Power Switching Devices

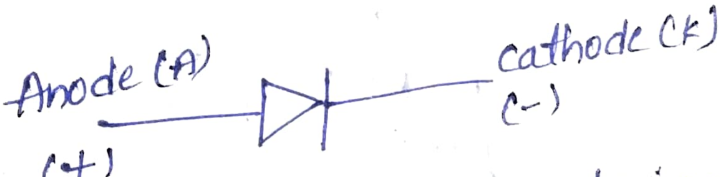
Diode:- A diode is a two-terminal electronic component that conducts electricity primarily one direction it has high resistance at one end and low resistance on the other end.

→ These devices are used to protect circuits by limiting the voltage and to also transform AC into DC.

→ Semiconductors like Silicon & germanium are used to make the most of the diodes. Even though they transmit current in a single direction. the way with which they transmit differs

→ There are different kinds of diodes and each type has its own applications

Diode construction and Symbol:-



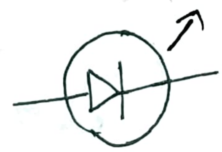
→ The terminal entering the flat edge of the triangle represents anode and the other end the cathode. The current always flows from anode to cathode but never the other way round.

→ Diodes can be made of either of the two semi conductor materials. silicon and germanium.

→ when the anode voltage is more positive than the cathode voltage the diode is ~~used~~ said to be forward - biased and it conducts readily with a relatively low - voltage drop.

→ likewise, when the cathode voltage is more positive than the anode, the diode is said to be reverse - biased.
→ The arrow in the diode symbol represents the direction of conventional current flow when the diode conducts

Types of diodes:-

1. light emitting diode 
2. Laser diode
3. Avalanche diode
4. Zenor diode
5. Schottky diode 
6. photo diode 

Light Emitting Diode (LED):-

When electric current b/w the electrodes passes through this diode, light is produced. In other words, light is generated when a sufficient amount of forwarding current passes through it.
→ In many diodes, the light generated is not visible as they are frequency levels that do not allow visibility.
→ LEDs are available in different colours. There are tricolour LEDs which can emit three colours at a time.
→ light colour depends on the energy gap of the semi conductor used.

Laser diode:-

→ It is a different type of diode as it produces coherent light. it is highly used in CD drives, DVDs and laser devices

→ These are costly when compared to LEDs and are cheaper when compared to other laser generators.

→ limited life is the only drawback of these diodes.

Avalanche Diode:-

→ This diode belongs to a reverse bias type and operates using the avalanche effect.

→ when voltage drop is constant and is independent of current, the break down of avalanche takes place.

→ They exhibit high levels of sensitivity and hence used for photo detection.

Zenor diode:-

→ it is the most useful type of diode as it can provide a stable reference voltage.

→ These are operated in reverse bias and break down on the arrival of a certain voltage.

→ If current passes through the resistor is limited, a stable voltage is generated.

→ Zenor diodes are widely used in power supplies to provide a reference voltage.

Schottky Diode :-

→ it has a lower forward voltage than other Silicon PN Junction diodes. The drop will be seen where there is low current and at that stage voltage ranges b/w 0.15 and 0.4 volts.

→ These are constructed differently in order to obtain that performance.

→ schottky diodes are highly used in rectifier applications.

photo diode :-

→ A photo diode can identify even a small amount of current flow resulted from the light.

→ These are very helpful in the detection of the light

→ These are reverse bias diode and used in Solar cells and photo meter. They are even used to generate electricity

Diode characteristics :-

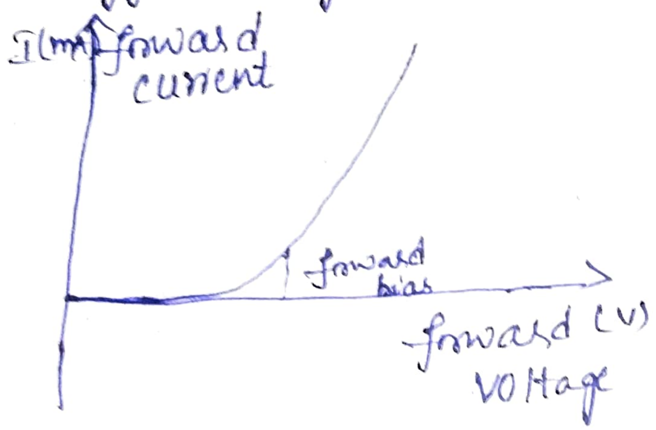
following are the characteristics of the diode

1. forward - biased diode
2. Reverse - biased diode
3. Zero - biased diode

Forward- biased diode:-

→ There is a small drop of voltage across the diode when the diode is forward biased and current is conducting. for silicon diode, the forward voltage is 690mv and for germanium, 300mv is.

→ The potential energy across the p-type material is +ve and across the n-type material, the potential energy is negative.

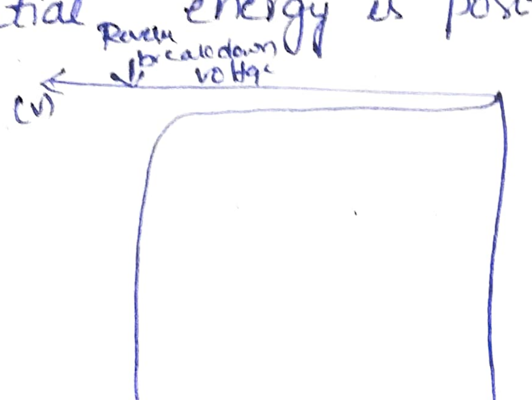


Reverse- bias diode:-

→ A diode is said to be reverse- biased when the battery's Voltage is dropped completely.

→ for silicon diode, the reverse voltage is -20 μA. and for germanium, -50μA is the reverse voltage.

→ The potential energy across the p-type material is negative across the n-type material. the potential energy is positive.



Zero-biased Diode:-

When the diode is zero-biased, the voltage potential across the diode is zero.

Diode Applications:-

→ Diode as a rectifier
→ Diodes in the clipping ckt
→ Diodes in clamping ckts
→ Diodes in logical gates
→ Diodes in reverse current protection.

Diode equation:-

Actually, forward voltage drop is more complex. An equ describes the exact current through a diode given the voltage dropped across the junction, the temp of the junction, and several physical constants. it is commonly known as the diode equ

$$I_D = I_S\left(e^{qV_D/NKT} - 1\right)$$

where I_D = diode current in Amps
I_S = Saturation current in Amps (typically 1×10^{-12} Amps)
e = Euler's constant ($\sim 2.7182812 8$)
q = charge of electron (1.6×10^{-19} columbs)
V_D = Voltage applied across diode in volts
N = "Nonideality" or "Emission" coefficient (typically b/w 1 & 2)
K = Boltzmann's constant (1.38×10^{-23})
T = junction temperature in kelvins

The term KT/q describes the voltage produced within the P-N Junction due to the action of temp. and is called thermal voltage.
At room temperature, this is about 26 mV.

$$I_D = I_s (e^{V_D/0.026} - 1)$$

where I_D = Diode current in amps
I_s = Saturation current in amps
e = Euler's Number
V_D = Voltage applied across diode in volts

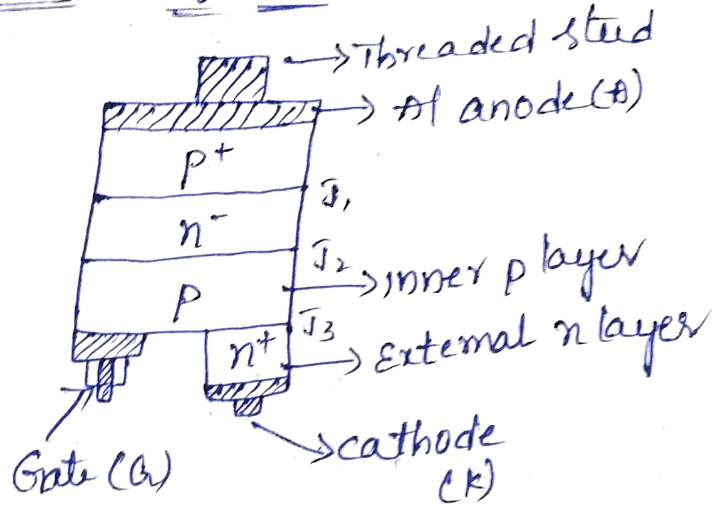
Thyristor :-

→ It consists of a group of semiconductor devices including SCR, TRIAC, GTO, SIT
→ But since SCR is a formers members, it is also called as thyristor (pnpn device)
→ SCR is the oldest member of the thyristor family
→ The name thyristor comes from combination of two words thyratron + transistor
→ Its characteristic is similiar to that of a thyratron tube and its construction is similiar to transistor

Silicon controlled Rectifier (SCR) :-

→ It is made up of silicon, it is unidirectional device like a diode. → Also it blocks the current flow from anode to cathode until it is triggered.
→ it is a solid state device
→ it is compact and having low loss

Construction of SCR :-

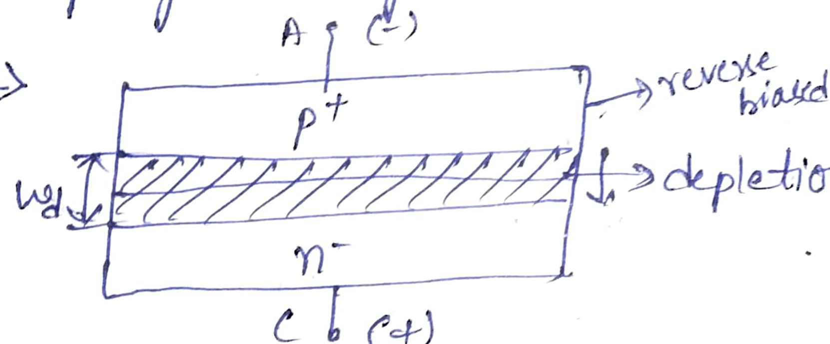


→ The doping density of external p and n layer is very high

→ Generally $\begin{cases} n^+/p^+ \rightarrow 10^{19}/cm^3 \\ n/p \rightarrow 10^{17}/cm^3 \\ n^-/p^- \rightarrow 10^{14}/cm^3 \end{cases}$

→ The inner n layer has very low doping density whereas the inner p layer ~~and~~ has normal doping density.

