CHAPTER 17

ELECTRONICS

INTRINSIC SEMICONDUCTOR

→ A perfect, pure semiconductor crystal containing no impurities is called an intrinsic semiconductor.

→ A semiconductor nearly at 0K (zero K) cannat conduct and behave as a perfect insulator.

→ The energy band structure of a semiconductor is characterized by a valence band and a conduction band separated by the band gap E_g

→ The electrons in the valence band do not possess enough energy to jump into the conduction band. Therefore, an externally applied electric field cannot cause a flow of current and the semiconductor nearly at zero K behaves as an insulator

INTRINSIC SEMICONDUCTOR AT ROOM TEMPERATURE

→ ~~From~~ At room temperature, some of the electrons convert part of their thermal energy into potential energy. Those electrons, which acquire P.E equal to, or in excess of, the bandgap energy E_g are excited from the valence band to the conduction band

→ Bandgap energy E_g is the minimum amount of energy required to excite an electron from valence band to conduction band.

→ E_g is characteristic of the material.

→ The number of electrons excited to the conduction band depends on the amount of thermal energy received by the crystal.

→ In intrinsic semiconductors, conduction arises from thermally (or optically) excited electrons.

INTRINSIC CARRIERS:

→ In pure semiconductors, a single event of bond breaking leads to two carriers, namely an electron and a hole.

→ The electron and hole are created as a pair and the phenomenon is called electron-hole pair generation.

→ At any temperature, the number of electrons generated will be equal to number of holes generated.

$$N = P = N_i$$

N_i : intrinsic density or intrinsic concentration

→ The electrons move in the conduction band and the hole moves in the valence band.

DOPING OF IMPURITIES

→ An addition of impurity into an intrinsic semiconductor is called doping.

→ The impurity added is called a dopant.

→ A semiconductor doped with impurity atoms is called extrinsic semiconductor.

N-TYPE SEMICONDUCTOR

→ Group V Dopant

→ Phosphorus and Arsenic are the dopants normally used.

→ These Group V dopants contribute electrons to the conduction band and are called donor atoms. They produce electrons without producing holes in valence band.

→ At very low temperature, the donor atoms are not ionized and the conduction band is empty

→ At slightly elated temperature, the donor electrons populate the conduction band.

→ At ordinary temperatures, some electrons from the valence band are also excited into the conduction band through intrinsic process.

→ Majority Carriers : Electrons

→ Minority Carriers : Holes

P-TYPE SEMICONDUCTOR

- → Group III dopants
- → Trivalent atoms such as boron and aluminium are the dopants.
- → The trivalent dopant falls short of one electron for completing the four covalent bonds with its neighbours.
- → When the free electron from the neighbouring atom acquires energy and jumps to form a bond, it leaves behind a hole.

- → The boron atom having acquired an additional electron becomes a negative ion
- → The hole can move freely in the valence band whereas the impurity ion is immobile.
- → As a whole this material is neutral bcz neutral boron is added to ~~exactly~~ neutral silicon.
- → The impurity atoms which accept electrons from the valence band are known as acceptor atoms.
- → The acceptor impurity atoms produce holes without the simultaneous generation of the electrons, in conduction band.
- → Majority Carriers : Holes

  Minority Carriers : Electrons

P-N JUNCTION OR JUNCTION DIODE

→ Diode is an electronic circuit component which allows current to pass only in one direction.

→ P-N Junction is developed from a single crystal by introducing donor impurities on one side and acceptor into the other side.

→ Due to density difference across the junction the holes initially diffuse towards N-side, where the number of holes is lesser. Similarly, electron diffuse to P-side of junction.

→ Migration of electrons and holes across junction due to concentration difference is termed diffusion.

→ At the junction on both sides a region is formed which is depleted of charge carriers. This region is called depletion region whose thickness is about 10^{-6} m.

→ An electric field is developed across the junction which is in direction to oppose the further diffusion of electrons from N-side.

→ The potential developed across the barrier layer is called barrier potential. It is 0.7 volts for silicon diode and 0.3 volts for germanium diode.

→ When no external source is connected to diode, it is called unbiased.

→ The width of depletion layer depends on carrier concentration.

FORWARD BIASED P-N JUNCTION

→ When negative terminal of battery is connected to N-side and positive terminal to P-side the connection is called forward bias.

