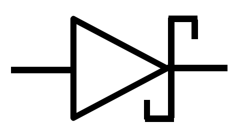
Session 5: MS junction

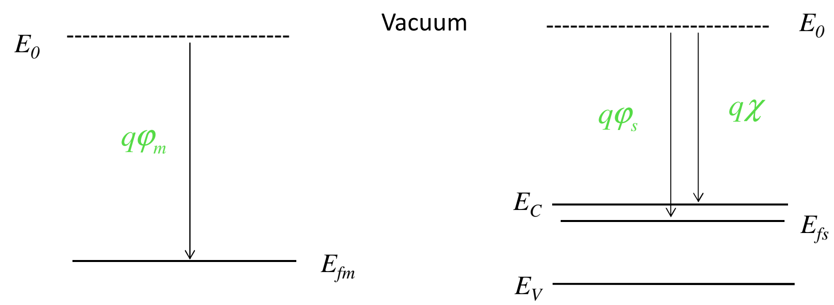
Solid State Devices:



MS Junctions: Electrostatics & IV curve

The Junction

MS junctions - Before being joined



$q\varphi_m$ work function (4.75eV for Au)

$q\chi$ electron affinity(4eV for Si)

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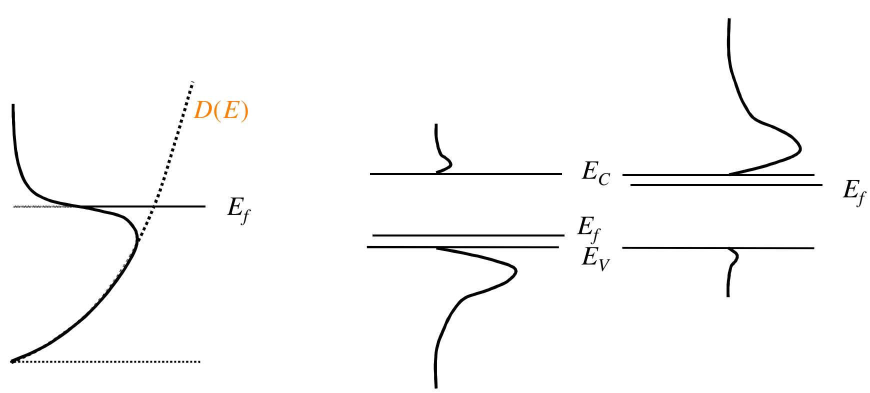
Reminder



metal

p-type

n-type

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Plotting Energy Band for MS junction

Step by step:

1. Vacuum energy (E_0) is continuous.
2. E_G and χ are intrinsic properties of materials and should remain constant. (which means E_C, E_V, and E_0 are all parallel)
3. At equilibrium E_f is constant while by applying voltage ΔE_f=-qV .

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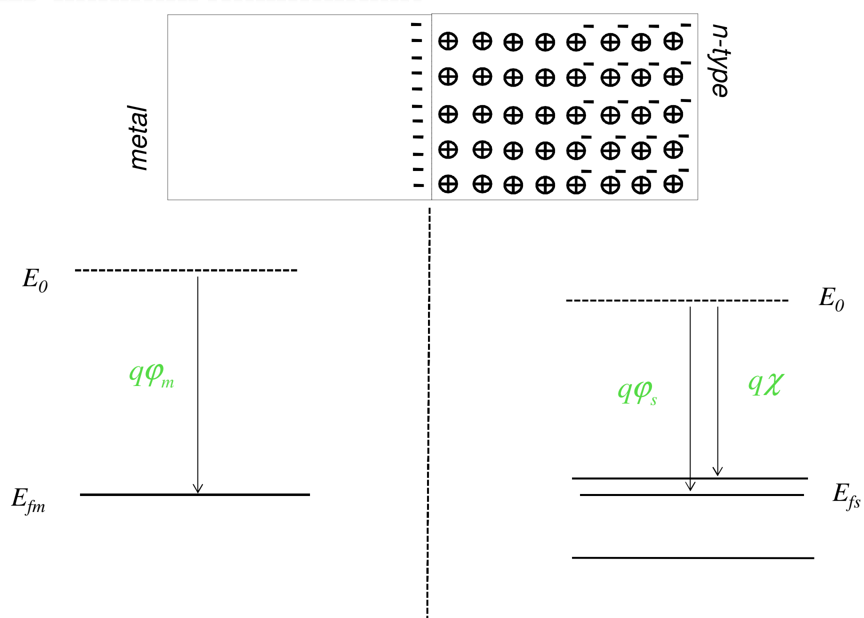
MS junction (Qualitative)



