Basics of Electrical and Electronics Engineering

APJ Abdul Kalam Technological University

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Rajath Publishers

MODULE- IV

Introduction to Semiconductor devices

Evolution of electronics

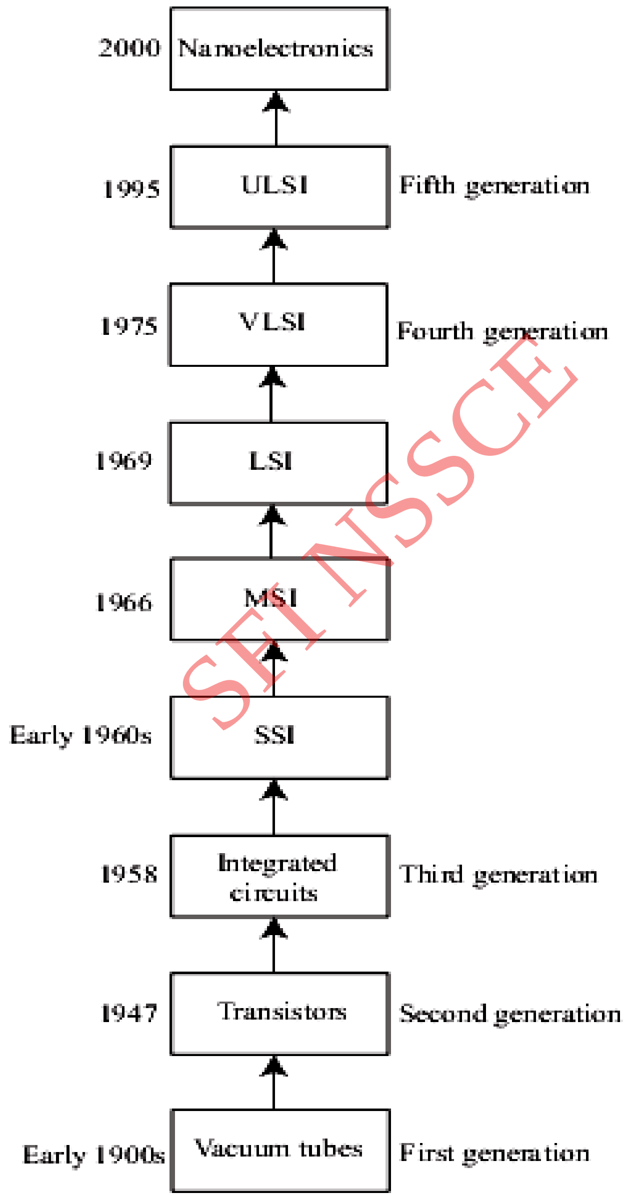
The evolution of electronics is mainly through three key components;

The vacuum tube,

The transistor and

The integrated circuit.

Evolution of electronics



Basic Terminology

An electric circuit is a closed connection formed by various electric elements

Passive element

An element which receives energy (or absorbs energy) is called a passive element. They dissipate (in the form of heat) or store energy in an electric or magnetic field.

Example; resistor, inductor, capacitor, etc.

Active element

An element that supplies energy to the circuit is called an active element.

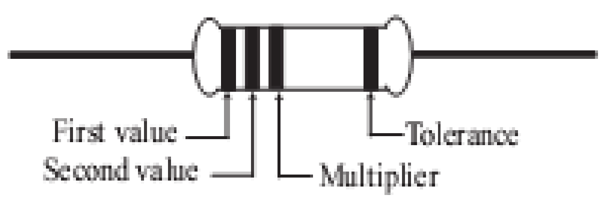
Examples: voltage and current sources, generators, and electronic devices that require power supplies.

Resistors

✓The property of a material by which it opposes the flow of current

✓Used to oppose the flow of current

✓Colour coding



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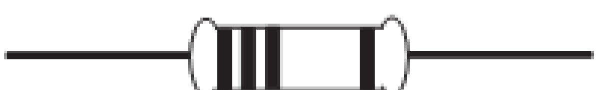


Resistors

- Types

Fixed and variable

- Fixed resistors
  1. Carbon composition resistors
  2. Carbon film resistors
  3. Wire-wound resistors
  4. Metal film resistors
- Variable Resistors
  1. Potentiometers
  2. Rheostat
  3. Preset

Resistors

Colour	I band (I value)	II band (II value)	III band (Multiplier)	IV band (Tolerance)
Black	0	0	1	—
Brown	1	1	10	—
Red	2	2	10^2	—
Orange	3	3	10^3	—
Yellow	4	4	10^4	—
Green	5	5	10^5	—
Blue	6	6	10^6	—
Violet	7	7	10^7	—
Gray	8	8	10^8	—
White	9	9	10^9	—
Gold	—	—	0.1	$\pm 5\%$
Silver	—	—	0.01	$\pm 10\%$
No colour	—	—	—	$\pm 20\%$

Capacitors

✓ Electronic component used to store electric charge.

✓Consists of two metal plates separated by a dielectric (insulating material) in between.

(a) Symbol for capacitor without polarity

(b) Symbol for capacitor with polarity

✓Capacitor passes ac signals and blocks dc signals

✓Unit for capacitance is Farad (F).

Capacitors

- Types

Fixed and variable

- Fixed capacitors

    1 Electrolytic capacitor

    2. Ceramic capacitor

    3. Mica capacitor

    4. Paper capacitor

    5. Tantalum capacitor

- Variable capacitors

    1. Gang capacitor
    2. Trimmer and
    3. Padder

Capacitance

Energy stored in a capacitor

$$E = \frac{1}{2}Cv^2$$

Voltage across a capacitor cannot change instantaneously. Thus capacitors are used for smoothening varying dc voltage in ac to dc conversion.