→ When battery voltage exceeds the barrier potential (0.7V for Silicon and 0.3V for Germanium), majority of charge carriers start crossing the junction.

→ The resistance of the junction in forward bias is quite low

→ The electrons from N-side drift towards the junction and cross it and holes move in opposite direction.

→ Under proper forward biasing of a P-N Junction diode the width of the depletion layer decreases or the barrier potential decreases and the diode conducts.

→ In internal circuit current in N-region is due to electrons and in P-region due to holes. But in external circuit the current is due to free electrons.

REVERSE BIASED P-N JUNCTION

→ The negative terminal of the battery is connected to the P-side and positive terminal to N-side.

→ The applied reverse voltage establishes an electric field which acts in the same direction as the electric field in the potential barrier. Therefore, the potential barrier is increased.

→ The increased potential barrier prevents the flow of charge carriers across the junction.

→ The battery act as a reverse bias to majority charge charged carriers but as a forward bias to minority charge carriers.

→ The minority charge carriers move across the junction. This constitutes reverse saturation current which is very small of the order of 1 μA

→ The resistance of the junction in reverse bias is 10 kΩ

→ Under reverse biasing of P-N junction diode, the width of depletion region increases or the barrier potential increases.

KNEE VOLTAGE

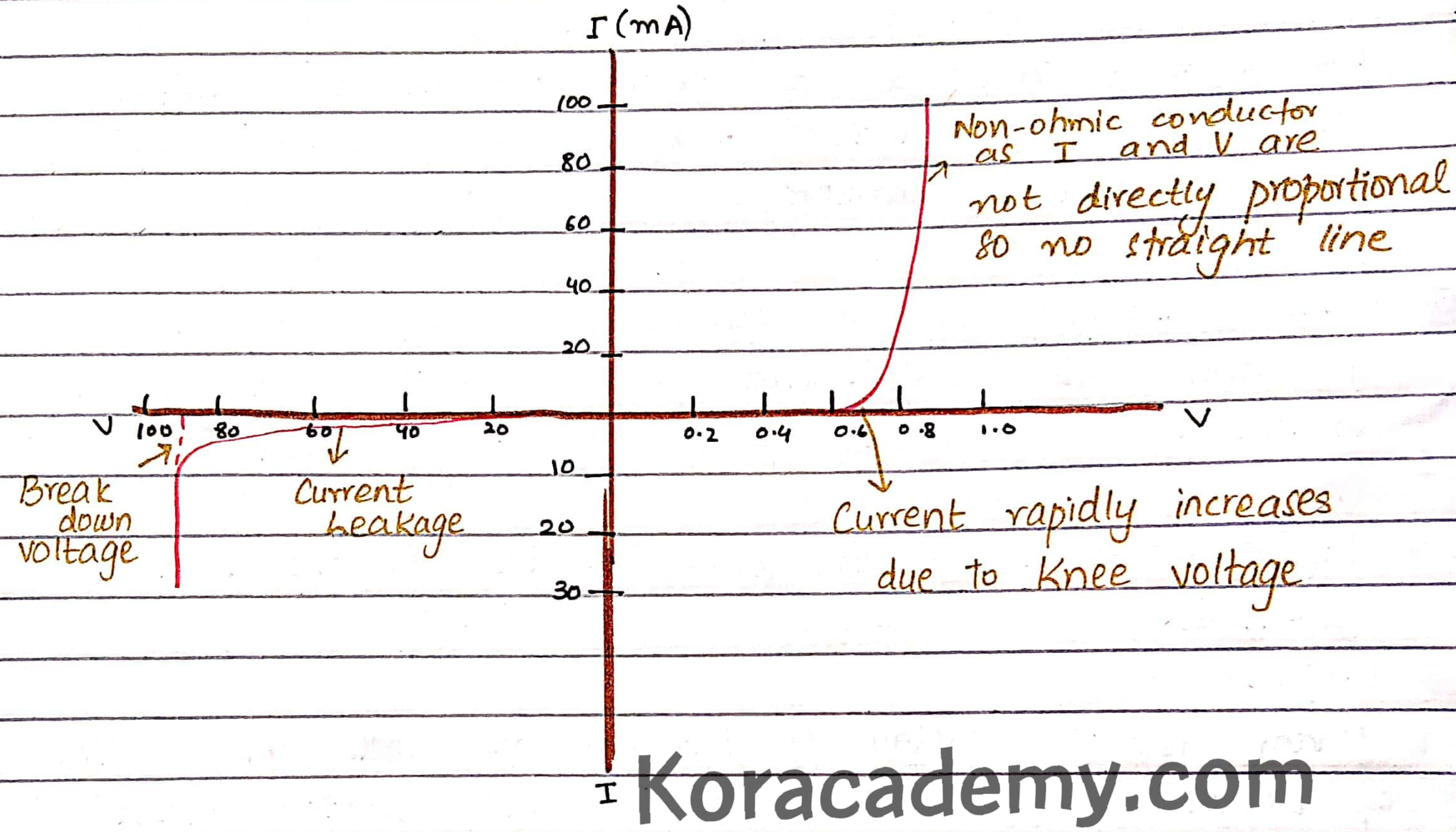
The point at which majority charge carriers cross the junction and current flows is called knee voltage. This is called forward bias and the current is called forward current.

