MOSFET (MISFET, IGFET)

ELEC 424

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Field Effect Transistors

- Proposed in the 1930's by Lilienfeld
  - Not practical because of role of surface defects/states
- Bardeen and Brattain were trying to demonstrate an FET when they serendipitously invented the point contact bipolar transistor.
  - Schockley extended the FET concept to the BJT
- First MOSFET finally happened in 1960

Bipolar vs Unipolar

- P-N Junction Dominate Features
  - Minority carrier injection at forward bias
  - Depletion width modulation at reverse bias
- Bipolar devices rely primarily on minority carrier injection across the narrow base region.
- Both hole and electron current matter, so they are called BIPOLAR devices.
- Junction FETs rely primarily on reverse bias to control channel width, and subsequently majority carrier current.
- FETs are sometimes called UNIPOLAR devices.

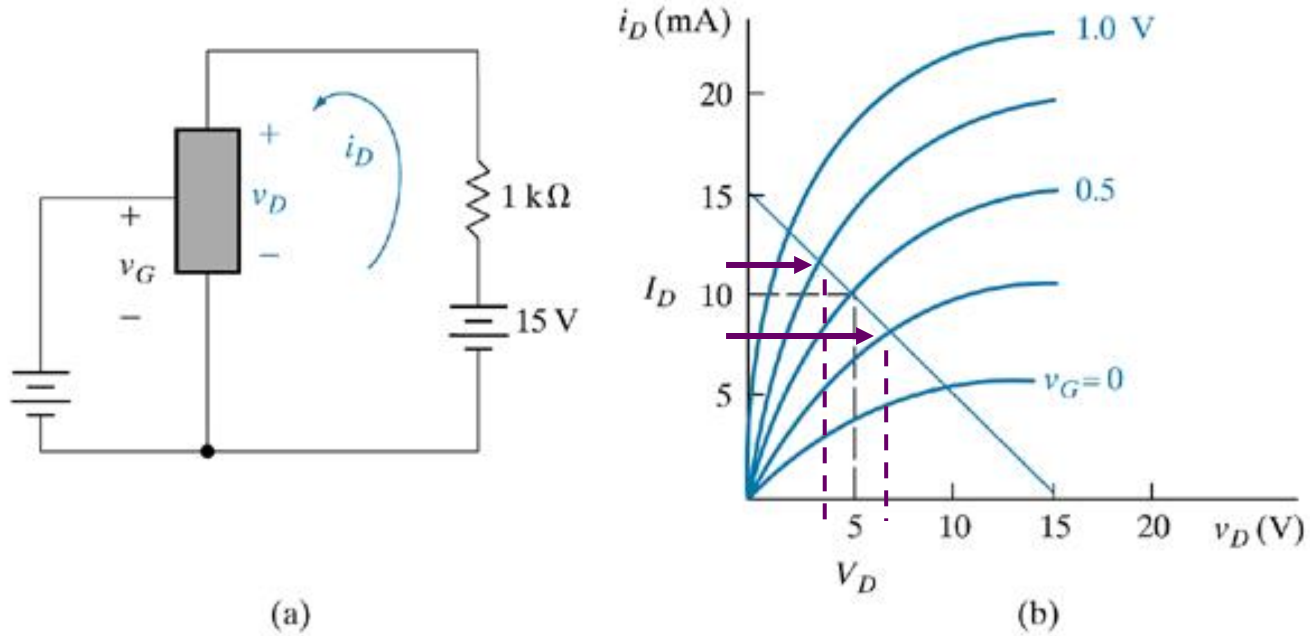
Similar but Different

- BJTs and FETs
  - Both three terminal devices
  - Current through two terminals is regulated by the third
- BUT
  - Base *current* controls emitter/collector current in BJTs
  - Gate *voltage* controls source/drain current in FETs

What Transistors Do

- Amplify
  - The electrical character of the source/drain or emitter/collector is a *reflection of the character of the gate or base, but increased or decreased by a gain factor*.
- Switch
  - Source/drain or emitter/collector current can be *turned on or off* by applying the proper signal to the gate or base.

Amplification



If V_G is increased or decreased by 0.25 V, V_D will increase or decrease by ~2 volts.

