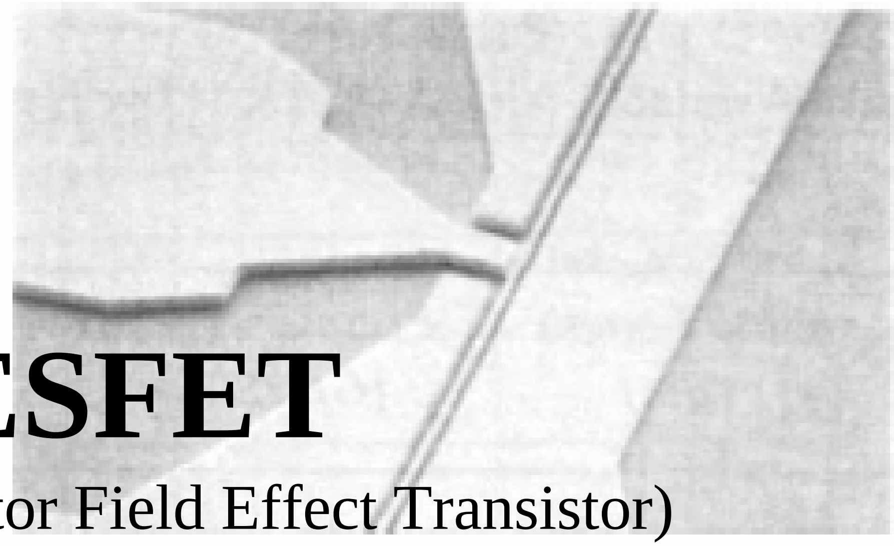
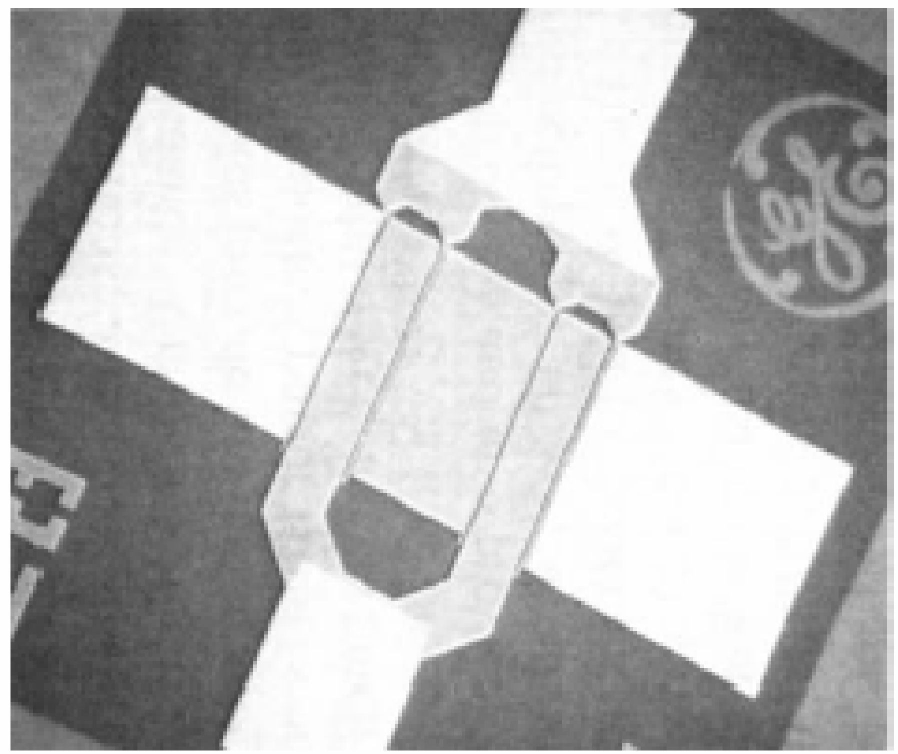


MESFET

(Metal Semiconductor Field Effect Transistor)