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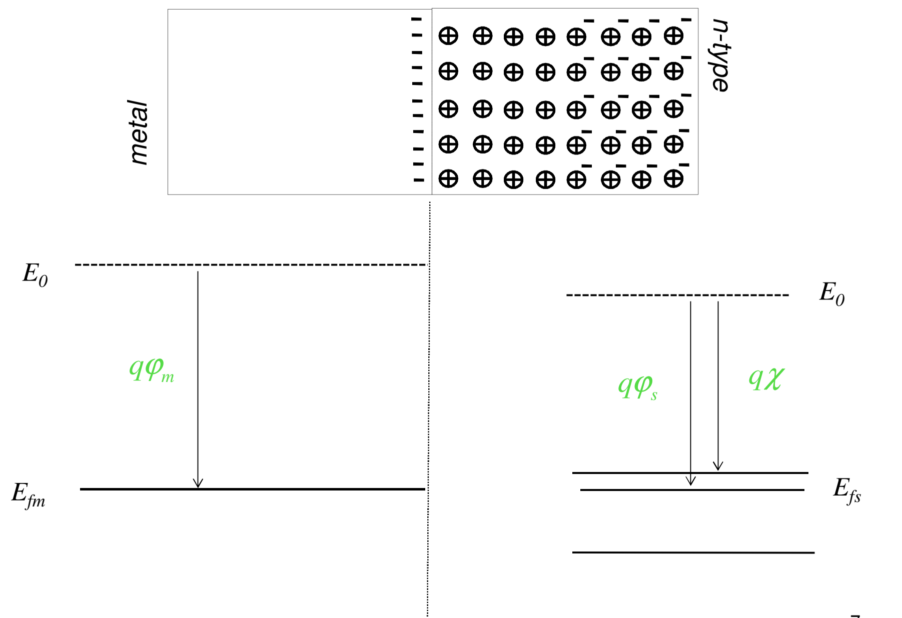
MS junction (Qualitative)



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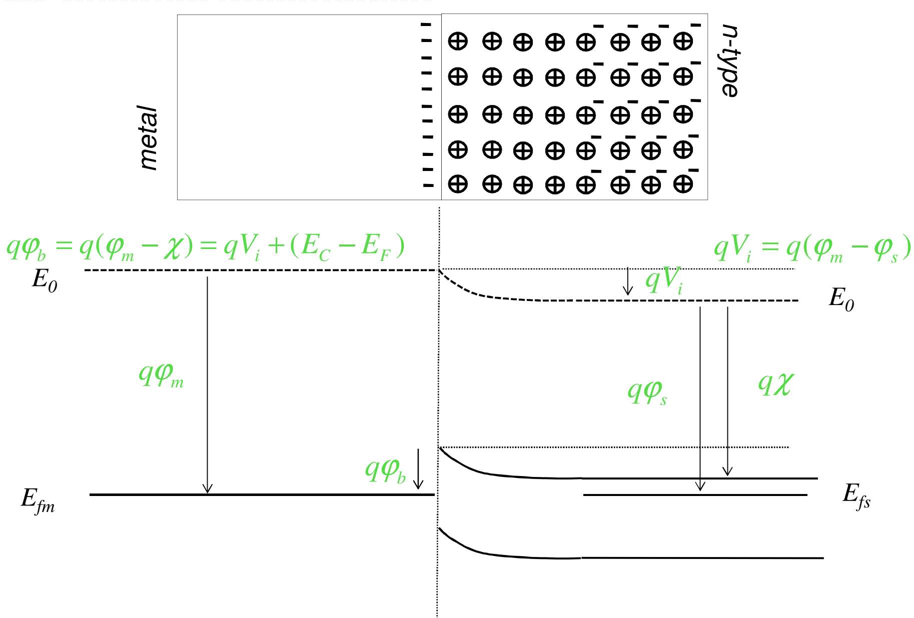
MS junction (Qualitative)



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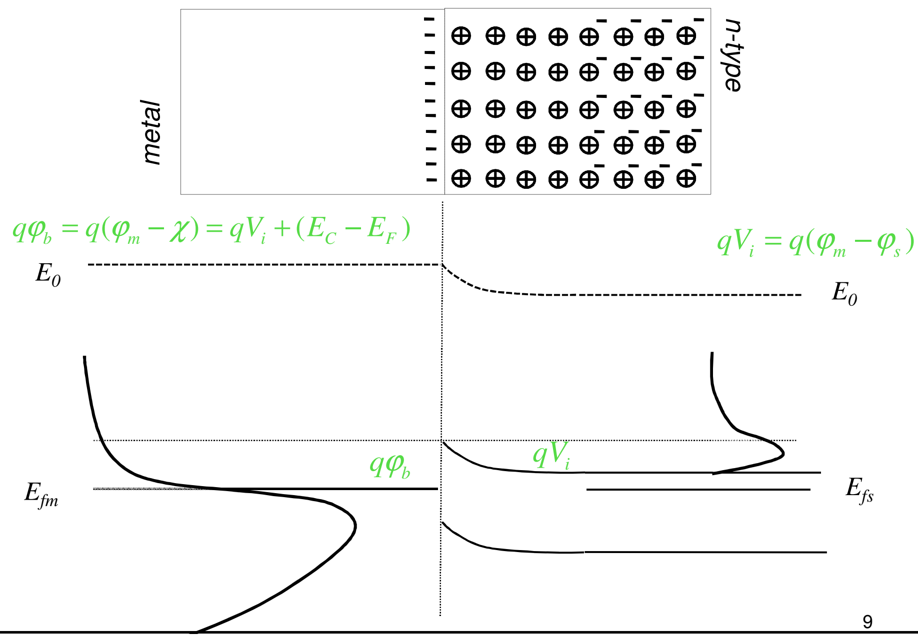
MS junction (Qualitative)