Inductor

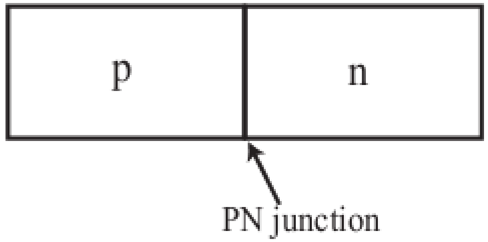
The property of materials by which it opposes any change in the current flowing through it.

✓The current through an inductor cannot be changed instantaneously

✓Inductor passes dc components but blocks ac components.

Types- air core inductor, iron core inductor, ferrite core inductor and powder core inductor

Semiconductor Diode



(a) p-n junction

(b) Symbol for diode

✓The terminal connected to p-layer is called anode (A) and the terminal connected to n-layer is called cathode (K).

✓Ability to con-duct current in one direction only.

p-n junction with no external voltage

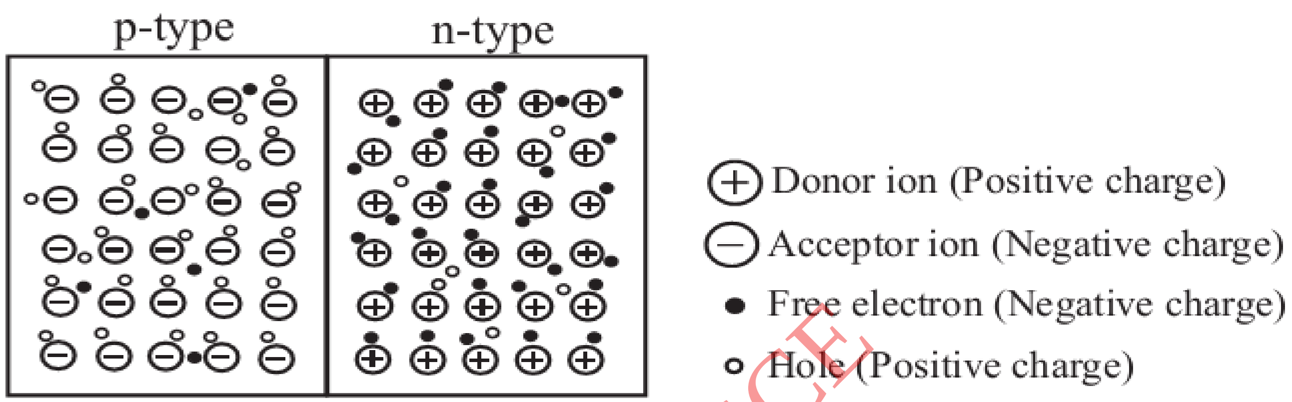
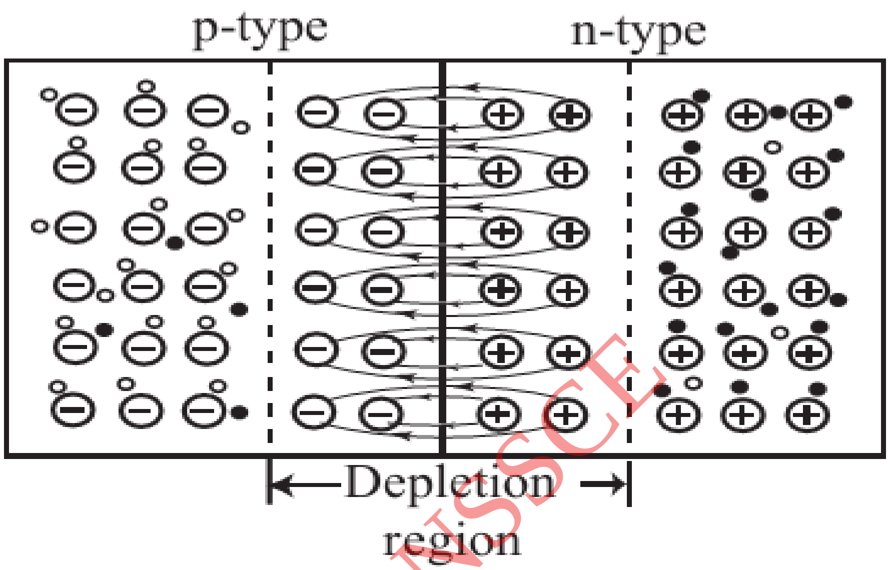


Figure 11.2: A p-n junction just formed

✓The combining of electrons and holes depletes the holes in the p-region and the electrons in the n-region near the junction.

✓This region in a p-n junction which contains only immobile ions and devoid of free carriers is called **depletion region.**

Barrier potential

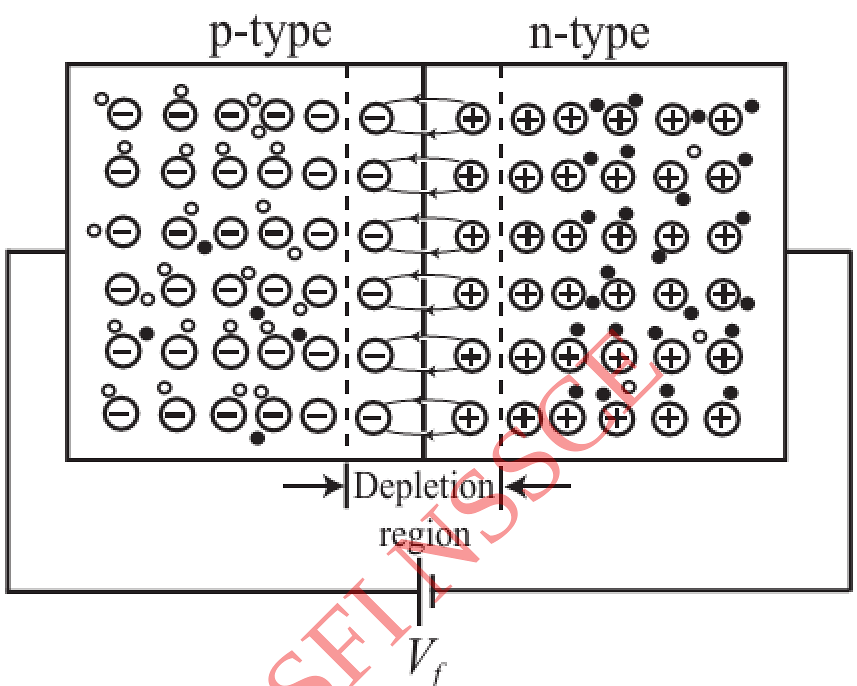


•Since the depletion region contains immobile ions which are electrically charged, it is also called the space charge region

•These ions create an electric field that provides a force opposing the further diffusion of charge carriers. The electric field creates a potential difference across the junction which is called space charge potential or **barrier potential**.

