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HW 8

1/

$$I_n = qA\frac{D_n}{L_n}n_p\left(e^{qV/k_BT}-1\right) \qquad I_p = qA\frac{D_p}{L_p}p_n\left(e^{qV/k_BT}-1\right)$$

$$\frac{I_n}{I} = \frac{I_n}{I_n+I_p} = \frac{1}{1+\frac{I_p}{I_n}} = \frac{1}{1+\left(\frac{\cancel{qA}\frac{D_p}{L_p}p_n\cancel{(e^{qV/k_BT}-1)}}{\cancel{qA}\frac{D_n}{L_n}n_p\cancel{(e^{qV/k_BT}-1)}}\right)} = \frac{1}{1+\frac{D_pL_np_n}{D_nL_pn_p}}$$

$p_n = \frac{n_i^2}{N_d}$ $\quad n_p = \frac{n_i^2}{N_A}$ $\quad \frac{p_n}{n_p} = \frac{N_A}{N_d}$

$$= \frac{1}{1+\left(\frac{D_pL_n}{D_nL_p}\cdot\frac{N_a}{N_d}\right)}$$

when $n_n >> p_p$, $N_d >> N_a$, $\therefore \frac{N_a}{N_d}$ approaches 0

$\therefore$ denominator approaches 1 and $\frac{I_n}{I}$ also approaches 1 (100%)

Increasing the n-side doping relative to the p-side ($n_n >> p_p$) ensures that almost all the current is carried by electrons.

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channel $\frac{1}{2}$ width $a = 10^{-4}$ cm $\qquad n_i = 1.5\times10^{10}\ cm^{-3}$

channel doping $N_d = 10^{16}\ cm^{-3}$ $\qquad \varepsilon_{Si} = \varepsilon_R\varepsilon_0 = 1.044\times10^{-14}$ F/cm

gate doping $N_a = 10^{18}\ cm^{-3}$ $\qquad k_BT/q = .0259$ $\qquad q = 1.6\times10^{-19}$

$$V_{bi} = \frac{k_BT}{q}\left(\frac{N_aN_d}{n_i^2}\right) = .0259\left(\frac{10^{18}\times10^{16}}{2.25\times10^{20}}\right) = .814\ V$$

$$V_p = \frac{qa^2}{2\varepsilon}\left(\frac{N_aN_d}{N_a+N_d}\right) = \frac{(1.6E{-19})(10^{-4})^2}{2\times1.044E{-12}}\left(\frac{10^{18}\times10^{16}}{10^{18}+10^{16}}\right) = 7.59\ V$$

$$V_{GD} = V_{bi} - V_p = .814 - 7.585 = -6.77\ V$$

for $V_G = -3V$

saturation gate voltage $V_{DSAT} = V_G - V_{GD(\text{pinch off})}$

$= -3V - {}^-6.77$

$= 3.77V$

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$Z/L = 10$ $\qquad N_d = 10^{16}\ cm^{-3}$ $\qquad$ pinch off voltage $V_p = 7.585$ V

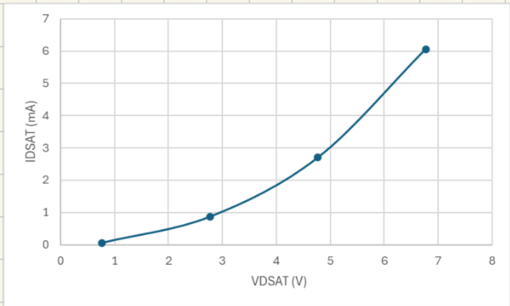
$\mu_n = 1000\ cm^2/V\cdot s$ $\qquad V_0 = .814$ V

$a = 10^{-4}$ cm $\qquad$ Gate-drain pinch off $V_{GD} = -6.77$ V

$$V_{DSAT} = V_{GS} - V_{GD}^P \qquad I_{DSAT} = \frac{2q\mu_nN_daZ}{L}\left\{\left(V_{GS}-V_{GD}^P\right) - \frac{2}{3}\left(V_0 - V_{GD}^P\right)\left[1-\left(\frac{V_0-V_{GS}}{V_0-V_{GD}^P}\right)^{3/2}\right]\right\}$$