→



n^- decides the width of depletion layer.
reverse bias increases depletion layer width.

→ V_{BR} depends on W_d ~~losses~~

→ its a four ~~f~~ layer, 3 junction pnpn switching devices

→ it has 3 terminals - anode, cathode, gate

→ Gate is usually kept near the cathode

→ Terminal connected to outer p layer is called anode
→ Terminal connected to outer n layer is called cathode
→ Terminal connected to inner p layer is called gate

Symbol of SCR:-

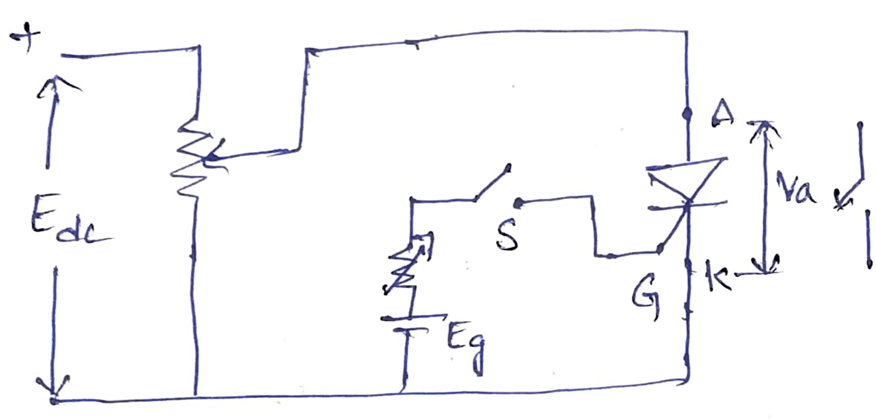
→ The threaded portion is for begin lightening the thyristor to the heat sink

→ The rating of SCR is 10 KV & 3KA with power handling capacity of 30mw

Characteristics of SCR:-

→ SCR has 3 basic characteristics
a) Static V-I charac
b) Dynamic / switching characteristics
c) Gate characteristics

1) Static V-I characteristics:-



→ There are 3 modes of operation:-
a) forward blocking mode
b) reverse blocking mode
c) forward conduction mode.

a) forward blocking mode :-

→ it is same as forward biased conduction of diode

→ when anode is +ve w r to cathode and switch s is open is called forward blocking mode

→ If A is +ve w r to cathode (K) then

$$\underbrace{V_1 + V_2 + V_3}_{\text{Junction Voltages}} = V \rightarrow \text{total Voltage applied}$$

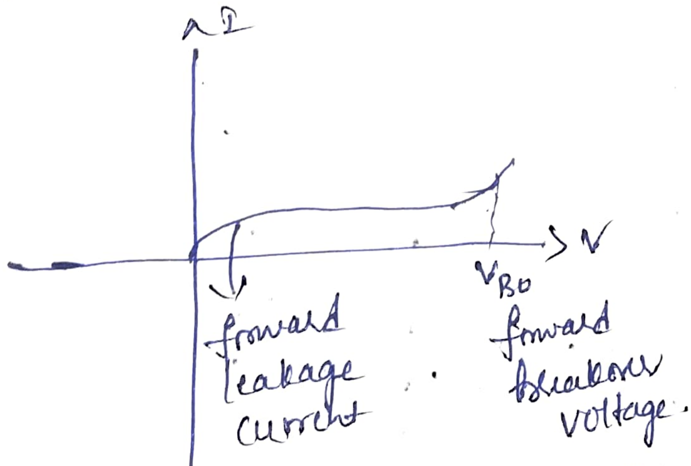
→ Then J_1 → forward biased $p^+ \rightarrow +ve$, $n^- \rightarrow -ve$

J_2 → reverse biased $n^- \rightarrow +ve$, $p \rightarrow -ve$

J_3 → forward biased, $p \rightarrow +ve$, $n^+ \rightarrow -ve$

→ J_1 & J_3 are forward biased but J_2 is reverse biased.

→ Due to this, a small leakage current flows through the SCR, until the voltage applied across the SCR is more than the break over voltage of it, the SCR offers a very high resistance to the current flow.



→ upto V_{BO} is called forward blocking mode

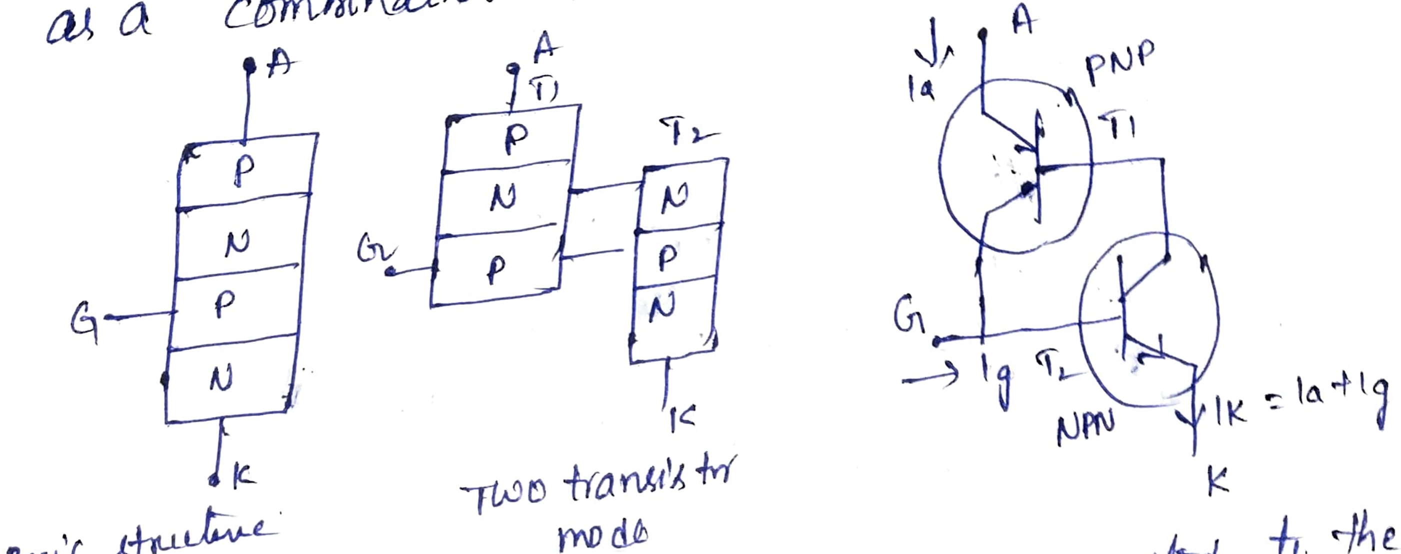
→ In this mode, a very small current called as forward leakage current from A to K.

→ when the forward voltage increases beyond V_{BO} junction J_2 will breakdown and conduction takes place

→ for $V_a < V_{BO}$, the SCR offers high impedance and acts as a open switch

Two transistor Analogy of SCR:-

→ The two transistor model of SCR expresses the easiest way to understand the working of SCR as a combination of two transistors



→ The collector of each transistor is connected to the base of the other transistor

→ Assume that load resistance is connected b/w the anode & cathode terminals and a small voltage is applied at the gate and cathode terminals.

→ when there is no gate voltage, the transistor 2 is in cut-off mode due to zero base current

∴ no current flows through the collector and hence the base of transistor T_1. Hence both transistors are open circuited and thereby no current flows through the load

→ when a particular voltage is applied b/w the gate & cathode, a small base current flow through the base of the transistor 2 and thereby collector current will increase.

→ Hence the base current at the transistor T_1 drives the transistor into saturation mode and thus load current flows from anode to cathode.

from fig ad the base current of transistor T_1 becomes the collector current of Transistor T_1 & viceversa.

Hence

$$I_{B2} = I_{C1} \quad \& \quad I_{C2} = I_{B1}$$

Also current through the cathode terminal,

$$I_K = I_g + I_a \longrightarrow (1)$$

for a transistor, $I_{B1} = I_{e1} - I_{C1} \longrightarrow (2)$

and $I_{C1} = \alpha_1 I_{e1} + I_{co1} \longrightarrow (3)$

where I_{co1} is the leakage current

substituting equ (3) in equ (2) we get

$$I_{B1} = I_{e1}(1-\alpha_1) - I_{co1} \longrightarrow (4)$$

from the fig anode current is equal to the emitter current of Transistor T_1

$$I_a = I_{e1}$$

Then $I_{B1} = I_a(1-\alpha_1) - I_{co1}$

And also for Transistor T_2

$$I_{C2} = \alpha_2 I_{e2} + I_{co2}$$

but $I_K = I_{e2}$

Therefore $I_{C2} = \alpha_2 I_K + I_{co2}$

$$I_{C2} = \alpha_2(I_g + I_a) + I_{co2} \longrightarrow (5)$$

but $I_{B1} = I_{C2} \longrightarrow (6)$

$$I_a(1-\alpha_1) - I_{co} = \alpha_2(I_g + I_a) + I_{co2}$$

$$I_a = [\alpha_2 I_g + I_{co1} + I_{co2}] / [1 - (\alpha_1 + \alpha_2)]$$

By assuming the leakage currents are negligible in both transistors, we get

$$I_a = [\alpha_2 I_g] / [1 - (\alpha_1 + \alpha_2)]$$

where α_1 & α_2 are the respective gains of the two transistors

SCR Turn ON methods:-

→ from the above equⁿ, if $(\alpha_1 + \alpha_2)$ is equal to one then I_a becomes infinite. That means anode current suddenly rises to a high value and latches into conduction mode from non-conductive state of SCR. This is called regenerative action of SCR.