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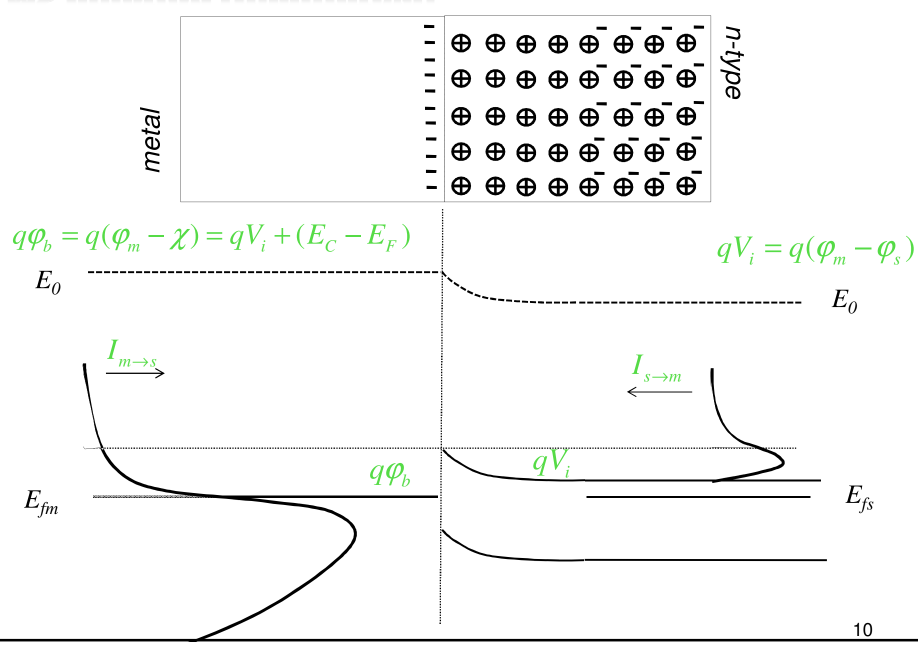
MS junction (Qualitative)



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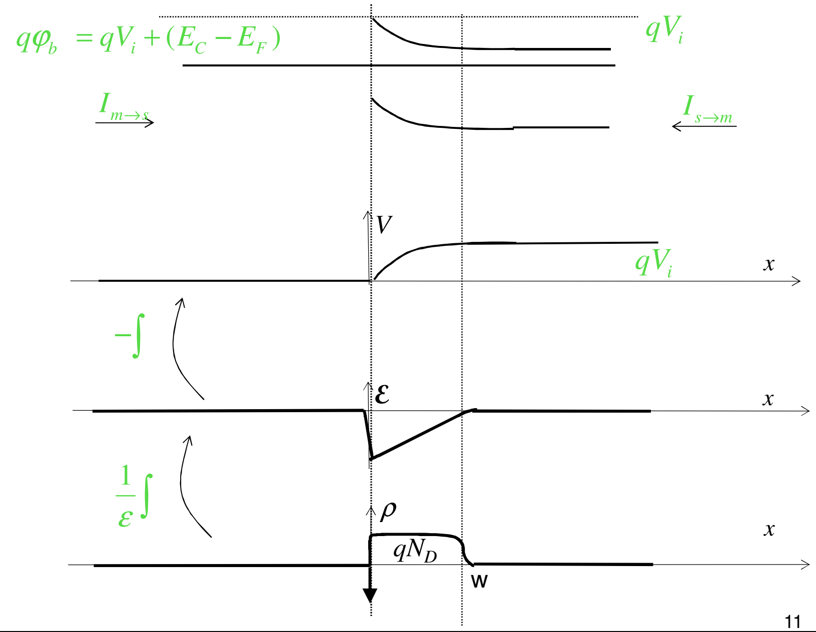
MS junction (Quantitative)



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MS junction (Schottky Effect)

$$\mathcal{E}(0) = -qN_D W/\varepsilon$$

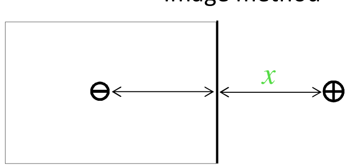
$$V_i = \tfrac{1}{2}W\mathcal{E}(0) = qN_D W^2/2\varepsilon$$

$$W = \sqrt{\frac{2\varepsilon}{qN_D}(V_i - V_a)} \qquad \mathcal{E}(0) = -\sqrt{\frac{2qN_D}{\varepsilon}(V_i - V_a)}$$

as $qV_i = q(\varphi_m - \varphi_s)$ seems that Vi is independent of the applied voltage

But it is not! This is known as "Schottky Effect." This will lower Vi (φb) a little bit.

