Module 6:

Semiconductor Devices and Applications

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- BJT
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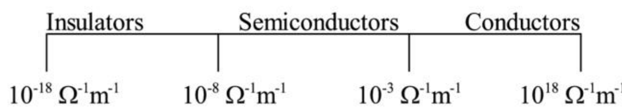
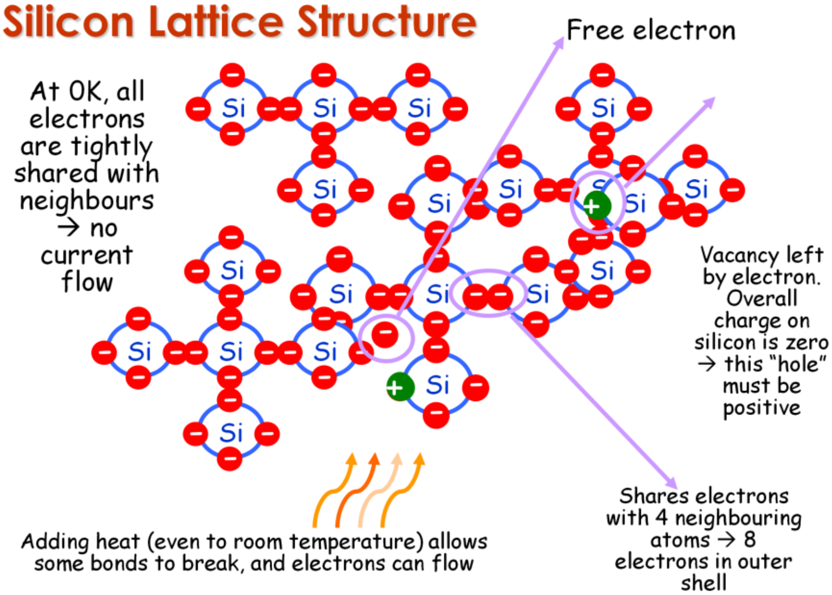
- Applications:
  - Rectifier
  - Voltage regulator
  - Operational amplifier

Semiconductor materials

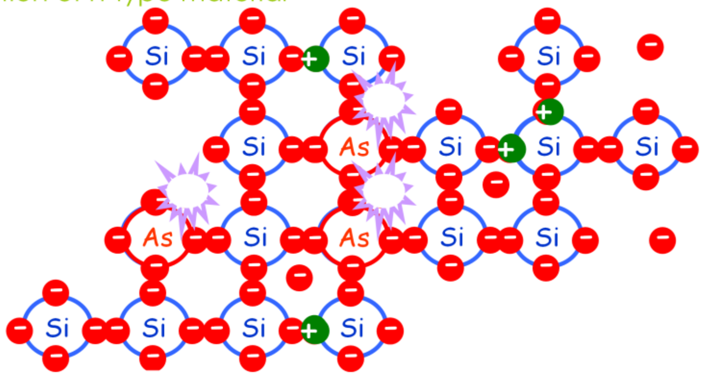
- Semiconductors are materials whose electrical properties lie between Conductors and Insulators.
- Elemental semi-conductors
  - **Silicon & Germanium**
- Compound semi-conductors
  - Binary- **GaAs**, Ternary- **GaAsP**, Quaternary- **InGaAsP**
- Conductivity difference



Silicon Lattice Structure

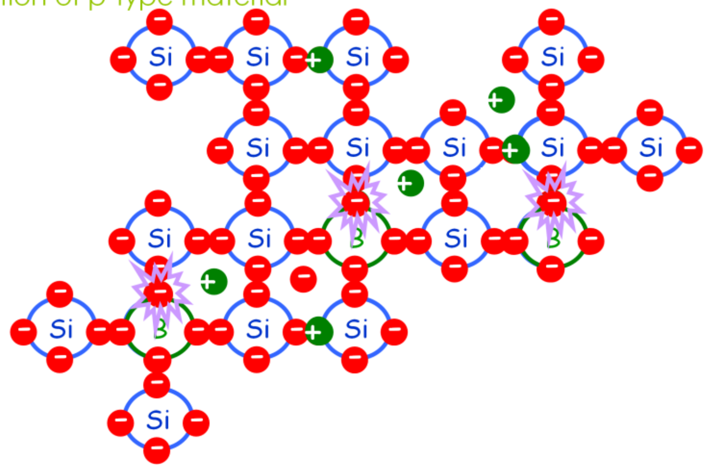


Formation of n-type material



- Inject Arsenic into the crystal with an implant step.
- Arsenic is Group5 element with 5 electrons in its outer shell, (one more than silicon).
- This introduces extra electrons into the lattice which can be released through the application of heat and so produces and electron current
- The result here is an N-type semiconductor (n for negative current carrier)