Stephen Nowell

gth253a

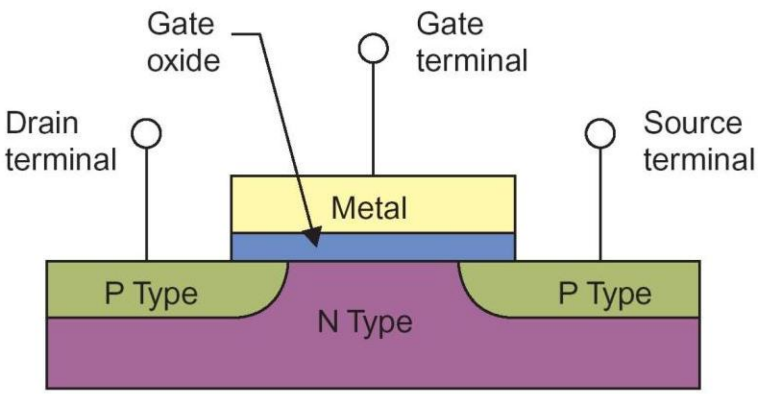
ECE 3080

Spring 2008

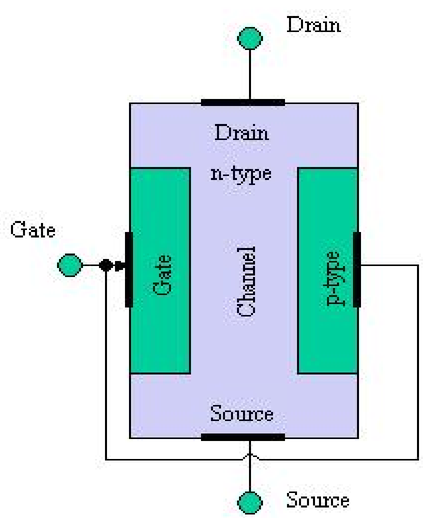
W.Alan Doolittle

Image from E.F.Schubert, Rensselaer Polytechnic Institute, 2003

Quick Comparison to Other FETS



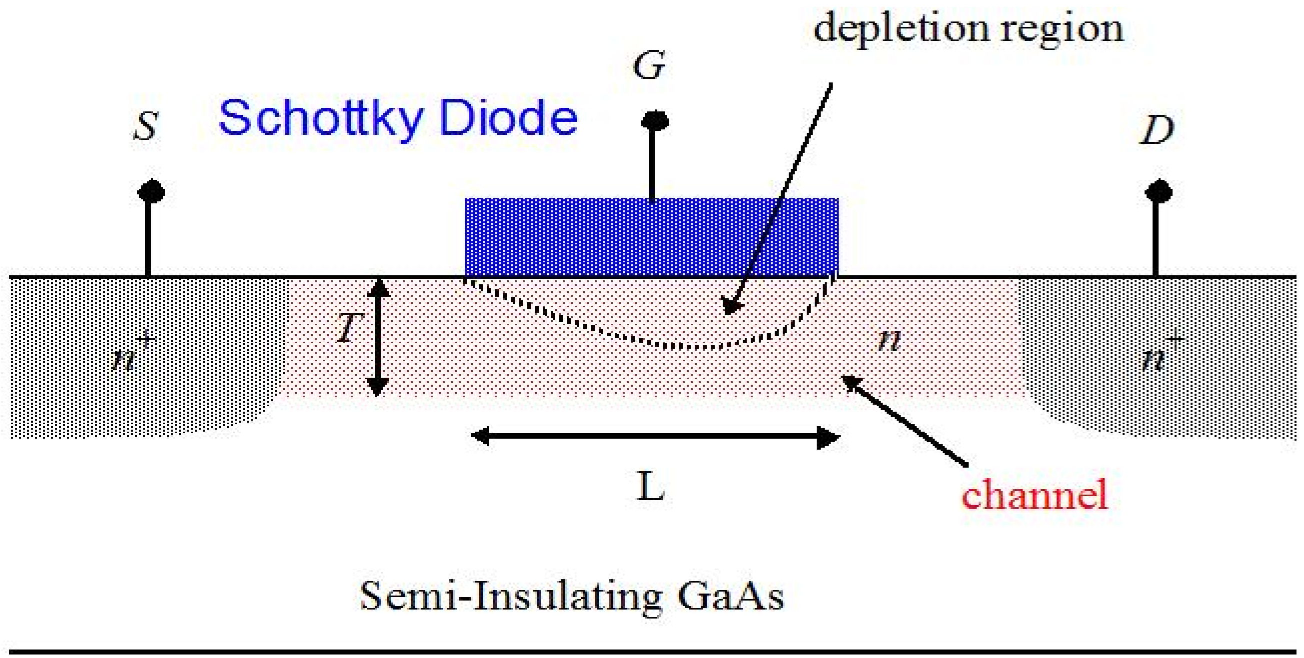
- MOSFETs form a channel with inversion and have an oxide gate.



- JFETs deplete the channel to cut off current flow.

Mosfet image from http://info.tuwien.ac.at/theochem/si-srtio3_interface/mosfet.jpg and Jfet image from http://www.onr.navy.mil/sci_tech/31/312/ncsr/devices/jfet.asp

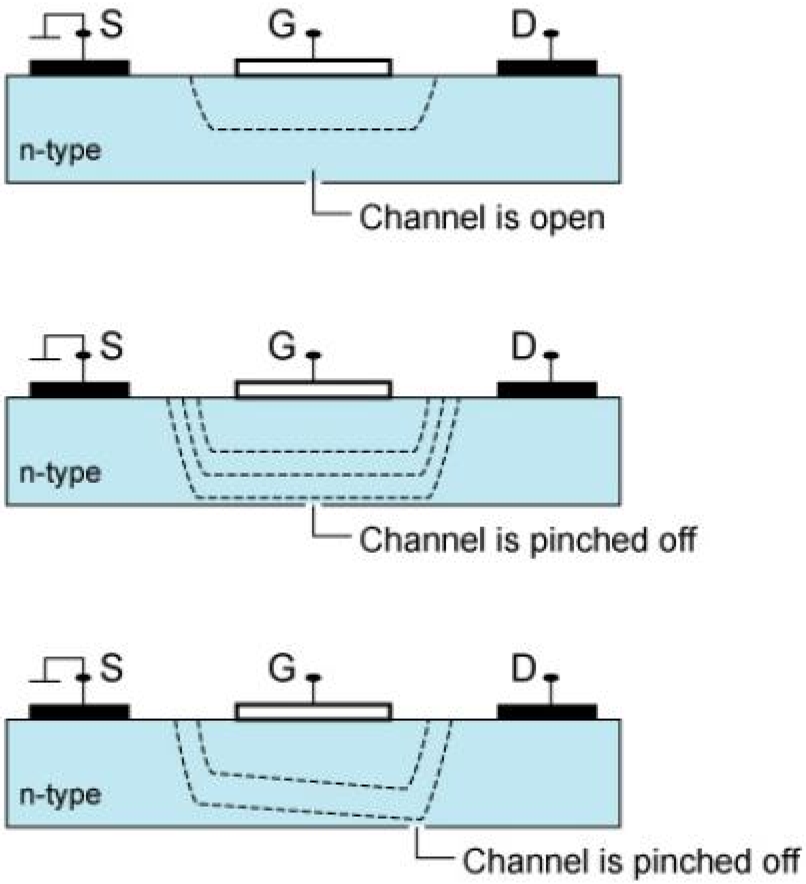
The MESFET



- MESFETs (MEtal Semiconductor Field Effect Transistor) have a metal gate, not oxide, and work similar to JFETs by pinching off the conducting channel.