Image method



$$F(x) = \frac{-q^2}{16\pi\varepsilon x^2} \rightarrow \varphi(x) = -qV(x) = \frac{-q^2}{16\pi x}$$

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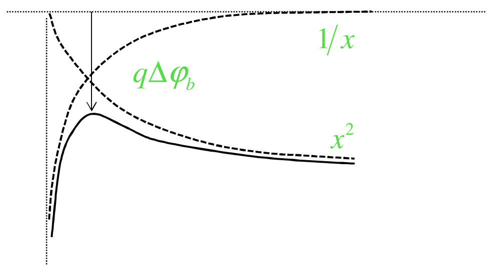
MS junction , I-V Curve



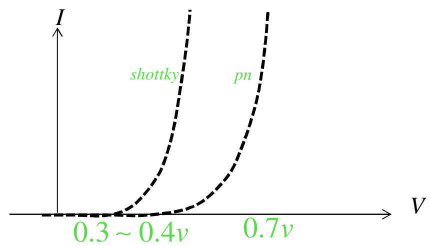
$$\varphi_b' = \varphi_b - \Delta\varphi_b$$

$$\Delta\varphi_b = \sqrt[4]{\frac{q^3 N_D}{8\pi^2\varepsilon^2}(V_i - V_a)}$$

$$I_{m\to s} = AR^*T^2 e^{-q(\varphi_b' - V_a)/kT}$$

$$I_{s\to m} = -AR^*T^2 e^{-q\varphi_b'/kT}$$

$$I = I_{m\to s} - I_{s\to m} = AR^*T^2 e^{-q\varphi_b'/kT}\left[e^{qV_a/kT} - 1\right] = I_s(e^{qV_a/kT} - 1)$$



$$I_{s-shottky} \approx 100 - 1000 I_{0-pn}$$

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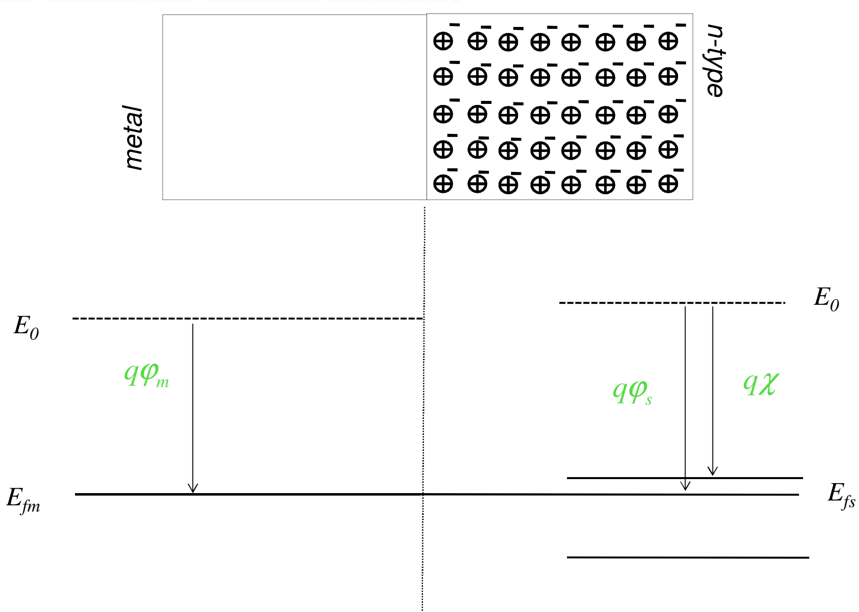
MS junction, Ohmic contact



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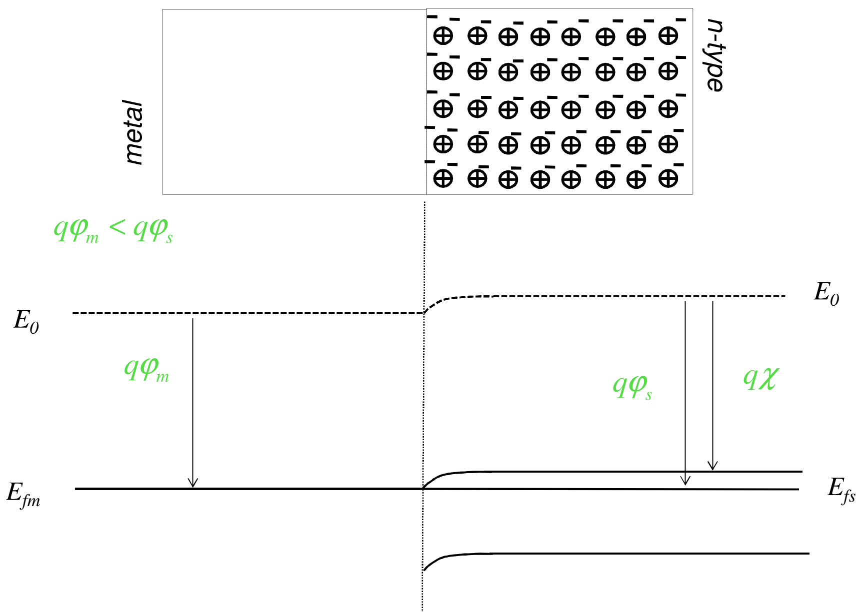
MS junction, Ohmic contact



