Power Electronics

Prepared by: Er. Shiva Shrestha

syllabus

Power Electronics (3 – 1 - 2)

Evaluation:

	Theory	Practical	Total
Sessional	30	20	50
Final	50	-	50
Total	80	20	100

Course Objectives:
To understand the behavior of power semiconductor devices and their use in power electronic controllers.

Course Contents:

1. **Power Semiconductor Diodes and Transistors** **10 hrs**
   1.1 Power diode : V-I and switching characteristics, types of power diodes
   1.2 Power transistor: V-I and switching characteristics
   1.3 Power MOSFET: V-I and switching characteristics
   1.4 IGBT: V-I and switching characteristics, comparison with MOSFET
   1.5 Thyristor: V-I and switching characteristics, turn on-off mechanism, protection schemes
      1.5.1 Improvement of thyristor characteristics
      1.5.2 Firing/triggering circuits: Pulse transformer triggering (short pulse, long pulse and train pulse)
      1.5.3 Series and parallel operation of thyristors
      1.5.4 Various commutation techniques: self and forced commutation.
      1.5.5 Members of thyristor family: TRIAC (V-I characteristics and operating modes of triac), Diac (V-I characteristics), Gate turn off thyristor (GTO): Structure, I-V Characteristics, Comparison between GTO and Thyristor.

2. **Single Phase AC to DC Conversion** **8 hrs**
   2.1 Half wave rectification circuit using diodes and thyristors (R load, R-L load, RL load with freewheeling diode)
   2.2 Full wave rectification circuit using diodes and thyristor for both resistive and inductive load
   2.3 Performance parameters and filtering schemes
   2.4 Single phase semi converter and full converter
   2.5 Power factor improvement
      2.5.1 Extinction angle control
      2.5.2 Symmetrical angle control
      2.5.3 Pulse width modulation control
   2.6 Effect of source impedance on the performance of single phase full converter

3. **Three Phase AC to DC Conversion** **4 hrs**
   3.1 Three phase half wave rectifier and bridge rectifier using diodes
   3.2 Three phase semi converter and full converter with R-L load
   3.3 Effect of source impedance on the performance of three phase full converter

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4. DC to DC Conversion — 4 hrs

4.1 Introduction, principle of step up and step down operation.
4.2 Step up and step down chopper circuit
4.3 Classification of chopper
4.4 Switching regulators (Buck and Boost regulators)

5. Inverter — 5 hrs

5.1 Single phase inverter
5.2 Application of single phase inverter with ac motor load
5.3 Three phase inverter
5.4 Pulse width modulated (PWM) inverters
- 5.4.1 Single pulse modulation
- 5.4.2 Multiple pulse modulations
- 5.4.3 Sinusoidal pulse width modulation

6. AC Voltage Controller — 5 hrs

6.1 Single phase voltage controller with phase control using resistive and inductive load
6.2 Principle of operation of single phase cycloconverter
6.3 Step-up and step down single phase cycloconverter
6.4 Three phase cycloconverter
6.5 AC voltage controllers with PWM control

7. Power Supplies and Circuit Protection — 5 hrs

7.1 Introduction
7.2 Switched mode dc power supplies
7.3 AC power supplies
- 7.3.1 Uninterruptible power supply (UPS)
- 7.3.2 Switched mode power supply

7.4 Protection of Devices and circuits
- 7.4.1 Cooling and heat sinks
- 7.4.2 Snubber circuits
- 7.4.3 Voltage and current protection

8. HVDC Power Transmission — 4 hrs

8.1 HVDC station configuration (Filter, converters and Inverters)
8.2 Comparison of HVDC and HVAC transmission
8.3 AC line commuted converters for reversible power flow and control in dc line, pulse and 12-pulse operation
8.4 Series and parallel operation of converters

Laboratory:

1. Study the characteristics of thyristors (SCRs)
2. Power control using SCR.
3. Study of single phase rectification with diode and thyristor
4. Study of dc conversion using chopper circuit
5. Study of dc to ac conversion with resistive load
6. Study of ac voltage controller with resistive load

Course Overview:

- Unit 1: Power Semiconductor Diode and Transistor
- Unit 2: Single Phase AC to DC Conversion
- Unit 3: Three Phase AC to DC Conversion
- Unit 4: DC to DC Conversion
- Unit 5: Inverter
- Unit 6: AC Voltage Controller
- Unit 7: Power Supplies and Circuit Protection
- Unit 8: HVDC Power Transmission

