (10.35), $C_{ox} = \dfrac{\varepsilon_{ox}}{t_{ox}} = \dfrac{3.9(1.602176634 \bullet 10^{-12}\ \text{F/m})}{22 \bullet 10^{-9}\ \text{m}} \Rightarrow \underline{C_{ox} = 1.569606 \bullet 10^{-3}\ \text{F/m}^2}$.

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 (10.4), $\phi_{fp} = V_t \ln\left(\dfrac{N_a}{n_i}\right) = 0.025852 \ln\left(\dfrac{7.9 \bullet 10^{15}}{1.5 \bullet 10^{10}}\right) \Rightarrow \underline{\phi_{fp} = 0.3405826\ \text{V}}$.

Per (10.6),

$$x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{eN_a}\right)^{0.5} = \left(\frac{4\,(11.7)\,8.8541878 \bullet 10^{-12}\,(0.3405826)}{1.602176634 \bullet 10^{-19}\,(7.9 \bullet 10^{21})}\right)^{0.5} \Rightarrow \underline{x_{dT} = 3.33918 \bullet 10^{-7}\ \text{m}}.$$

Per (10.27),

$$\left|Q'_{SD}(\max)\right| = eN_a x_{dT} = 1.602176634 \bullet 10^{-19}(7.9 \bullet 10^{21})(3.33918 \bullet 10^{-7})$$
$$\Rightarrow \underline{\left|Q'_{SD}(\max)\right| = 4.226465 \bullet 10^{-4}\ \text{C/m}^2}.$$

$$V_{TN} = \frac{\left|Q'_{SD}(\max)\right|}{C_{ox}} - \frac{Q'_{SS}}{C_{ox}} + \phi_{ms} + 2\phi_{fp}$$

Per (10.31a),

$$= \frac{4.226465 \bullet 10^{-4}}{1.569606 \bullet 10^{-3}} - \frac{1.602176634 \bullet 10^{-19}(2 \bullet 10^{15})}{1.569606 \bullet 10^{-3}} + 0.3 + 2(0.3405826).$$
$$= 0.269269 - 0.2041502 + 0.3 + 0.691652 \Rightarrow \underline{V_{TN} = 1.046284\ \text{V}}$$

C_{ox} = **1.5696×10^{-3} F/m^2** max. depl. layer thickness = **$x_{dT} = 3.3392 \times 10^{-7}$ m**

max. space charge density mag. = **$|Q_{SD}'(max)| = 4.2265 \times 10^{-4}$ C/m^2** ϕ_{fp} = **0.34058 V**