→ So, for triggering of SCR the gate current value $(\alpha_1 + \alpha_2)$ must approach to unity. from the obtained equⁿ the conditions to turn the SCR into turn ON are

1. The leakage current through the SCR will increase when the temperature of the device is very high. This turns the SCR into conduction

2. when the current flowing through the device is extremely small then α_1 & α_2 are very small. The conditions for break over voltage are the larger values of election multiplication factor M_n and hole multiplication factor M_p near the junction J_2 ∴ by increasing the voltage across the device to

'g' SCR can be turned

SCR Turn OFF Methods :-

→ An SCR cannot be turned OFF through the gate terminal like turning ON process.

→ To turn OFF the SCR, anode current must be reduced to a level below the holding current level of the SCR.

→ The process of turning OFF the SCR is called commutation. Two major types of commutating the SCR are

1. Natural commutation & 2. forced commutation

→ forced commutation is again classified into several types such as

a) class A commutation
b) class B commutation
c) class C commutation
d) class D commutation
e) class E

Advantages of SCR:-

1. As compared with electro mechanical or mechan switch, SCR has no moving parts. Hence with a high efficiency it can delieves noise l operation.
2. The switching speed is very high as it can perform 1 nano operations per second.
3. These can be operated at high voltage and curren ratings with a small gate current
4. More suitable for AC operations because at every zero position of the AC cycle the SCR will automatically switch ~~of~~ off
5. Small in size, hence easy to mount and trouble free service.
6. it is simple to control, 7. low cost,
8. it's able to control AC power

Disadvantages

1. The SCR is unidirectional devices, so it can control power only in DC power during +ve half cycle of AC supply. Thus only DC power is controlled with the help of SCR
2. In AC ckt, it needs to be turned on each cyc
3. It can't be used at higher frequencies
4. The gate current cannot be negative.

power Mosfets:-

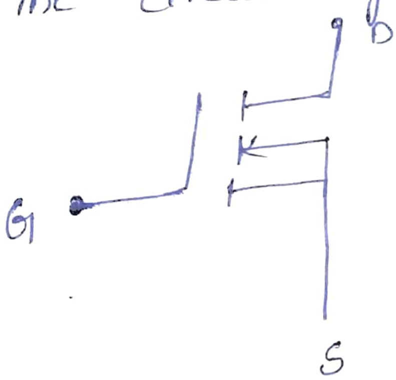
A metal oxide semi conductor field effect transistor is a recent device developed by combining the areas of ei field - effect concept and Mos technology.

field effect :- FET is a type of Transistor that uses an electric field to control the flow of current. FET generally display very high ~~output~~ input impedance at low frequiencies.

Mos Technology:- it is known as CSG [commodore semiconductor group), was a semiconductor design and fabrication company. it is most famous for its 6502 microprocessor & various designs for home computers.

→ A pMosfet has three terminals called Drain (D), Source (S) and gate (G)

→ The circuit symbol of Mosfet is



→ Here arrow indicates the flow direction of electrons flow.

→ As its operation depends upon the flow of majority carriers only.

→ Mosfet is a unipolar device.

→ The control signal, or base current in BJT is much larger than the control signal (or gate current) required in a Mosfet.

→ This is because of the fact that gate ~~current~~ circuit impedance in MOSFET is extremely high, of the order of 10^9 ohm

→ This large impedance permits the MOSFET gate to be driven directly from micro electronic circuits

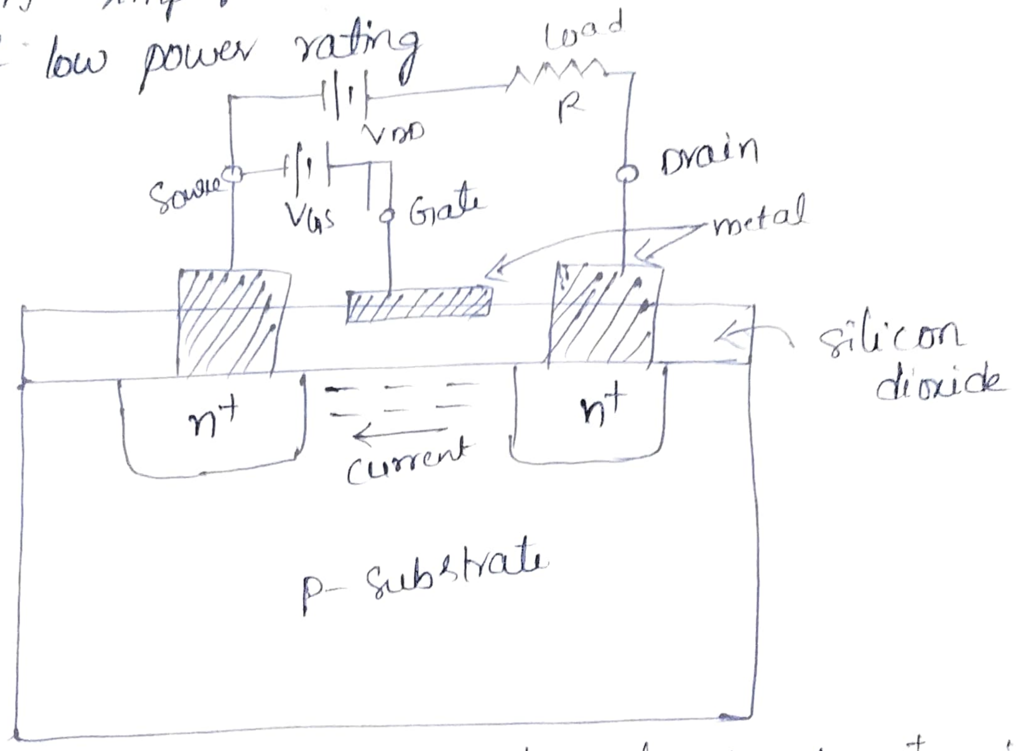
→ BJT, SCR suffers from second break down voltage whereas MOSFET is free from this problem.

→ power MOSFETs are now finding increasing applications in low - power high frequency converters.

→ power Mosfets are of two types ; n- channel enhancement Mosfet and p channel enhancement MOSFET.

→ out of these two types, n- channel enhancement Mosfet is more common because of higher mobility of electrons. As such, only this type of MOSFET

→ A simplified structure of n- channel planar MOSFET of low power rating



→ On p- Substrate, two heavily doped n^+ regions are diffused. An insulating layer of SiO_2 is grown on the surface.

→ Now this insulating layer is etched in order to embed metallic Source and drain terminals.

→ A layer of metal is also deposited on SiO_2 layer So as to form the gate of MOSFET in blw Source and drain terminals.

→ when gate ckt is open, junction b/w n^+ region below drain and p-substrate is reverse biased by i/p voltage V_{DD}
∴ no current flows from drain to source and load.

→ when gate is made positive with respect to source. an electric field is established.

→ Eventually, induced negative charges in the p-substrate below SiO_2 layer are formed. thus causing the p layer below gate to become an induced n layer. These negative charges called electrons

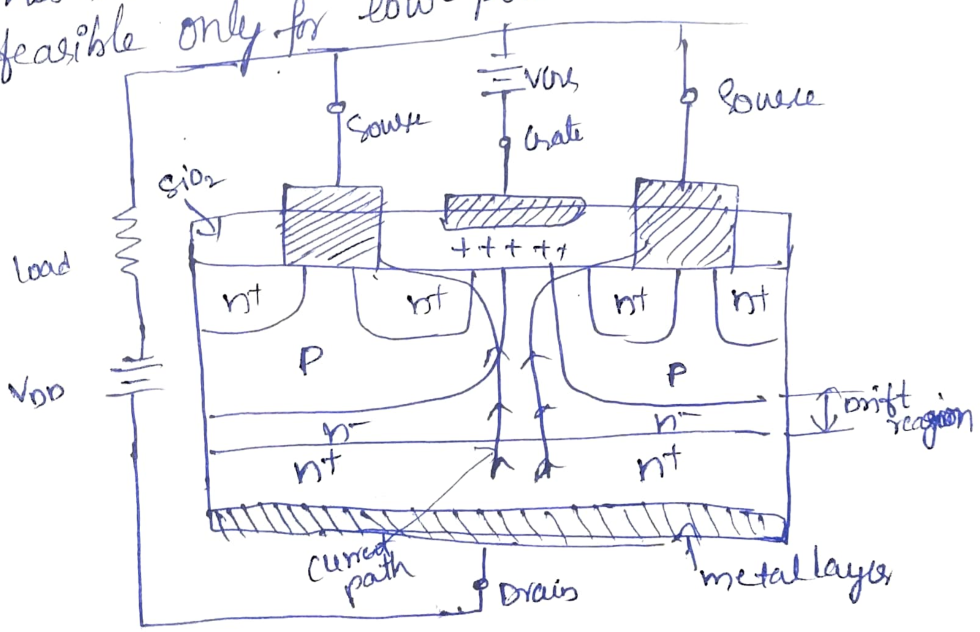
→ The n-channel b/w two n^+ regions and current can flow from drain to source. as shown by the arrow.

→ If V_{GS} is made +ve, induced n-channel becomes more deep and therefore more current flows from D to S.

→ This shows that drain current I_D is enhanced by the gradual increase of gate voltage, hence the name enhancement MOSFET.

→ The main disadvantage of n-channel planar mosfet is that conducting n-channel in b/w drain and source gives on-state resistance. This leads to high power dissipation in n-channel.
This shows that planar MOSFET construction ~~of~~ is feasible only for low-power MOSFETS

→



→ when gate circuit voltage is zero, and V_{DD} is present, n^{-}-p junctions are reverse biased and no current flows from Drain to Source.

→ when gate terminal is made positive with respect to Source, an electric field is established and electrons form n-channel in the p-region.

→ So a current from drain to source is established as indicated by arrows with gate voltage increased, current I_D also increases

→ length of n-channel can be controlled and therefore on-resistance can be made low if short length is used for the channel.

→ Source is negative and drain is positive. Therefore electrons flow from source to n^{+} layer, then through n-channel of p-layers and further through n^{-} & n^{+} layers to drain

→ The current must flow opp. to the flow of electrons as indicated.