Unit 1:- Power Semiconductor Diode and Transistor

- 1.1 Power Diode : V-I and Switching characteristics type of power diodes
- 1.2 Power transistor: V-I and switching characteristics
- 1.3 Power MOSFET: V-I and switching characteristics
- 1.4 IGBT: V-I and switching characteristics, comparison with MOSFET
- 1.5 Thyristor: V-I and switching characteristics, turn on-off mechanism, protection schemes
  - 1.5.1 improvement of Thyristor characteristics
  - 1.2.2 firing/triggering circuits: Pulse transformer triggering(short pulse, long pulse and train pulse)
  - 1.5.3 Series and parallel operation of Thyristor
  - 1.5.4 Various commutation techniques: self and forced commutation
  - 1.5.5 Members of thyristor family: TRIAC(V-I characteristics and operating modes of triac), Diac(V-I characteristic), Gate turn off thyristor(GTO): structure, I-V characteristic, comparison between GTO and Thyristor.

1.1 Power Electronics:

- It's a technology associates with efficient conversion and control of electric power by power semiconductor.
- The main motive of PE is to control the flow of energy form electrical source to load .

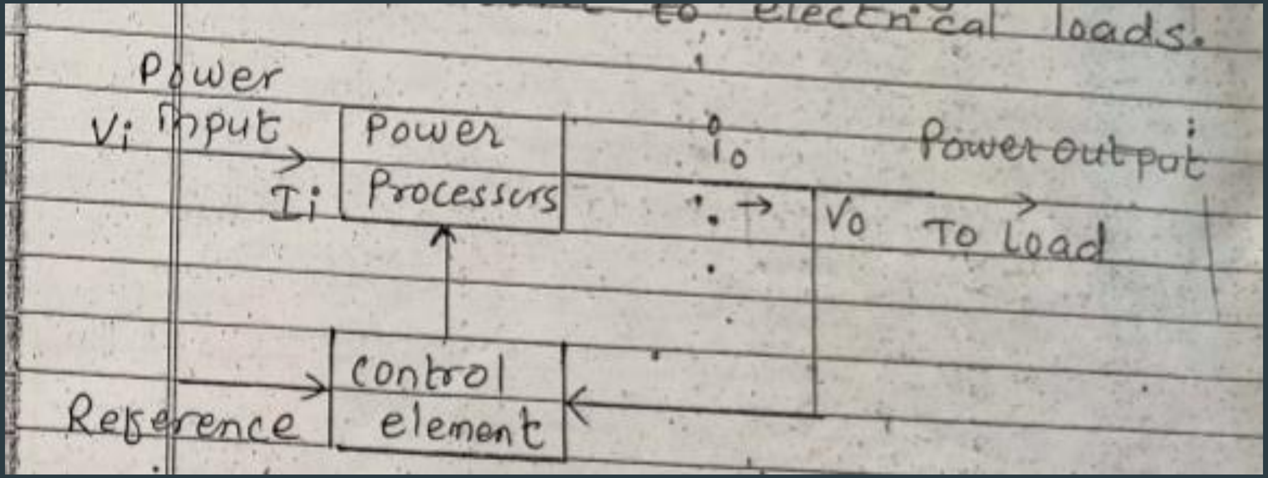
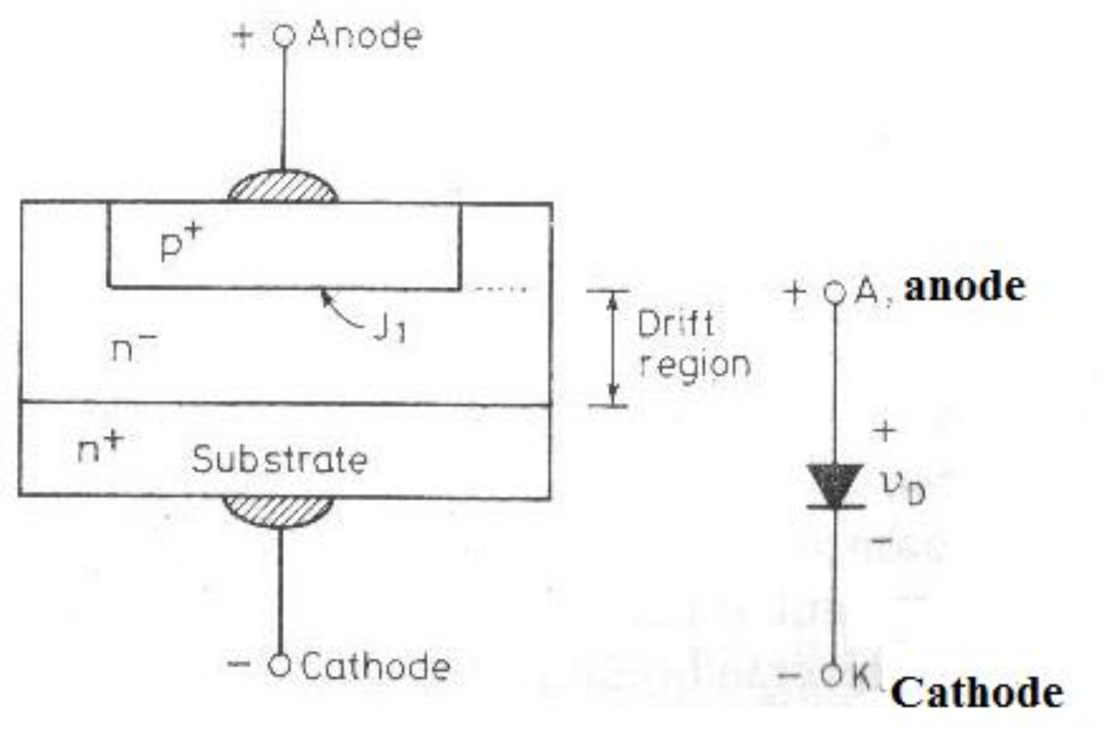