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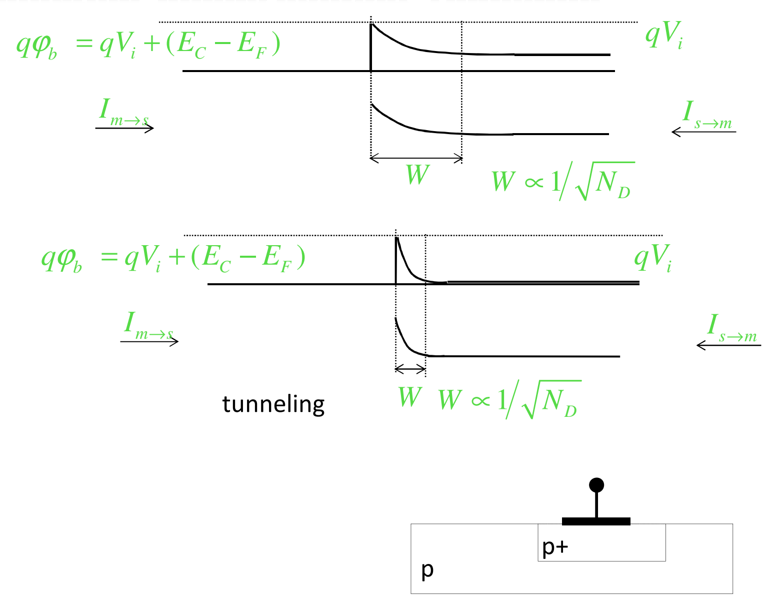
MS junction, Ohmic contact, Tunneling



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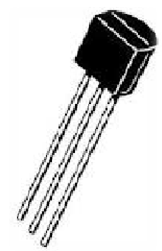

FET: Electrostatics & IV curve

The Junction FET

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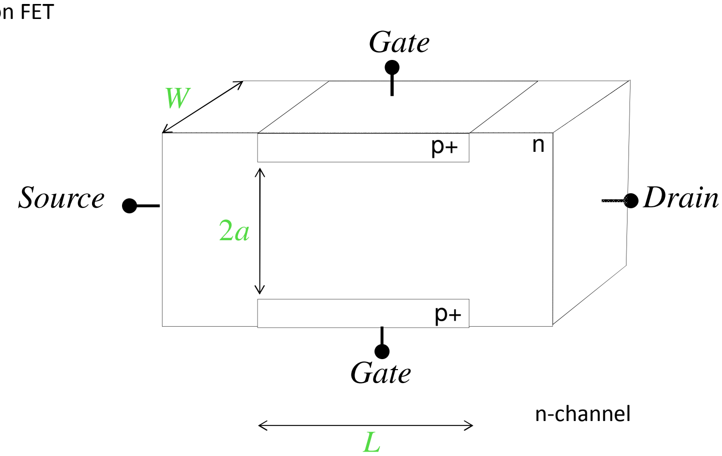
JFET (Qualitative)

Junction FET



n-channel

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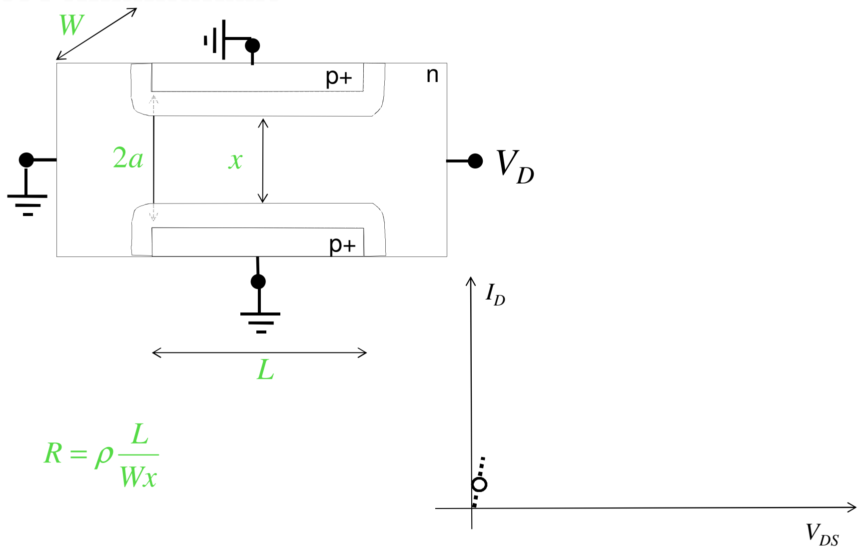
JFET (Qualitative)



