18. Semiconductors

Metals
They have very low resistivity or high conductivity
Their Conduction band is partially filled and the valence band is partially empty or the conduction and valence band overlap.
Electrons from valence band can easily move into the conduction band
Semi-conductors
They have resistivity or conductivity intermediate to metals and insulators
There exists energy band gap E_g ($E_g < 3eV$) between conduction band and the valence band.
At room temperature, some electrons from valence band cross the energy gap and enter the conduction band.
Insulators
They have high resistivity (or low conductivity)
Large band gap E_g exists. ($E_g > 3$ eV)
There are no electrons in the conduction band, no electrical conduction is possible.
The electron cannot be excited from the valence band to the conduction band by thermal excitation.

Intrinsic Semi-conductor

- They are pure semiconductors which are free from impurity.
- In intrinsic semi-conductors, the number of free electrons n_e is equal to the number of holes n_h.
- The number of the free electrons in conduction band is equal to the number of holes in valence band.
- They behave like insulators at 0 K.
- Examples of Intrinsic semiconductors are Germanium(Ge) and Silicon(Si).
- A semi-conductor with impurity atom added to it is called extrinsic semi-conductor.

Types of extrinsic semiconductors:

- n- type semiconductors:
  - Doped with pentavalent impurity atoms for ex arsenic.
  - Majority carriers are electrons while holes are minority carriers.
- p- type semiconductors:
  - Doped with trivalent impurity atoms for ex boron.
  - Majority carriers are holes while electrons are minority carriers.

- **p-n junction** is formed by doping one side of a semiconductor with p-type impurity and other side of the semiconductor with n-type impurity. This is called **junction diode** or a **semiconductor diode**.

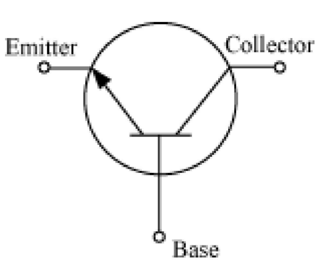
- **Forward biasing:**
  - Positive terminal of the source emf is connected to p-side and negative terminal to n-side of a p-n junction.

- **Reverse biasing:** Positive terminal of the source emf is connected to n-side and negative terminal to p-side of a p-n junction.
- A diode allows current to flow only in one direction. This application of diode is used in rectifiers.
- Uses of diodes:
  - Used to convert AC into DC.
  - Used in voltage regulation systems.

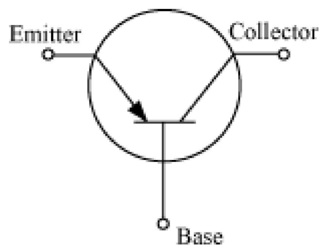
Special purpose diodes:

- Zener diodes
  - They are heavily doped p-n junctions.
  - They work in the reverse breakdown voltage region.
  - They are used for voltage regulation.
- Photodiodes
  - They are made of photosensitive semiconducting materials.
  - When light falls on them, electrons jump from the valence band to the conduction band, increasing the current in the circuit.
  - They are used to measure light intensity.
- Solar cells
  - They generate emf when solar radiation fall on their *p-n* junction.
  - They convert photon energy into electricity.
  - They harness solar energy that is free from all kinds of pollutions. Thus, they are eco-friendly.
  - Solar cells are used in satellites, sensors, communication stations, watches, TV, etc.
  - They are also used to power emergency phones on express highways.
- Light emitting diodes (LEDs)
  - It working is based on the fact that electrons excitation by a bias voltage results in the generation of light.
  - LEDs have low operational voltage and consumes less power. They requires less warm-up time.
  - They are light weight and durable.
  - They are used in advertising boards, rolling displays in offices, banks, airports, stations, etc.

- **Transistor** is a three terminal semiconductor device in which the middle region is called as **base** and the two end regions are called the **emitter** and the **collector**.
- It has two types:
  - npn transistor: two segments of n-type semiconductor are separated by a segment of p-type semiconductor. Its symbol is



- pnp transistor: two segments of p-type semiconductor are separated by a segment of n-type semiconductor. Its symbol is



- Transistor is used as
  - amplifier,
  - oscillators
  - switching circuits.