Fig: block diagram of power electronics system

Basic structure of Power Diode:

- A low power diode can be called as signal diode where as high power diode known as power diode.
- The voltage and current rating of power diode and transistor are much higher than that of signal diode.
- Generally range form few volts to KV,KA.
- It operates in higher switching speed.
- A typical power diode has P-I-N structure that is, it is P-N junction with Intrinsic s/c layer (I layer) in the middle to sustain reverse voltage.
- Where n^+ is heavily doped,
  n^- is lightly doped
- The breakdown voltage needed in a power diode governs the thickness of n layer.
- Breakdown voltage ↑ n-layer thickness ↑



a) Construction of P-I-N Diode b) Symbol

- The drawback of n^- layer is to add significant ohmic resistance to the diode, when it is conducting in a forward current.
- This lead to large power dissipation in the diode.
- So proper cooling arrangement in large diode rating are essential.
- V-I characteristics of power diode:-

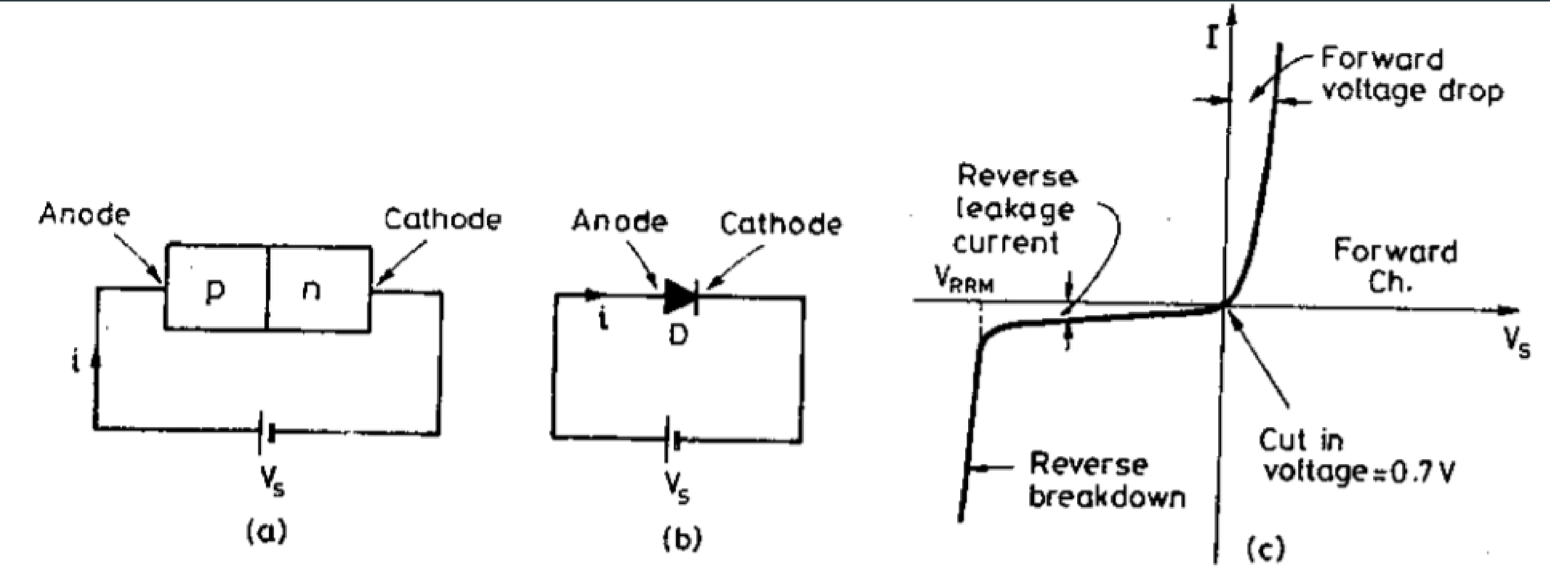


Fig. 2.1. (a) p-n junction (b) diode symbol (c) V-I characteristics of diode.

