EE 362 Electronic, Magnetic, & Optical Properties of Materials
Examination #3 (Spring 2026)

Name __KEY__

Instructions: Closed book. Put answers in indicated spaces, use notation as given in class & **show all** work for credit. Insert equation sheet in exam. Answers should have **4-5 significant figures** (use more for constants).

1) A MOS capacitor has an oxide layer thickness of 28 nm, equivalent oxide trapped charge concentration of 8×10^{10} cm^{-2}, and a p-type silicon substrate with $N_a = 3 \times 10^{16}$ cm^{-3} @ **300 K**. Find the oxide capacitance (F/m^2), oxide trapped surface charge density (C/m^2), ϕ_{fp}, maximum depletion layer thickness, and maximum space charge density (C/m^2). If the metal-semiconductor work function is 0.24 V, find the flat band andthreshold voltages at zero bias.

Per Table B.4, $n_i = 1.5 \times 10^{10}$ cm^{-3} and $\varepsilon_s = 11.7\varepsilon_0$ for silicon at 300 K.

Per Table B.6, $\varepsilon_{ox} = 3.9\varepsilon_0$ for silicon dioxide at 300 K.

Per (10.1), $C' = \varepsilon / d \Rightarrow C_{ox} = \varepsilon_{ox} / t_{ox} = 3.9\,(8.8541878 \times 10^{-12})/28\times10^{-9}$

$\Rightarrow$ **$C_{ox} = 1.233262 \times 10^{-3}$ F/m^2.**

$Q'_{SS} = 8 \times 10^{14}\,(1.602176634\times10^{-19})$ $\Rightarrow$ **$Q'_{SS} = 1.28174\times10^{-4}$ C/m^2.**

Per (7.10), $V_t = \dfrac{8.617333\bullet10^{-7}\ \text{eV/K}\,(300\,\text{K})}{e}$ $\Rightarrow$ $V_t = 0.025852$ V

Per (10.4), $\phi_{fp} = V_t \ln\left(\dfrac{N_a}{n_i}\right) = 0.025852 \ln\left(\dfrac{3\times10^{16}}{1.5\times10^{10}}\right)$ $\Rightarrow$ **$\phi_{fp} = 0.375078$ V**

Per (10.6) w/ MKS units, $x_{dT} = \sqrt{\dfrac{4\varepsilon_s \phi_{fp}}{e N_a}} = \sqrt{\dfrac{4(11.7)8.8541878\times10^{-12}(0.375078)}{1.602176634\times10^{-19}\,(3\times10^{22})}}$

$\Rightarrow$ **$x_{dT} = 1.798217\times10^{-7}$ m = 179.822 nm**

Per (10.27), $|Q'_{SD}(\max)| = e N_a x_{dT} = 1.602176634 \times 10^{-19}\,(3\times10^{22})\ 179.822 \times 10^{-9}$

$\Rightarrow$ **$|Q'_{SD}(\max)| = 8.643185 \times 10^{-4}$ C/m^2.**

Per (10.25), $V_{FB} = \phi_{ms} - \dfrac{Q'_{SS}}{C_{ox}} = 0.24 - \dfrac{1.28174\times10^{-4}}{1.233262\times10^{-3}}$ $\Rightarrow$ **$V_{FB} = 0.13607$ V.**

Per (10.31c), $V_{TN} = \dfrac{|Q'_{SD}(\max)|}{C_{ox}} + V_{FB} + 2\phi_{fp} = \dfrac{8.643185\times10^{-4}}{1.233262\times10^{-3}} + 0.1361 + 2(0.3751)$.

$\Rightarrow$ **$V_{TN} = 1.58706$ V.**

C_{ox} = **1.23326×10^{-3} F/m^2** Q'_{ss} = **1.28174×10^{-4} C/m^2** ϕ_{fp} = **0.375078 V**

x_{dT} = **179.822 nm** $|Q'_{SD}(\max)|$ = **8.6432×10^{-4} C/m^2** V_{FB} = **0.1361 V** V_{T0} = **1.5871 V**

2) A diode ($\varepsilon_r = 15$, $n_i = 3\times10^{12}$ cm^{-3}) at **260 K** is doped ($N_a = 4\times10^{16}$ cm^{-3} on p-side & $N_d = 2\times10^{16}$ cm^{-3} on n-side), has minority carrier lifetimes of $\tau_{n0} = 10^{-8}$ s & $\tau_{p0} = 4\times10^{-8}$ s, diffusion coefficients $D_n = 85$ cm^2/s & $D_p = 36$ cm^2/s, and has a cross-sectional area of 80×10^{-9} m^2. Find the built-in & thermal voltages, minority thermal carrier concentrations, and diffusion lengths. If the diode is forward-biased $V_a = 1.2V_{bi}$, find the electron, hole, & total diffusion currents through the depletion layer.

Per (7.10), $V_t = \dfrac{k_B T}{e} = \dfrac{8.617333\times10^{-5}\,\text{eV/K}\,(260\,\text{K})}{e}$ $\Rightarrow$ **$V_t = 0.0224051$ V.**

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.0224051 \ln\left(\frac{4\times10^{16}(2\times10^{16})}{(3\times10^{12})^2}\right) \Rightarrow \mathbf{V_{bi} = 0.4100776\ V}.$$

$V_a = 1.2V_{bi} = 1.2(0.4100776) = \underline{0.492093\text{ V}}$.

p-side Since $N_a >> n_i$, $p_{p0} \cong N_a = 4\times10^{16}$ cm^{-3}.