Formation of p-type material

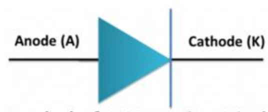


- Inject Boron into the crystal with an implant step.
- Boron is Group3 element is has 3 electrons in its outer shell (one less than silicon)
- This introduces holes into the lattice which can be made mobile by applying heat. This gives us a hole current
- The result is a P-type semiconductor (p for positive current carrier)

PN Junction formation

1. When one side of a single semiconductor crystal is doped with acceptors and the other side is doped with donors.
2. A n type semiconductor wafer is doped with trivalent impurities and then heated for short time

Practical Diode



Symbol of PN Junction Diode

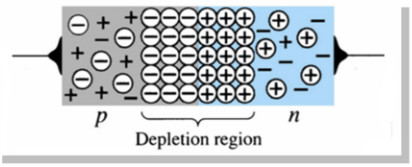
Practical Diode

Depletion region

At the *p*-*n* junction, the excess conduction-band electrons on the *n*-type side are attracted to the valence-band holes on the *p*-type side.

The electrons in the *n*-type material migrate across the junction to the *p*-type material (electron flow).

The electron migration results in a **negative** charge on the p-type side of the junction and a **positive** charge on the n-type side of the junction.



Due to this diffusion a region is created on both sides of this artificial metallurgical junction which is devoid of mobile charge carriers and highly resistive called the **depletion region**.

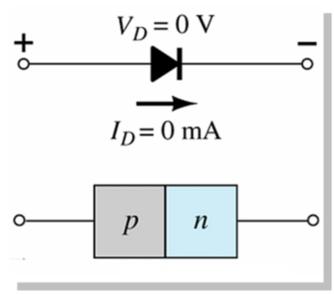
Diode Operating Conditions

A diode has three operating conditions:

- No bias
- Forward bias
- Reverse bias

No Bias

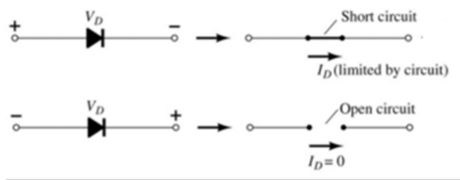
- No external voltage is applied: $V_D = 0$ V
- No current is flowing: $I_D = 0$ A
- Only a modest depletion region exists

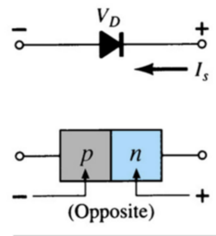


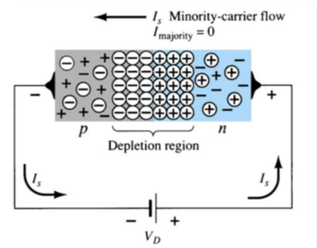
Diode Operating Conditions

Reverse Bias

External voltage is applied across the *p-n* junction in the opposite polarity of the *p-* and *n*-type materials.



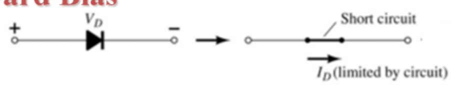


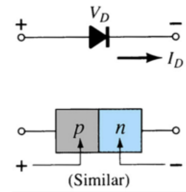


- **The reverse voltage causes the depletion region to widen.**
- **The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.**
- **The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.**