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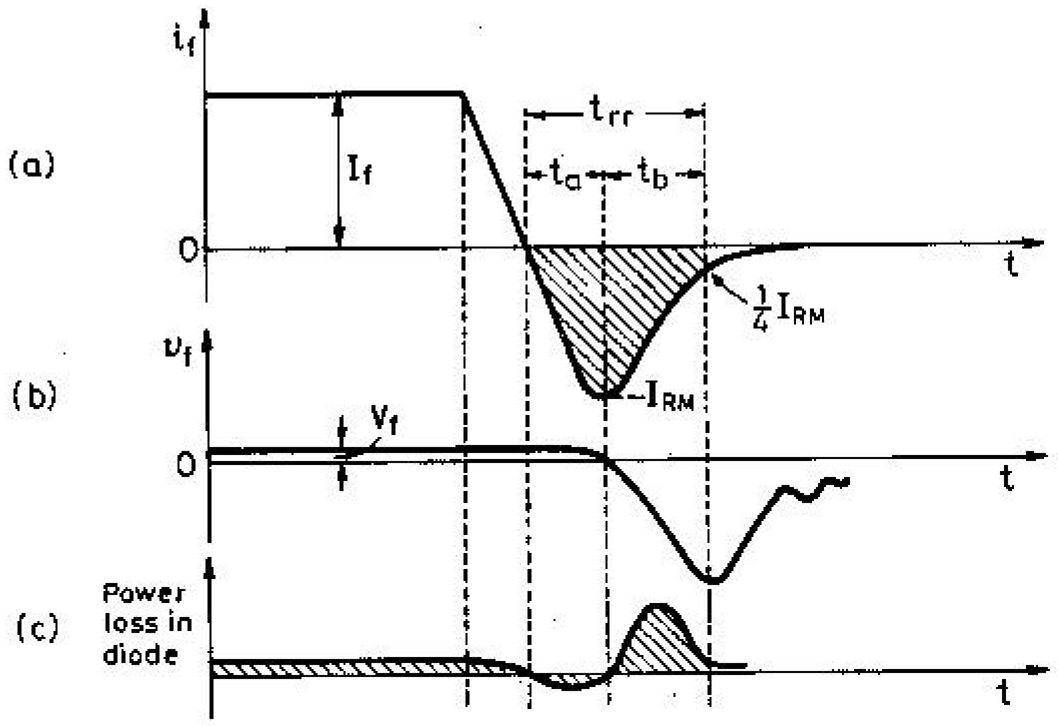
Diode V-I characteristics:

- Operation:
  - When anode is positive w.r.t. cathode, it is said to be forward biased.
  - When input voltage increase, diode start to conducts there is a voltage drop across the diode.
  - Voltage drop is known as Cut-in voltage/threshold voltage/turn on voltage.
  - Generally that forward voltage drop range from 0.3 to 1 V.
  - When FV(forward voltage) increase, it will simultaneously increase the forward current exponentially in linear form.as shown in fig.
  - Greater the input voltage ↑ = lower will be the ohmic resistance ↓ of diode to some extent.
  - When cathode is positive w.r.t anode, it is said to be reverse biased.
  - At this condition, small reverse current flow known as leakage current.
  - Leakage current is very small until it reach to the breakdown voltage(reverse breakdown).

Diode Reverse Recovery Characteristics:-



(a)Variation of Forward Current If (b) Forward Voltage DropVf (c) Power loss in the Diode

Short note imp

Operation:-

- After FC decay to zero the diode continuous to conduct in a reverse direction because of pressure of storage charge to the depletion layer of s/c layer.
- The diode remains its blocking capacity until the reverse recovery current decay to zero.
- The reverse recovery time t_{rr} is defined as the time between the instant forward diode current becomes zero and the instant reverse recovery current decay to 25% of its reverse peak value I_{RM} .
- The reverse recovery time is composed of 2 segment of time t_a & t_b.

  i.e. $t_{rr} = t_a + t_b$
- The time t_a is the time between zero crossing of FC and peak reverse current I_{RM} .
- During the time t_a, the charge stored in the depletion layer is removed.
- Time t_b is measured from the instant of reverse peak value I_{RM} to the instant when 0.25 I_{RM} is reached.

- During t_b ,charge from the s/c layer is removed.

Continue..