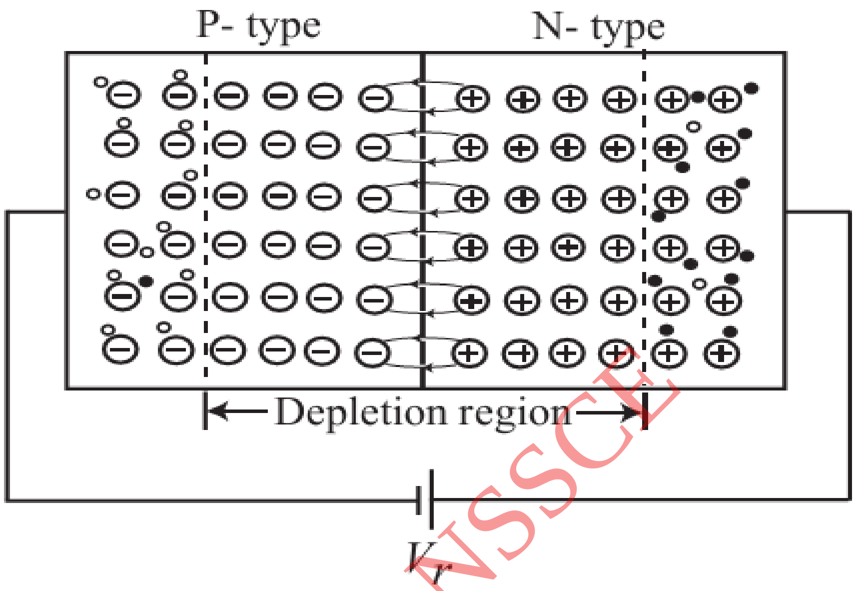
•0.7 V for Si and 0.3V for Ge

Forward biased p-n junction



- ✓The width of depletion region is reduced.
- ✓The potential barrier is reduced and at some forward voltage, it is eliminated completely.
- ✓The junction offers low resistance to the current flow. The magnitude of current depends on the applied voltage.

Reverse biased p-n junction



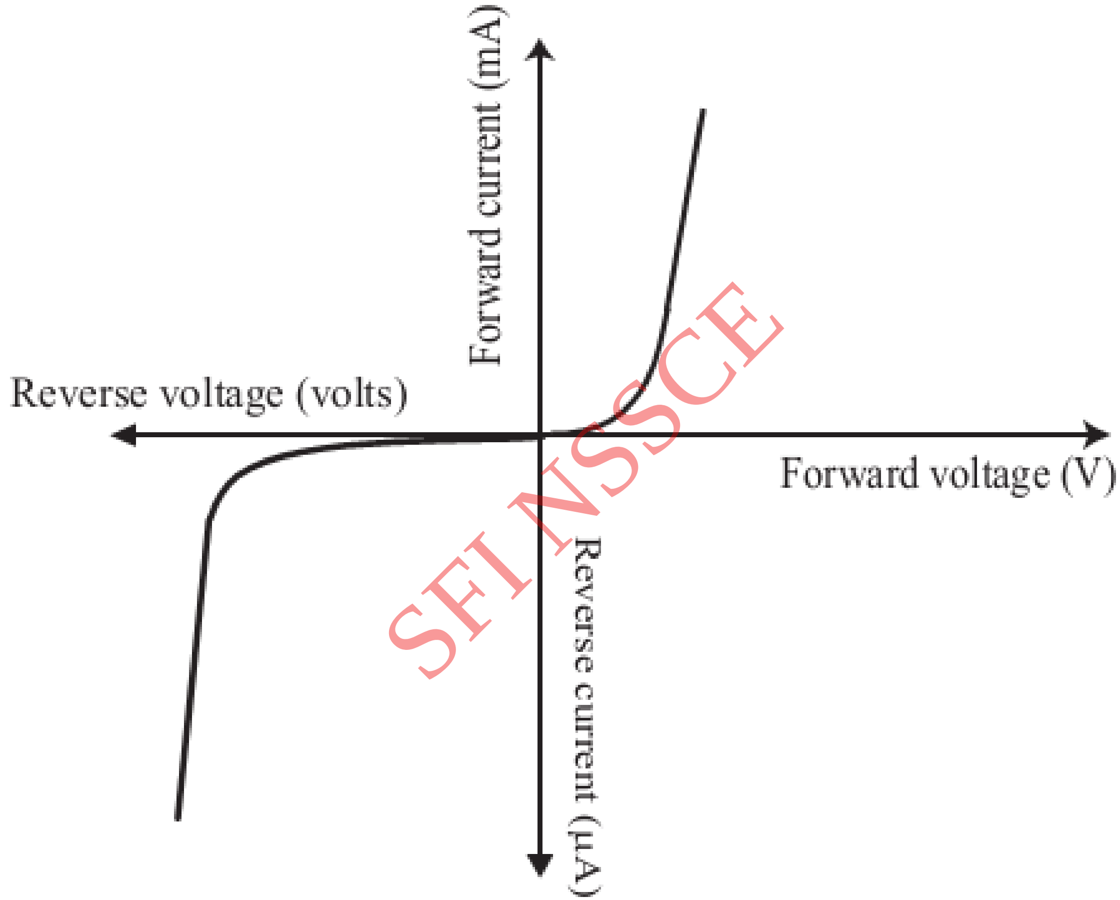
✓The width of depletion region is increased.

