# EE 207 [Spring 24-25] ***HW-6 Solutions***

**1.** Consider metal-oxide-semiconductor (MOS) capacitors on p-type substrates that are ideal, meaning the workfunction of the metal and semiconductor are equal. Assume no charge inside the oxide or at the interfaces. Then the gate voltage $V_G$ may be written as the sum of the voltage drops in the semiconductor and the oxide: $V_G = \psi_s + V_{ox}$.

**(a)** Assume the MOS is in depletion. How does the voltage drop in the semiconductor vary (qualitatively) as a function of the oxide thickness $t_{ox}$ for a given $V_G$? Share your reasoning.

(a) The gate voltage drop is divided between the oxide and the semiconductor (band-bending $\psi_s$).

$$V_G = \psi_s + V_{ox} = \psi_s - Q_d / C_{ox}, C_{ox} = \varepsilon_{ox} / t_{ox}$$

$$\Rightarrow V_G = \psi_s + \frac{qN_a W}{C_{ox}} = \psi_s + \frac{qN_a}{C_{ox}}\sqrt{\frac{2\varepsilon_s \psi_s}{qN_a}}$$

$$\Rightarrow V_G = \psi_s + \sqrt{2\varepsilon_s qN_a \psi_s} / C_{ox}$$

Thus, other things remaining the same, $t_{ox} \uparrow \Rightarrow C_{ox} \downarrow \Rightarrow \psi_s \downarrow$

**(b)** Suppose the semiconductor substrate is silicon, with doping of $N_a = 10^{16} cm^{-3}$; and the oxide is $SiO_2$, with $\varepsilon_r(SiO_2) = 4$, and thickness $t = 10nm$. Calculate the threshold voltage $V_T$.

The threshold voltage in this ideal case is given by: $V_T = 2\varphi_F + \sqrt{2\varepsilon_s qN_a \cdot 2\varphi_F} / C_{ox}$

$$\varphi_F = (kT/q)\ln(N_a/n_i) = 0.36V$$

$$C_{ox} = \varepsilon_{ox}/t_{ox} = 3.54 \times 10^{-3} F/m^2$$

$$\sqrt{2\varepsilon_s qN_a \cdot 2\varphi_F} / C_{ox} = 0.14\text{V}$$

$$V_T = 2\varphi_F + \sqrt{2\varepsilon_s qN_a \cdot 2\varphi_F} / C_{ox} = 0.72V + 0.14V = 0.86V$$