- The shaded area in the fig represent the storage charge or reverse recovery charge Q_r which must be removed during the reverse recovery time.
- It is noticed from fig, the peak reverse current can be expressed as:

$$I_{RM} = t_a \frac{di}{dt} \qquad \text{——— } 1$$

Where , di/dt is the rate of change of reverse current.

$$Q_R = \frac{1}{2} I_{RM} \cdot t_{rr} \qquad \text{——— } 2$$

$$I_{RM} = \frac{2\,Q_R}{t_{rr}} \qquad \text{——— } 3$$

If $t_{rr} \cong t_a$, then from Eq. 1

$$I_{RM} = t_{rr} \cdot \frac{di}{dt} \qquad \text{——— } 4$$

From Eqs. 3 and 4 we get

$$t_{rr} \cdot \frac{di}{dt} = \frac{2\,Q_R}{t_{rr}}$$

$$t_{rr} = \left[\frac{2\,Q_R}{(di/dt)}\right]^{1/2} \qquad \text{——— } 5$$

From Eq. 4, with $t_a \cong t_{rr}$, we get

$$I_{RR} = t_{rr} \cdot \frac{di}{dt} = \left[\frac{2\,Q_R}{(di/dt)}\right]^{1/2} \cdot \frac{di}{dt}$$

$$= \left[2\,Q_R \left(\frac{di}{dt}\right)\right]^{1/2} \qquad \text{——— } 6$$

Continue…

- Two important parameter for diode that has to be used in high frequency circuit are reverse recovery time and reverse recovery charge.
- Lower the faster the diode can be switched.
- Types of diode:-
- 1. line frequency diode
- 2. fast recovery diode
- 3. schottky diode
- 4. silicon carbide diode
- Assignment 1- write difference type of power diode that can be used in telecommunication line.

Thyristor:

- The modern era of solid state power electronics started due to the introduction of this device in 1957.
- The SCR simply referred to a thyristor.
- It is a 4 layer current controlled s/c power device with three terminal: Anode(A), the cathode (K) and gate(G).
- The anode and cathode are power terminals and gate is control terminal.
- Thyristor can be turn ON by positive gate current.
- When the Anode is positive, the device can be triggered into conduction by a short gate pulse, but once the device is conducting the gate loses its control to turn off the device.