$$= 2\times(1.6\times10^{-19})(1000)(10^{16})(10^{-4})(10) = 3.2\ mA/V$$

VGS (V)	VDSAT (V)	IDSAT (mA)
0	6.77	6.06
-2	4.77	2.7
-4	2.77	0.87
-6	0.77	0.06



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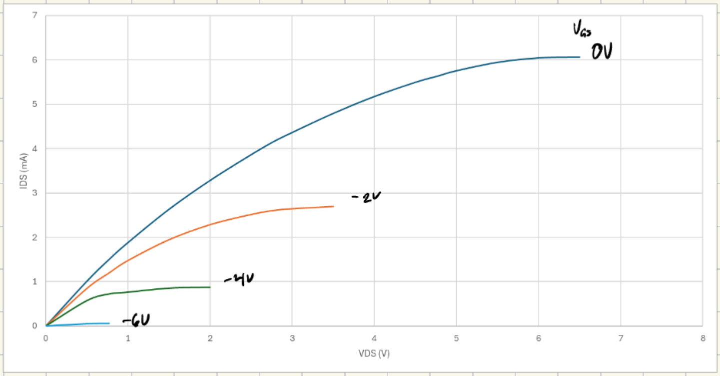
$$I_{DS} = \underset{\underset{3.2\ mA}{\downarrow}}{2q\mu_n N_d a}\frac{Z}{L}\left\{V_{DS} - \frac{2}{3}(V_0 - V_{GO}^P)\left[\left(\frac{V_{DS}+V_0-V_G}{V_0 - V_{GD}^P}\right)^{2/3} - \underbrace{\left(\frac{V_0-V_G}{V_0-V_{GO}^P}\right)}_{7.585}{}^{2/3}\right]\right\}$$

.84V

Vds (V)	Id (mA) @ Vgs=0V	Id (mA) @ Vgs=-2V	Id (mA) @ Vgs=-4V	Id (mA) @ Vgs=-6V
0	0	0	0	0
0.5	1.01	0.85	0.57	0.05
0.77	1.5	1.2	0.72	0.06
1	1.88	1.48	0.76	
1.5	2.63	1.95	0.85	
2	3.28	2.29	0.87	
2.5	3.86	2.52		
2.77	4.15	2.61		
3	4.36	2.65		
3.5	4.79	2.7		sat
4	5.17		sat	
4.5	5.49			
4.77	5.63	sat		
5	5.75			
5.5	5.94			
6	6.04			
6.5	6.06			
6.77	sat			



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$a = 10^{-3}$ cm

$N_d = 7E17$

$Z/L = 20$

$\epsilon = 1.044E-12$

$V_p = \frac{8a^2 N_d}{2\epsilon} = 5.36V$

$V_{bi} = V_p - V_{DSAT}(0V) = 5.36V - 4.35 = 1.01\ V$

$V_{GO}^P = V_{bi} - V_p = 1.01 - 5.36 = -4.35$

$V_{DSAT} = V_{GS} - V_{GD}^P$

$$I_{DS} = \underbrace{2q\mu_n N_d a}\frac{Z}{L}\left\{V_{DS} - \frac{2}{3}(V_0 - V_{GO}^P)\left[\left(\frac{V_{DS}+V_0-V_G}{V_0 - V_{GD}^P}\right)^{2/3} - \left(\frac{V_0-V_G}{V_0-V_{GO}^P}\right)^{2/3}\right]\right\}$$

Vds (V)	Id (mA) @ Vgs=0V	Id (mA) @ Vgs=-1V	Id (mA) @ Vgs=-2V	Id (mA) @ Vgs=-3V	Id (mA) @ Vgs=-4V	Id (mA) @ Vgs=-5V
0	0	0	0	0	0	0
0.5	4.38	3.51	2.52	1.44	0.35	0
1	8.16	6.37	4.34	2.05	0.35	0
1.5	11.36	8.58	5.38	2.05	0.35	0
2	13.99	10.15	5.38	2.05	0.35	0
2.5	16.03	11.08	5.38	2.05	0.35	0
3	17.43	11.08	5.38	2.05	0.35	0
3.5	18.15	11.08	5.38	2.05	0.35	0
4	18.25	11.08	5.38	2.05	0.35	0
4.35	18.26	11.08	5.38	2.05	0.35	0
4.5	18.26	11.08	5.38	2.05	0.35	0
5	18.26	11.08	5.38	2.05	0.35	0

All 0 because the pinch off voltage (V_P) threshhold is -4.35 V

@ $V_{GS} = -5V$ the JFET is in cutoff