✓The potential barrier is increased and the junction offers high resistance.

✓No current flows due to majority carriers.

✓A small current due to minority carriers known as **reverse saturation current** flows through the junction.

V-I characteristics of a p-n junction diode



Diode current equation

The total current through a diode I_D is given by

$$I_D = I_\circ(e^{\frac{V}{\eta V_T}} - 1)$$

where $I_\circ$ = Reverse saturation current or leakage current due to flow of minority carriers through the junction.

V = Applied voltage (positive for forward bias and negative for reverse bias).

η = A constant, 1 for germanium and 2 for silicon ($\eta = 1$ for germanium and 2 for silicon for relatively low value of diode current and $\eta = 1$ for germanium and silicon for higher values of diode current).

V_T = Volt-equivalent of temperature or thermal voltage.

Diode current equation

$$\text{Here, } V_T = \frac{kT}{q}$$

where q = absolute value of electron charge, 1.602×10^{-19} C
k = Boltzmann's constant, 1.3806×10^{-23} J/°K
T = Absolute temperature (°K)

Then diode equation becomes

$$I_D = I_\circ(e^{\frac{qV}{\eta kT}} - 1)$$

At room temperature, $T = 300$°K, $V_T = 26$ mV

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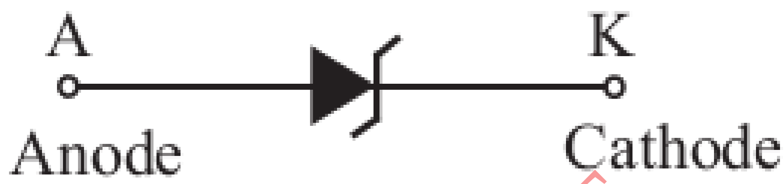
Zener diode



✓Designed to operate in the breakdown region.

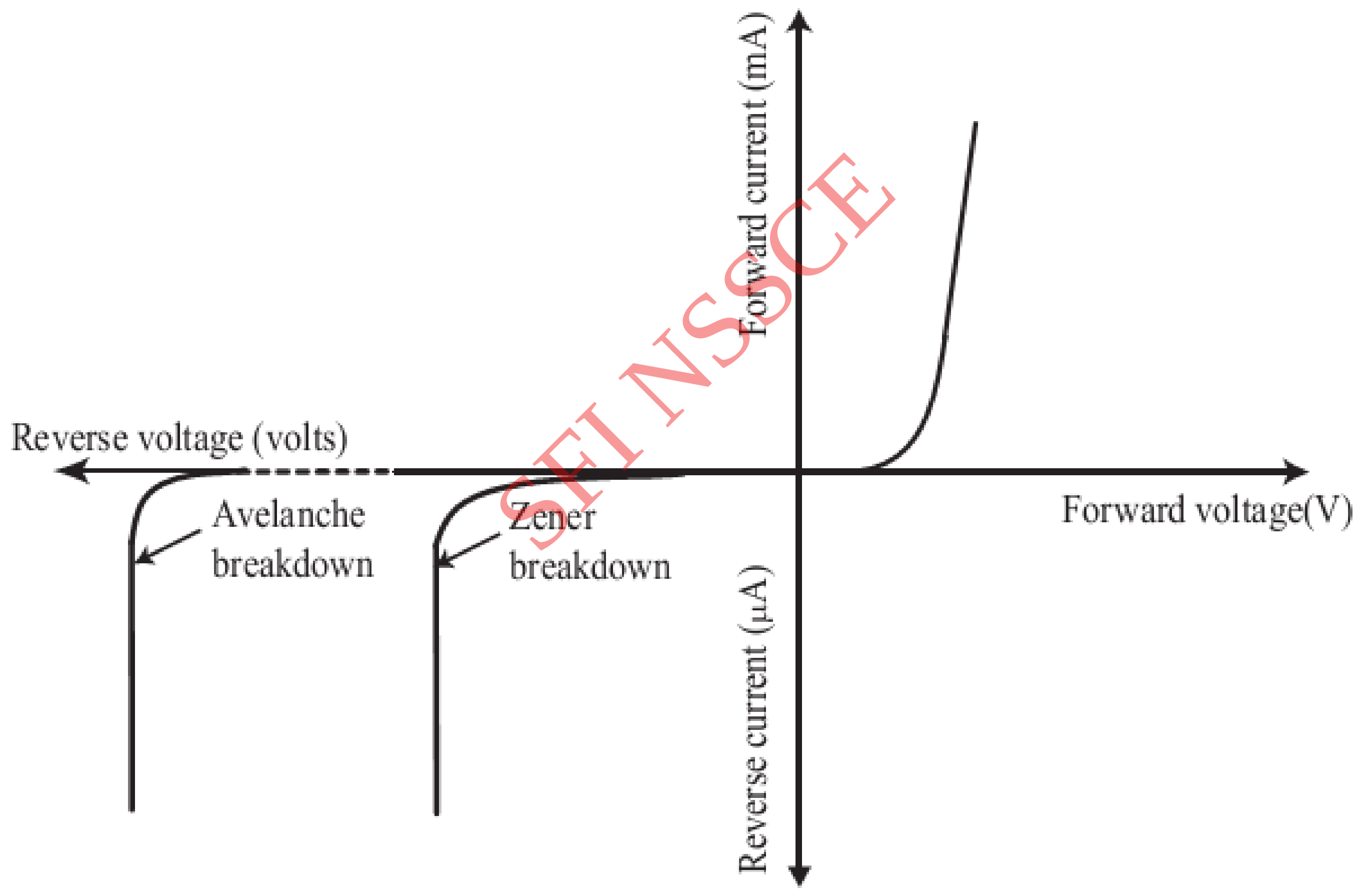
✓Zener diode is heavily doped and hence depletion region is very thin.

