UNIT-5

Special Semiconductor Devices

Priniple of operation, Char. of and Application of - Varactor diode, Tunnel Diode, Uni Junction Transistor, Silicon controlled Rectifier, Scottky diode, LED, Photo transistor.

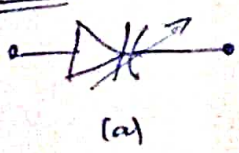
Varactor Diode:-

* As the transition capacitance of a diode varies with the applied voltage, it can be used as a voltage variable capacitance in many application.

* In practice, special type of diodes are manufactured which shows the transition capacitance property more predominally as compared to the normal diode, such diodes are called "Varactor diodes", "Varicap", VVC (Volt. Variable capacitance) and 'tuning diode'.

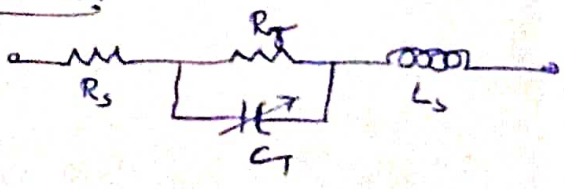
* It is also a junction diode with a small impurity dose at its junction, which has the useful property that its junction transition capacitance is easily varied electronically.

Symbol:



(a)

Equ. ckt



Where,

R_r - Reverse Resistance, this is very large ($\geq 1 M\Omega$)

R_s - The geometric resistance of diode (0.1 - 12Ω) (i.e; small)

L_s - The Inductance it indicates that there is a high freq limit associated with the use of Varactor diode

C_T - Transition Capacitance.

* $$C_T = \frac{K}{(V_j + V_R)^n}$$

where, K - constant depends on semiconductor material and construction technique.

V_j - junction potential.

V_R - magnitude of reverse bias voltage.

$n = \frac{1}{2}$ for the alloy junction, $\frac{1}{3}$ for diffused junction

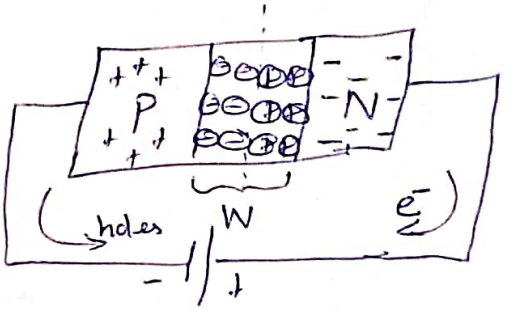
* $W \propto \sqrt{V_0} = V_0^{1/2}$ (or) $W \propto \sqrt[3]{V_0} = V_0^{1/3}$

* At the zero bias condition, the capacitance is C(0).

In terms of C(0), the transition Capacitance is,

$$C_T = \frac{C(0)}{\left[1 + \frac{V_R}{V_j}\right]^n}$$

Principle of operation of Varactor Diode:-



* When diode is RB, the depletion Region is formed.
* The Large Reverse biased applied across the diode, the width of the depletion region 'W' becomes wider.
* For small Reverse bias, depletion layer width will becomes narrow.
* This depletion Region is devoid of majority Carriers and acts like an insulator preventing conduction b/w the N and P regions of the diode, which represents like two plates of a capacitor.

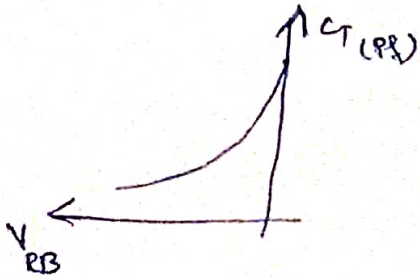
$$C_T \propto \frac{1}{W} \quad (or) \quad C_T = \frac{\varepsilon A}{W}$$

where, ε - permittivity
A - Area
W - distance b/w plates.

$V_{RB} \uparrow \; W \uparrow \; C_T \downarrow$

* Increasing RB Volt is increase depletion region width and decreasing transition capacitance C_T.
* At Zero Volt, the Varactor depletion region is small and the capacitance is large at approximately 600 pf.

$V=0$, W-small, $C_T \uparrow$



Application:

1. FM radio & TV Receivers.
2. AFC CKts i.e; Automatic frequency control.
3. self Adjusting bridge circuit
4. Adjustable band pass filter.
5. PLL i.e; Phased locked loop
6. Voltage Controlled oscillators.
7. Electronic tuning devices, mobiles.