$$R = \rho \frac{L}{Wx}$$

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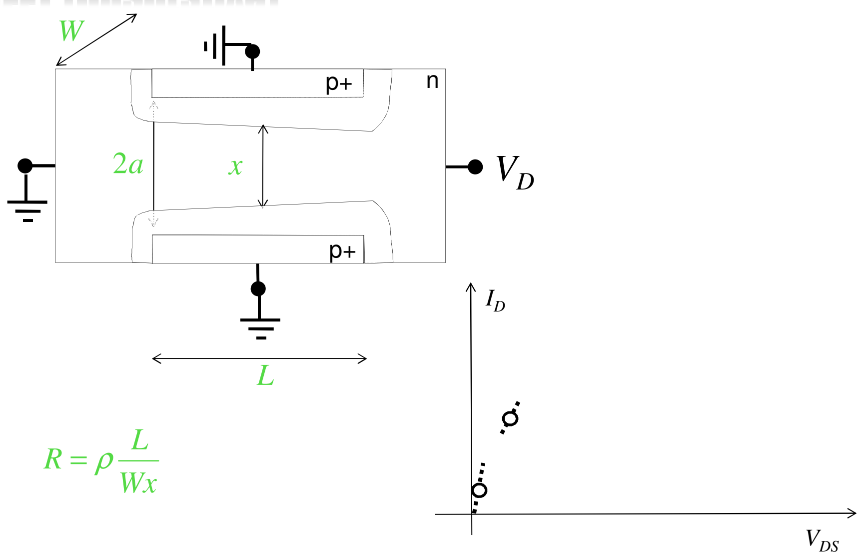
JFET (Qualitative)



$$R = \rho \frac{L}{Wx}$$

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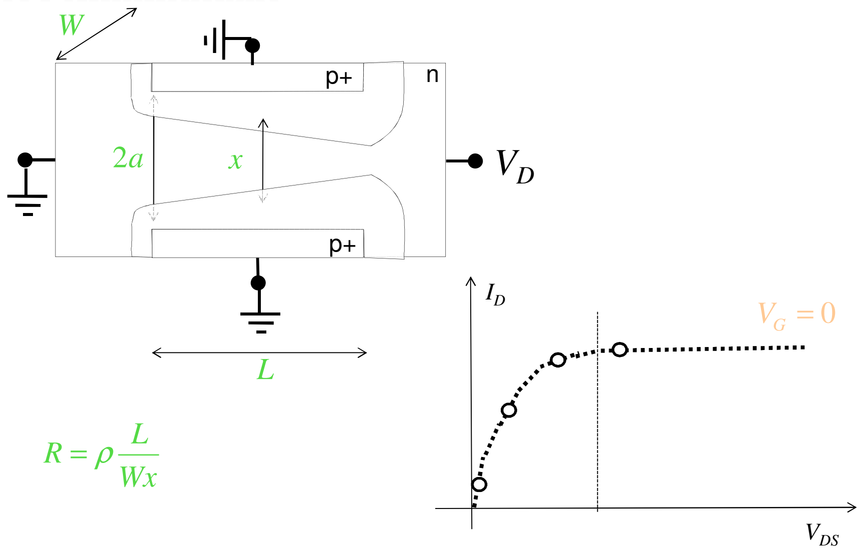
JFET (Qualitative)



$$R = \rho \frac{L}{Wx}$$

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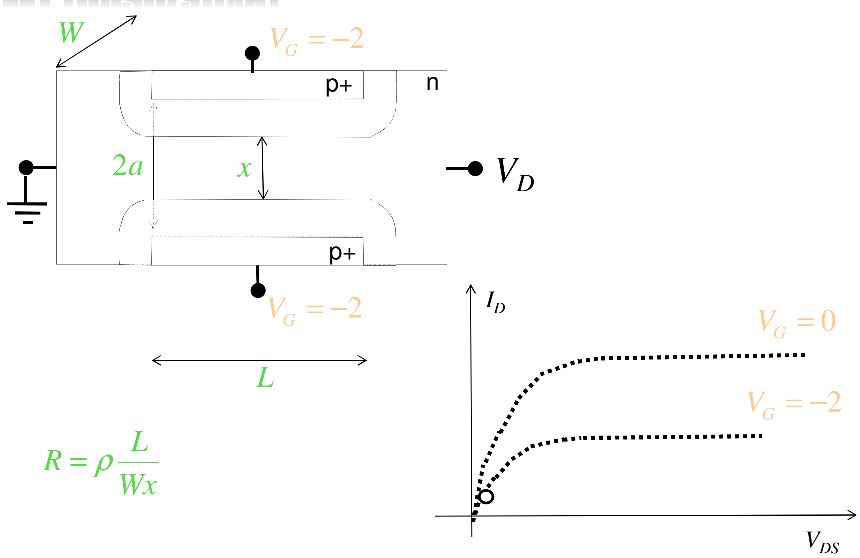
JFET (Qualitative)