Image from Digital Circuits High Speed, prentice hall 2005

Bias on the MESFET



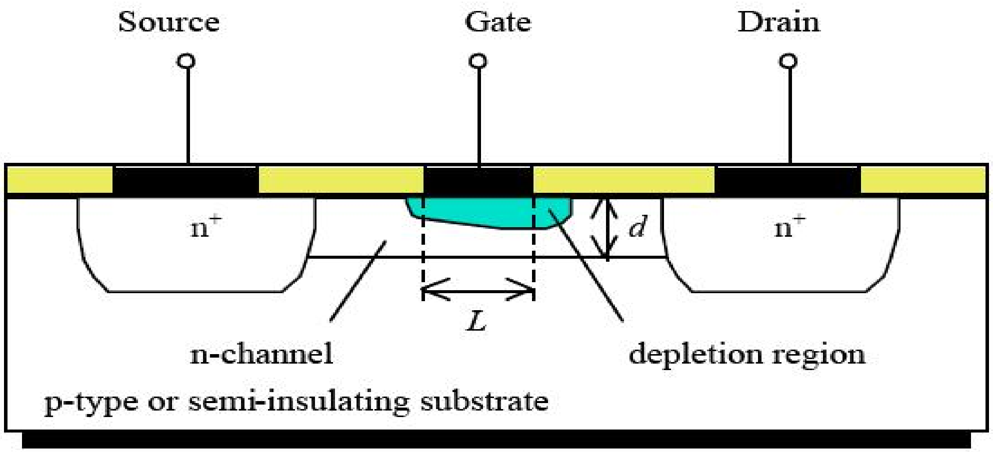
- With no voltage's applied electrons are not inhibited or motivated to flow.

- No voltage across source and drain, but reverse bias on the gate. With enough reverse bias channel is pinched and no electrons can flow.

- Voltage across the drain and source create a current and cause the depletion region to pinch off sooner on the drain side.

Image from http://www.ecse.rpi.edu/~schubert/Course-ECSE-6290%20SDM-2/1%20JFETs%20and%20MESFETs.pdf

Calculations



$$V_T = \phi_i - V_P$$

- V_T is the threshold voltage required to fully deplete the doped channel layer.

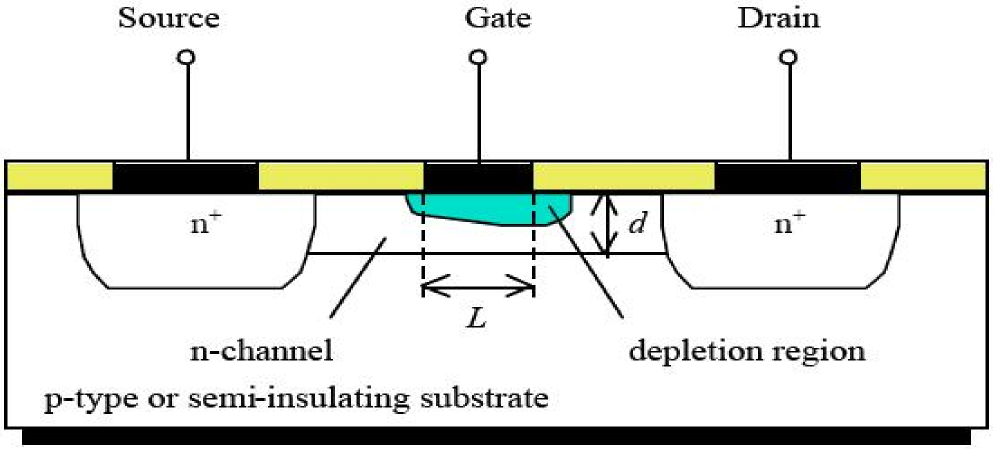
$$V_P = \frac{qN_d d^2}{2\varepsilon_s}$$

- V_P is the pinch-off voltage.

- ϕ_i is the built in potential.

Image of MOSFET and Images of Calculations from http://ece-www.colorado.edu/~bart/book/book/chapter3/pdf/ch3_6.pdf

Calculations cont.



$$J = qnv = qN_d \mu_n E$$

- Current density in the doped layer

$$I_D = -JW(d - x_n(y))$$

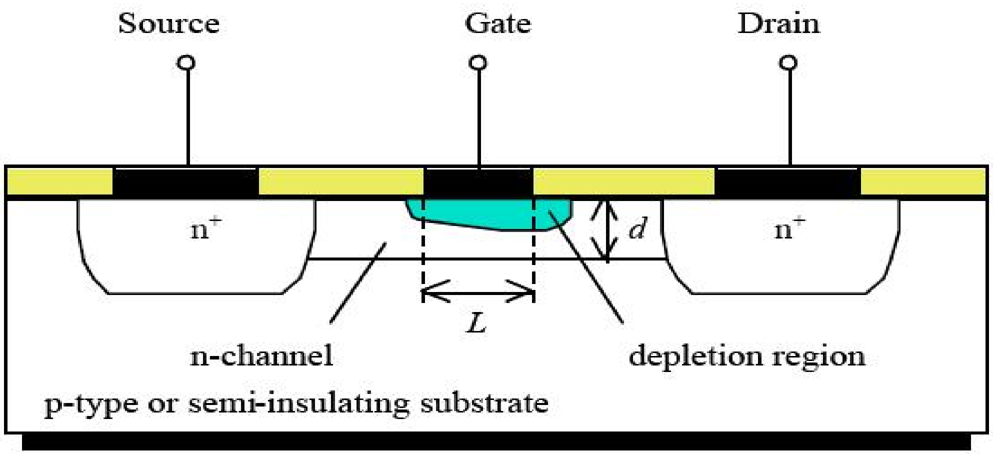
- Current in the doped layer

$$x_n(y) = \sqrt{\frac{2\varepsilon_s(\phi_i - V_G + V_C(y))}{qN_d}}$$

- Depletion layer width of the depletion region.

Image of MOSFET and Images of Calculations from http://ece-www.colorado.edu/~bart/book/book/chapter3/pdf/ch3_6.pdf

Calculations cont.