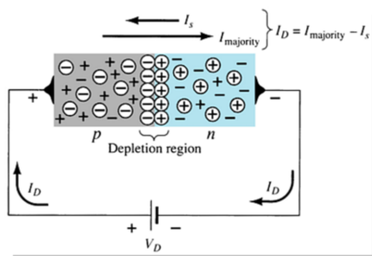
Diode Operating Conditions

Forward Bias



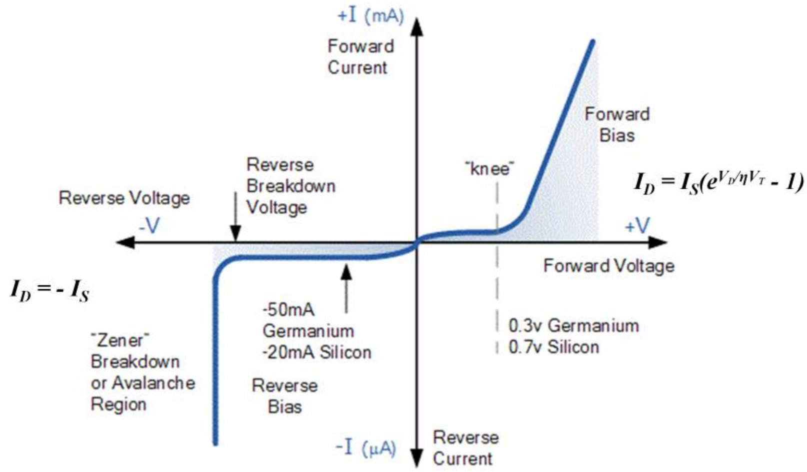


External voltage is applied across the *p-n* junction in the same polarity as the *p-* and *n*-type materials.



- The forward voltage causes the depletion region to narrow.
- The electrons and holes are pushed toward the *p-n* junction.
- The electrons and holes have sufficient energy to cross the *p-n* junction.

Diode Characteristics



Zener diode

- A Zener diode is a type of diode that permits current not only in the forward direction like a normal diode, but also in the reverse direction if the voltage is larger than the breakdown voltage known as "Zener knee voltage" or "Zener voltage".
- The device was named after Clarence Zener, who discovered this electrical property.
- Breakdown voltage for commonly available zener diodes can vary widely from 1.2V to 200V.
- The maximum reverse voltage that won't take a diode into the zener region is called the peak inverse voltage or peak reverse voltage.
- The Zener region is in the diode's reverse-bias region. At some point the reverse bias voltage is so large that the diode breaks down and the reverse current increases dramatically.

Diode applications

1. Rectifiers: *Circuits that used for converting* ***a.c voltage (bidirectional) into pulsating dc voltage (unidirectional).***

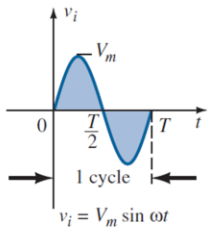
   Two types:

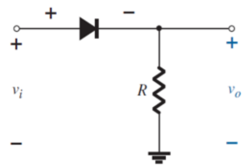
   - *Half wave* and
   - *Full wave rectifiers*

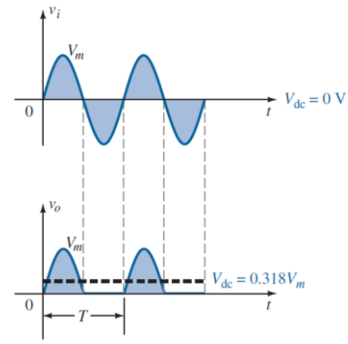
2. Voltage Regulator: *Zener diode used as voltage regulator under* ***Line regulation*** *and* ***Load regulation .***

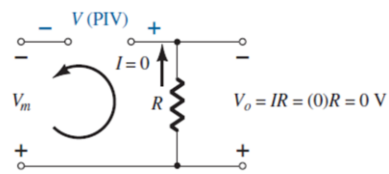
3. Operational Amplifier: *Diodes are used in op-amp to limit the output swing so that the* ***op-amp doesn't go into saturation***