✓When the reverse voltage across it is increased, the electric field across the junction becomes very high.

Comparison between avalanche breakdown and zener breakdown

Sl. No.	Avalanche breakdown	Zener breakdown
1	Breakdown occurs due to increase in current as a result of multiplication of charge carriers.	Breakdown occurs due to high electric field across the junction.
2	Breakdown occurs at high reverse bias.	Breakdown occurs at low reverse bias.
3	Width of depletion region is high.	Width of depletion region is low.
4	The increase in temperature increases the breakdown voltage.	The increase in temperature decreases the breakdown voltage.
5	It occurs in lightly doped diodes	It occurs in heavily doped diodes.

Comparison between avalanche breakdown and zener breakdown



Bipolar Junction Transistors

✓Three terminal semiconductor device

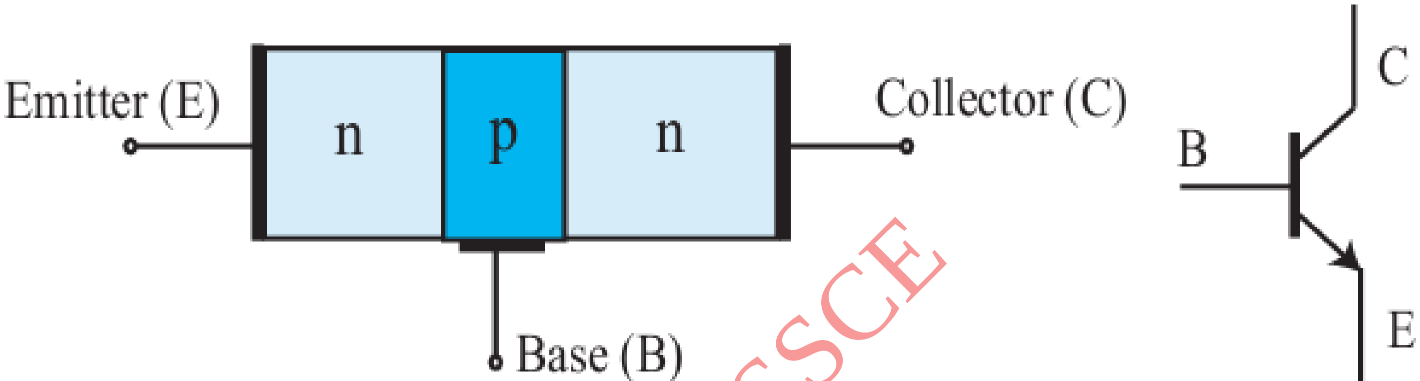
✓Two types- npn and pnp

✓Three semiconductor regions: the emitter region, the base region and the collector region

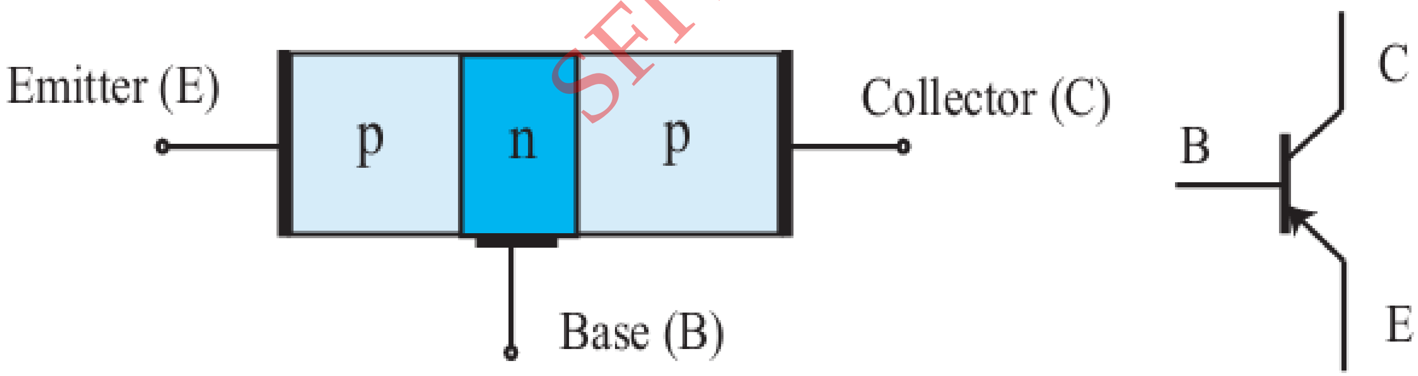
✓Two junctions, the Emitter-Base Junction (EBJ) and the Collector-Base Junction (CBJ).

✓Charge carriers of both polarities, i.e., electrons and holes participate in the current conduction process in a BJT, hence the name bipolar.