Knee Voltage for:

Germanium → 0.3V

Silicon → 0.7V

VI CHARACTERISTICS OF P-N JUNCTION



→ Forward current increases rapidly beyond the knee voltage. There exists a maximum current limit for junction, which is decided by power ratio of junction. Beyond that, the junction is destroyed.

→ In reverse bias, if voltage is increased, due to available energy, covalent bonds break and large number of electrons are released. This causes a sudden increase in current. This is called zener effect.

If reverse bias is increased further, minority charge carriers attain high velocity and knock down the bound electrons from covalent bonds and current increases. This is called avalanche effect.

Using these effects, zener diodes are formed

DRIFT OF MINORITY CARRIER

Electric field across the junction prevents the diffusion of majority carriers. However, the electric field has the right direction to promote the flow of minority carriers across the junction. Electrons arriving at the junction from the bulk of P-region are assisted by the electric field to move into N-region. Similarly, holes in the N-region are helped to move into P-region. As a consequence, an electric current flows across the junction.

As the current is caused by the electric field it is a drift current. The net drift current through the junction is due to electron and hole which is given by:

$$I_{(drift)} = I_e + I_h$$

The minority carriers are generated through breaking of covalent bonds.

DIFFUSION CURRENT

Diffusion current is a current in a semiconductor caused by the diffusion of charge carriers. This is the current which is due to the transport of charges occuring bcz of non-uniform concentration of charged particles in a semiconductor.

Whenever two different type of material are joined together i-e N-Type and P-Type, then there exist a charge concentration difference. This difference leads to flow of free electrons from N-Type material to P-Type material. Thus flow of electrons constitute flow of charge, hence a current exist across the junction. This current is very small and also termed as leakage current.

DRIFT CURRENT

Drift current is the electric current, or movement of charge carriers, which is due to applied electric field, often stated as electromotive force over a given distance. When an electric field is applied across a semiconductor material, a current is produced due to flow of charge carriers. This current is also called load current which flows through the applied load in the circuit.

* Diffusion current can be in same or opposite direction to drift current.

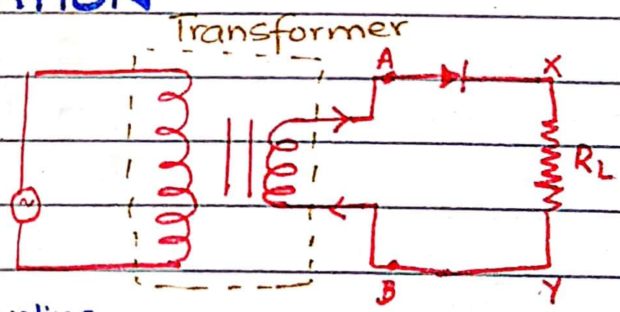
RECTIFICATION

→ Conversion of AC into DC is called rectification.
→ Device used for rectification is called rectifier.
→ Diodes can be used as a rectifier. When diode is forward biased it allows the current to pass and in reverse bias it (almost) stops the current. Thus it can be used as unidirectional device (or rectifier).

* There are two very common types of rectification
  1. Half-wave rectification
  2. Full-wave rectifier.

1. HALF WAVE RECTIFICATION

→ One diode is used
→ A transforener is used to couple the AC input voltage from source to rectifier



→ Advantages of transformer coupling:
(i) allows the source voltage to be stepped up or stepped down.
(ii) The AC source is electrically isolated from the rectifier thus preventing a shock hazard in secondary circuit.