Half wave rectifier



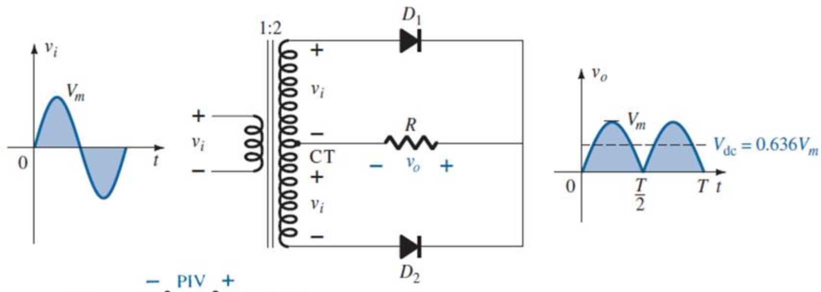


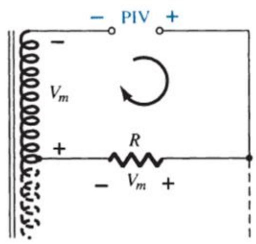




$\boxed{\text{PIV rating} \geqq V_m}$ half-wave rectifier

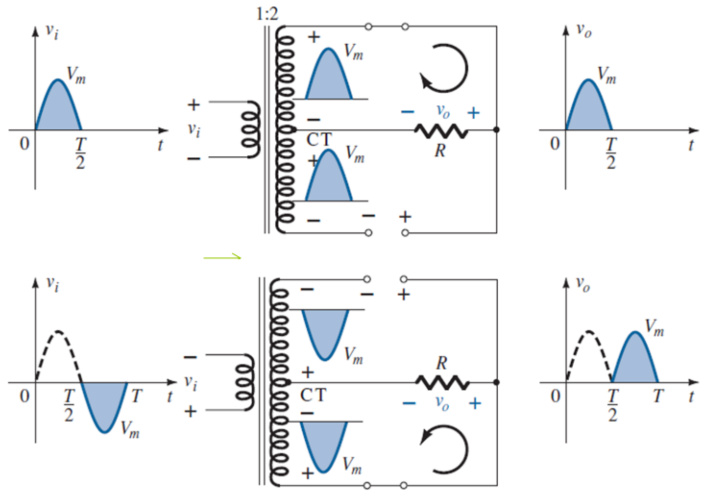
Full wave (Center-tapped) rectifier



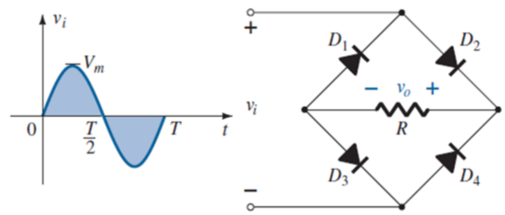


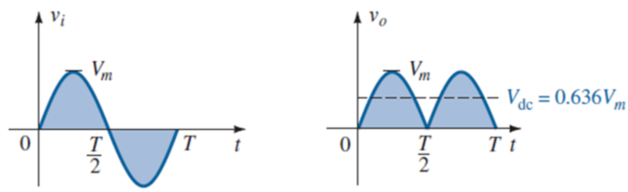
$\boxed{PIV \geqq 2V_m}$ CT transformer, full-wave rectifier

Full wave (Center-tapped) rectifier working



Full wave (Bridge) rectifier

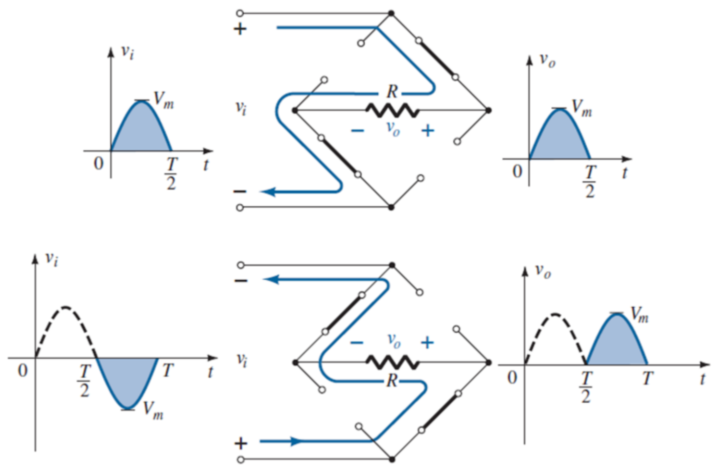




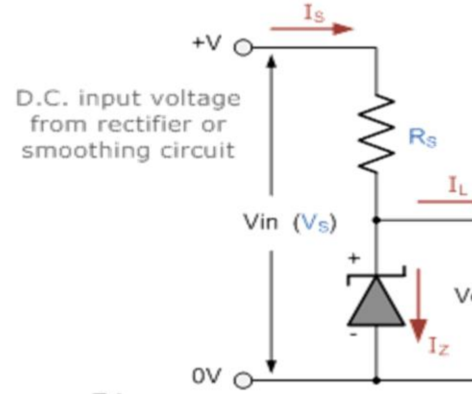
$V_{dc} = 0.636\, V_m$ full-wave

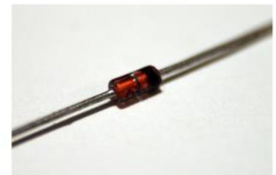
$\text{PIV} \geqq V_m$ full-wave bridge rectifier