Bipolar Junction Transistors



(a) npn



(b) pnp

Bipolar Junction Transistors

Doping profile of BJT

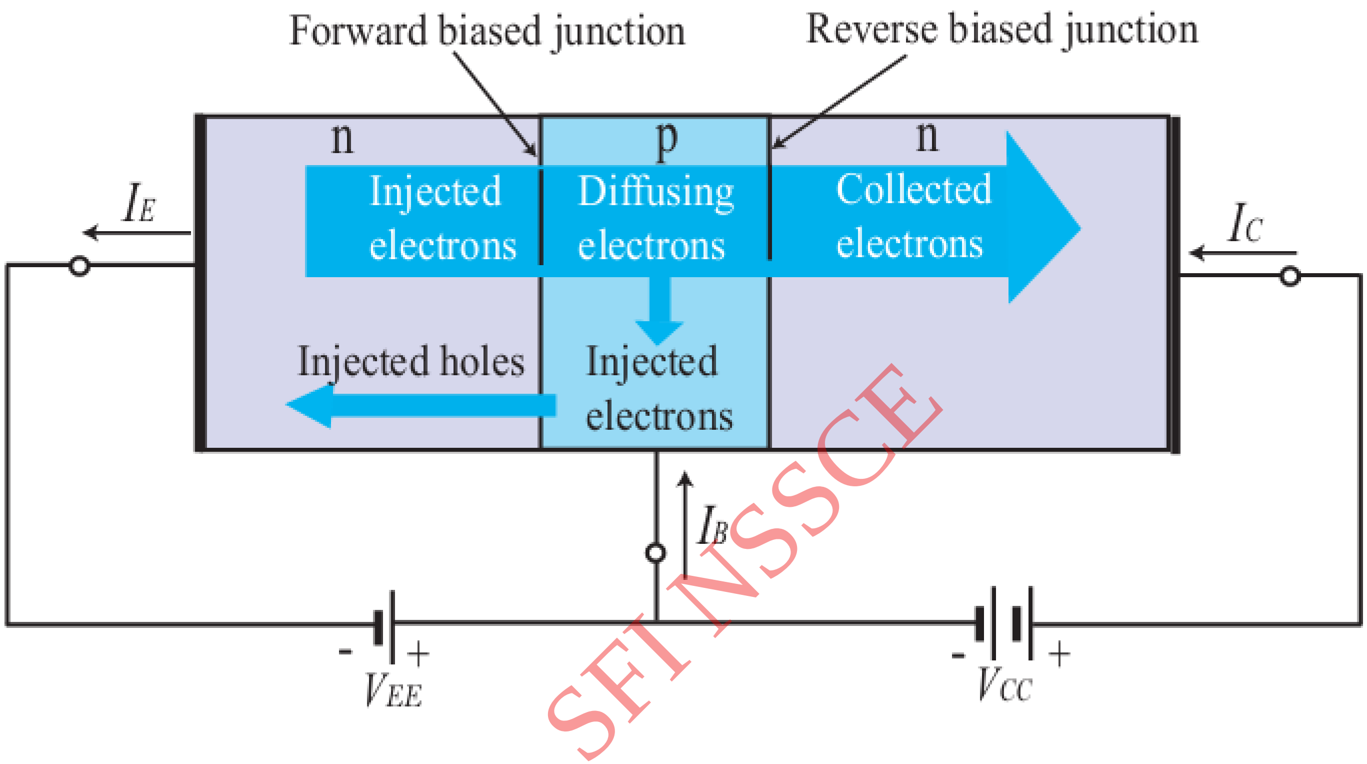
- ✓Emitter is heavily doped
- ✓Base is lightly doped
- ✓Collector is moderately doped

Bipolar Junction Transistors

Operation of BJT

Mode	Emitter-base junction	Collector-base junction
Active	Forward	Reverse
Saturation	Forward	Forward
cut-off	Reverse	Reverse
Reverse active	Reverse	Forward

BJT operation



The voltage between two terminals controls the current through the third terminal which is the basic principle of the BJT.

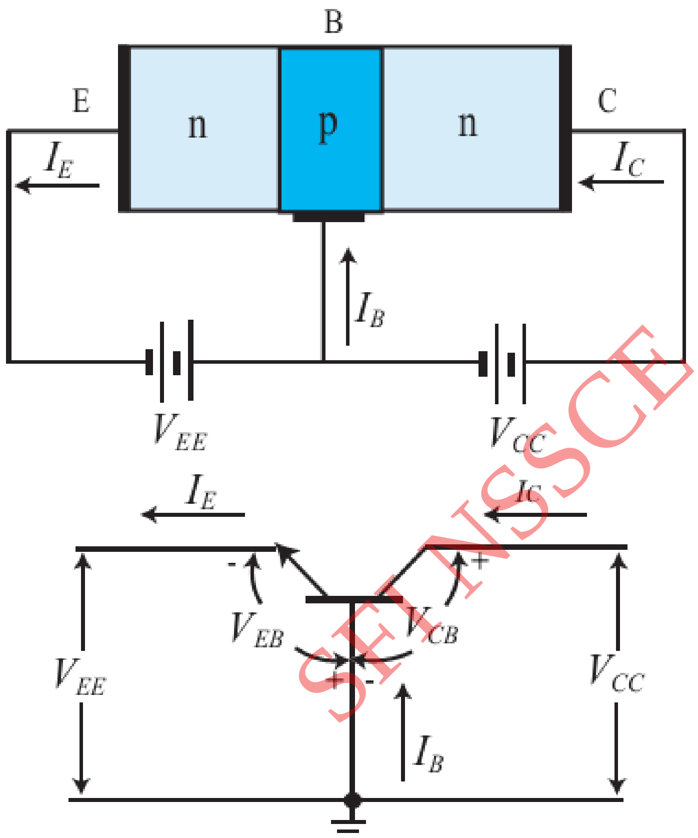
The emitter current as sum of base current and collector current.

$$I_E = I_B + I_C$$

Common base configuration

- ✓Base terminal of transistor is common to both the input and output signals.
- ✓The input is applied between emitter and base terminals.
- ✓The output is taken between collector and base terminals