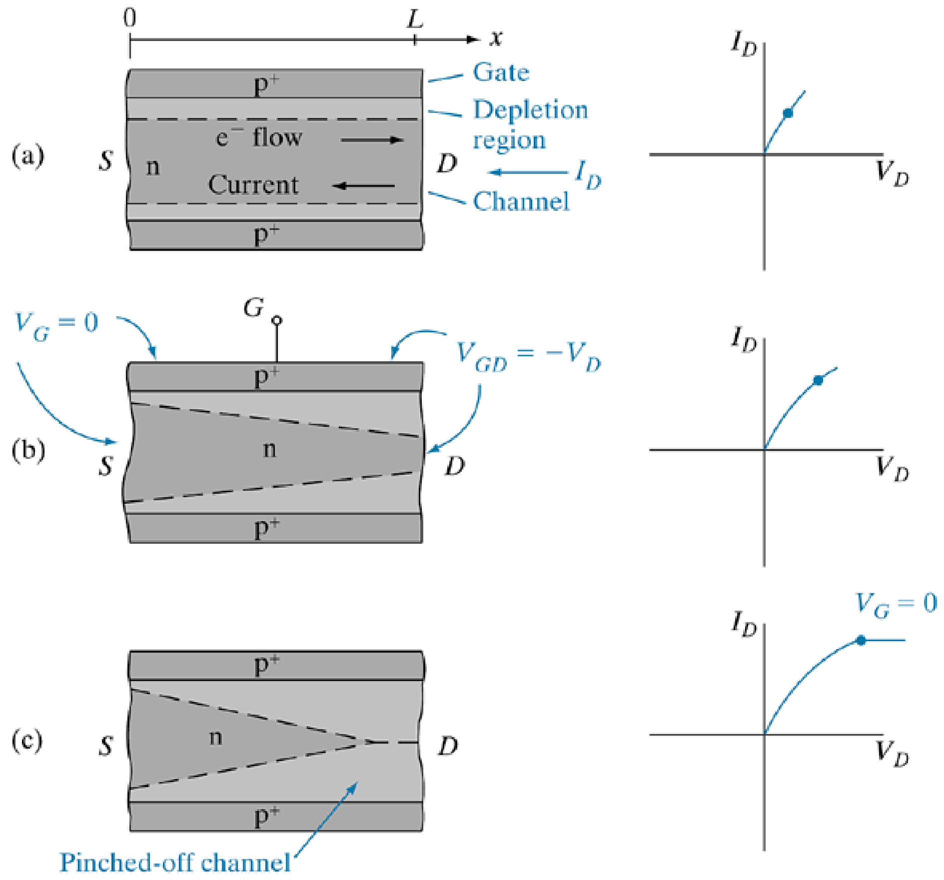
Gain = V_{out}/V_{in} = 8.