→ Since the conduction of current is due to the movement of electrons only. pMosfet is the majority carriers. device.

→ Hence, time delays caused by removal or recombination of minority carriers are eliminated. during the turn-off process of this device.

→ pMosfet with a turn-off time of 100 ns of available.

→ owing to its low turn-off time, pMosfet can be operated in a frequency range of 1 to 10 MHZ.

PMOSFET Characteristics:

The static charac. of power MOSFET are now described briefly.

→ The basic ckt diagram for n-channel PMOSFET. where voltages & currents are as indicated.

→ The source terminal S is taken as common terminal, as usual b/w the i/p & o/p of a MOSFET

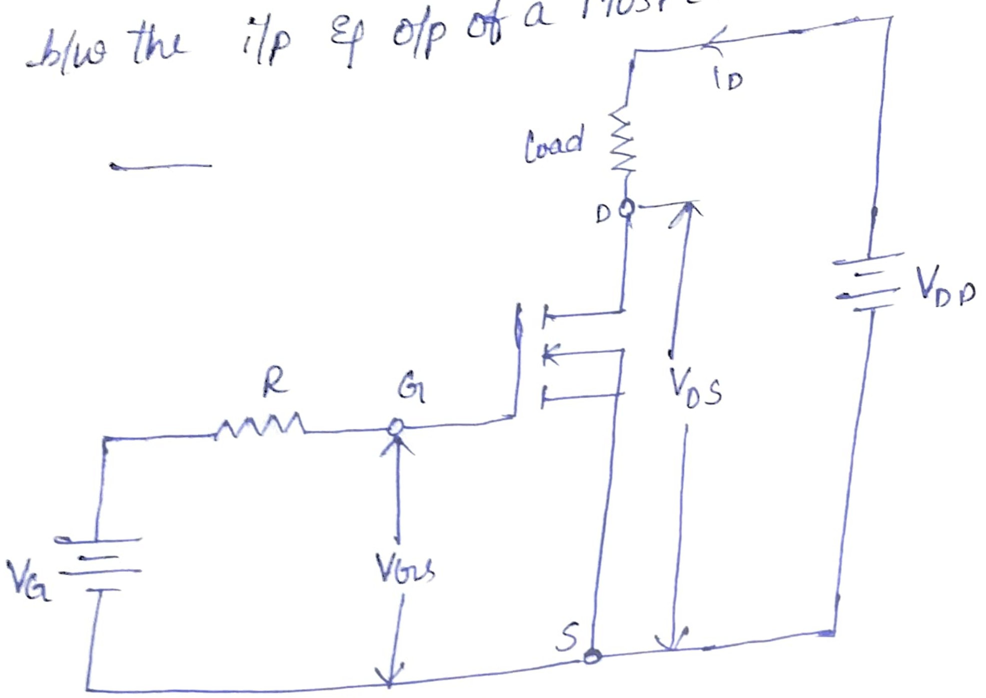
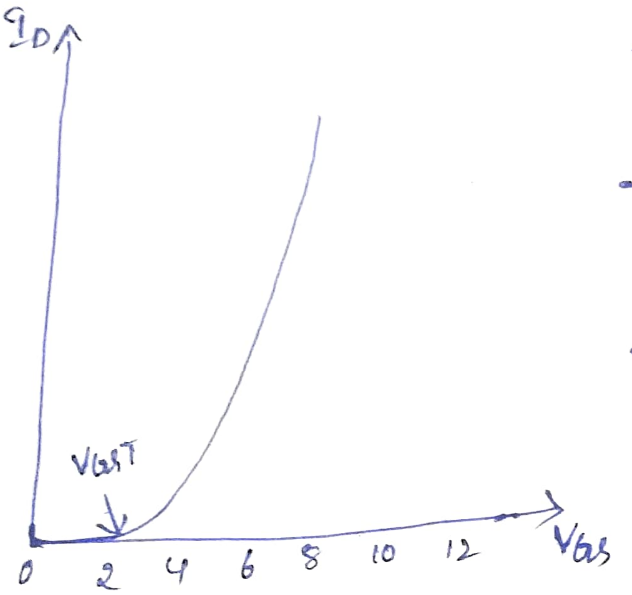


fig: circuit diagram

a) Transfer characteristics :- This charac. shows the variation of drain current I_D as a function of gate-source voltage V_{GS}



(b) Transfer charac

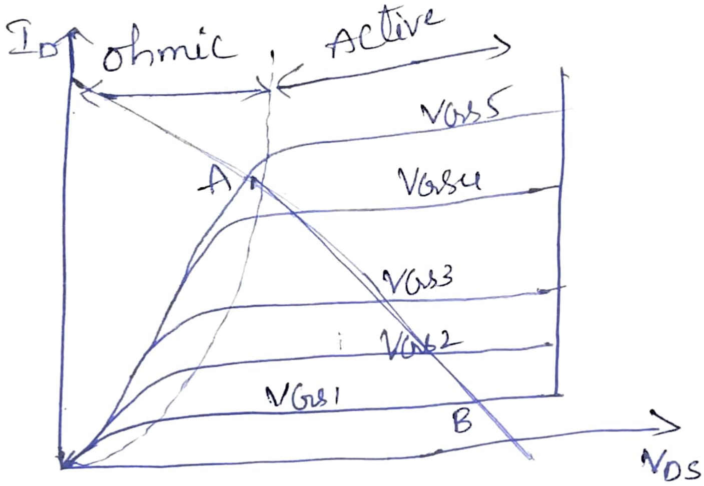
→ Threshold voltage V_{GST} is an imp parameter of MOSFET.

→ V_{GST} is the min +ve voltage b/w gate & source to induce n-channel.

→ Thus, for threshold voltage below V_{GST}, device is in the off-state.

→ Magnitude of V_{GST} is of the order ~~of~~ 2 to 3V

b) O/p characteristics:-



→ Indicate the variation of drain current I_D as a function of drain-source voltage V_{DS}, with gate source voltage V_{GS} as a parameter.

→ For low values of V_{DS}, the graph b/w I_D-V_{DS} is almost linear; this indicates a constant value of on-resistance

$R_{DS} = V_{DS}/I_D$

→ For given V_{GS}, if V_{DS} is increased, o/p characteristic is relatively flat, indicating that drain current is nearly constant.

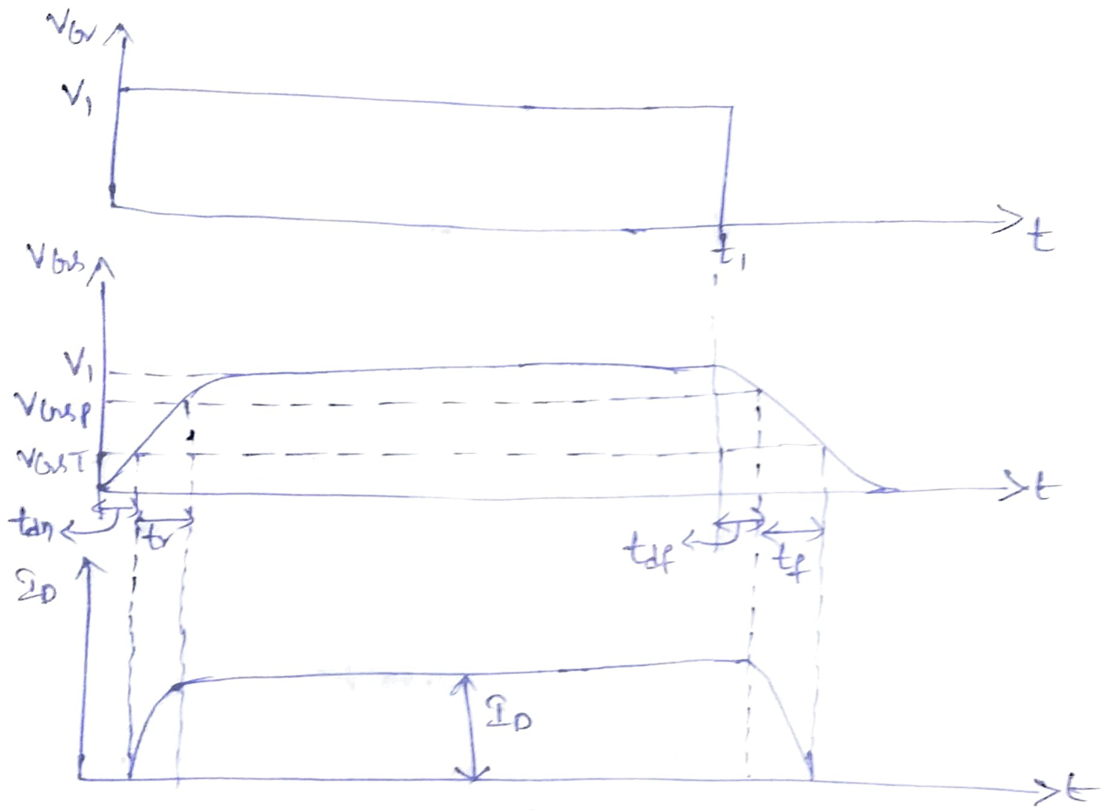
→ A load line intersects the o/p characteristics at A & B. Here A indicates fully-on condition & B fully-off state. MOSFET operates as a switch

→ when MOSFET is driven with large gate source voltage, MOSFET is turned on, V_{DS-ON} is small

→ Here, the MOSFET acting as a closed switch, is said to be driven into ohmic region (called saturation region in BJT)

→ when device turns on, pMOSFET traverses, $i_D - V_{DS}$ charecteristics from cut-off, to active region and then to the ohmic region.
when MOSFET turns off, it takes backward journey from ohmic region to cut off state

c) Switching characteristics:-



→ The switching charactestics of a p MOSFET are influenced to a large extent by the internal capacitance of the device and the internal impedance of the gate drive circuit.

→ At turn-on, there is an initial delay t_{dn} during which input capacitance charges to gate threshold voltage V_{GST}, t_{dn} is called turn-on delay time.

→ Here t_{dn} is called ...
→ There is further delay t_r, called rise time, during which gate voltage rises to V_{GSP}, a voltage sufficient to drive the MOSFET into on state.