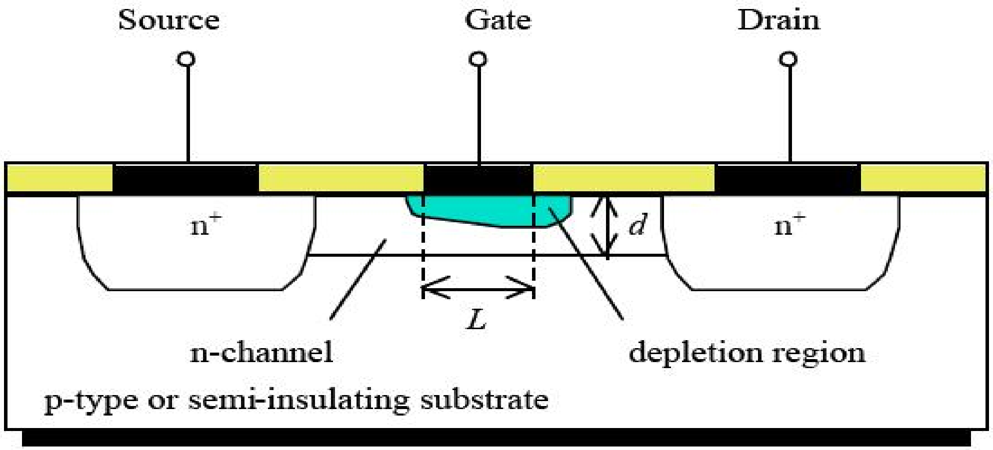


$$\int_0^L I_D \, dy = qN_d \mu_n dW \int_0^{V_D} \left(1 - \sqrt{\frac{\phi_i - V_G + V_C}{V_P}}\right) dV_C$$

- Integrating from the source to the drain we can calculate the current of the MESFET

Image of MOSFET and Images of Calculations from http://ece-www.colorado.edu/~bart/book/book/chapter3/pdf/ch3_6.pdf

Calculations cont.



$$I_D = qN_d\mu_n d\frac{W}{L}\left(V_C\Big|_0^{V_D} - \frac{(\phi_i - V_G + V_C)^{3/2}}{\sqrt{V_P}}\Bigg|_0^{V_D}\right)$$

$$I_D = q\mu_n N_d d\frac{W}{L}\left[V_D - \frac{2}{3}\left(\frac{(\phi_i - V_G + V_D)^{3/2}}{\sqrt{V_P}} - \frac{(\phi_i - V_G)^{3/2}}{\sqrt{V_P}}\right)\right]$$

- Equations are valid for $V_D \leq V_G - V_T$

Image of MOSFET and Images of Calculations from http://ece-www.colorado.edu/~bart/book/book/chapter3/pdf/ch3_6.pdf

Linear Region of the MESFET

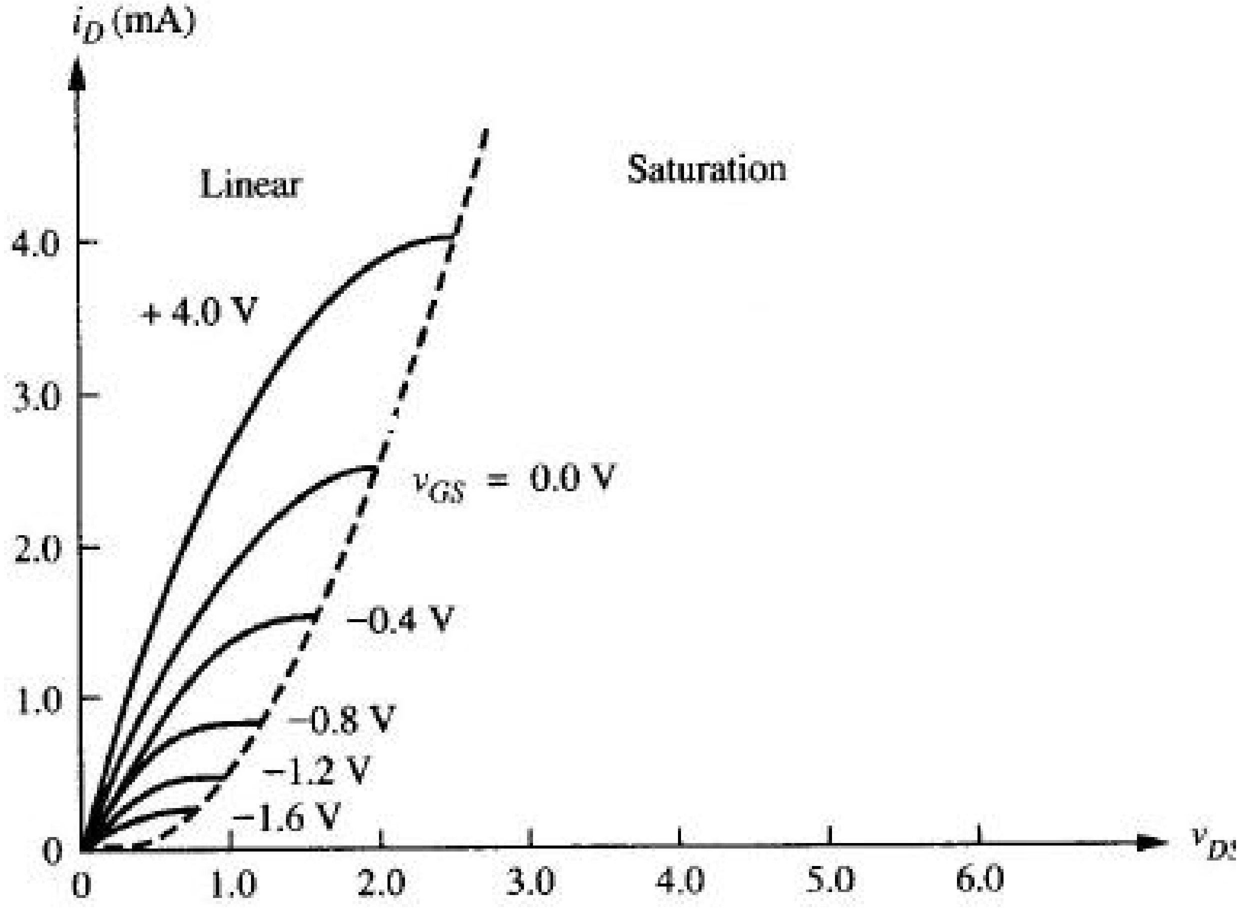


Image from http://ocw.mit.edu/NR/rdonlyres/Electrical-Engineering-and-Computer-Science/6-772Spring2003/6624143B-7CFF-4104-A127-43E3E3A4D0FC/0/Lecture9v2.pdf

Resistance in the Channel

$$R = \rho \frac{L_G}{A} = \rho \frac{L_G}{Z\,h(x)} = \frac{1}{e n \mu} \frac{L_G}{Z\left(W_{ch} - W_D\right)}$$

$$R = \frac{1}{e n \mu} \frac{L_G}{Z\left(W_{ch} - \sqrt{\frac{2\varepsilon}{e N_D}\left(-V_{GS}\right)}\right)}$$

- Resistance can be controlled by the gate voltage in the triode region. At $V_{GS} = -V_{PO}$ the resistance of the channel is infinite.