JFET Operating Regions

Linear region

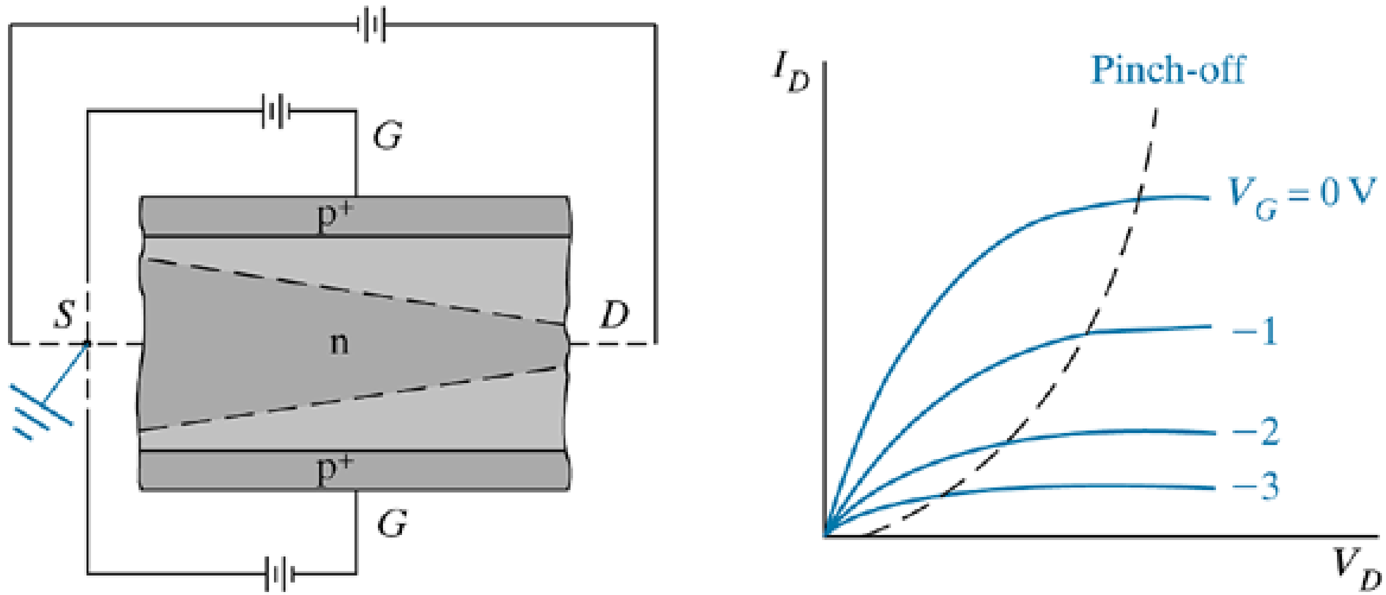
Approaching Pinchoff

Beyond Pinchoff



Source is the region from which the majority carriers flow. They flow to the *Drain*.

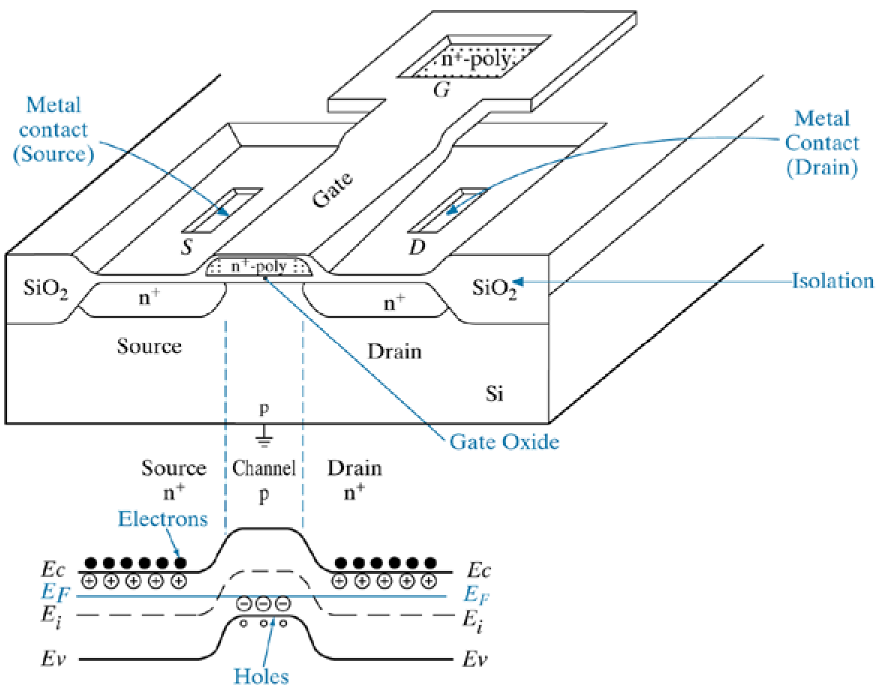
Family of Curves



(a) (b)

V_G determines the operating curve
V_D determines the region (linear, approaching saturation, pinch-off) of operation.

MOSFET Band Diagram



Equilibrium

Invariant Fermi level bends the p-type valence band up, creating an energy barrier to electron/hole flow.

Positive Gate Voltage

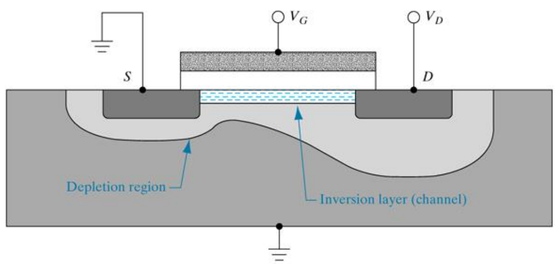
flattens the barrier

At V_T (threshold voltage)

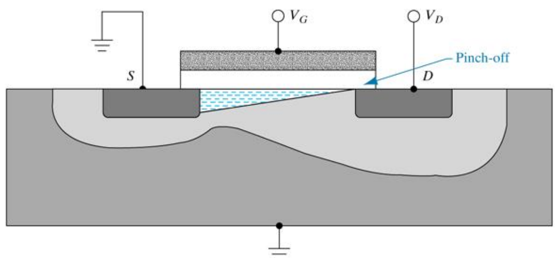
Allows current to flow with proper source to drain bias

