- 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  $\psi_s$ ).

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

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

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<sub>2</sub>, 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:  $V_T = 2\varphi_F + \sqrt{2\varepsilon_s q N_a \cdot 2\varphi_F} / C_{ox}$ 

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

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

$$\sqrt{2\varepsilon_s q N_a \cdot 2\varphi_F} / C_{ox} = 0.14V$$

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