metal-semiconductor work function = **$\phi_{ms} = 0.3$ V** V_T = **1.04628 V**

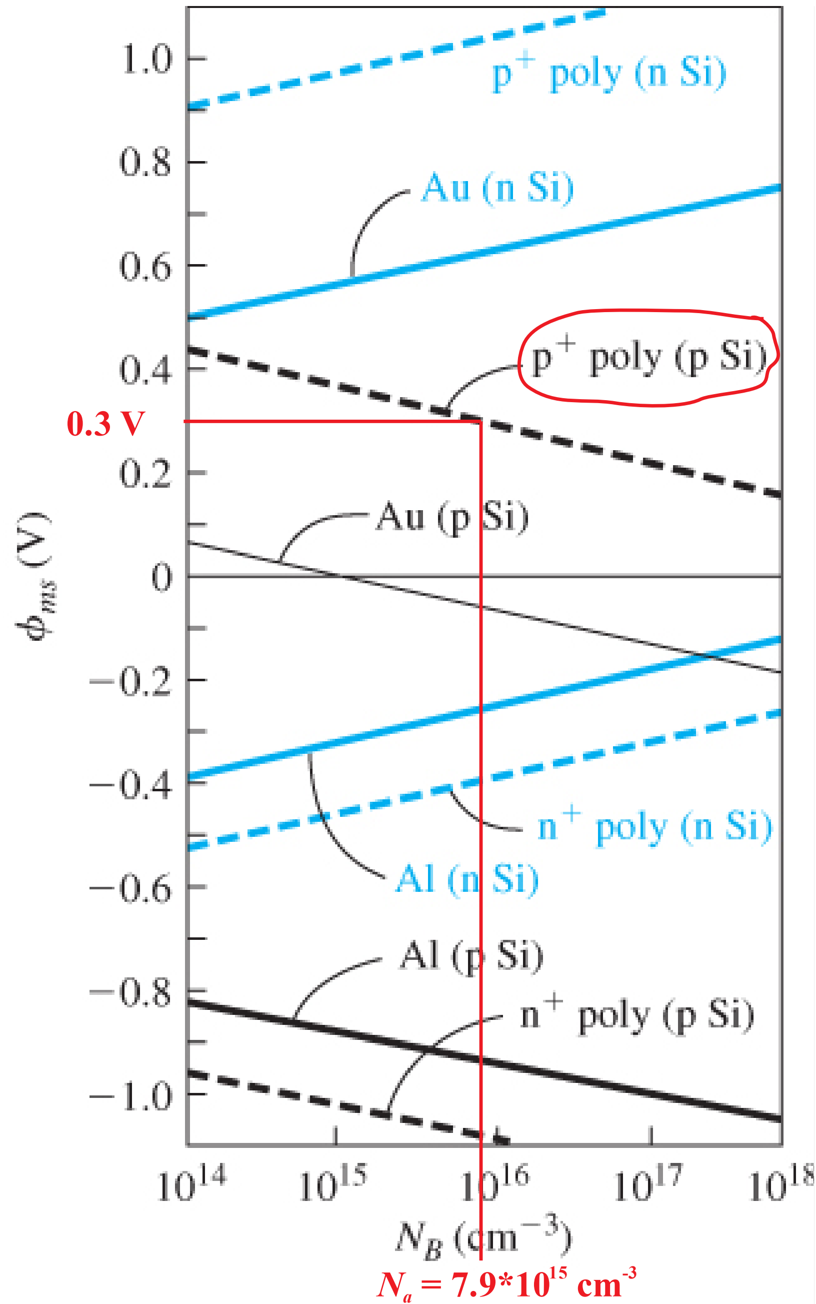

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n$^-$ and p$^-$ polysilicon gates.
(From Sze [17] and Werner [20].)

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Name KEY C

Instructions: Open book & notes. Place answers in indicated spaces. Show **all** work. Use 4-5 significant figures.

At 300 K, a MOS capacitor with a silicon substrate uniformly doped with acceptor atoms (2×10^{17} #/cm^3). It has a 18 nm thick silicon dioxide layer with an equivalent trapped charge density of 4×10^{11} #/cm^2. The gate is made with p$^+$ polysilicon. Find the oxide capacitance C_{ox} (F/m^2), maximum depletion layer thickness (m), maximum space charge density magnitude (C/m^2), ϕ_{fp} (V), metal-semiconductor work function (V), and threshold voltage V_T (V).

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.

From Figure 10.16, $\underline{\phi_{ms} = 0.2 \text{ V}}$.

Per (10.35), $C_{ox} = \dfrac{\varepsilon_{ox}}{t_{ox}} = \dfrac{3.9(1.602176634 \cdot 10^{-12}\text{ F/m})}{18 \cdot 10^{-9}\text{ m}} \Rightarrow \underline{C_{ox} = 1.918407 \cdot 10^{-3}\text{ F/m}^2}$.

Per (7.10), $V_t = \dfrac{k_B T}{e} = \dfrac{8.617333 \cdot 10^{-5}\text{ eV/K}(300\text{ K})}{e} = 0.025852\text{ V}$.

Per (10.4), $\phi_{fp} = V_t \ln\left(\dfrac{N_a}{n_i}\right) = 0.025852 \ln\left(\dfrac{2 \cdot 10^{17}}{1.5 \cdot 10^{10}}\right) \Rightarrow \underline{\phi_{fp} = 0.424122\text{ V}}$.

Per (10.6),

$$x_{dT} = \left(\frac{4\varepsilon_s \phi_{fp}}{eN_a}\right)^{0.5} = \left(\frac{4\,(11.7)\,8.8541878 \cdot 10^{-12}\,(0.424122)}{1.602176634 \cdot 10^{-19}\,(2 \cdot 10^{23})}\right)^{0.5} \Rightarrow \underline{x_{dT} = 7.40581 \cdot 10^{-8}\text{ m}}.$$

Per (10.27),

$$\left|Q'_{SD}(\max)\right| = eN_a x_{dT} = 1.602176634 \cdot 10^{-19}(2 \cdot 10^{23})(7.40581 \cdot 10^{-8})$$
$$\Rightarrow \underline{\left|Q'_{SD}(\max)\right| = 2.373083 \cdot 10^{-3}\text{ C/m}^2}.$$