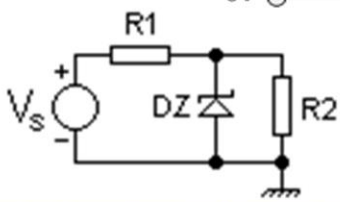
Full wave (Bridge) rectifier working



Zener diode as Voltage regulator



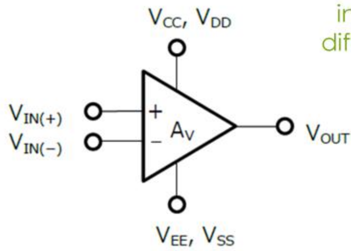




$$R1 = \frac{V_S - V_Z}{I_Z + I_{R2}}$$

Operational Amplifier

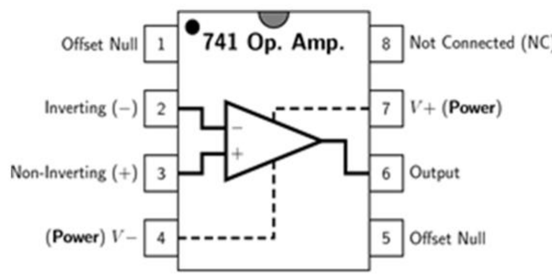
An operational amplifier (**op-amp**) is an integrated circuit (IC) that amplifies the difference in voltage between two inputs.



V_{CC}, V_{DD}: Positive power supply
V_{EE}, V_{SS}: Negative power supply
$V_{IN(+)}$: Noninverting input
$V_{IN(-)}$: Inverting input
V_{OUT}: Output

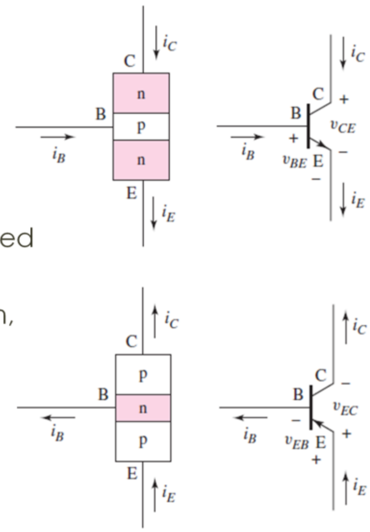
It is used to amplify both dc and ac input signals.

Originally designed to perform different mathematical operations mainly addition, subtraction, multiplication and integration and hence the name.



BJT

- **B**ipolar **J**unction **T**ransistor
- **3 layers, 2 junctions**
  - **E**mitter-Heavily doped
    Moderate size
  - **B**ase -Lightly doped
    Thin area
  - **C**ollector-Moderately doped
    Wide area
- Depending on bias condition,
- **4 operation modes**
  - Active
  - Reverse active
  - Cutoff
  - Saturation



Transistor relations

- Transistor current equation $I_E = I_B + I_C$

$$I_C = \alpha I_E$$

- Value of α is very close to unity, and for a typical low-power signal transistor it ranges from about 0.950 to 0.999.

$$I_C = \beta I_B$$

- β varies from 20 for high current power transistors to over 1000 for high frequency low power type bipolar transistors.