→ Determine the transition capacitance of a diffused junction Varactor diode at a reverse bias volt. of 4.2V of C(0) = 80 pf. and junction potential of 0.7V. Also calculate constant 'K' for diode.

Sol Given Data: $V_R = 4.2V$, $V_j = 0.7V$, $C(0) = 80pf$; $n = 1/3$

$$C_T = \frac{C(0)}{\left[1 + \left(\frac{V_R}{V_j}\right)\right]^n} = \frac{80\times10^{-12}}{\left[1 + \left(\frac{4.2}{0.7}\right)\right]^{1/3}} = 41.82\,pf.$$

and

$$C_T = \frac{K}{[V_R + V_j]^n} \Rightarrow K = C_T [V_R + V_j]^n = 41.82\times10^{-12} \times (4.2+0.7)^{1/3}$$

$$= 71.03\times10^{-12}$$

Tunnel Diode:-

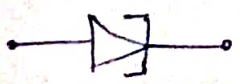
* A Tunnel diode is a type of semiconductor diode which is capables of very fast operation.

* A tunnel diode is a thin-junction diode which exhibits negative resistance under low forward bias conditions.

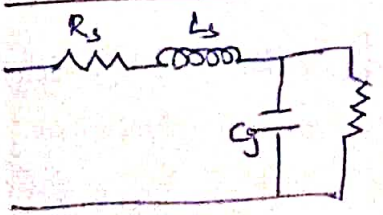
* Introduced by Leo Esaki in 1958. So, it is called as 'Esaki diode'. These are high impurity density normal PN Junction diodes.

* Normally an electron or holes must have energy greater than or equal to potential energy barrier, to move to other side of the barrier. For very thin barrier there is a large probability of electron penetrating through the barrier which is called as Tunneling (Quantum-Mechanical behaviour).

Symbol



Equalent circuit:



where,

R_s – Series Resistance due to ohmic conduct resistance.

L_s – Series Inductance due is depends upon the lead lengths & geometry of the diode package.

C_j – Junction capacitance depends upon the bias represents junction diffusion capacitance.

$-R_n$ – -ve resistance has a minimum at the point of inflection b/w Peak ct & Valley ct.

Principle of operation:

Under Forward bias:

* As voltage begins to increase, electrons at first tunnel through the very narrow Pn-junction barrier ~~become~~ because filled electron states in the conduction band on the n-side become aligned with empty valance band hole states on the p-side of the Pn junction.
* As voltage increases further there states become more misaligned and the current drops. It is called -ve resistance because current decreases with increasing voltage.
* As voltage increases yet further, the diode begins to operate as a normal diode where electrons travel by conduction across Pn junction.

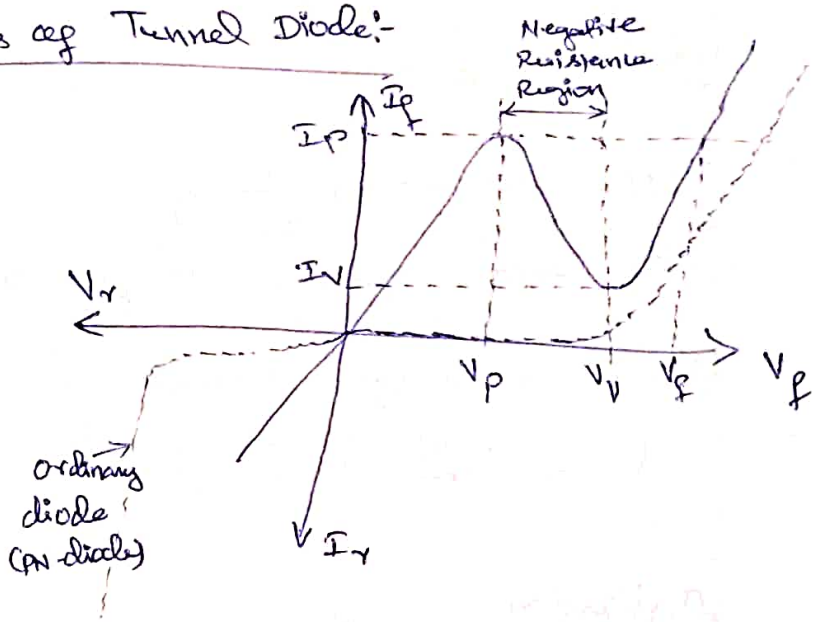
Under Reverse bias:

*When used in the Reverse direction they are called 'back diodes' and can act as fast rectifiers with zero offset voltage and extreme linearity for power signals.