Per (10.31a),

$$V_{TN} = \frac{\left|Q'_{SD}(\max)\right|}{C_{ox}} - \frac{Q'_{SS}}{C_{ox}} + \phi_{ms} + 2\phi_{fp}$$
$$= \frac{2.373083 \cdot 10^{-3}}{1.918407 \cdot 10^{-3}} - \frac{1.602176634 \cdot 10^{-19}(4 \cdot 10^{15})}{1.918407 \cdot 10^{-3}} + 0.2 + 2(0.424122).$$
$$= 1.237007 - 0.334064 + 0.2 + 0.848244 \Rightarrow \underline{V_{TN} = 1.951187\text{ V}}$$

C_{ox} = **1.9184×10^{-3} F/m^2** max. depl. layer thickness = **$x_{dT} = 7.4058 \times 10^{-8}$ m**

max. space charge density mag. = **$|Q_{SD}'(\max)| = 2.3731 \times 10^{-3}$ C/m^2** ϕ_{fp} = **0.42412 V**

metal-semiconductor work function = **$\phi_{ms} = 0.2$ V** V_T = **1.9512 V**

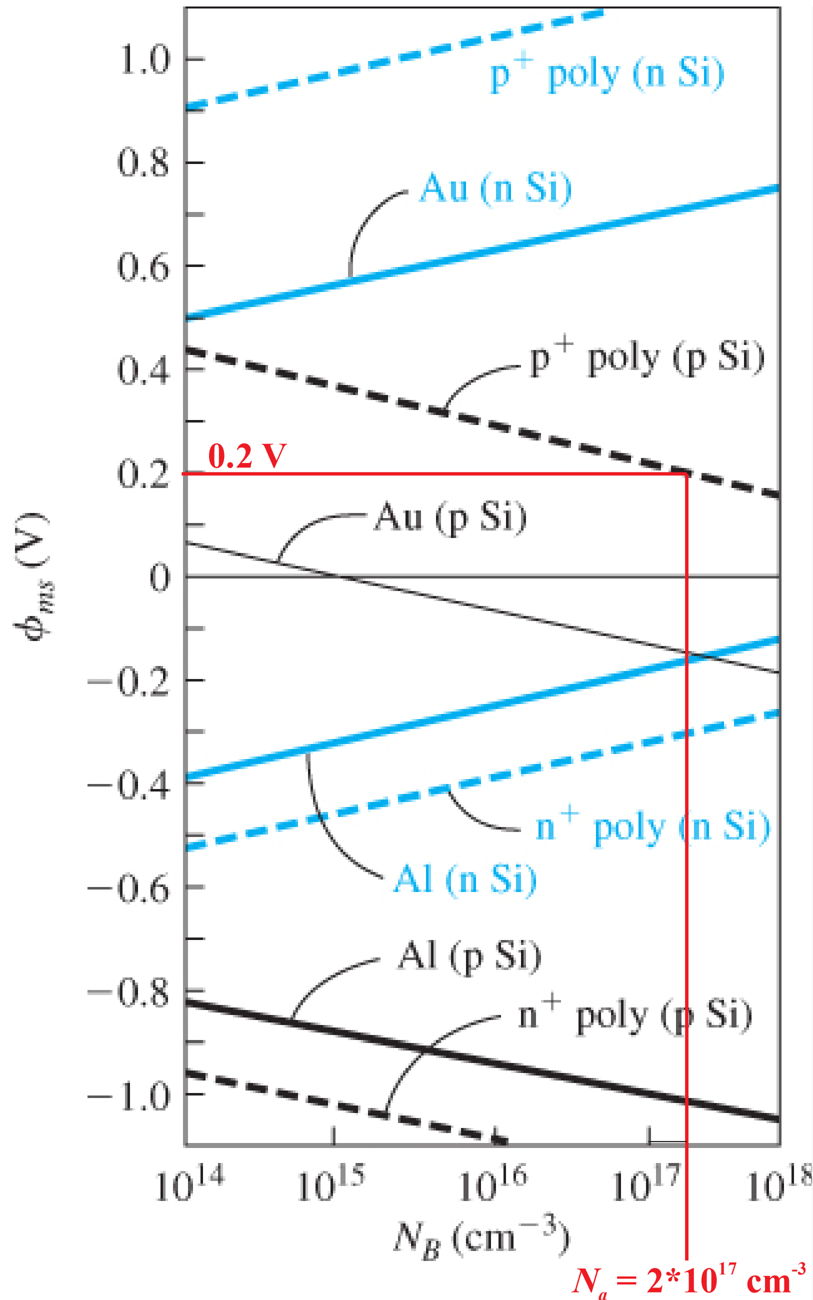

Figure 10.16 | Metal–semiconductor work function difference versus doping for aluminum, gold, and n⁻ and p⁻ polysilicon gates.
(*From Sze [17] and Werner [20].*)