→ When point A is positive w.r.t B, the diode is forward biased and current flows through the load.
→ When point A is negative w.r.t B, the diode is reverse biased and no current flows.

→ When diode is reverse biased, total voltage appears across the diode.

→ Peak Inverse Voltage (PIV) is the maximum voltage that the rectifying diodes has to withstand when it is reverse- biased.

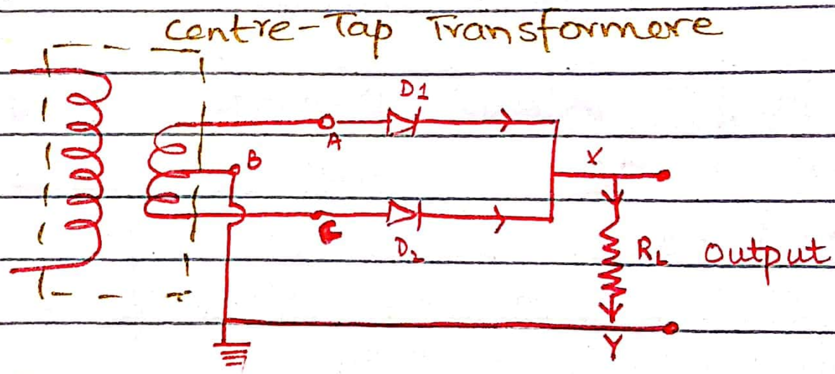
2. FULL WAVE RECTIFIER

Two Types

(1) Center- Tap Transformer (Two Diodes are used)

(2) Bridge Rectifier (Four Diodes are used)

* CENTER - TAP ~~Bioi~~ RECTIFIER



→ Two diodes in alternate switching mode are used

→ Transformer with center- tapped secondary winding is used

→ Centre Tap Transformer is a special purpose device in which (i.e point B) always remains at zero volt.

→ In first half cycle, D_1 is forward biased and D_2 is reverse biased. Current flows due to D_1 only

→ In second half cycle, D_1 is reverse biased and D_2 is forward biased. Current flows due to D_2 only

* LIGHT EMITTING DIODE

→ It is a heavily doped P-N Junction which under forward bias emits spontaneous radiation.

→ LEDs are made from special semiconductors such as gallium arsenide and gallium arsenide phosphide.

→ When an electron combines with a hole during forward bias conduction, a photon of visible light is emitted

→ convert electrical energy into light

→ used in remote controls, burglar alarm systems, optical communication etc

* PHOTO DIODE

→ Photo diode is a P-N Junction diode, operated under reverse bias.

→ used for detection of light

→ When the photodiode is illuminated with light with energy greater than the energy gap (E_g) of the semiconductor, then electron-hole pairs are generated due to absorption of electrons.

→ The diode is fabricated such that the generation of electron-hole pairs takes place in or near the depletion region of the diode.

→ Due to electric field of the junction, electrons and holes are separated before they recombine. Electrons are collected on N-side and holes are collected on P-side giving rise to an emf. When an external load is connected, current flows.

→ The magnitude of photocurrent depends on intensity of incident light.

* SOLAR CELL OR PHOTO VOLTAIC CELL

→ A solar cell is a P-N Junction which generates emf when solar radiation falls on the P-N Junction.

→ No external bias is applied

→ Junction area is kept much larger.

→ The potential barrier between p and n regions is used to drive a current through external circuit when light is incident on junction.

→ Solar cells are used to power electronic devices in satellites and space vehicles and calculators

TRANSISTOR

Bipolar Transistors: whose function depends upon both (majority and minority) charge carriers.

Unipolar Transistors: whose function depends upon majority charge carriers e.g field effect transistors.

PNP or NPN Transistors:

In transistor, there are two PN junctions which form either PNP or NPN transistor.

In NPN, electrons and in PNP, holes are the majority charge carriers.

Emitter: The first region is emitter and it is heavily doped. Its function is to emit the charges.

Collector: The last region collects the charges and it is called collector.

Emitter and collector made of same material. Just emitter is smaller in size and have high impurity concentration.

Base: The middle region is ~~the~~ base which is thin and lightly doped.

→ The emitter junction is forward biased, so it offers low resistance.