*Under Reverse bias filled states on the p-side become increasingly aligned with empty state on the n-side and electrons now tunnel through the Pn junction barrier in Reverse direction.

V-I Characteristics of Tunnel Diode:-

Where,
V_p - peak voltage
V_v - Valley voltage
V_f - Peak Forward voltage
I_p - Peak current
I_v - Valley current



* Thus the most important operating Region for a tunnel diode is the negative resistance Region.

* The value of current b/w I_p and I_v can be obtained with these different voltage values. So the characteristics is triple values. This multivalued features makes the tunnel diode useful in the pulse and digital circuits.

Advantage:-

(1) Environmental Immunity i.e; peak point (V_p, I_p) is not a sensitive function of temperatures.
(2) Low cost.
(3) Low power consumption.
(4) High speed i.e; tunneling takes places at the speed of light.
(5) Low noise.

Disadvantage :-

(1) Low o/p voltage swing, i.e; even for small voltage while the current goes to large values. so the swing is limited.

(2) Circuit design difficulty. Since it is a two terminal device and there is no isolation b/w I/p and o/p.

Application :-

(1) As a high speed switch

(2) In pulse and digital circuit.

(3) In negative resistance and high freq (microwave) oscillator.

(4) In switching Networks.

(5) In timing and computer logic circuitry.

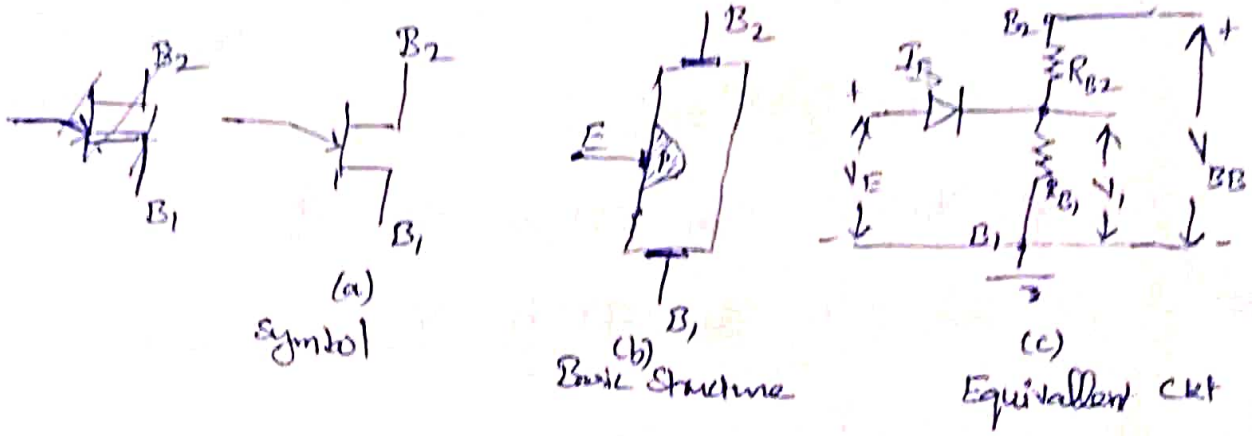
(6) Design of pulse generators and amplifiers.

Unijunction Transistor (UJT):-

* UJT is a 3-terminal semiconductor switching device. It has only one PN junction and 3-leads.

* P-type emitter alloyed to a highly doped n-type material.

* Terminals are, Emitter(E), Base1(B1) and Base-2(B2).



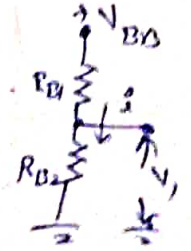
(a) Symbol (b) Basic Structure (c) Equivalent ckt

* originally this device was named as 'double base diode' but now it is commercially known as UJT.