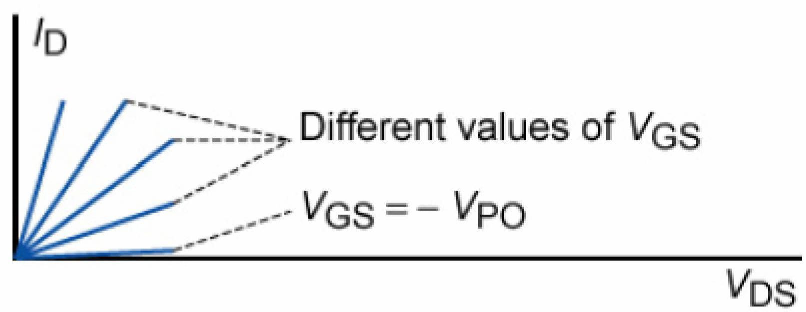
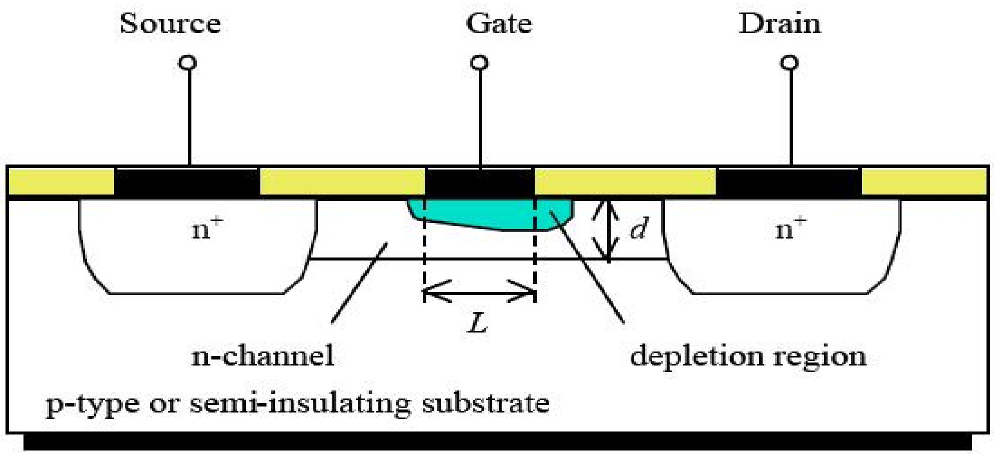


Image from http://www.ecse.rpi.edu/~schubert/Course-ECSE-6290%20SDM-2/1%20JFETs%20and%20MESFETs.pdf

More calculations



- For the condition when: $V_D = V_G - V_T = V_{D,sat}$

- The current saturates described by the following current equation for saturation current

$$I_{D,sat} = q\mu_n N_d d \frac{W}{L}\left[V_G - V_T - \frac{2}{3}\left(V_P - \frac{(\phi_i - V_G)^{3/2}}{\sqrt{V_P}}\right)\right]$$

Image of MOSFET and Images of Calculations from http://ece-www.colorado.edu/~bart/book/book/chapter3/pdf/ch3_6.pdf