Common base configuration

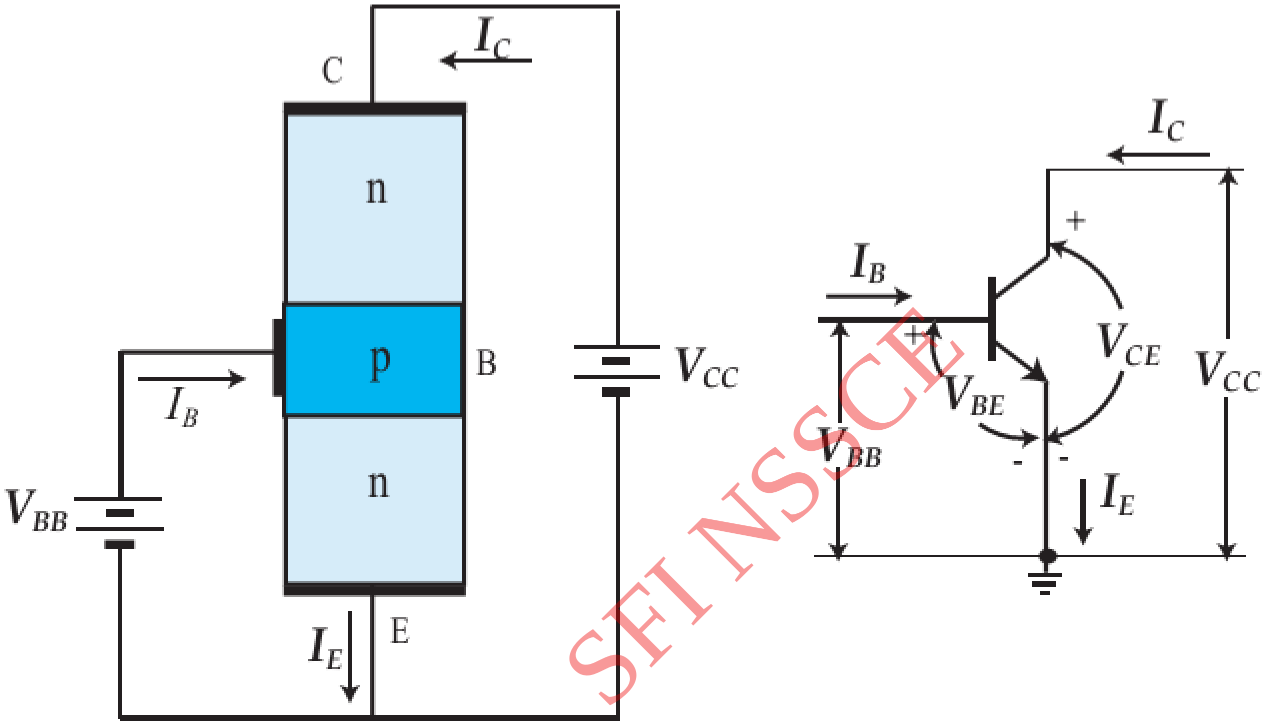


CB current gain

$$\alpha = \frac{I_C}{I_E}$$

α is close to unity

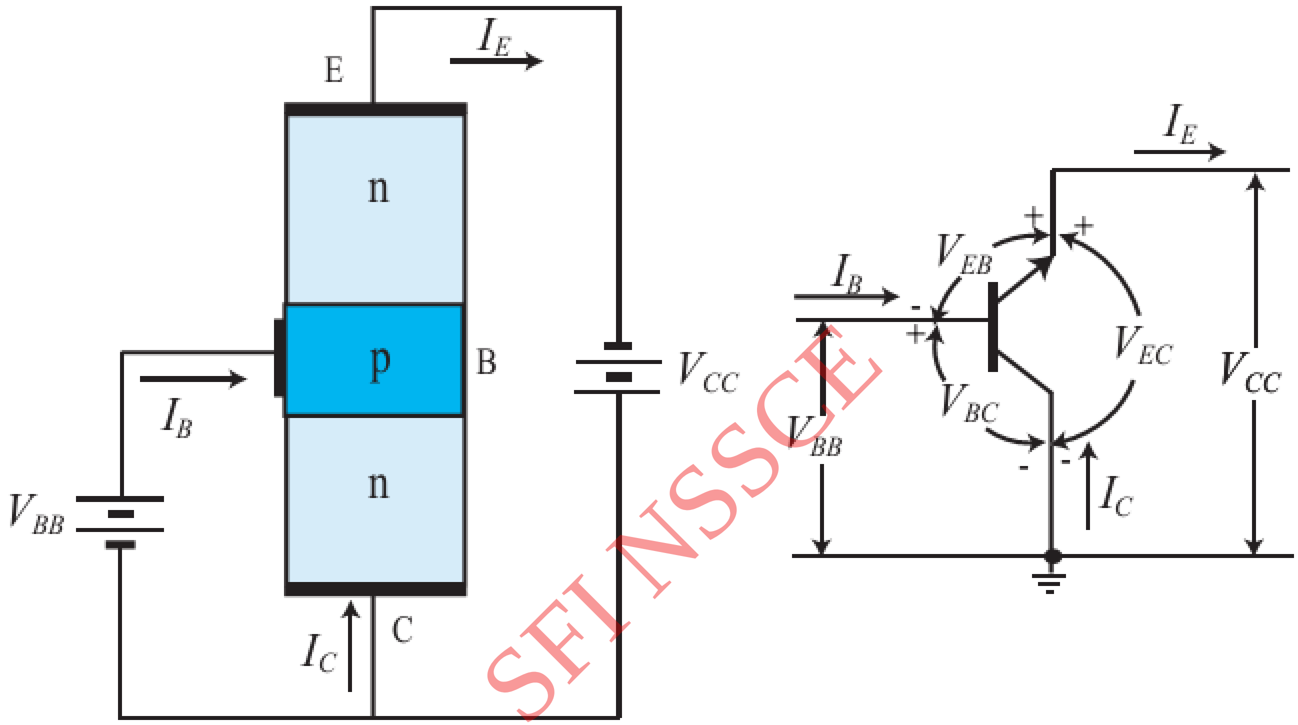
CE configuration of transistor



CE current gain $\qquad \beta = \frac{I_C}{I_B}$

Range of value of β varies typically from 20 to 500.