Principle of operation & VI characteristics:-

* If emitter $I_E = 0$, due to supply voltage V_{BB}, a current 'i' is,

$$i = \frac{V_{BB}}{R_{B1}+R_{B2}}$$



$$V_1 = i R_{B1} = \frac{V_{BB}}{R_{B1}+R_{B2}} \times R_{B1}$$

$$V_1 = \frac{R_{B1}}{R_{B1}+R_{B2}} \times V_{BB} = \eta V_{BB}$$

Where, η = Intrinsic stand off ratio.

* It is evident that the diode cannot conduct unless the emitter voltage

$$V_E = V_\gamma + V_1$$

[where, V_γ – cut in volt. of the diode

* The value of the emitter voltage which make the diode conduct is termed as 'peak voltage' and it is denoted as 'V_p'.

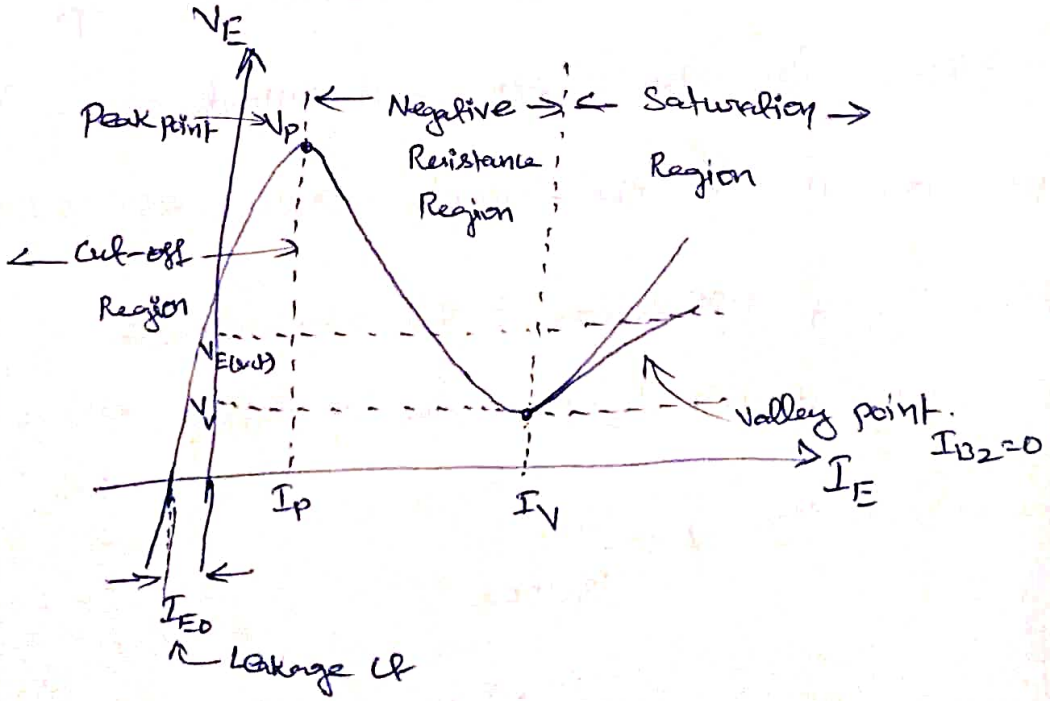
$$V_p = V_\gamma + V_1 \quad \text{where, } V_1 = \eta V_{BB} = \frac{R_{B1}}{(R_{B1}+R_{B2})} V_{BB}$$

$\eta = 0.56$ to 0.82

$$V_p = V_\gamma + \eta V_{BB}$$

ie; If $V_E < V_p$ then UJT is OFF and

$V_E > V_p$ then UJT is ON.



* If a -ve voltage is applied to the emitter, PN-junction remains reverse biased and the emitter current is cut-off. The device is now in the off state. upto the left of the peak point is called 'cut-off region'.

* The UJT has a stable firing voltage 'V_p' & small firing current I_p (25 μA). At 'P' the peak voltage $V_p = V_\gamma + \eta V_{BB}$, the diode starts conducting and holes are injected into N-region, Hence resistance decreases there by decreasing V_E for the increasing in I_E (Negative resistance Region).

* After the valley point, the device is driven into saturation and behaves like a normal PN junction diode. In valley point the resistance changes from negative to positive.

* For large I_E, the characteristics asymptotically approaches the curve for $I_{B2}=0$

Application :-

1. Sawtooth wave generator
2. Pulse generator
3. Switching, timing and Phase control circuits
4. UJT used as Relaxation oscillator.