Saturation Region

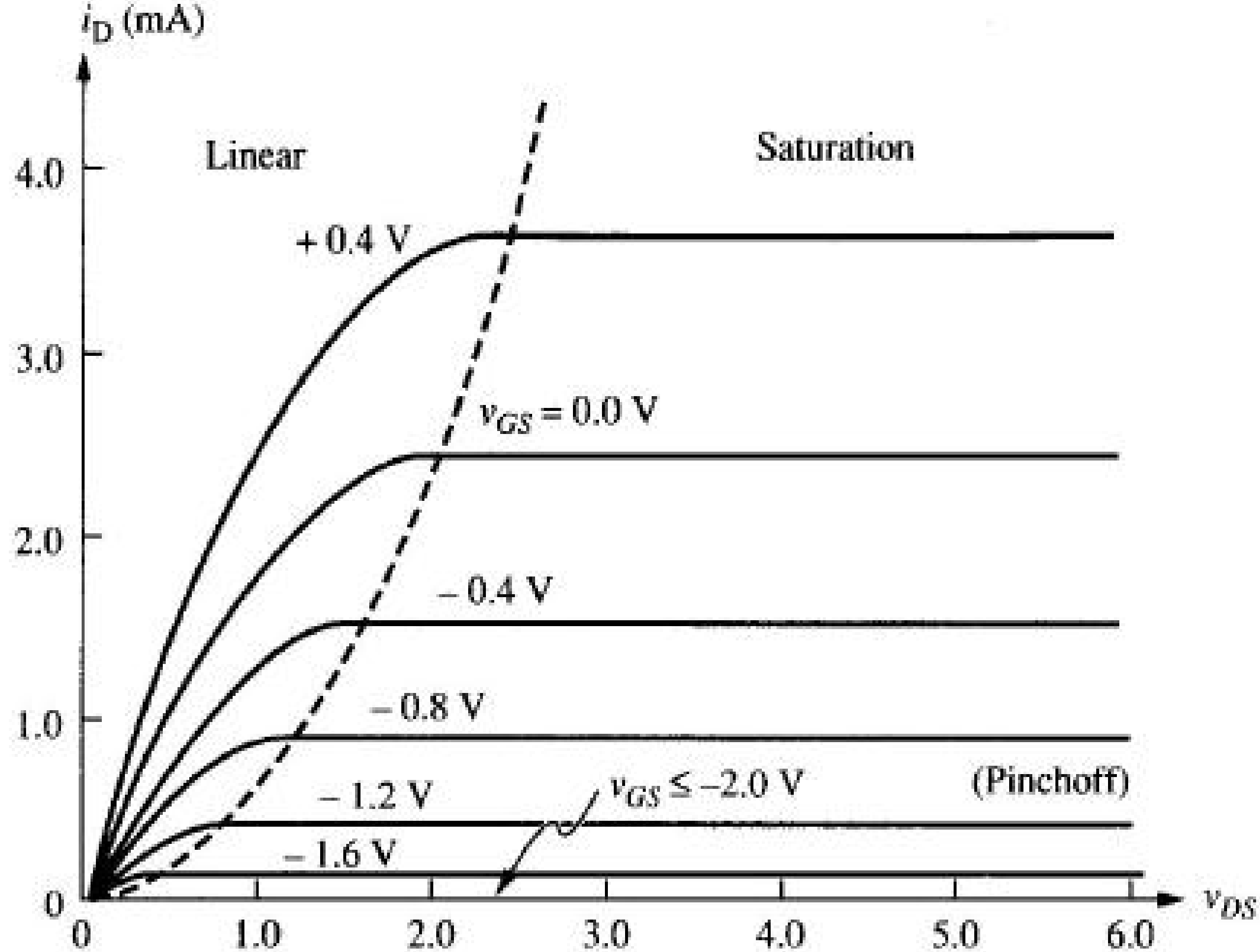


Image from http://ocw.mit.edu/NR/rdonlyres/Electrical-Engineering-and-Computer-Science/6-772Spring2003/6624143B-7CFF-4104-A127-43E3E3A4D0FC/0/Lecture9v2.pdf

Schottky Diode

- The metal contact of the gate creates a schottky diode.
- The presence of the diode limits the forward bias voltage of the gate to that of the diode turn on voltage.

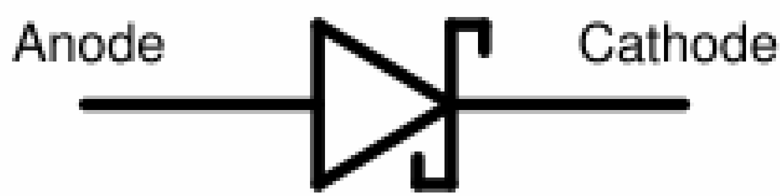
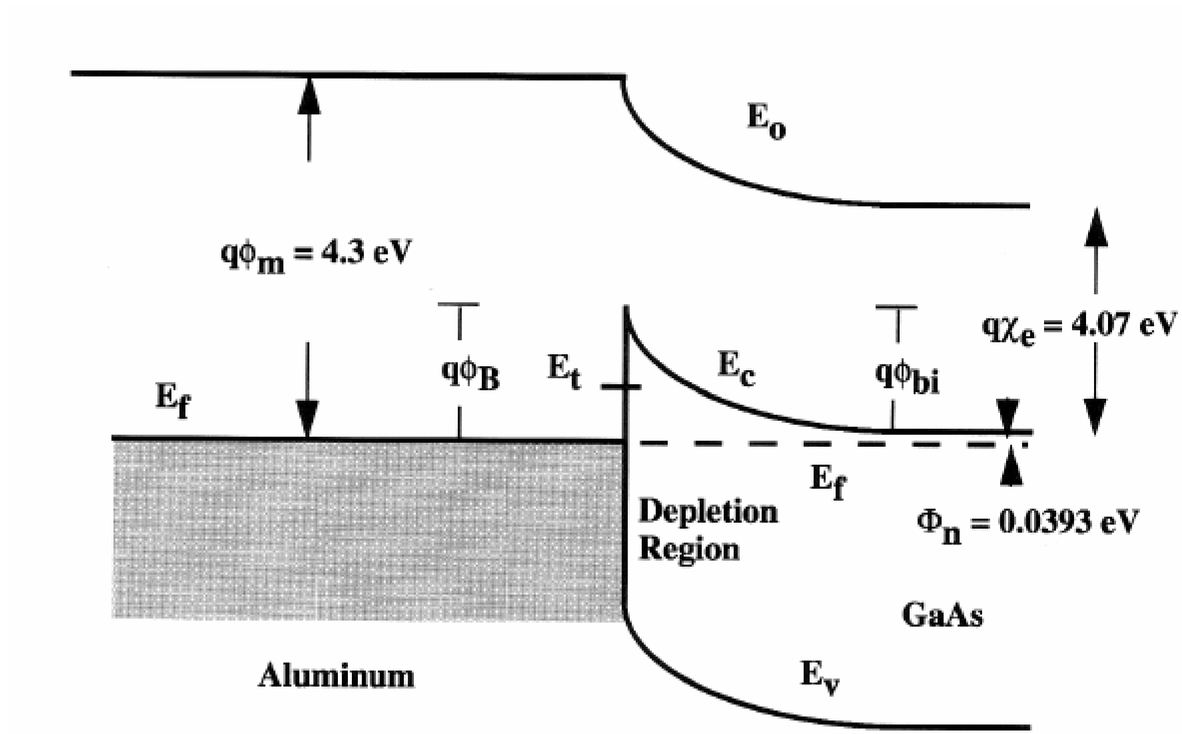