Per (4.43), $n_{p0} = n_i^2 / p_{p0} = (3\times10^{12})^2 / 4\times10^{16}$ $\Rightarrow$ **$n_{p0} = 2.25\times10^8$ cm^{-3}.**

From p. 283, $L_n = \sqrt{D_n\,\tau_{n0}} = \sqrt{85\times10^{-4}\,(10^{-8})}$ $\Rightarrow$ **$L_n = 9.219544\times10^{-6}$ m.**

n-side Since $N_d >> n_i$, $n_{n0} \cong N_d = 2\times10^{16}$ cm^{-3}.

Per (4.43), $p_{n0} = n_i^2 / n_{n0} = (3\times10^{12})^2 / 2\times10^{16}$ $\Rightarrow$ **$p_{n0} = 4.5\times10^8$ cm^{-3}.**

From p. 283, $L_p = \sqrt{D_p\,\tau_{p0}} = \sqrt{36\times10^{-4}\,(4\times10^{-8})}$ $\Rightarrow$ **$L_p = 12\times10^{-6}$ m.**

Per (8.24),

$$J_n(-x_p) = \frac{e D_n n_{p0}}{L_n}\left(e^{V_a/V_t} - 1\right) = \frac{1.602176634\times10^{-19}(85\times10^{-4})\,2.25\times10^{14}}{9.219544\times10^{-6}}\left(e^{0.492/0.0224} - 1\right)$$

$\Rightarrow$ $J_n = 1.14873\times10^8$ A/m^2 and $I_n = J_n A = 1.14873\times10^8\,(80\times10^{-9})$ $\Rightarrow$ **$I_n = 9.189869$ A.**

Per (8.22),

$$J_p(x_n) = \frac{e D_p p_{n0}}{L_p}\left(e^{V_a/V_t} - 1\right) = \frac{1.602176634\times10^{-19}(36\times10^{-4})\,4.5\times10^{14}}{12\times10^{-6}}\left(e^{0.492/0.0224} - 1\right)$$

$\Rightarrow$ $J_p = 7.47586\times10^7$ A/m^2 and $I_p = J_p A = 7.47586\times10^7\,(80\times10^{-9})$ $\Rightarrow$ **$I_p = 5.980688$ A.**

$I_{tot} = I_n + I_p = 9.189869 + 5.980688$ $\Rightarrow$ **$I_{tot} = 15.170557$ A.**

V_t = **0.022405 V** n_{p0} = **2.25×10^8 cm^{-3}** p_{n0} = **4.5×10^8 cm^{-3}**

V_{bi} = **0.410078 V** L_n = **9.219544×10^{-6} m = 9.2195 µm** L_p = **12×10^{-6} m = 12 µm**

I_n = **9.18987 A** I_p = **5.98069 A** I_{tot} = **15.1706 A**

3) At 300k, a silicon n-channel MOSFET with a SiO_2 oxide layer has: $t_{ox} = 16$ nm, $L = 3$ μm, $W = 48$ μm, $\mu_n = 450$ cm^2/V-s, and $V_T = 0.76$ V. The source and body are grounded. Find the oxide capacitance C_{ox} (F/m^2) and conduction parameter K_n. If the gate-source voltage is $V_{GS} = 2.2$ V and $V_{DS} = 0.8$ V, find the mode of operation (e.g., cutoff, linear, or saturation) and drain current I_D. If $V_{GS} = 0.5$ V and $V_{DS} = 1.5$ V, find the mode of operation and drain current I_D.

From Table B.6, $\varepsilon_r = 3.9$ for SiO_2 at 300 K.

Per (10.35), $C_{ox} = \dfrac{\varepsilon_{ox}}{t_{ox}} = \dfrac{3.9(8.8541878\times10^{-12})}{16\times10^{-9}}$ $\Rightarrow$ **$C_{ox} = 2.1582083\times10^{-3}$ F/m^2.**

Per (10.44a) & (10.45c), $K_n = \dfrac{W\mu_n C_{ox}}{2L} = \dfrac{48\times10^{-6}(450\times10^{-4})2.1582\times10^{-3}}{2(3\times10^{-6})}$

$\Rightarrow$ **$K_n = 7.76955\times10^{-4}$ A/V^2.**

V_{GS} = 2.2 V and V_{DS} = 0.8 V

Per (10.43b), $V_{DS}(\text{sat}) = V_{GS} - V_T = 2.2 - 0.76$ $\Rightarrow$ $V_{DS}(\text{sat}) = 1.44$ V.

Since $V_{DS} = 0.8$ V $< V_{DS}(\text{sat}) = 1.44$ V & $V_{GS} = 2.2$ V $> V_T = 0.76$ V $\Rightarrow$ **linear mode.**

Per (10.44c),

$$I_D = K_n[2(V_{GS} - V_T)V_{DS} - V_{DS}^2] = 7.796955\times10^{-4}[2(2.2-0.76)0.8-0.8^2]$$

$\Rightarrow$ **$I_D = 1.2974\times10^{-3}$ A = 1.2974 mA.**

V_{GS} = 0.5 V and V_{DS} = 1.5 V

Here, $V_{GS} = 0.5$ V $< V_T = 0.76$ V $\Rightarrow$ No inversion layer! $\Rightarrow$ **cutoff mode** $\Rightarrow$ **$I_D = 0$.**

C_{ox} = **2.1582083×10^{-3} F/m^2** K_n = **7.76955×10^{-4} A/V^2**

V_{GS} = 2.2 V & V_{DS} = 0.8 V: Operation mode: **linear** I_D = **1.2974 mA**

V_{GS} = 0.5 V & V_{DS} = 1.5 V: Operation mode: **cutoff** I_D = **0**