ECE 3030 Spring 2025 HW 9

1. *An n-channel Si JFET with* N_a = $10^{18}cm^{-3}$ *in the* p^+ *gate regions and* N_d = $10^{16}cm^{-3}$ *in the channel has* $\alpha = 1\ \mu m$. *Find* V_0, V_P *and* V_τ.
Find V_D *(sat.) if* V_G = -3 *V.*

$V_0 = (kT/q)\ln(N_aN_d/n^2_i) = 0.0259 \ln (10^{34}/2.25 \times 10^{20}) = 0.814$ V

$V_P = q\alpha^2N_d/2\varepsilon = 1.6 \times 10^{-19} \times 10^{-8} \times 10^{16}/2 \times 11.8 \times 8.85 \times 10^{-14} = 7.66$V

$V_T = V_P - V_o = 6.85\text{V} = V_D\ (\text{sat.}) - V_G$

$V_D\ (\text{sat.}) = V_T + V_G = 6.85 - 2 = 4.85$V

2. For the JFET in Problem 1, Z/L = 10 and μ_n = 1000cm^2/Vs. Plot I_D (sat.) vs V_D (sat.) for V_G = 0, -2, -4, -6 V

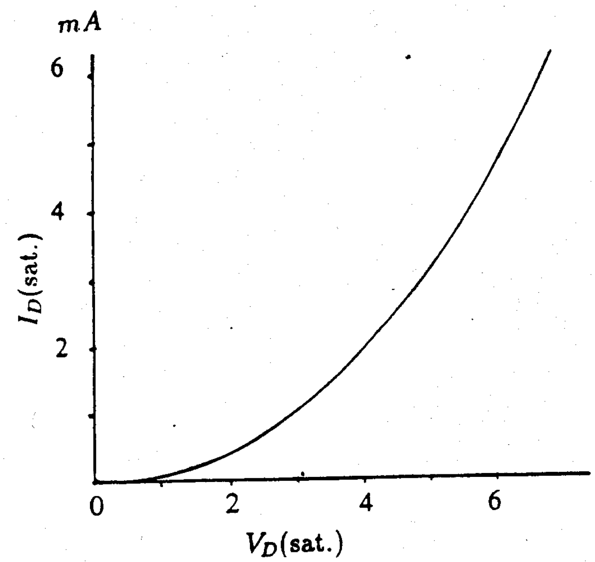
$G_O = 2\alpha q\mu_n nZ/L = 2 \times 10^{-4} \times 1.6 \times 10^{-19} \times 10^3 \times 10^{16} \times 10 = 3.2 \times 10^{-3}$S
Then from Problem 1,

I_D (sat.) = $G_OV_P[((V_G - V_O)/V_P) + 2/3((V_O - V_G)/V_P)^{3/2} + 1/3]$ See Problem 1for V_O and V_P

I_D (sat.) = $3.2 \times 10^{-3} \times 7.66[(V_G - 0.814/7.66) + 2/3\ (0.814 - V_G/7.66)^{3/2} + 1/3]$

We can plot this vs. V_D (sat.) $= 6.85 + V_G$

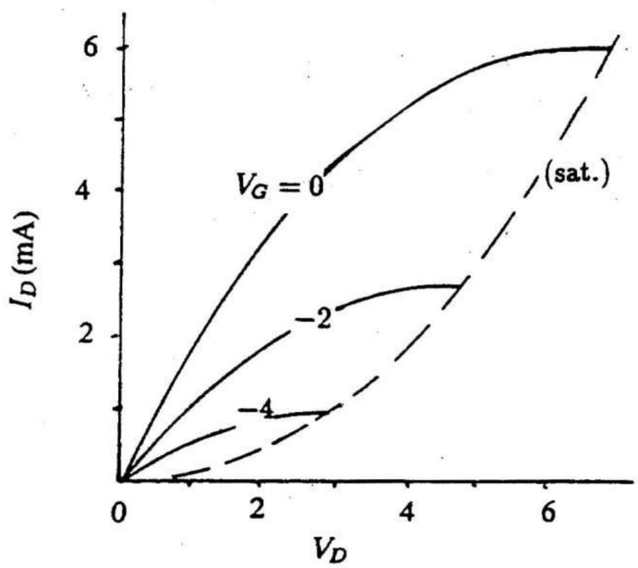
V_G	V_D(sat.)	I_D(sat.)
0 V	6.85 V	6.13 mA
−1	5.85	4.25
−2	4.85	2.80
−3	3.85	1.707
−4	2.85	0.907
−5	1.85	0.372
−6	0.85	0.076