There are three types of configuration of the transistor configurations:

- Common-emmiter transistor
- Common-collector transistor
- Common-base transistor

Transistor as a device

- Transistor as a switch
  - It works as a switch in cut-off or saturation region.
  - when the input voltage v_i (base-emmiter voltage) is less than 0.6 V the transistor is in cut-off region and output voltage(v_o) is high.
  - when the input voltage v_i (base-emmiter voltage) is greater than 0.6 V the transistor is in saturation region and output voltage(v_o) is low.
- **Transistor as** Amplifier:
  - Transistor works as an amplifier in active region only
  - Transistor can be used in two configurations as an amplifier
  - Common base configuration
    - There is no phase shift between input and output.
  - Common emitter configuration
    - There is a phase shift of 180^o between input and output.
  - **Various gains in common base amplifier:**

  - **DC current gain**
  - αdc=IcIe
  - **AC current gain**

- $\alpha ac=\Delta Ic\Delta Ie$, when V_{cb} is constant

- **AC voltage gain**
- $Av=\Delta Ic\Delta Ie\times RoRi$
  Or $A_v = a_{ac} \times$ Resistance gain
- **AC power gain**
- AC power gain $=\Delta Ic\Delta Ie2\times RoRi$

  Various gains in common emitter amplifier:
- **DC current gain**
- $\beta=IcIb$
- **AC current gain**
- $\beta ac=\Delta Ic\Delta Ib$

- **AC voltage gain**
- $Av=\beta ac\times RoRi$
  $= \beta_{a.c} \times$ Resistance gain
- **AC power gain**
- AC power gain $= \beta_{a.\,c} \times A_v$

Transistor as an amplifier(CE configuration)

- It can be used as amplifier when operating point is fixed in middle of active region.
- Mostly common-emitter configuration is used due to its large current gain and large voltage gain.
- Ac input is given on emmiter-base terminals and is superimposed on the bias voltage and the amplified output is observed at collecter-emitter terminals.
- **Various gains in common emitter amplifier:**
  - **DC current gain**
  - $\beta=\alpha 1-\alpha$; $\alpha=IcIe$
  - **AC current gain**
  - $\beta ac=\Delta Ic\Delta Ib$

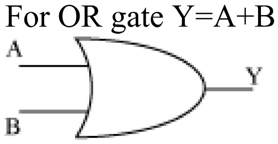
  - **AC voltage gain**
  - $Av=\Delta Vc\Delta Vi=\Delta Ic\times Ro\Delta Ib\times Ri=\beta a.c\times RoRi$
    $=\beta a.c \times$ Resistance gain

- **AC power gain**
- AC power gain = βa.c × A_v

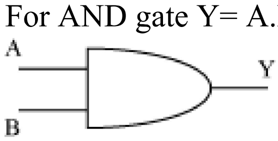
- **Feed back amplifier and transistor oscillator**
    - In oscillator, the ac o/p is produced without any external i/p signal.
    - An oscillator is a device in which the o/p power is returned back to the i/p, in phase with the starting power (i.e., as a positive feedback).
    - Feedback is accomplished by inductive coupling of transistor circuit.
    - Resonant frequency of this tuned circuit determines the frequency at which the oscillator will oscillate.
    - Oscillator frequency is given as ν=12πLC

Logic Gates

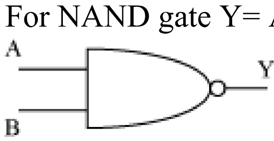
- A gate is a digital circuit that follows a certain logical relationship between the input and output voltage.
- The gates used commonly are OR, AND, NOT, NAND, and NOR gates.
- For input A and B and output Y the relationship followed by each gate is
    - For OR gate Y=A+B



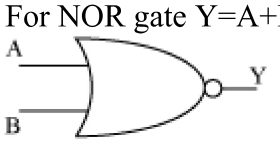
    - For AND gate Y= A.B



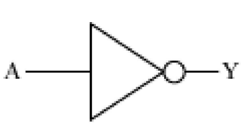
    - For NAND gate Y= A.B‾



    - For NOR gate Y=A+B



NOT gate is also called inverter for input A the output Y=A.



- Integrated Circuits
    - It is the circuits in which the circuit containing resistors, capacitors ,diodes and transisitors etc. are fabricated on a single chip.

- There are two types of ICs :
  - Analog ICs: ICs that process analog signals
- Digital ICs: ICs that process digital signals that have only two levels of the voltage.
- **Classification of the ICs**
- (Logic gate $\leq$ 10) $\rightarrow$ Small scale integration
- (Logic gate $\leq$ 100) $\rightarrow$ Medium scale integration
- (Logic gate $\leq$ 1000) $\rightarrow$ Large scale integration
- (Logic gate > 1000) $\rightarrow$ Very large scale integration