Common Collector configuration of transistor



$$\text{CC current gain, } \gamma = \frac{I_E}{I_B}$$

Relation between α, β and γ

$$\alpha = \frac{\beta}{1+\beta}$$

$$\beta = \frac{\alpha}{1-\alpha}$$

$$\gamma = \beta + 1$$

$$\gamma = \frac{1}{1-\alpha}$$

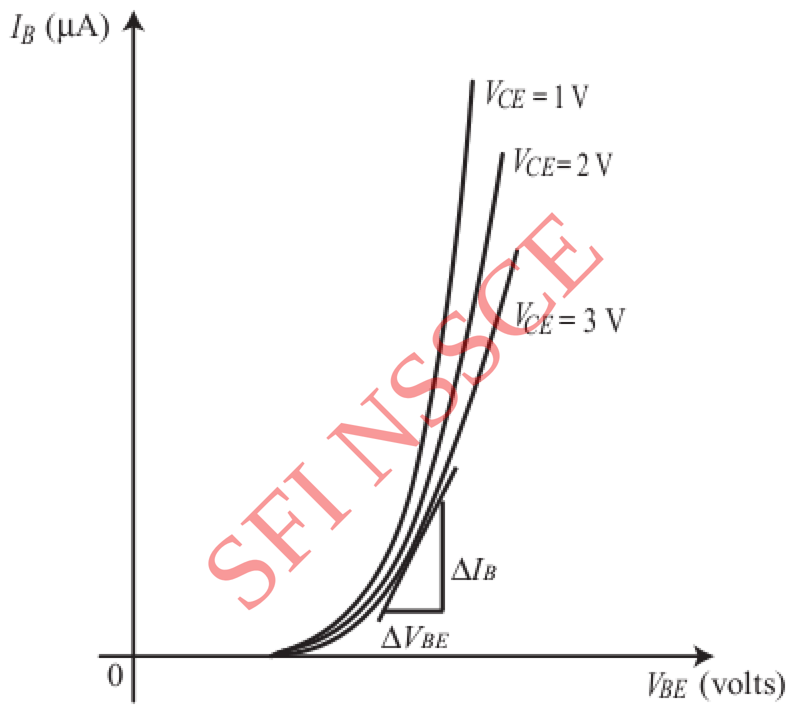
Transistor characteristics

Input chara. : Input voltage *Vs* input current$|_{\text{output voltage constant}}$

Output chara. : Output voltage *Vs* output current$|_{\text{Input current constant}}$

Transistor characteristics in CE configuration

CE input characteristics

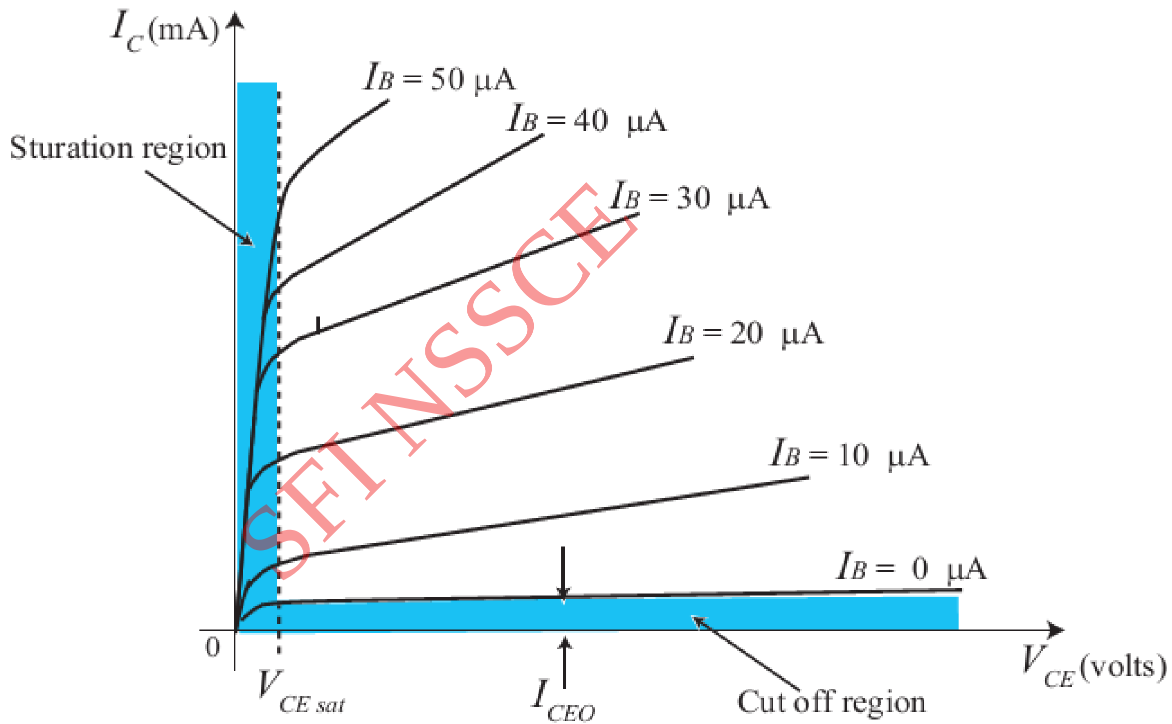


$$\text{ac input resistance, } r_i = \left.\frac{\Delta V_{BE}}{\Delta I_B}\right|_{V_{CE} \text{ constant}}$$

It typically varies from 600 to 4000 Ω.

Transistor characteristics in CE configuration

CE output characteristics



$$\text{ac output resistance, } r_\circ = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B \text{ constant}}$$

It ranges from 10 kΩ to 50 kΩ.

Summary of BJT configurations

Characteristic	Common Base	Common Emitter	Common Collector
Input resistance	Low	Medium	High
Output resistance	Very high	High	Low
Voltage gain	High	Medium	Low
Current gain	Low	Medium	High

Reference

Text book- "**Basics of Electrical and Electronics Engineering- APJ Abdul Kalam Technological University**", K. A Navas and T. A. Suhail, Rajath Publishers

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