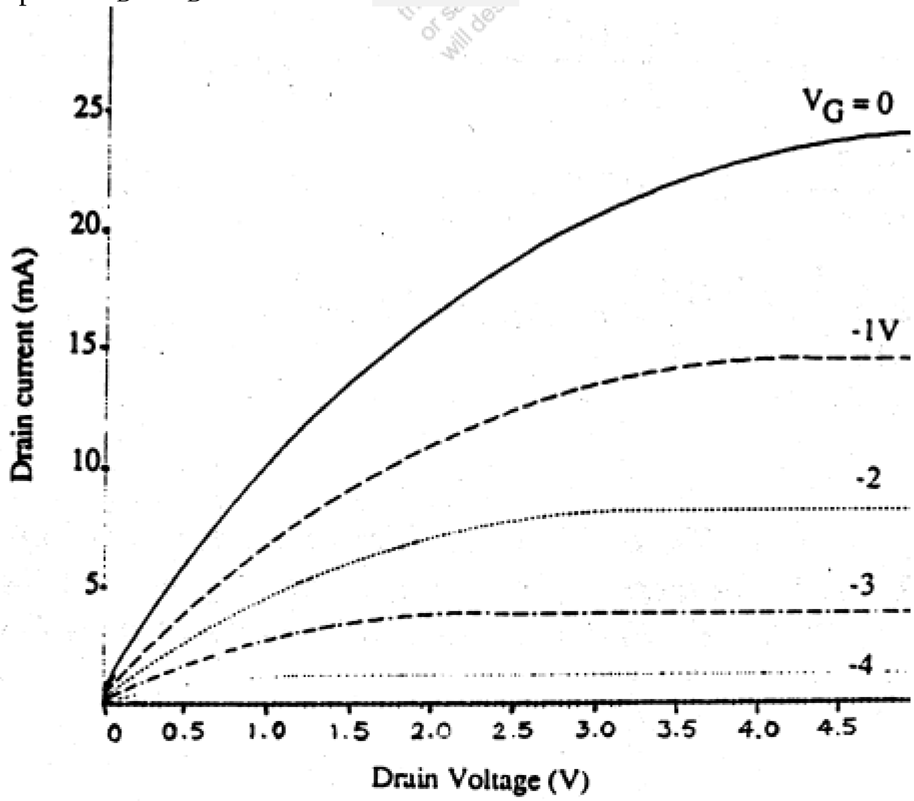
3. Graph I_D versus V_D for V_G = 0 V, -2 V, -4 V, and -6 V for the JFET in Problem 2.

$$I_D = G_O \cdot V_P \cdot \left[\frac{V_D}{V_P} + \frac{2}{3} \cdot \left(\frac{V_O - V_G}{V_P} \right)^{\frac{3}{2}} - \frac{2}{3} \cdot \left(\frac{V_O + V_D - V_G}{V_P} \right)^{\frac{3}{2}} \right]$$

$$I_D = 3.2 \cdot 10^{-3} S \cdot 7.66V \cdot \left[\frac{V_D}{7.66V} + \frac{2}{3} \cdot \left(\frac{0.814V - V_G}{7.66V} \right)^{\frac{3}{2}} - \frac{2}{3} \cdot \left(\frac{0.814V + V_D - V_G}{7.66V} \right)^{\frac{3}{2}} \right]$$



4. Graph the $I_D - V_D$ curve.



5. Find the maximum depletion width, minimum capacitance, and threshold voltage.

$$\Phi_F = \frac{kT}{q}\ln\frac{N_a}{n_i} = 0.0259\text{V}\ln\frac{10^{16}\,\frac{1}{\text{cm}^3}}{1.5\cdot 10^{10}\,\frac{1}{\text{cm}^3}} = 0.347\text{V}$$

$$W_m = 2\sqrt{\frac{\epsilon_s\cdot\Phi_F}{q\cdot N_a}} = 2\left[\frac{11.8\cdot 8.85\cdot 10^{-14}\,\frac{\text{F}}{\text{cm}}\cdot 0.347\text{V}}{1.6\cdot 10^{-19}\text{C}\cdot 10^{16}\,\frac{1}{\text{cm}^3}}\right]^{1/2} = 3.01\cdot 10^{-5}\,\text{cm} = 0.301\,\mu\text{m}$$

$$C_i = \frac{\epsilon_i}{d} = \frac{3.9\cdot 8.85\cdot 10^{-14}\,\frac{\text{F}}{\text{cm}}}{10^{-6}\text{cm}} = 3.45\cdot 10^{-7}\,\frac{\text{F}}{\text{cm}^2}$$