$$R = \rho \frac{L}{Wx}$$

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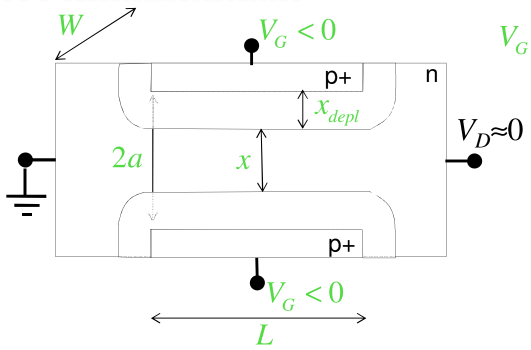
JFET (Quantitative)



$$V_G=0\rightarrow \quad x_{depl}=\sqrt{\frac{2\varepsilon}{qN_D}\varphi_0}$$

$$\varphi_0=\frac{kT}{q}\ln\left(\frac{N_AN_D}{n_i^2}\right)$$

$$\varphi_0=\frac{E_G}{2q}+\frac{kT}{q}\ln\left(\frac{N_D}{n_i}\right)$$

$$x_{depl}=\sqrt{\frac{2\varepsilon}{qN_D}(\varphi_0-V_G)}$$

$$\delta I_D=\sigma\frac{A}{L}\delta V_D=q\mu_nN_D\frac{2(a-x_{depl})W}{L}\delta V_D$$

Pinch-off $\quad x_{depl}=a\rightarrow V_p=\varphi_0-\frac{qN_Da^2}{2\varepsilon}$

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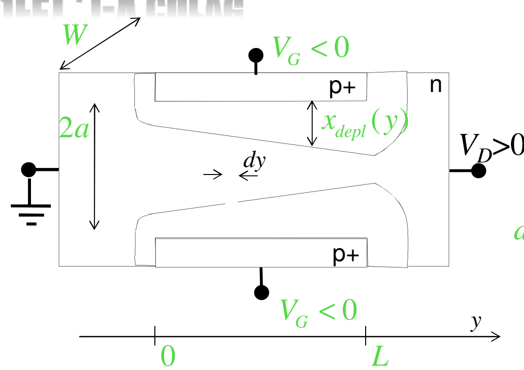
JFET , I-V curve



$$x_{depl}=\sqrt{\frac{2\varepsilon}{qN_D}(\varphi_0-V_G+V(y))}$$

B.D. $\quad V(0)=0, V(L)=V_D$

$$dR(y)=\frac{1}{q\mu_nN_D}\frac{dy}{2(a-x_{delp}(y))W}$$

$$dV(y)=I_DdR(y)$$

$$dV(y)=\frac{I_D}{q\mu_nN_D}\frac{dy}{2(a-x_{delp}(y))W}$$

$$2q\mu_nN_D\int_0^{V_D}\left[a-\sqrt{\frac{2\varepsilon}{qN_D}(\varphi_0-V_G+V(y))}\right]dy=I_D\int_0^{L}dy=I_DL$$

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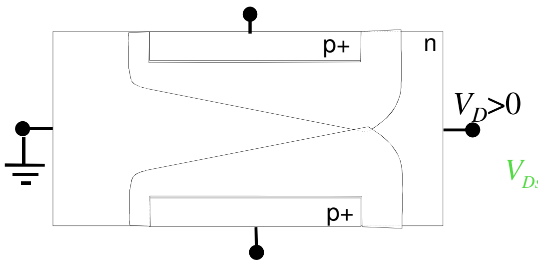
JFET , I-V curve

$$I_D = g_0\left\{V_D - \tfrac{2}{3}\sqrt{\frac{2\varepsilon}{qN_D a^2}}\left((V_D+\varphi_0-V_G)^{3/2}-(\varphi_0-V_G)^{3/2}\right)\right\}$$

$$as\ g_0 = 2qN_D aW\mu_n/L$$



$$V_{Dsat} = V_G - V_P = V_G - \varphi_0 + \frac{qN_D a^2}{2\varepsilon}$$

$$I_{Dsat} = I_D\big|_{V_D=V_{Dsat}} = g_0\left\{\frac{qN_D a^2}{6\varepsilon} - (\varphi_0-V_G) + \tfrac{2}{3}\sqrt{\frac{2\varepsilon}{qN_D a^2}}(\varphi_0-V_G)^{3/2}\right\}$$