→ The charges emitted by the emitter are attracted by the collector.

→ The collector junction is reverse biased, there exists a large potential gradient, which attracts the charges.

→ If the collector is open (means not connected to power supply) charges return via base region.

→ The addition of base current and collector current is equal to emitter current.

$$I_E = I_B + I_C$$

→ There is no difference in operation of PNP and NPN transistor except the polarity of biasing.

→ In most of the cases NPN transistors are preffered bcz mobility of electrons is three times more than that of holes and therefore the operation is faster.

TYPES OF CONFIGURATION

1. Common Base Configuration
2. Common Emitter Configuration
3. Common Collector Configuration

1. COMMON BASE CONFIGURATION

→ Base is common to both input and output circuits.

→ Emitter is input terminal

→ Collector is output terminal

→ Base terminal is grounded so the common base configuration is also known as grounded base configuration

→ Base-emitter junction is forward biased and the collector-base junction is reverse biased

→ Common base amplifier provides a low input impedence and high output impedence.

→ Transistors with low input impedence and high output impedence provide a high voltage gain

→ Even though the voltage gain is high, the current gain is very low and overall power gain of the common base amplifier is low as compared to other transistor amplifier configuration

→ The common base amplifier is mainly used as a voltage amplifier or current buffer

→ To fully describe the behaviour of transistor with CB configuration, we need to set of characteristics

1. Input Characteristics
2. Output characteristics

1. Input Characteristics

The input characteristics describe the relationship between input current (I_E) and the input voltage (V_{BE})

The variation in the emitter current (I_E) w.r.t change in the base-to-emitter voltage (V_{BE}) at the constant collector-to-base voltage (V_{CB}) is input characteristics.

2. Output Characteristics:

The output characteristics describe the relationship between output current (I_c) and the output voltage (V_{CB})

The variation in the collector current (I_c) with change in collector-to-base voltage (V_{CB}) at the constant emitter current (I_E) is output characteristics.

The output characteristic has three regions of operation namely active, cut-off and saturation.

(a) Active Region: When the base-emitter junction is forward biased and the collector-base junction is reverse biased, it is active region.

There are different layers in Active Region

(b) Cut-off Region: When both collector-base and base-emitter junctions are reverse biased it is cut off region. The output current is zero in this case.

(c) Saturated Region: When both the junctions are forward biased, it is saturation region.

In saturated region very large amount of current will flow and within seconds the transistor will burn.

In this case the transistor is fully on i-e infinite amount of current will flow.

Q-Point : or Quality Point is the point in active region which is the optimum current for the working of transistor.

ALPHA FACTOR:

The ratio of I_C and I_E is called alpha factor. It is an amplification factor

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

For ideal transistor $\alpha = 1$

Values of alpha :

$$0 < \alpha < 1$$

2. COMMON EMITTER CONFIGURATION

→ base - emitter junction is forward biased
→ base- collector junction is reverse biased

Input Characteristics :- The variation in base current (I_B) with change in base-to-emitter voltage (V_{BE}) at constant collector-to emitter voltage (V_{CE}) are input characteristics.

Output Characteristics : The variation in collector current (I_C) with change in collector-to-emitter voltage (V_{CE}) at constant base current (I_B) are output characteristics.

Beta Factor :

→ ~~Be~~ Current gain or current amplification factor
→ Generally it ranges from 50 - 400
→ For ideal transistor, $\beta = \infty$

$$\beta = \frac{I_C}{I_B}$$

→ Relation of β with α

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

→ The value of α, β determined during manufacturing of transistor. Once it is manufactured, both remain constant

TRANSISTOR AS AN AMPLIFIER

→ A junction transistor in the common emitter mode can act as a voltage ~~amplitude~~ amplifier, if a suitable resistor, called a load is connected in the collector circuit.

→ $$\frac{V_{out}}{V_{in}} = \beta\left(\frac{R_c}{R_{ie}}\right)$$

R_{ie} : input emitter resistance

→ The ratio of V_{out}/V_{in} is called voltage gain of the amplifier.

TRANSISTOR AS A VOLTAGE SWITCH

→ Transistors are used as switches in many important electronic circuits

→ In order to turn on the switch, a large potential V_B is applied between control terminals.

→ An electronic computer is basically vast arrangement of electronic switches, which are made from transistors.