N-Channel MOSFET Operating Regions

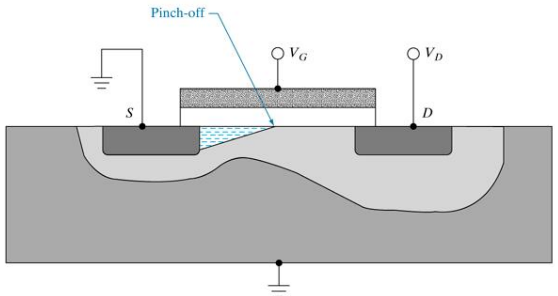
Linear Region
$V_G > V_T$ and $V_D < (V_G - V_T)$



Saturation onset
$V_G > V_T$ and $V_D = (V_G - V_T)$



Strong Saturation
$V_G > V_T$ and $V_D > (V_G - V_T)$



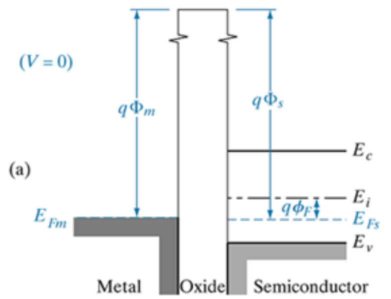
How to Build a MOSFET

http://microscopy.fsu.edu/electromag/java/transistor/index.html

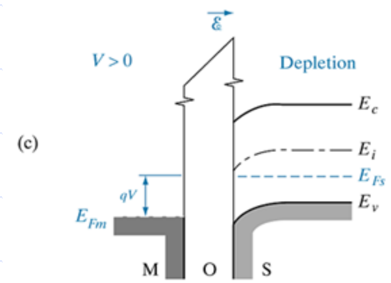
N-Channel Formation in P type Material

(M)etal = gate
(O)xide = gate oxide
(S)emiconductor = p-type

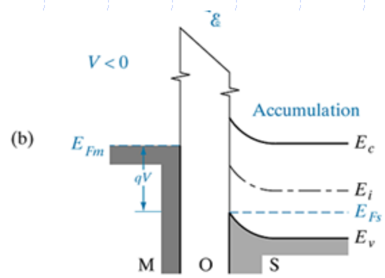
Equilibrium
$V_G=0$



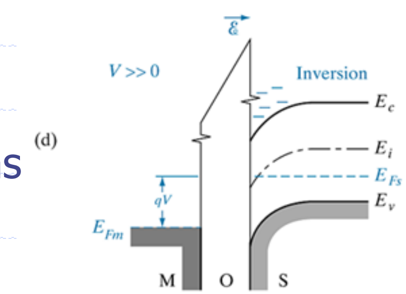
Depletion
$V_G>0$, repels holes
from surface region