Schottky Diode:-

* Schottky Diode is a diode of junction lightly dopped n-type semiconductor with a metalelectrode.

ie; A metal semiconductor junction is formed b/w a metal and a semiconductor, creating a schotty barrier diode.

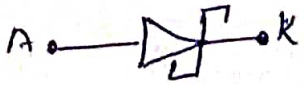
* Typically metal used are molybdencam, Platinum, chromium, tungsten and Allumimum.

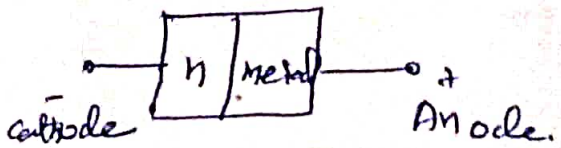
* Metal sides acts as the anode and n-type semiconductor acts as the Cathode.

* This Schottky diode results is both very fast switching diode and low forward volt. drops.

* Schottky diode can produce a very fast switching diode which is mainly used in high frequency circuits and high speeds digital circuits.

Symbol





Principles of operation:-

It is a unipolar device because it has electrons as majority carriers on both side of the junction. Hence there is no depletion layer formed near the junction.

* under Forward bias, the electrons move from n-type material to the metal and give up their energy quickly. There are no holes, so the conduction quickly stops upon change to reverse bias.

FB ⇒ e^- move to semi to metal quickly.
RB, condu. quickly stopped because no holes.

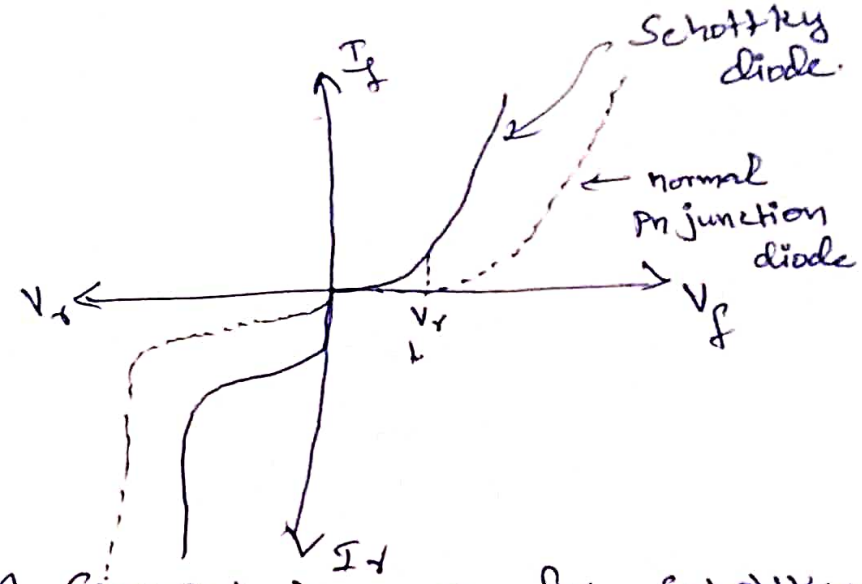
ie; The forward ct is dominanted by electrons flow from semiconductor to metal and the reverse ct is mainly due to electrons flow from metal to Semicondr

F.B → I ↑ from semi to metal
R.B → I↓ e^- flow from metal to semi is low.

As there is very little minority carrier injected from semiconductor into metal, so there are also said to be "Majority Carrier Devices".

* The diode is also referred to as "hot carrier diode" because unforward biased electrons plunge into the metal from semiconductor with large energy there are commonly called as hot carriers.

V-I Characteristics



* V_γ - cut in voltage is less for schottky diode.

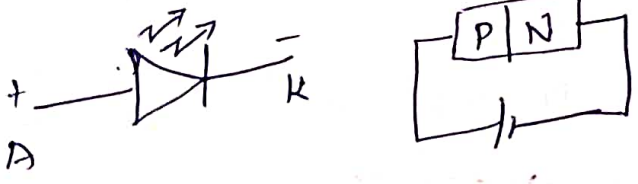
* Reverse saturation current is more for schottky diode compared normal PN-junction diode for silicon.