→ During t_r, drain current rises from zero to full-on

→ Thus, the total turn-on-time is $t_{on} = t_{dn} + t_r$

The turn-on time can be reduced by using low impedance gate-drive source.

→ As MOSFET is a majority carrier device, turn-off process is initiated soon after removal of gate voltage at time t_1.

→ The turn-off delay time, t_{df}, is the time during which i/p capacitance discharges from overdrive gate voltage V_1 to V_{GSP}.

→ The fall time, t_f, is the time during which i/p capacitance discharges from V_{GSP} to threshold voltage.

→ During t_f, drain current falls from I_D to zero.

So when $V_{GS} \leq V_{GST}$, PMOSFET turn-off is complete.

Applications:

→ The on-resistance of MOSFET increases with voltage rating. This makes the device very lossy at high current applications.

→ Since the on-resistance has positive temp coefficient. Parallel operation of PMOSFET is relatively easy.

→ The positive temperature coefficient also reduces the second breakdown effect in PMOSFETs.

→ In high-frequency switching applications, varying from a few watts to few kws.

→ The device is very popular in switched-mode power supplies and inverters.

→ These are, at present available with 500V, 140A ratings.

IGBT :- (Integrated Gate Bipolar Transistor)·

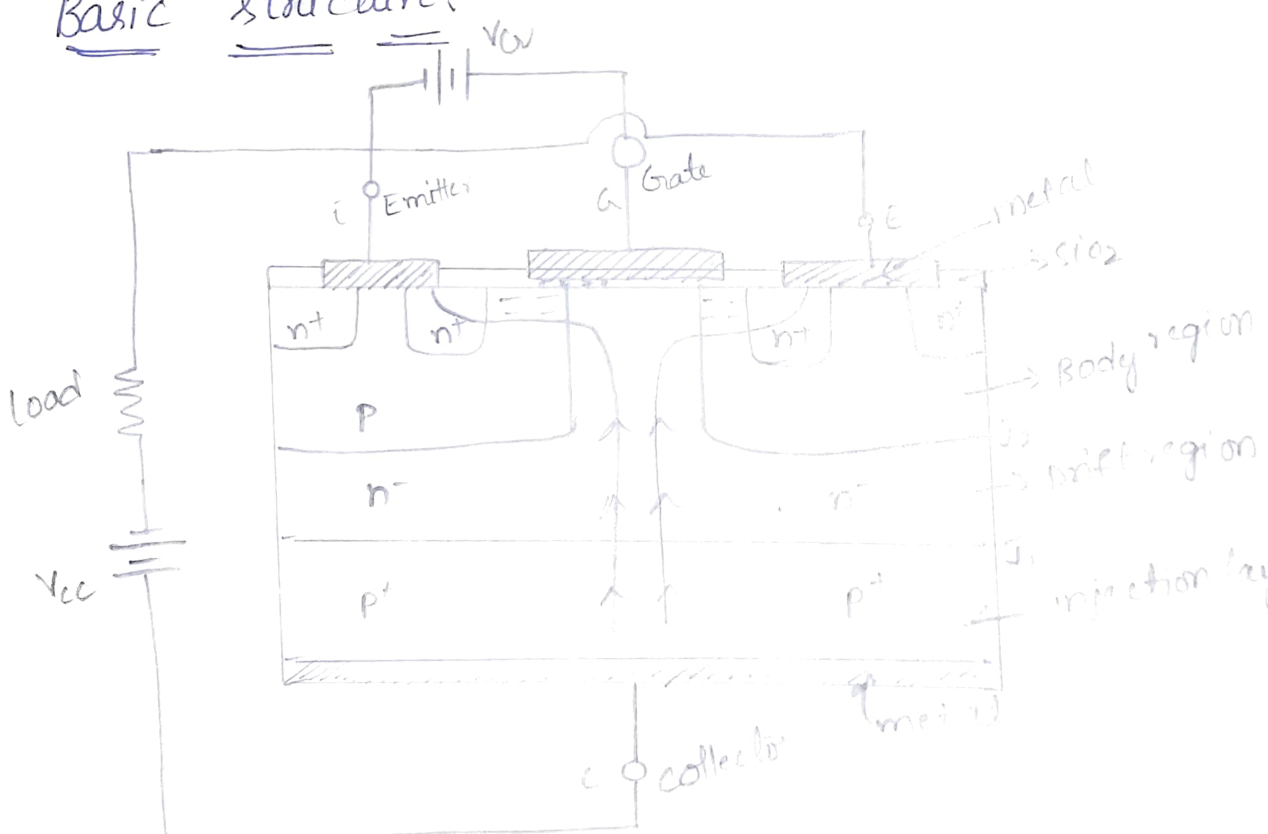
→ IGBT has combining the best qualities of both BJT and MOSFET

→ IGBT possesses high input impedance like a MOSFET and low on-state power loss as in a BJT.

→ IGBT is free from second breakdown problem present in BJT

→ IGBT is also known as metal oxide insulated gate transistor (MOS IGT), conductively-modulated field effect transistor (COMFET) or gain-modulated FET (GEMFET) insulated gate transistor (IGT)

Basic structure :-



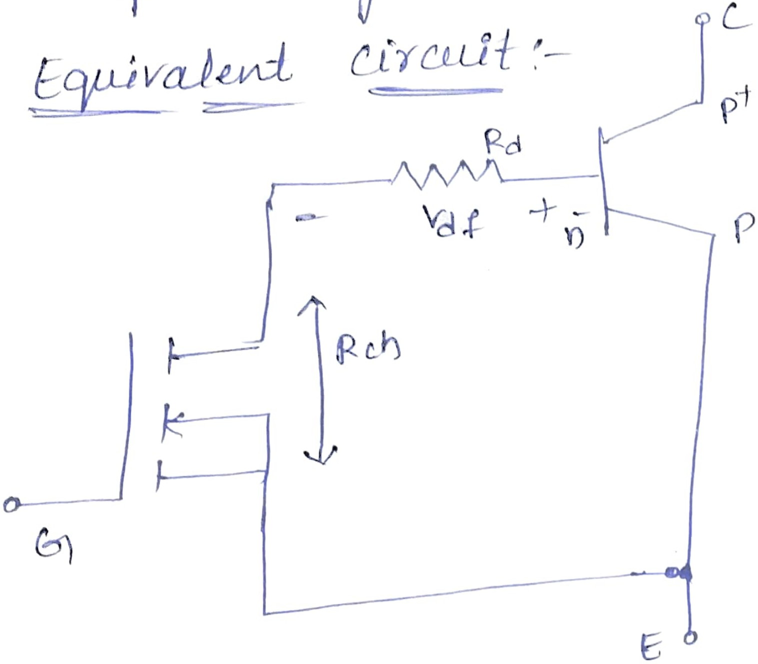
→ it is constructed virtually in the same manner as a power MOSFET. There is, however, a major difference in the substrate.

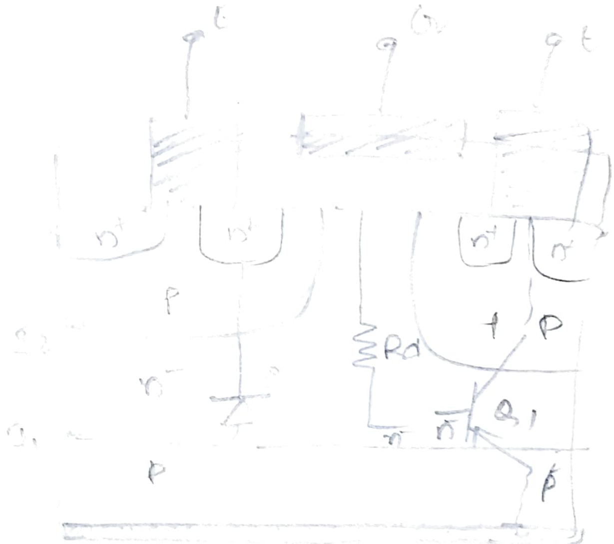
→ The n^+ layer substrate at the drain in a MOSFET is now substituted in the IGBT by a p^+ layer substrate called collector called drift region.

→ As in other semiconductor devices, thickness of n^- layer determines the voltage blocking capability of IGBT.
The p layer is called body of IGBT.

→ The n^- layer in b/w p^+ & p regions serves to accommodate the depletion layer of pn^- junction, i.e., J_2