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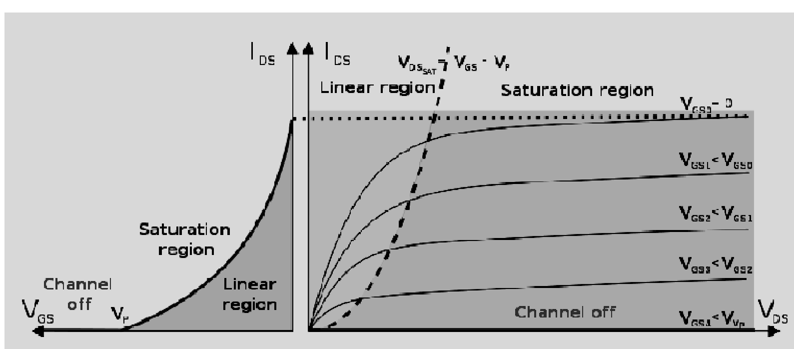
JFET , I-V curve



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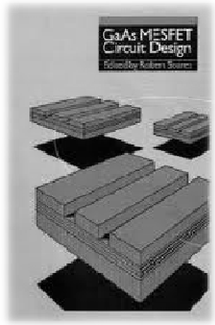


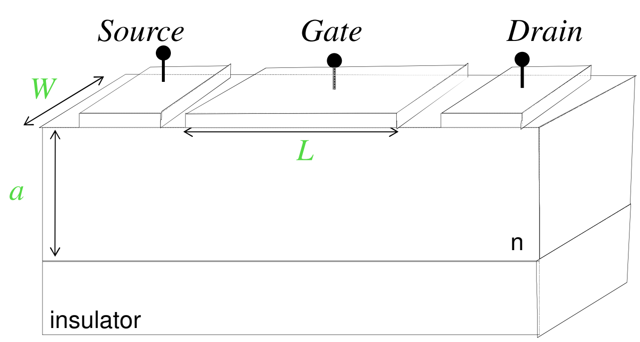
Metal Semiconductor FET: Electrostatics & IV curve

The MES FET

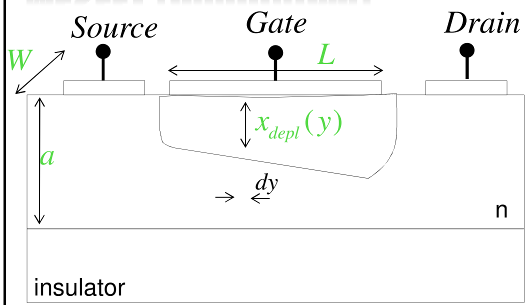
MESFET

MESFET (metal semiconductor field effect transistor)

f_T>100GHz



MESFET (Qualitative)



$$V_D = 0 \rightarrow x_{depl} = \sqrt{\frac{2\varepsilon}{qN_D}(V_i - V_G)}$$

$$x_{depl}\Big|_{V_G=V_{Th}} = a \rightarrow V_{Th} = V_i - \frac{qN_D a^2}{2\varepsilon}$$

$$V_D > 0 \rightarrow x_{depl}(y) = \sqrt{\frac{2\varepsilon}{qN_D}(V_i - V_G + V(y))}$$

$$V(0) = 0, V(L) = V_D$$

$$dV = I_D dR = I_D \frac{1}{q\mu_n N_D}\frac{dy}{(a - x_{delp}(y))W} = \frac{I_D dy}{q\mu_n N_D (a - \sqrt{\frac{2\varepsilon}{qN_D}(V_i - V_G + V(y))})}$$

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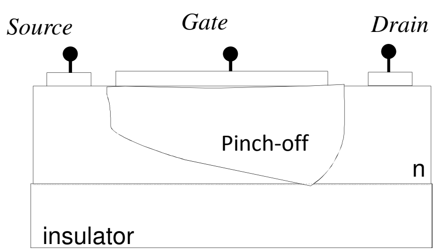
MESFET (Qualitative)

$$I_D = g_0\left(V_D - \frac{2}{\sqrt{V_p}}\left[(V_D + V_i - V_G)^{3/2} - (V_i - V_G)^{3/2}\right]\right)$$

$$g_0 = \frac{1}{L} q\mu_n N_D W$$

$$V_p = \frac{qN_D a^2}{2\varepsilon}$$



$$V_{Dsat} = V_P - V_i + V_G = V_G - V_{Th}$$

$$I_{Dsat} = g_0\left(\frac{V_p}{3} + \frac{2}{\sqrt[3]{V_p}}(V_i - V_G)^{3/2} - V_i + V_G\right)$$

$$g_m = \frac{\partial I_D}{\partial V_G}\Big|_{V_D} = g_0\left(1 - \sqrt{\frac{V_i - V_G}{V_p}}\right)$$

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