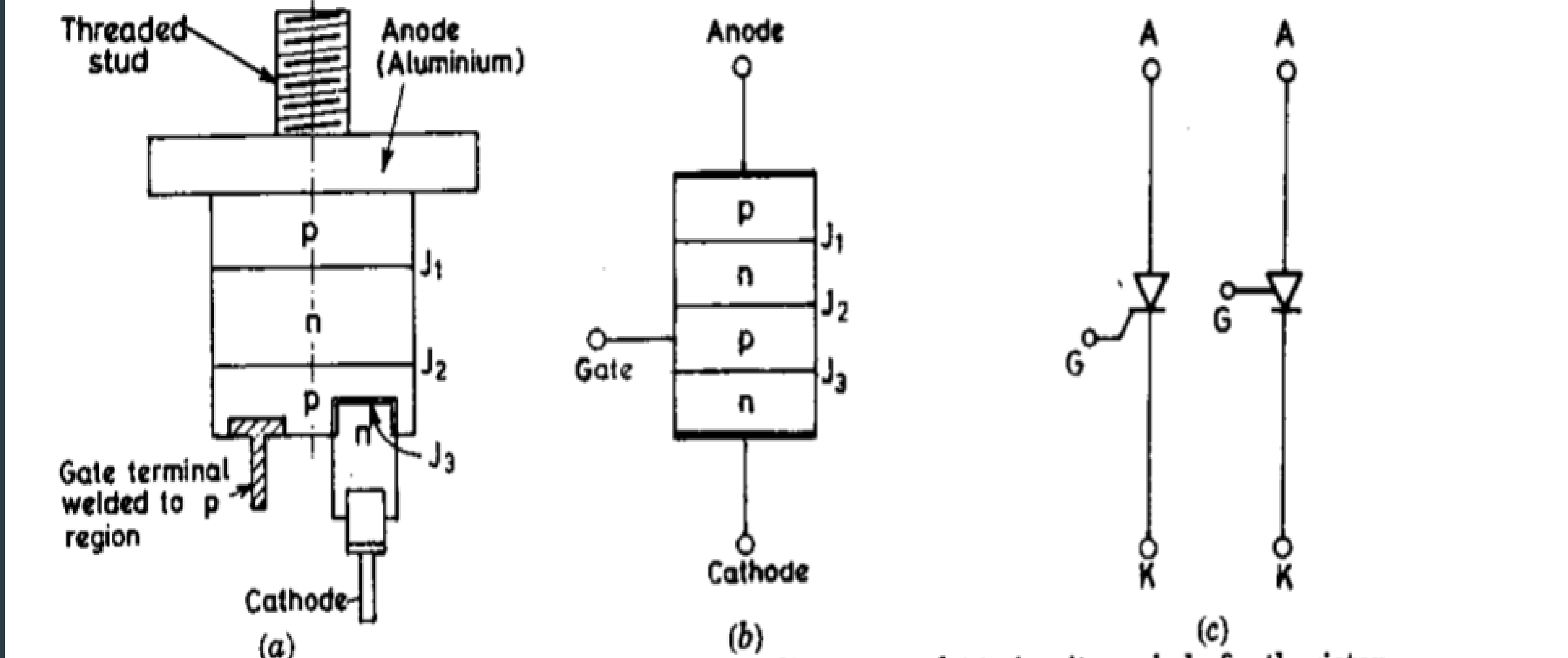


Fig. 4.1. (a) Constructional details (b) Schematic diagram and (c) circuit symbol of a thyristor.

- The cathode is the most heavily doped, the gate and anode are the next heavily doped, the lowest doping level is within the central N type layer.
- Junction J_3 has less breakdown voltage at either direction.

- Modes:

1. When $V_{AK} > 0$
   1. J_1 & J_3 are forward biased
   2. J_2 is reverse biased which hold the entire voltage.

2. When $V_{AK} < 0$
   1. J_2 is forward bias where as J_1 & J_3 are reverse bias.
   2. J_3 can not support high reverse voltage.
   3. J_1 should block the entire voltage when reverse bias