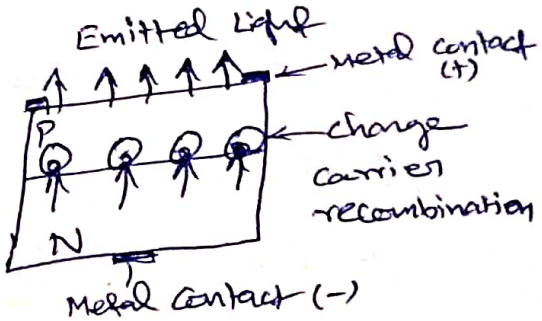
Application

1. schottky diode can be used for rectification of signals of frequencies even exceeding 300MHz.
2. used in switching power supplies of freq. of 10GHz.
3. used in sensitive communication receivers like RADARs.
4. used in clipping and clamping circuit and in computer gating.

LED - Light Emitting Diode

* LED is a PN junction device which emits light when forward biased, by a phenomenon called Electroluminescence.





Operation

* In all semiconductor PN Junctions some of the energy will be rediated as heat and some in the form of photons.

* In Si and Ge greater percantange of energy is given out in the form of heat and Emitted light is insignificant.

* In other materials like GaAsP (gallium arsenide Phosphide), GaP (gallium phosphide) the no. of photons of light energy emitted is sufficient to create a visible light source.

* When forward bias is applied the barrier potential is reduced and the depletion region is narrowed. i.e, Holes injected into n-region & recombined with free electrons

like electrons injected into p-region and recombine with hole current results & Excess energy is transferred to an emitted Photon and light is generated.

* The brightness of the light is directly proportional to the forward current.

* LED radiate different colours such as Red, Green, Yellow and orange, Blue and white. The wavelength of emitted light depends on the energy gap of the material. Hence the colour of the emitted light depens on the type of Materials used as,

✓ GaAs (gallium arsenide) – Infrared radiation (Invisible)

✓ GaP (gallium phosphide) – Red, Green.

✓ GaAsP (gallium arsenide phosphide) – Red and Yellow.

* In order to protect LEDs, Resistance of 1 kΩ or 1.5 kΩ must be connected in series with the LED.

* LEDs emit no light when reverse biased.

* LEDs operate at voltage levels from 1.5 to 3.3V

* LEDs can be switched ON and OFF at very fast speed of 1 nsec.

Applications :

(1) Burglar alarams Systems

(2) Picture phone

(3) Multimeters

(4) calculators

(5) Digital meters

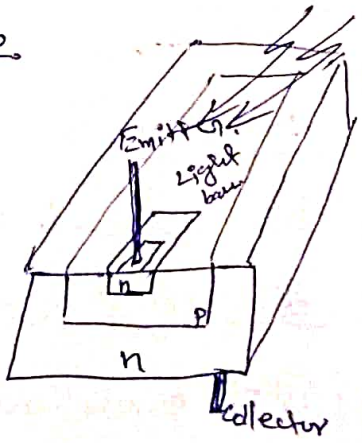
(6) Microprocessors.

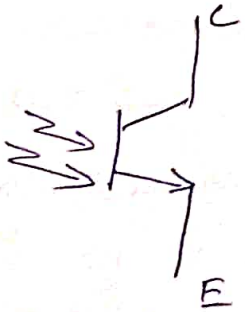
Photo Transistor :

* As transistor providing Internal Current Multiplication when exposed to light is called photo transistor.

* It has light Sensitive Collector to base junction. A lens is used so that the base is exposed to the light.

* The base collector area is kept large as it is light Sensitive.





* The base terminal is generally not brought out hence phototransistor act as a two terminal devices.

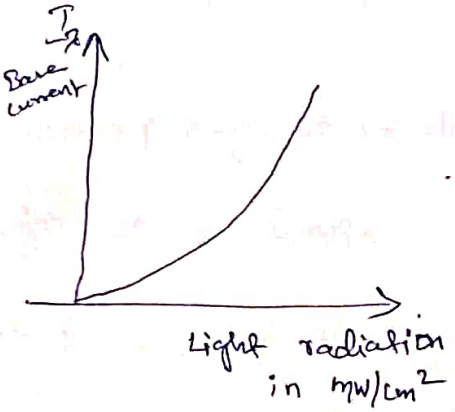
* The construction of a phototransistor is shown in the figure.