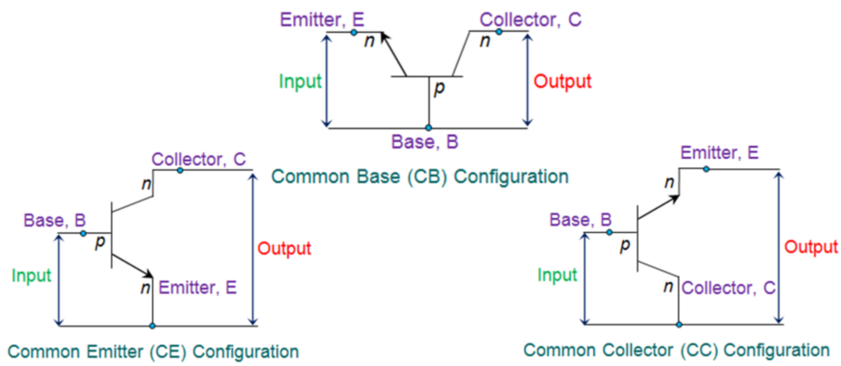
Putting; $I_C = \alpha I_E$ and $I_C = \beta I_B$ in $I_E = I_B + I_C$

$$I_C = \frac{\alpha}{1-\alpha} I_B \quad \& \quad I_C = \frac{\beta}{1+\beta} I_B$$

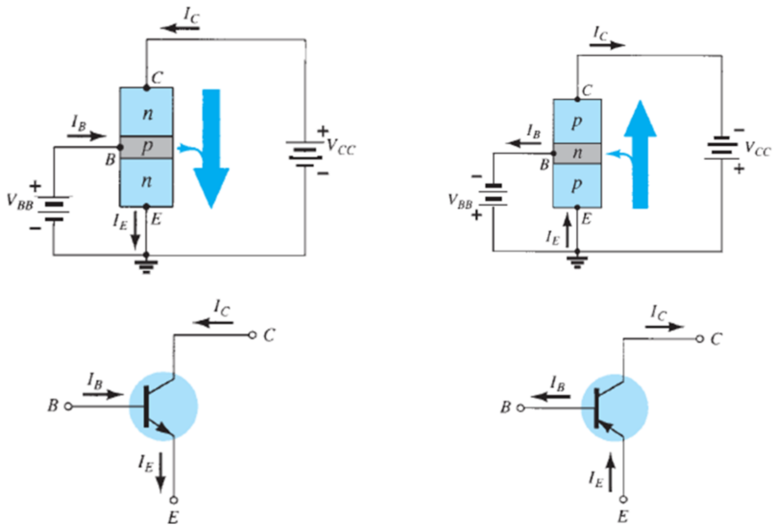
Therefore; $\boxed{\beta = \frac{\alpha}{1-\alpha}}$ & $\boxed{\alpha = \frac{\beta}{1+\beta}}$

Transistor Configurations

- Depending on the common terminal between input and output circuits
  - Common Base (**CB**) configuration
  - Common Emitter (**CE**) configuration
  - Common Collector (**CC**) configuration

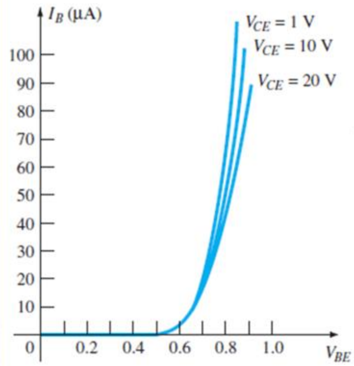


Common Emitter Configuration

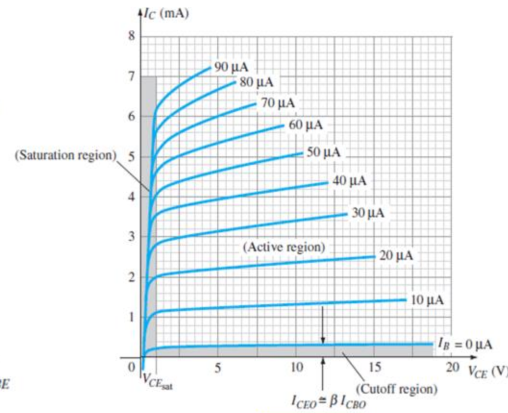


Static Characteristics (CE)

- Input characteristics – I_i vs V_i with V_o as a parameter.
- Output characteristics – I_o vs V_o with I_i as a parameter.