V-I characteristics of thyristor:-

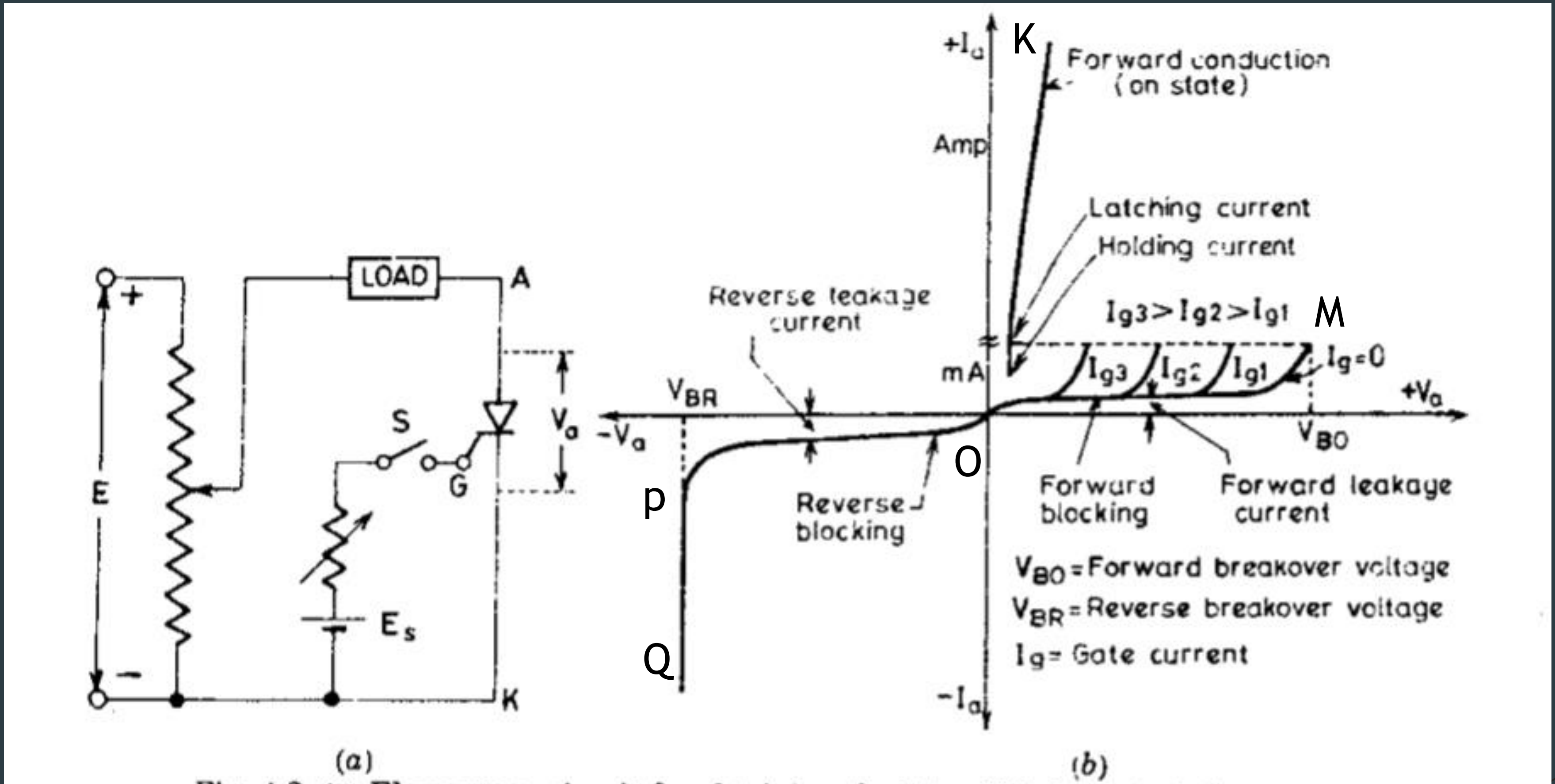


Fig. 4.2. (a) Elementary circuit for obtaining thyristor V-I characteristics
(b) Static V-I characteristics of a thyristor.

- The thyristor has three basic mode of operation which are given below:
   a) Reverse blocking mode(OFF State)
   b) Forward blocking mode
   c) Forward conduction mode(ON State)

- a) Reverse blocking mode(OFF state):

In this mode,

- Also known as OFF state of thyristor.
- Junction J_1 & J_3 are reverse bias where as J_2 is forward bias
- In the reverse bias mode, the characteristics is similar to PN diode.
- A small leakage current flows in the circuit.
- In fig. OP is the reverse blocking mode.
- if the reverse voltage is increase then at the critical breakdown called reverse breakdown voltage V_{BR} an avalanche occurs at J_1 & J_3 which cause reverse current increase rapidly.
- A large current associate with V_{BR} gives rise to more losses in the SCR.

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- This may lead to thyristor(SCR) damage as the junction temp may exceed its permissible temp rise.
- Always make sure it do not cross reverse voltage V_{BR}.
- PQ is the reverse avalanche region.

- b) Forward blocking mode:
  - OM is the forward blocking mode.
  - When the anode is positive w.r.t cathode with gate terminal open, thyristor is said to be forward biased.
  - In this mode J_1 & J_3 are FB but J_2 is reverse biased.
  - A small current called forward leakage current flows.
  - As forward leakage current is small thyristor offer high impedance, can be treated as open switch.

Contue…

- c) Forward conduction mode:
  - When anode to cathode voltage increased with gate circuit open, reverse biased junction J_2 will have an avalanche breakdown at the voltage called forward break over voltage V_{BO}.
  - After this breakdown, thyristor get turn-on.
  - NK = represent forward conduction mode.

Thyristor turn-on methods:

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- With anode positive w.r.t cathode a thyristor can be turn-on by one of the following technique.
  a) Forward Voltage Triggering
  b) Gate Triggering
  c) dv/dt triggering
  d) Temperature Triggering
  e) Light Triggering
- a) Forward Voltage Triggering:-
  - If the forward voltage across anode to cathode is gradually increased. A stage comes when depletion layer across J_2 breakdown.
  - At this moment, reverse biased junction J_2 is said to have avalanche breakdown and voltage at which it occurs is called forward breakdown voltage V_{BO}.

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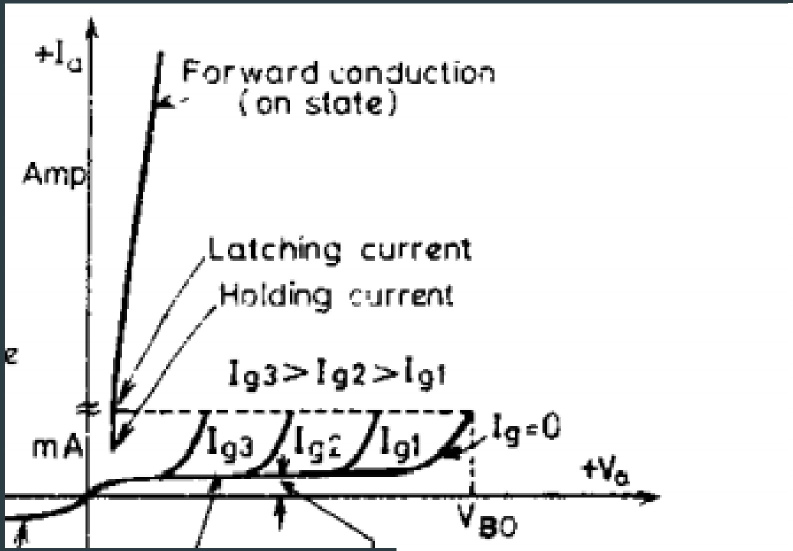
- Breakdown of junction J_2 allows free moment of charge carrier across three junction as a result of large forward anode current flows.
- After the avalanche breakdown junction J_2 losses its reverse blocking capability. Therefore of the anode voltage is reduced below V_{BO}, thyristor will continue conduction of current.
- The thyristor(SCR) can now be turn-off only by reducing the anode current below the certain value called holding current.