<u>Equivalent circuit</u> :-



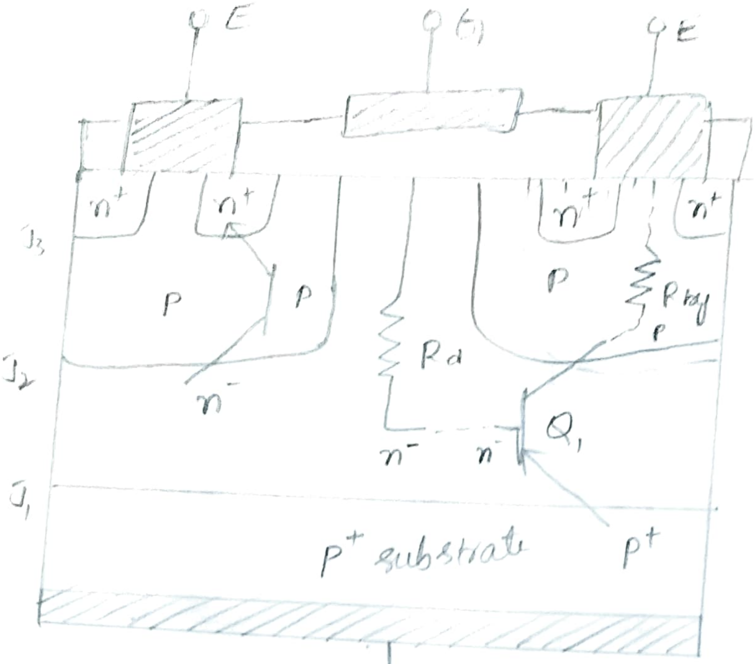


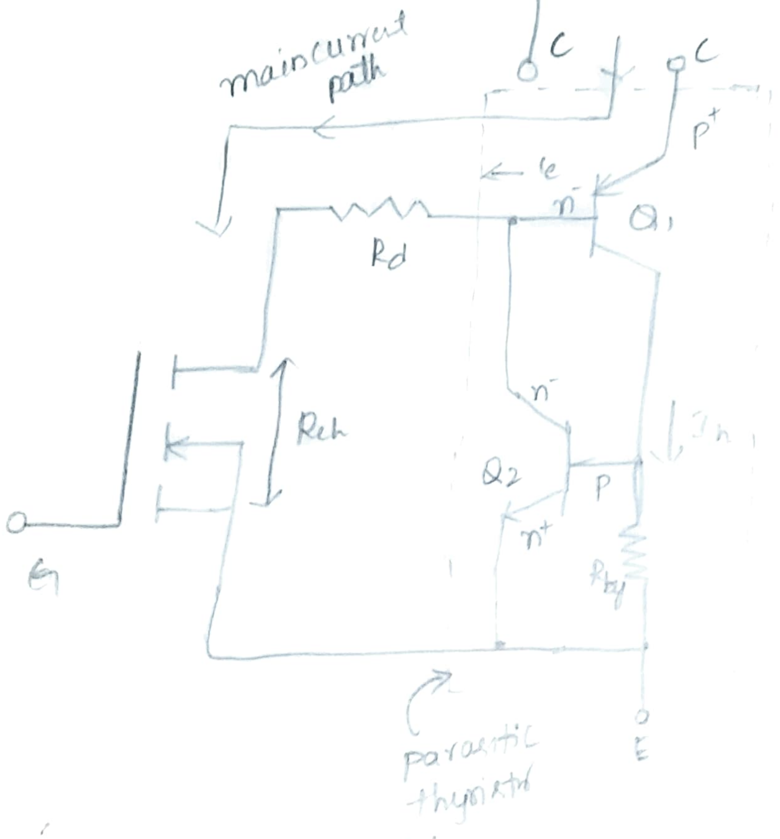
→ If one moves vertically up from collector to emitter, one comes across p^+, n^-, p layers.

→ Thus, IGBT can be thought of as the combination of MOSFET and p^+n^-p transistor Q_1

→ Rd is the resistance offered by n^- drift region.

→ for deriving an exact equivalent ckt of an IGBT





exact equ ckt

ckt symbol

where transistor Q_1 is shown p^+n^-p and R_{by} is the p-body resistance. This figure also shows that another Q_2 is formed by layers n^-, p and n^+.

→ Therefore, IGBT structure is equivalent to two transistors Q_1 and Q_2. Note that collector p of Q_1 is the same as base of Q_2.

→ Similiarly, Q_1 base n^- is the same as collector of Q_2.

→ The interconnection b/w two transistors Q_1 & Q_2

Here R_{by} is the resistance offered by p-region to the flow of hole current I_h

working :-

→ when collector is made positive with respect to emitter with no voltage between gate and emitter, IGBT gets forward biased. two junctions b/w n^- region and p region are reverse biased. ; So no current flows from collector to emitter

→ when gate is made positive with respect to emitter by voltage V_G, with gate emitter voltage more than the threshold voltage V_{GET} of IGBT an n-channel or Inversion layer is formed in the upper part of p region

→ This n-channel short ckt the n^- region with n^+ emitter regions.

→ Electrons from the n^+ emitter begin ~~from~~ to flow to n^- drift region through n-channel

→ As IGBT is forward bias with collector positive & emitter negative, p^+ collector region injects holes into n^- drift region. is flooded with electrons from p-body region and holes from p^+ collector region.

→ Collector current I_c or emitter current I_E, consists of two current components

i) hole current I_h due to injected holes flowing from collector, transistor Q_1 p-body region resistance R_{by} and emitter.

ii) electronic current I_e due to injected electrons flowing from collector, injection layer p^+, drift region n^-, n^+ & emitter,

i.e., emitter current $I_E = I_h + I_e$.

Major component of collector current is electronic current I_e, $I_C \cong I_E$

→ Main current path for collector, or load, current is through p^+, n^-, drift region resistance R_d

∴ The voltage drop in IGBT in its on-state is

$$V_{CE.on} = I_c \cdot R_{ch} + I_c \cdot R_d + V_{J1}$$

$$= \text{Voltage drop}$$

Turn-ON methods of thyristor:-

Let us take the structure of SCR as a ref.

If the anode (outer 'p' region) is made positive with respect to the cathode (outer 'n' region). junction J_1 and J_3 become forward biased but the junction J_2 becomes reverse biased

→ As a result, there is no flow of current through the device except for a small magnitude of leakage current.
So, even though the SCR is forward biased, there is no flow current, and hence this state is known as forward Blocking state (OFF state)

→ The SCR can be made to conduct or switched from blocking (non-conducting or OFF) state to conduction (ON) state by any one of the following methods.

1. forward voltage triggering
2. Temperature triggering
3. dv/dt triggering
4. light triggering
5. Gate triggering

Forward Voltage Triggering:-

→ In forward voltage triggering methods, the SCR is forward biased i.e., anode is more positive than cathode but this voltage is increased significantly.
the gate terminal is kept on.

→ As the voltage increases, junction J_2 is depletion layer width increases, which in turn increases the accelerating voltage of minority carriers at this junction.

→ At a particular voltage, there will be an Avalanche Breakdown at the inner junction J_2 as a result of triggering:-

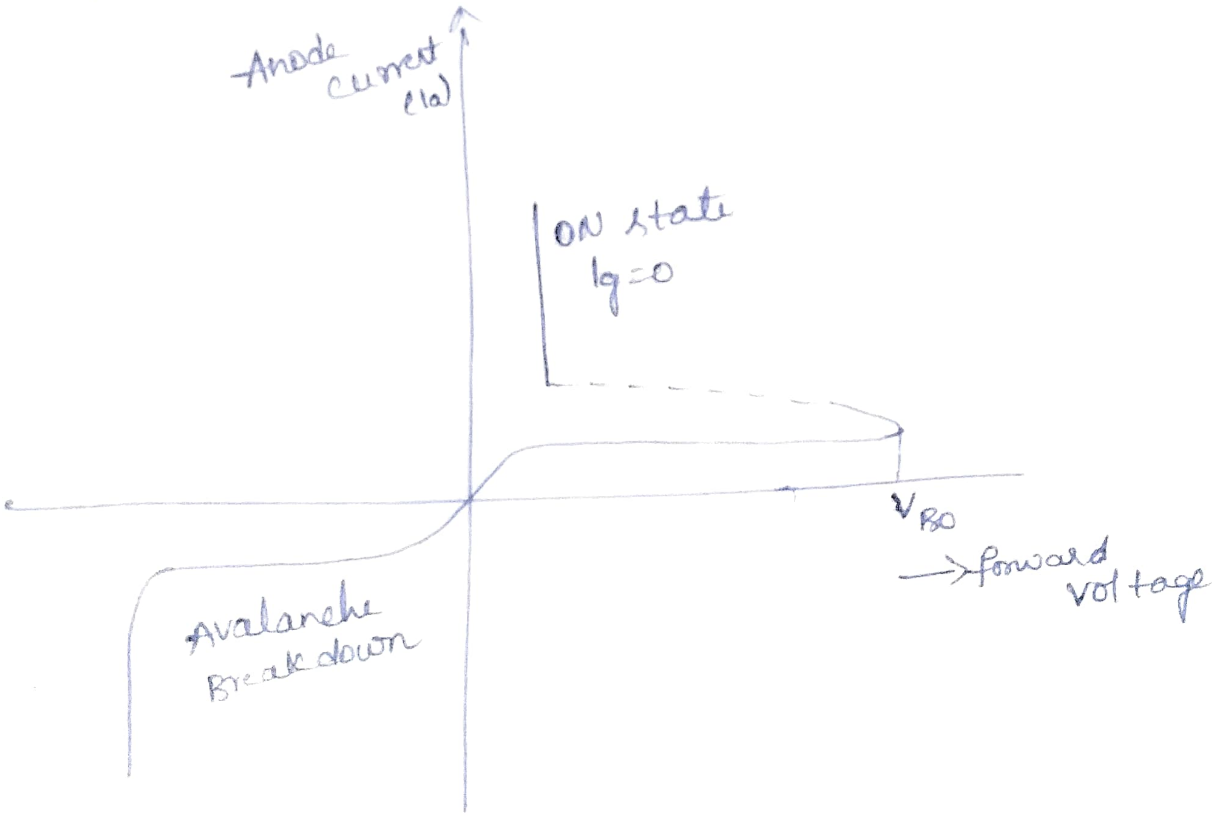
minority charge carriers colliding with atoms and releasing even more minority charge carriers

→ This voltage is known as forward Breakover voltage V_{BO}.
At this voltage, the junction J_2 becomes forward biased and the SCR turns into conduction state

→ A large current flows through the SCR (from Anode to cathode, which is limited by the load resistance) with a very low voltage drop across it

→ During the turn ON state, the forward voltage drop across the SCR is in the range of 1 to 1.5 volts and this may be increased with the load current

In practice this method is not employed because it needs a very large anode to cathode voltage
And also once the voltage is more than the V_{BO}, the SCR turns on and a very high current flows through it instantly, which may cause damage to the SCR. Therefore, most of the cases this type of triggering is avoided



This type ... is turned by ...
as the SCR is turned by ... depends on the temp. if temp
The reverse leakage current depends on the temp. if temp
is increased to a certain value, the num of holepairs
also increases.
→ This causes to increases the leakage current and further
it increases the current gains of the SCR.
→ This starts the regenerative action inside the SCR
Since the $(\alpha_1+\alpha_2)$ value approches to unity
(as current gains increases).
→ By increasing the temp at junction J_2, the width of
depletion layer decreases. So, when the forward bias
voltage is near to V_{BO}.
→ We can turn ON the SCR by to increasing the junction
temp (J_2). At a particular temp, the reverse bias of the
junction breaks down an the device starts to conduct
→ This triggering occur in some circumstances
particularly when it the device temperature is
more (also called false triggering).
This type of triggering is practically not employed
because it causes the thermal runaway so hence
the device or SCR may be damaged.

dv/dt triggering :-

In forward blocking state i.e., anode is more
than cathode, the junctions J_1 & J_3 are forward bi
and the junction J_2 is reverse biased
So, the junction J_2 behaves as a capacitor
(J_1, & J_3 as conducting plates with a dielectric J

due to the Space Charges in the depletion region.
The charging current of the Capacitor is given as

$$I_c = dQ/dt$$
$$= d(C_j V)/dt$$

Using product rule of differentiation, we get

$$= C_j\, dV/dt + V\, dC_j/dt$$

As the junction capacitance is always almost constant we can ignore the rate of change of junction capacitance dC_j/dt. So, the final charging current is:

$$I_c = C_j\, dV/dt$$

where, I_c is the charging current
C_j is the junction capacitance
Q is the charge
V is the voltage applied across the device.
dC_j/dt is the rate of change of junction capacitance
dV/dt rate of change of applied voltage

from the above eqn, if the rate of change of the applied voltage is large (i.e., it is applied suddenly) then the flow of charging current will increase, which causes the SCR to turn on without any gate voltage.