Input



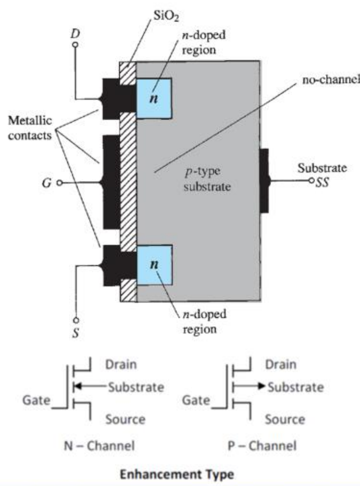
Output

MOSFET

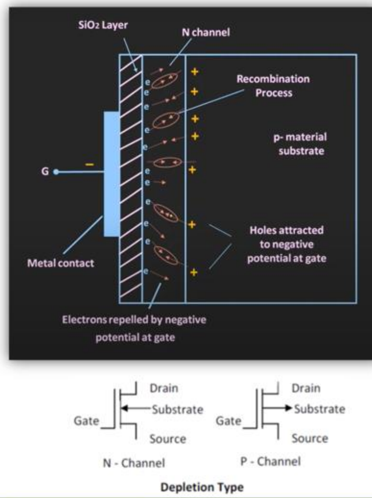
- Voltage controlled device
- Unipolar
- Several forms of FETs
  - JFET – Junction Field Effect Transistor
  - MOSFET – Metal Oxide Semiconductor Field Effect Transistor
- MOSFET are advantageous over BJT
- MOSFET's also called
  - IGFET – Insulated Gate FET
  - MISFET – Metal Insulator Semiconductor FET
- Types

MOSFET Structure & Symbol

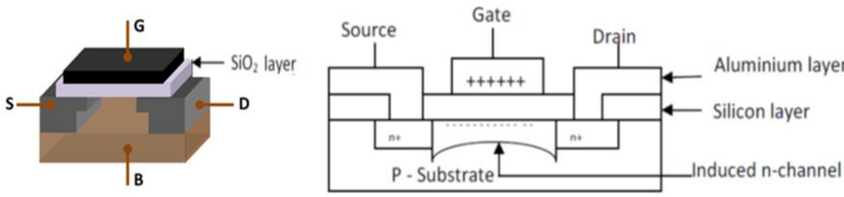
Enhancement MOSFET



Depletion MOSFET



Construction



N-channel MOSFET consists of highly doped 'P' type substrate into which two highly doped N regions are diffused. These 'N' regions act as source and drain. A thin layer of insulating silicon dioxide (SiO_2) is grown over the surface of structure and free electrons are cut into the oxide layer, allowing to move between source and drain

The body of the MOSFET is frequently connected to the source terminal making it a three terminal device like field effect transistor.

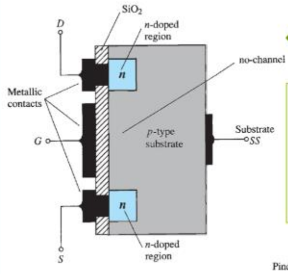
The metal area is overlaid on the entire oxide layer and metal contacts are made to source and drain. The SiO_2 layer insulates the gate from the channel due to which a negligible gate current flows even if the biasing is applied to gate. So no PN junction is existing in MOSFET and hence known as Insulated Gate Field Effect Transistor.

MOSFET working

In N-channel MOSFET, when we apply the positive gate voltage the holes present beneath the oxide layer experience repulsive force and the holes are pushed downwards in to the bound negative charges which are associated with the acceptor atoms (density of negative charges increases under oxide layer). This mode of operation is called as enhancement mode. The positive gate voltage also attracts electrons from n+ source and drain region in to the channel thus an electron reach channel is formed.

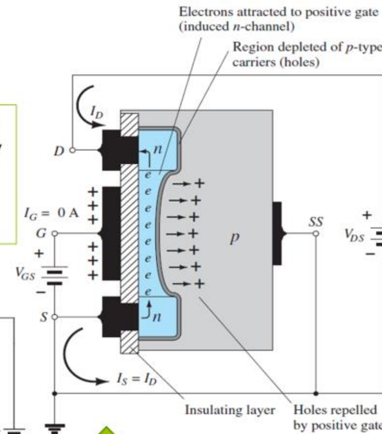
In N-channel MOSFET, the drain and source are heavily doped n+ region and the substrate is p-type. The current flows due to the flow of negatively charged electrons, also known as n-channel MOSFET. The MOSFET works by electronically varying the width of a channel along which charge carriers flow (electrons or holes). The charge carriers enter the channel at source and exit via the drain. The width of the channel is controlled by the voltage on an electrode is called gate which is located between source and drain. It is insulated from the channel near an extremely thin layer of metal oxide. The MOS capacity present in the device is the main part.