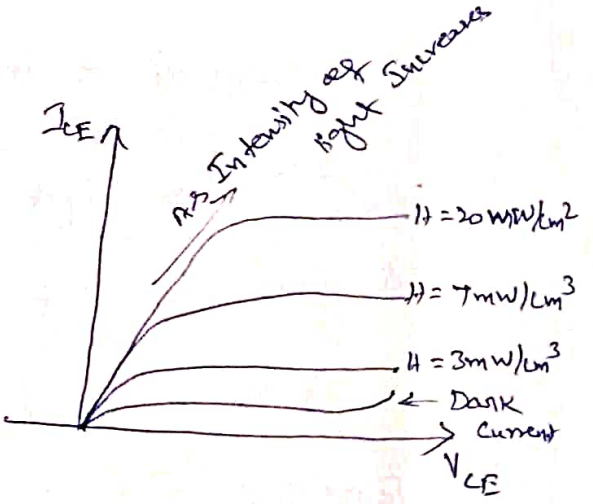
When no light is incident small leakage current flow from collector to emitter called I_{CEO} due to small thermal generation. This is called dark current which is very small (10^{-9} A).

* When base is exposed to light, base current is produce due to generated electron-hole pairs. This is photocurrent. This is denoted as I_λ.

* ∴ Collector current $I_C = \beta I_\lambda$ ✓

* light Indensity ↑ → I_λ ↑ → So collector current also Increase(E)





Characteristics

* In biasing, base kept open
* Collector connected to +ve terminal
* Emitter is ground.
* light Indensity ↑ then base ↑ I_λ ↑
* o/p char, Intensity ↑ then I_C ↑
* Speed is good but not fast then photodiode.

Application

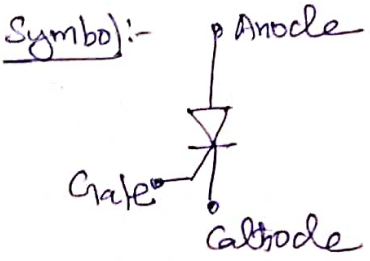
1. In computer logic circuits
2. In level Indicators and relays
3. In punch card readers
4. In alaram systems.
5. In various opto electronic systems like counting systems, smoke detector circuits, Intrusion detector circuits, etc.

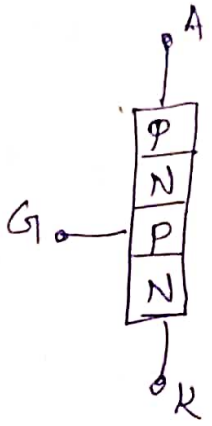
SCR - Silicon Controlled Rectifier:-

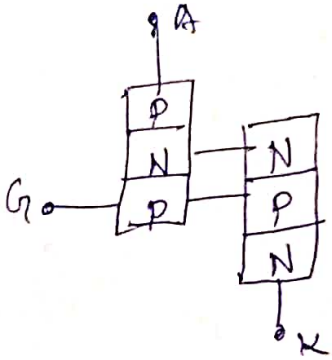
* An SCR consists of 4-Layers of Alternating P and N type semiconductor materials.

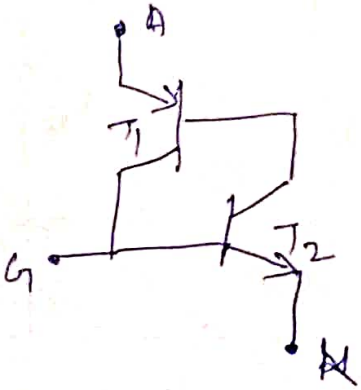
* SCR have 3-terminals, i.e; Anode - P layer
  Cathode - N-layer
  Gate - P-layer.