Image of Diode from http://en.wikipedia.org/wiki/Image:Schottky_diode_symbol.svg

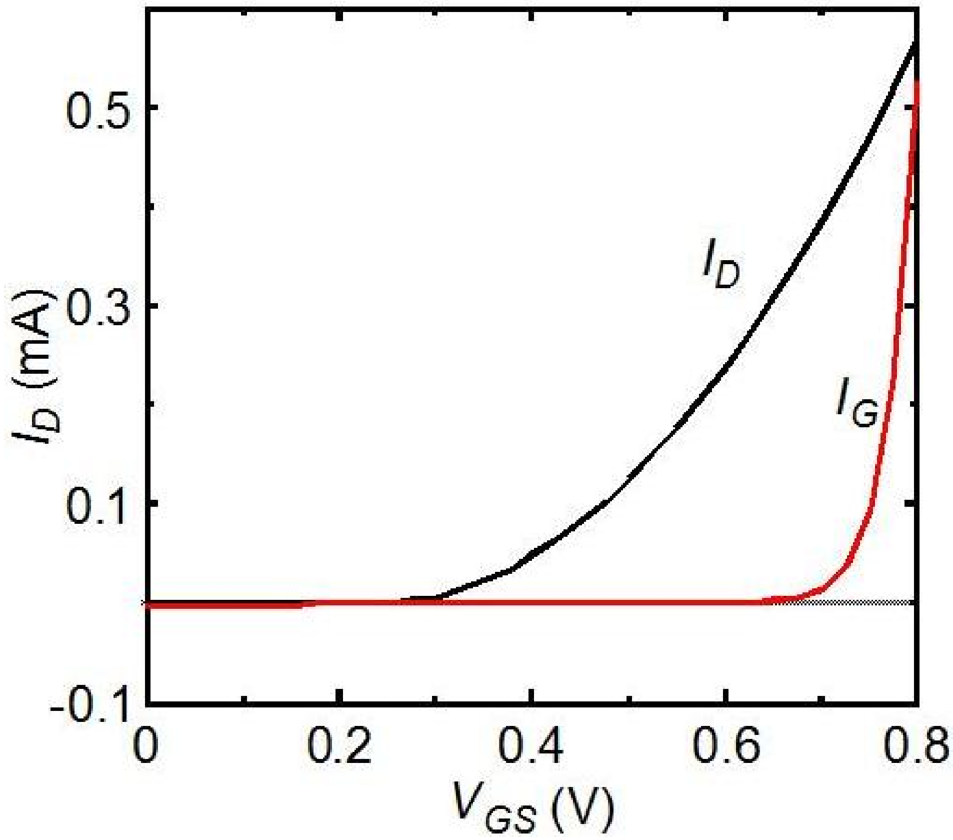
Schottky Barrier



- The gate behaves the same as a schottky diode with the schottky barrier.

Image from http://www.eas.asu.edu/~vasilesk/EEE532/mesfet_1.pdf

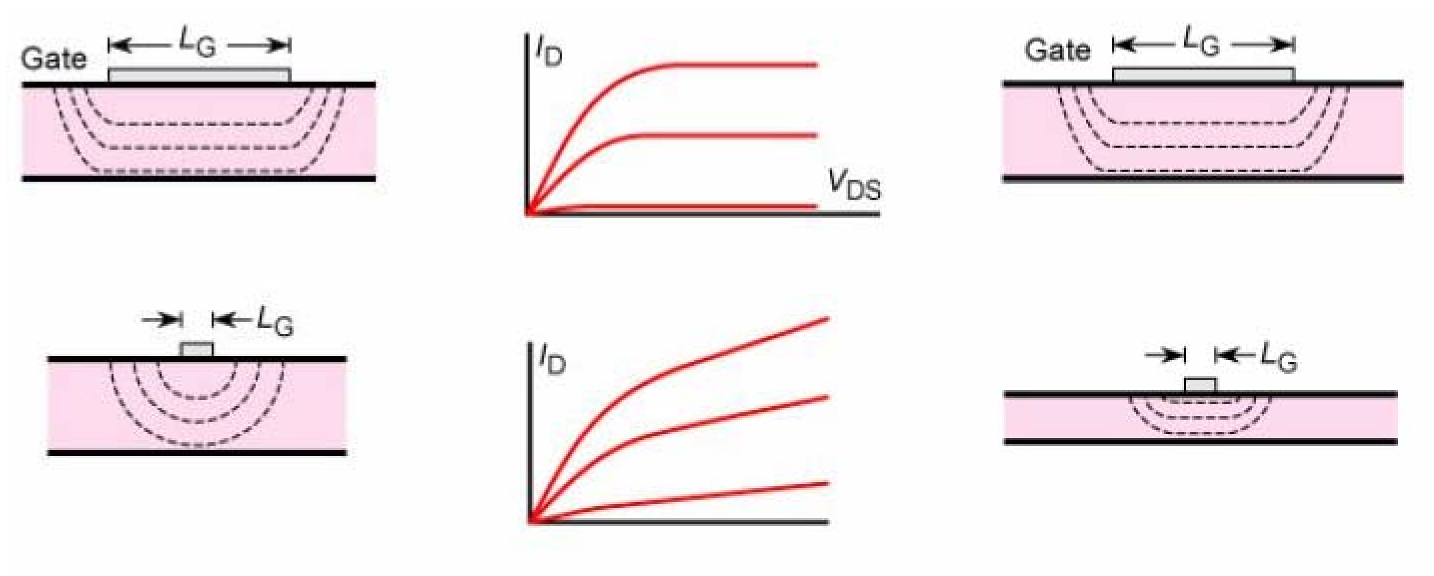
Diode Turned On



- When forward bias the diode turns on causing current to flow through the gate.