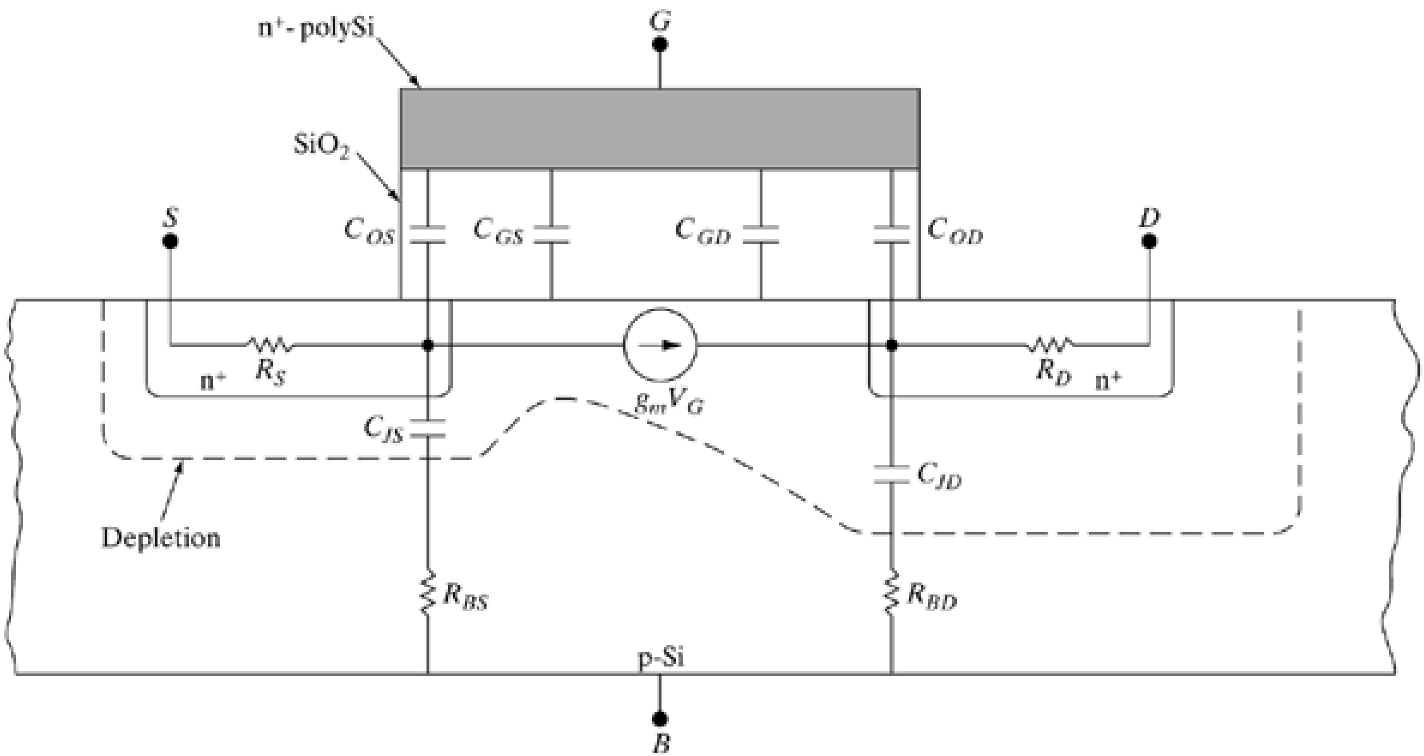
Accumulation
$V_G<0$, attracts holes
to surface region



Inversion
$V_G>>0$, attracts electrons
to surface region,
making it "N type"



MOSFET Equivalent Circuit



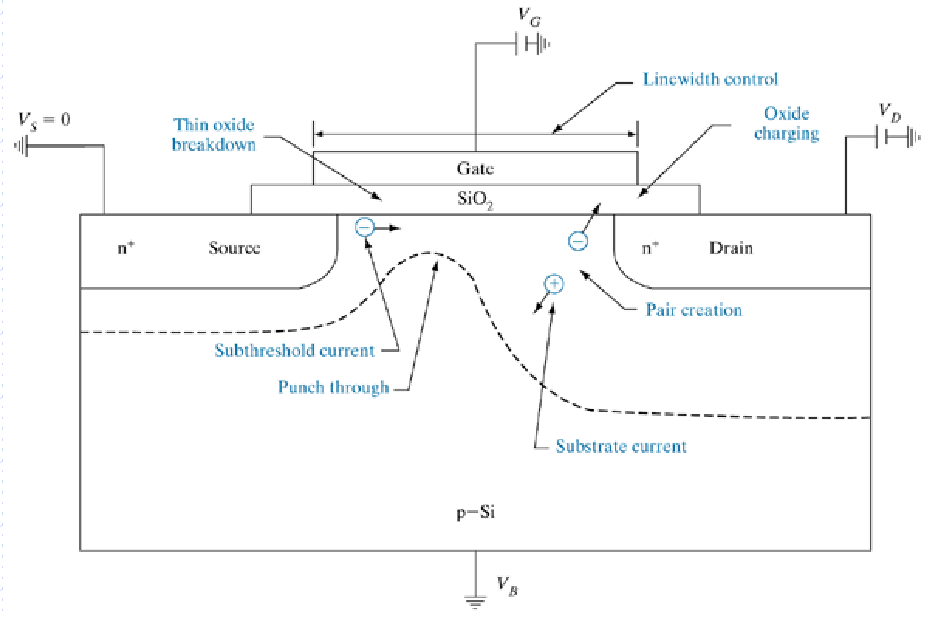
MOSFET Short-Channel Effects

Shorter channels incur higher electric fields and current densities.

- Charge accumulates within the gate oxide due to hot carrier generation

- Unwanted (leakage) current flows due to punchtrough from the source to the drain

- Devices fail catastophically due to thin gate oxide breakdown (rupture)



Threshold Shift due to Hot Carriers

"Hot" electrons are "trapped" in the gate dielectric, imparting a permanent charge and subsequent threshold shift, as shown in these before and after I-V curves.