Symbol:-









T_1 - PNP

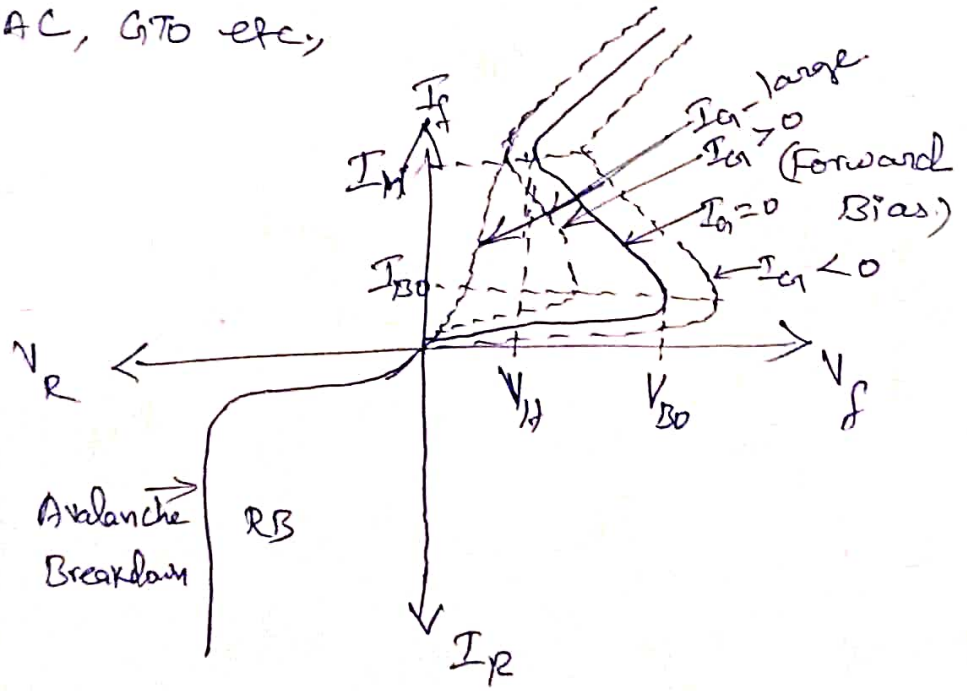
T_2 - NPN

* Silicon is used as the Intrinsic semiconductor to which proper dopants are added.
* The junctions are either diffused or alloyed.
* Since the PNPN pellet is required to handle large current.

Operation and Characteristics (V-I) of SCR:-

* Thyristor, It is a semiconductor device have 3-terminal (or) more (junction), such devices acts as a switch without any bias and can be fabricated to have voltage ratings of several hundred volt and ct rating from a few Ampers, almost thousand Amper

* The family of Thyristors consists of PNPN diode (Schockly diode), SCR, LASER (Light Activated SCR), TRIAC, DIAC, GTO etc;



where,
I_H - Holding ct
V_H - Holding Volt.
V_{BO} - Breakdown Volt
I_{BO} - Breakdown ct.

* SCR is a 3-terminal 4-layer semiconductor device.
* Leakage ct is very small for SCR
* SCR acts as a switch when it is forward biased

$I_g=0$ & V_a applied
P_1-N_1 - FB
P_2-N_2 - FB
N_1-P_2 - RB
IV

*When gate is open i.e; $I_g=0$ and anode volt. is applied junction on P_1-N_1 and P_2-N_2 are forward biased where N_1-P_2 is reverse biased, only small reverse current flows.

V_a↑

* If we Increase anode voltage further, at one stage anode current Increases suddenly and voltage across the SCR falls to holding voltage V_H.

conduction off at $I < I_H$

* One SCR fires (conducts), It will remain in conduction till the current through the device is reduced less than I_H, adding current by reducing applied voltage (to less than holding voltage) close to zero.

firing angle change by I_G

* The firing angle can be varied by varying the gate voltage. with very large positive gate current break over may occur at very low voltage and SCR works as If it is a normal PN diode.

Application :-

① SCR is mainly used in device where the control of high power possibly coupled with high volt. is demanded.
② In Relay control ③ In Motor control.

(5) In phase control

(6) In Battery Chargers

(7) In Heater control

(8) In Regulated power Suppliers

(9) In Inverts.

(10) In Static Switches.

(10) Their operation makes them suitable for use in medium to high ⌀ Voltage AC power control applications such as regulators.

Thyristor Ratings : SCR called as Thyristor.

(1) Latching Current (I_L) : It is minimum current required to latch or trigger the device from its OFF state to ON state.

(2) Holding Current (I_H) : It is the minimum value of the current to Hold the device in ON state (conduction).

(3) Gate Current (I_G) :- Gate side applied current for control purposes. ie; It is the mini Current for trigger the device.

(4) Voltage Safety factor (V_f) :- It is the ratio of PIV and RMS value of the normal operating voltage.

$$V_f = \frac{\text{PIV (Peak Inverse Voltage)}}{\sqrt{2} \times \text{RMS value of operating Voltage}} = 2 \text{ to } 2.7$$

For safe operation the normal working voltage is much below its PIV.

— x —