MOSFET working



1

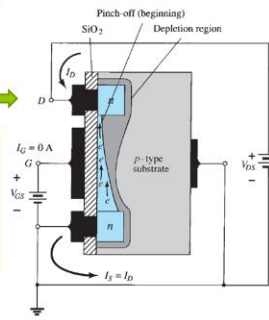
V_{GS} = 0, No current flow between drain & source



2

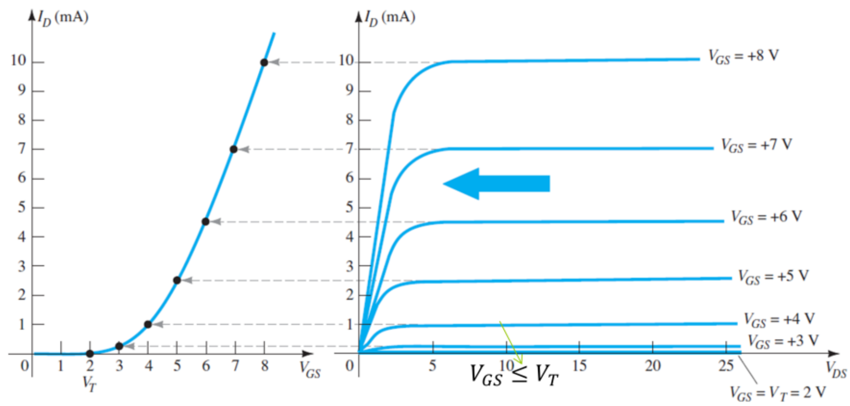
V_{GS} & V_{DS} positive voltage applied; channel induced

3



V_{DS} increased keeping V_{GS} constant; channel width reduces

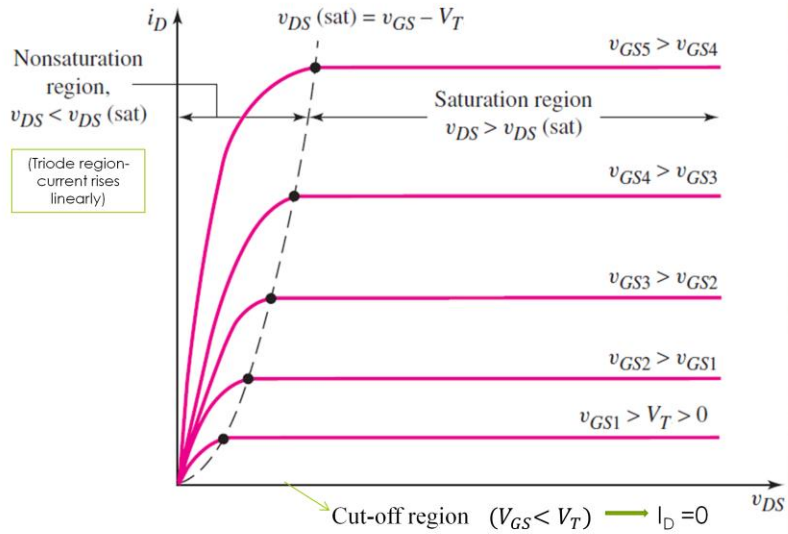
Transfer & Drain characteristics



$$I_D = k(V_{GS} - V_T)^2$$

$$V_{DS_{sat}} = V_{GS} - V_T$$

Transfer & Drain characteristics superimposed



BJT and MOSFET applications

- **BJT's** are ideal for use as amplifiers in common-emitter mode due to powerful amplification. Another applications of BJT is as a switch with the cut-off region as OFF state (0) and the saturation region as the ON state (1). BJTs are used in amplifiers, oscillators, multi-vibrators, wave-shaping circuits, timer and time delay circuits, switching circuits, detector circuits for demodulation and Logic circuits and gates .

- **MOSFET's** are ideal for use as electronic switches or as common-source amplifiers as their power consumption is very small. Typical applications for MOSFETs are in Microprocessors, Memories, Calculators and Logic CMOS Gates .