→ it is clear that we can turn SCR just by increasing the rate of change of voltage across the device rather than applying a large forward bias voltage.
However this method is practically avoided because it can cause a false turn ON process and also this can produce very high voltage across the SCR. So, there will be considerable damage to it.

A: light triggering:-

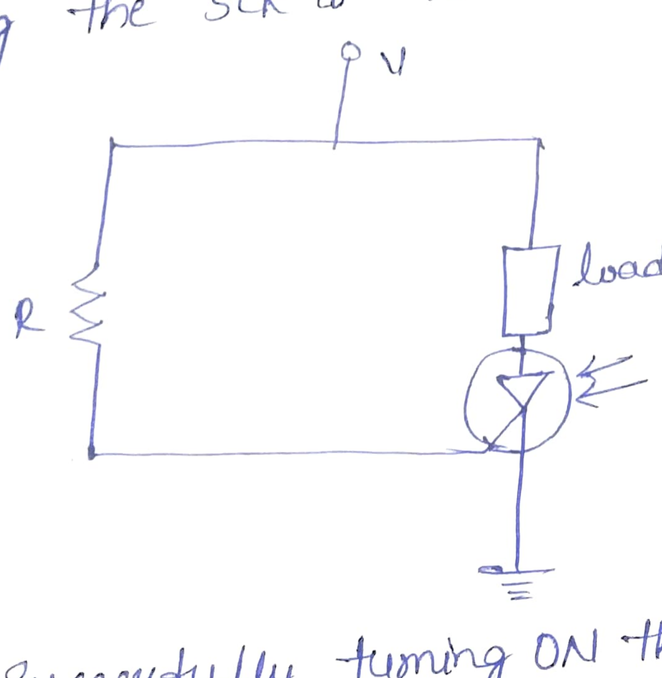
→ An SCR turned ON by light radiation is also called as lighted Activated SCR (LASCR).

Hence, light triggering is also known as Radiation triggering. Generally, this type of triggering is employed in phase controlled converters in HVDC transmission s/ms.

→ In this method, light rays with appropriate wavelength and intensity are allowed to strike the junction J_2.

The bombarded energy particles from the light (neutrons or photons) causes to break electron bonds as result, new electron - hole pairs are formed in the device.

→ As the number of charge carriers are increased, there is an instantaneous increase in the flow of current causing the SCR to turn ON.



Note:- For successfully turning ON the SCR with the help of light radiation, the rate of change of applied voltage (dv/dt) must be high.

Gate Triggering:-

This is the most common & most efficient method to turn ON the SCR. when the SCR is forward biased

→ A sufficient +ve voltage at the gate terminal injects some electrons into the junction J_2.

→ This results in an increase in the reverse leakage current & hence the breakdown of junction J_2 occurs even at a voltage lower than the V_{BO}

→ Depending on the size of the SCR, the gate current varies from a few milli-amps to 250 mamps or more.

→ If the gate current applied is more, than more electrons are injected into the junction J_2 and results to come into the conduction state at much lower applied voltage.

→ In gate triggering method, a positive voltage applied b/w the gate and the cathode terminals. we can use three ~~signals~~ types of gate signals to turn On the SCR. Those are DC signal, AC signal & pulse signal

DC gate triggering:-

→ In this triggering method, a positive voltage applied b/w the gate & the cathode terminals in such a way that the gate is made positive with respect to the cathode. The gate current drives the SCR into conduction mode

→ In this method, a continous gate signal is applied at the gate and hence it causes internal power dissipation

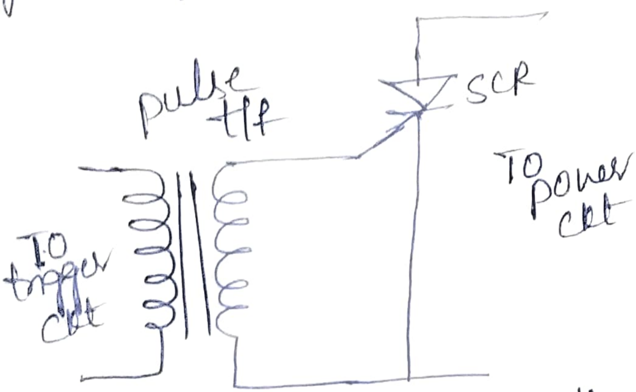
→ Draw back is there is no isolation b/w the power & control circuits

AC gate triggering:-

→ This is the most commonly used method of turning on the SCR, especially in AC applications

→ with proper isolation b/w the power & control circuits, the SCR is triggered by the phase-shift AC voltage derived from the main supply.

→ The firing angle controlled by changing the phase angle of the gate signal.



→ However, only one half of the cycle is available for the gate drive to control the firing angle and for the next half of the cycle. a reverse voltage is applied b/w the gate & cathode.

→ This is one of the limitation of AC triggering & other is need for separate step down or pulse t/f to supply the voltage to gate drive from the main supply

pulse Triggering:-

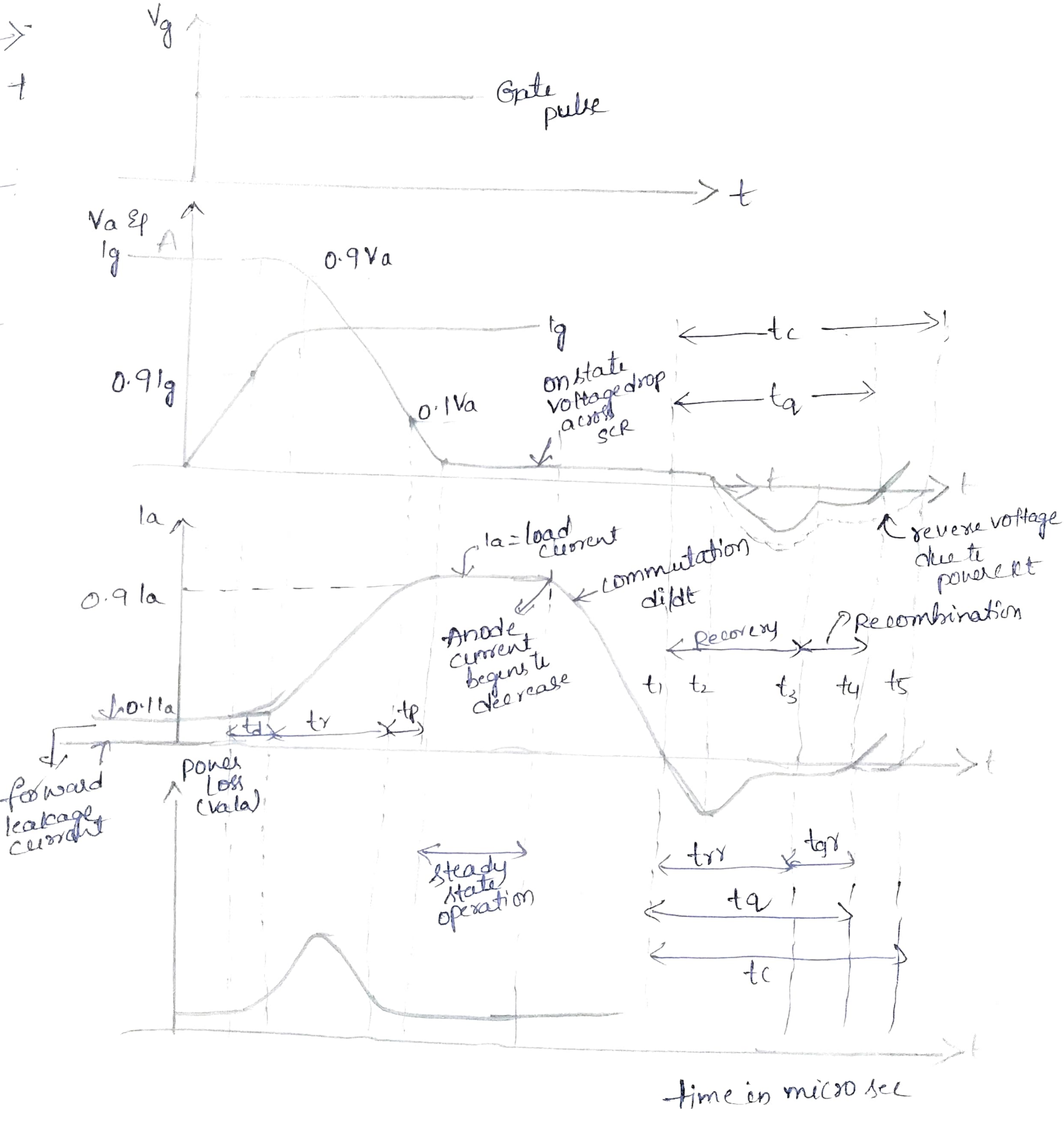
→ The most popular method of triggering the SCR is the pulse triggering.