$$Q_d = -q\cdot N_a\cdot W_m = -1.6\cdot 10^{-19}\text{C}\cdot 10^{16}\,\frac{1}{\text{cm}^3}\,0.301\cdot 10^{-4}\text{cm} = -4.82\cdot 10^{-8}\,\frac{\text{C}}{\text{cm}^2}$$

$$V_T = -\frac{Q_d}{C_i} + 2\cdot\Phi_F = \frac{4.82\cdot 10^{-8}\,\frac{\text{C}}{\text{cm}^2}}{34.5\cdot 10^{-8}\,\frac{\text{F}}{\text{cm}^2}} + 2\cdot 0.347\text{V} = 0.834\,\text{V}$$

At maximum depletion

$$C_d = \frac{\epsilon_s}{W_m} = \frac{11.8\cdot 8.85\cdot 10^{-14}\,\frac{\text{F}}{\text{cm}}}{0.301\cdot 10^{-4}\text{cm}} = 3.47\cdot 10^{-8}\,\frac{\text{F}}{\text{cm}^2}$$

$$C_{min} = \frac{C_i C_d}{C_i + C_d} = \frac{3.45\cdot 10^{-8}\,\frac{\text{F}}{\text{cm}^2}\cdot 3.47\cdot 10^{-8}\,\frac{\text{F}}{\text{cm}^2}}{3.45\cdot 10^{-8}\,\frac{\text{F}}{\text{cm}^2} + 3.47\cdot 10^{-8}\,\frac{\text{F}}{\text{cm}^2}} = 3.15\cdot 10^{-8}\,\frac{\text{F}}{\text{cm}^2}$$

6. Problem 6.11. Find W_m, V_{FB}, and V_T. (b) Sketch the C-V curve for this device and give important numbers for the scale.
Sketch the C-V curve.

$$\Phi_F = -kT \cdot \ln\frac{N_d}{n_i} = -0.0259V \cdot \ln\frac{5\cdot 10^{17}\,\frac{1}{cm^3}}{1.5\cdot 10^{10}\,\frac{1}{cm^3}} = -0.449V$$

$$W_m = 2\cdot\left[\frac{\epsilon_s \cdot (-\Phi_F)}{q\cdot N_d}\right]^{\frac{1}{2}} = 2\cdot\left[\frac{11.8\cdot 8.85\cdot 10^{-14}\,\frac{F}{cm}\cdot(0.449V)}{1.6\cdot 10^{-19}C\cdot 5\cdot 10^{17}\,\frac{1}{cm^3}}\right]^{\frac{1}{2}} = 0.049\mu m$$

$$Q_d = q\cdot N_d\cdot W_m = 1.6\cdot 10^{-19}C\cdot 5\cdot 10^{17}\,\frac{1}{cm^3}\cdot 0.049\cdot 10^{-4}cm = 3.92\cdot 10^{-7}\,\frac{C}{cm^2}$$

$$C_i = \frac{\epsilon_i}{d} = \frac{3.9\cdot 8.85\cdot 10^{-14}\,\frac{F}{cm}}{10^{-6}cm} = 3.45\cdot 10^{-7}\,\frac{F}{cm^2}$$

$$V_{FB} = \Phi_{ms} - \frac{Q_i}{C_i} = -0.15V - \frac{1.6\cdot 10^{-19}C\cdot 5\cdot 10^{10}\,\frac{1}{cm^3}}{3.45\cdot 10^{-7}\,\frac{F}{cm^2}} = -0.173V$$

$$V_T = 2\cdot\Phi_F - \frac{Q_d}{C_i} + V_{FB} = -0.898V - 1.136V - 0.173V = -2.2V$$

$$C_d = \frac{\epsilon_s}{W_m} = \frac{11.8\cdot 8.85\cdot 10^{-14}\,\frac{F}{cm}}{0.049\cdot 10^{-4}cm} = 2.13\cdot 10^{-7}\,\frac{F}{cm^2}$$

$$C_{min} = \frac{C_i\cdot C_d}{C_i + C_d} = \frac{3.45\cdot 10^{-7}\,\frac{F}{cm^2}\cdot 2.13\cdot 10^{-7}\,\frac{F}{cm^2}}{3.45\cdot 10^{-7}\,\frac{F}{cm^2} + 2.13\cdot 10^{-7}\,\frac{F}{cm^2}} = 1.32\cdot 10^{-7}\,\frac{F}{cm^2}$$