Image from Digital Circuits High Speed, prentice hall 2005

Other Considerations



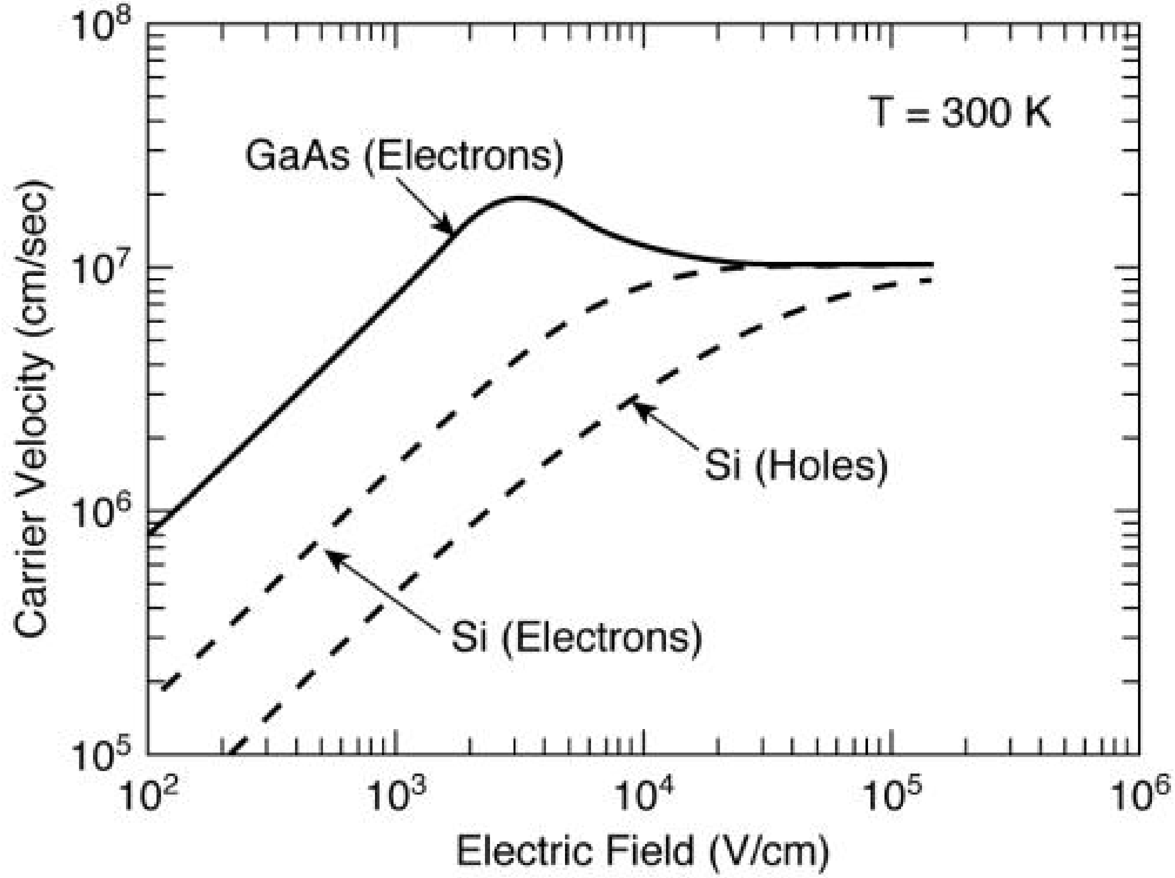
- Short-channel effect on depletion region. Selecting a gate that's too small will not pinch off properly but this can be corrected by adjusting the depth of the channel, doping, or fields strength.

Image from E.F.Schubert, Rensselaer Polytechnic Institute, 2003

Advantages

- Higher surface mobility of the carriers in the channel vs. MOSFET because carriers don’t go into the oxide.
- The depletion region separates the carriers from the surface.
- Can increase mobility by using GaAs over silicon MESFETs.
- Ease of fabrication compared to other FETs.

Mobility of GaAS



-Mobility of electrons GaAs (4000 – 9000) vs. Si (500 –1200)
-Maximum electron velocity of GaAs is 2x silicon electrons.
-Schottky barrier height GaAs 0.6V-0.8V vs. Si 0.4V- 0.6V.

Image from Digital Circuits High Speed, prentice hall 2005

GaAS vs. Silicon cont.

- Very low hole mobility GaAs 400 cm^2/V*sec vs. silicon 489 cm^2/V*sec meaning no complementary gates.
- Possible to fabricate semi-insulating GaAs substrates that eliminate the problem of absorbing microwave power in the substrate.
- Generally, if frequency > 2GHz GaAs

  if frequency < 2GHz Si

Disadvantages

- Schottky Diode limits forward active to turn on of diode.
- Tend to have high leakage currents.
- P-type have low mobility (mostly n-type).
- For enchantment mode MESFETs the threshold voltage much be lower then turn-on of schottky diode turn on making it difficult to fabricate circuits containing large number of them (depletion mode is more commonly used).

High Frequency Devices

- Cell phones, satellite receivers, radar, microwave devices.
- Typically depletion-mode devices are used because they provide larger currents and larger transconductance.
- Buried channel yields a better noise performance vs. trapping and release of carriers into and from surface states and defects are eliminated.

Cell phone from http://rtmulcahy.files.wordpress.com/2007/06/cellphone.gif and Radar from http://www1.istockphoto.com/file_thumbview_approve/261953/2/istockphoto_261953_radar.jpg

Image from http://libizblog.files.wordpress.com/2007/10/question-mark.jpg

References and Additional Info

In addition to images, information was used from the following sources:

-http://ece-www.colorado.edu/~bart/book/book/chapter3/pdf/ch3_6.pdf

-http://ece-www.colorado.edu/~bart/book/mesfet.htm (Bart J. Van Zeghbroeck, 1998)

-http://www.iue.tuwien.ac.at/phd/ayalew/node101.html (*T. Ayalew: SiC Semiconductor Devices Technology, Modeling, and Simulation*)

-http://books.google.com/books (GaAs High-speed Devices: Physics, Technology, and Circuit Applications By C. Y. Chang, Francis Kai)

-http://www.britannica.com/ebc/art-70994/MESFET-transistor-In-a-metal-semiconductor-field-effect-transistor-current

-http://ocw.mit.edu/NR/rdonlyres/Electrical-Engineering-and-Computer-Science/6-772Spring2003/6624143B-7CFF-4104-A127-43E3E3A4D0FC/0/Lecture9v2.pdf
(C.G. Fonstad, 3/03)

-http://www.ecse.rpi.edu/~schubert/Course-ECSE-6290%20SDM-2/1%20JFETs%20and%20MESFETs.pdf (E.F.Schubert, Rensselaer PolyTechnic Institute)

References Cont.

-http://www.eas.asu.edu/~vasilesk/EEE532/mesfet_1.pdf

-http://www.roke.co.uk/download/papers/SiC_MESFETs_for_Phased_Array_Radar_Applications.pdf (Evaluation of Commercially Available SIC Mesfets for Phased Array Radar Applications Mark G. Walden and Mathew Knight)

-Slide show “Very High Performance Logic” (Digital Integrated Circuits, High Speed, Prentice Hall 1995)

These URL’s where taken and accurate on April 7th, 2008

All images are referenced on the bottom slide they were used.