→ In this method, gate is supplied with single pulse or a train of high frequency pulses

→ Main advantage of this method is that gate drive is discontinous or doesn't need continous pulses to turn the SCR

→ hence gate losses are reduced in greater amount by applying single or periodically appearing pulses for isolating the gate drive from the main supply, a pulse tff is used.

Dynamic Turn ON Switching characteristics of SCR :-



→ The dynamic processes of the SCR are turn ON & turn off processes in both voltage & currents of an SCR vary with time.

→ The transition from one state to another takes finite time, but doesn't take place instantaneously

→ The VI characteristics of SCR give no indication about the speed at which the SCR has switched into forward conduction mode from forward blocking mode.

→ There will be a finite transition time that SCR takes to reach the forward conduction mode from blocking mode which is termed as turn ON time (t_{on}) of SCR.

→ The turn ON time of the SCR Ton can be sub divided into three distinct intervals namely delay time t_d, rise time t_r and spread time t_s.

Delay Time (t_d):-

→ The delay time is measured from the instant at which the gate current reaches 90 percent of its final value to the instant at which anode current reaches 10 % of its final value

→ it can also be defined as the time taken for the anode voltage to fall from initial anode voltage value V_a to $0.9V_a$

→ The SCR is in forward blocking mode, so the anode is a small leakage current

→ when the gate signal is applied $0.9I_a$ then the gate current is reached to $0.1I_a$ and also anode to cathode voltage falls to $0.9V_a$.

→ when the gate signal applied, there will be non-uniform distribution of current over the cathode surface so the current density is much higher at gate terminal.

→ And it rapidly decreases as the distance from gate increases.

→ Hence, the delay time t_d is the time during which anode current flows in a narrow region where the current density is highest

Rise Time (t_r):-

→ This is the time taken by the anode current to rise from 10% to 90% of its final value

→ Also defined as the time required for the forward blocking voltage to fall from $0.9V_a$ to $0.1V_a$

→ This rise time is inversely proportional to the gate current and its rate of building up

→ ∴ If high & steep current pulses are applied at the gate, it can significantly reduce the rise time t_r.

→ Also if the load is inductive, the rise time will be higher & for resistive and capacitive loads it is low

→ During this time, turn ON losses in the SCR are high due to large anode current and high anode voltage.

→ This can result in the formation of local hot spots and the SCR may be damaged.

Spread Time (t_s):

→ This is the time required for the forward blocking voltage to fall from 0.1Va to its ON-state voltage drop which is the range of 1 to 1.5 Volts.

→ During this time anode current spread over the entire conducting region of an SCR from a narrow conducting region

→ After the spreading time, a full anode current flows through the device with small ON-state voltage drop.

Gate drive circuits for Mosfet :-

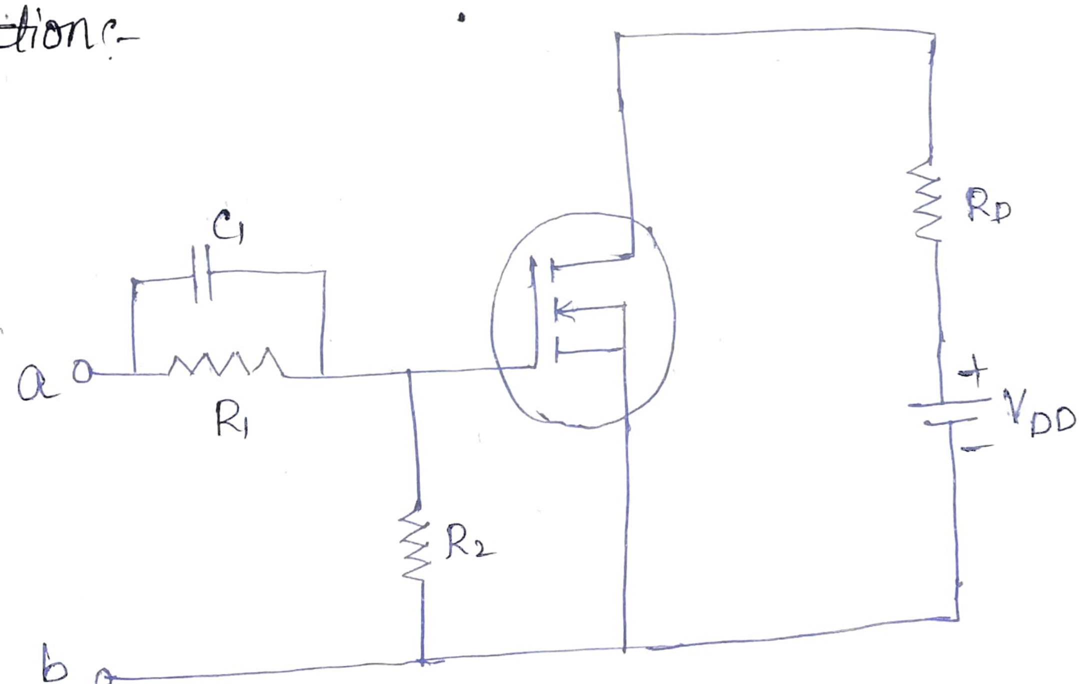
The gate drive circuit for Mosfet should satisfy the following requirements

i) The gate - Source input capacitance should be charged quickly.

ii) MOSFET turns ON when gate - source i/p capacitance is charged to sufficient level

iii) To turn-OFF MOSFET quickly, the negative gate current should be sufficiently high to discharge gate - Source i/p capacitance

operation :-



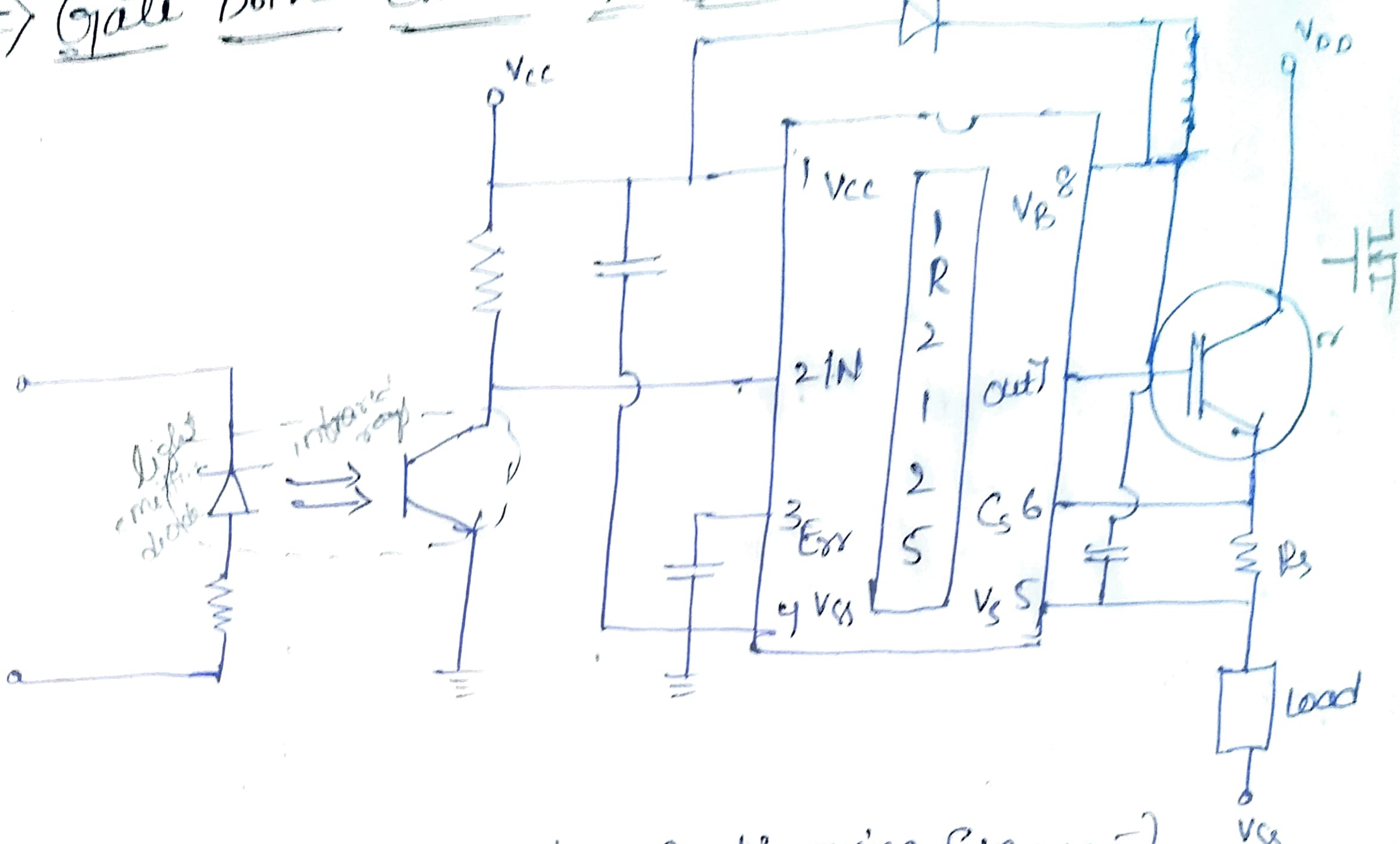
→ fig shows the gate drive as per our requirements. The gate drive is applied across the terminals a-b

→ initially the resistance R_1 is bypassed by C_1 and full drive voltage is applied to the gate.

→ This charges the gate - source capacitance quickly

→ As the capacitor C_1 charges, the gate current reduces. Once the MOSFET is turned on required gate current is very small

⇒ Gate Drive circuit for IGBT ~~by MOSFET~~



→ Here we are using IC for triggering [IR2125]

→ Here IR 2125 is the high voltage, fast switching MOS gate driver with single floating gate driver channel. This IC can be used to drive N-channel power MOSFET or IGBT

→ over floating through the IGBT is detected through Rs and Cs terminal of IC

→ The error pin of the IC indicates fault conditions