b) Gate triggering



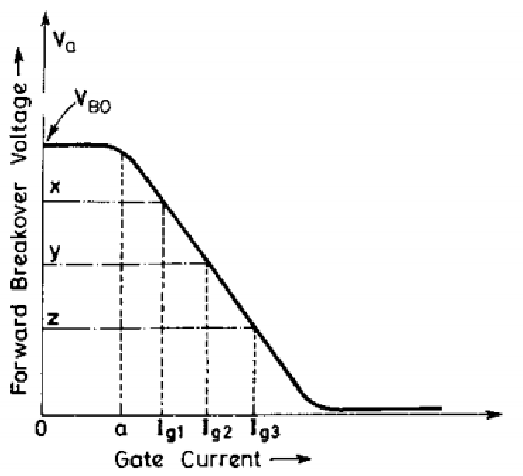
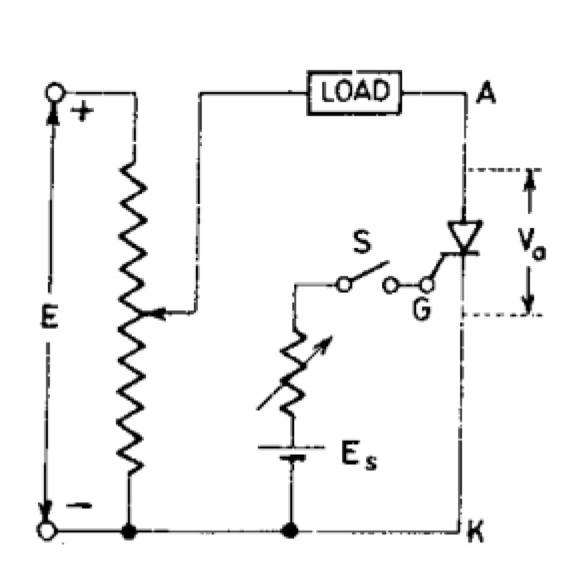


Fig. 4.4. Variation of forward breakover voltage with gate current.



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- If $I_g \neq 0$, voltage 'V' at which device goes into conduction mode reduce.
- Ig reduce the depletion layer around J_2.
- The gate current should be present till the current through device is higher than latching current.
- Having gone to the conduction mode the gate has no control.
- To turn off the device current through the device should fall to the value less than holding current i.e. $I_a < I_h$
- Ig should present till $I_a > I_L$.

Temperature triggering:

- During the forward blocking mode most of the applied voltage appears across reverse biased junction J_2.
- This voltage across $J_{2,}$ associated with leakage current would rise the temp of the junction j_2.
- With increase in temp, width of depletion layer decrease, this leads more further leakage current and more temp rise.
- With cumulative process, at some point(with in safe limit) depletion layer get vanish and thyristor(SCR) get turn on.

Light Triggering:

- For light triggering SCRs, a recess is made in the inner p layer(p_2).
- When this recess is irradiated, free charge carriers(pair of electrons and holes) are generated just like when gate signal is applied between gate and cathode.
- The pulse of light of appropriate wavelength is guided by optical fiber for irradiation.
- If the intensity of this light thrown on the recess exceeds a certain value, forward biased SCR is turned on.
- This type of SCR is known as LASCR(light activated SCR).

recess = a small space created by building part of a wall further back from the rest.

dv/dt:

- With forward voltage across anode and cathode of a SCR, J_1 & j_3 are F.B. and J_2 is R.B.
- Due to existing of charge across depletion layer of J_2 , it behaves like capacitance.
- If forward voltage is suddenly applied, a charging current through junction capacitance C_j may turn on SCR.
- $I_c = \frac{dQ}{dt} = \frac{d(Cj.Va)}{dt} = Cj\frac{dVa}{dt} + Va\frac{dCj}{dt}$
- Since, the junction capacitance is almost constant, $\frac{dCj}{dt} = 0,$
- $I_c = C_j \frac{dVa}{dt}$

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Thyristor Protection:

- for the proper operation of thyristor it should be operated within design limit.
- But in actual practice it might subjected in overvoltage or overcurrent, so that we have to protect it from such unwanted inputs.
- Not only supply input does the damage on SCRs but also unwated gate signaling may leads to SCR turn on.
- Principle factor responsible for unreliable operation of thyristor(SCR).
  1. Large di/dt during turn on
  2. Large dv/dt resulting in false triggering
  3. Spurious signals across gate to cathode terminals resulting in unwanted turn on
  4. Over voltage
  5. Over current

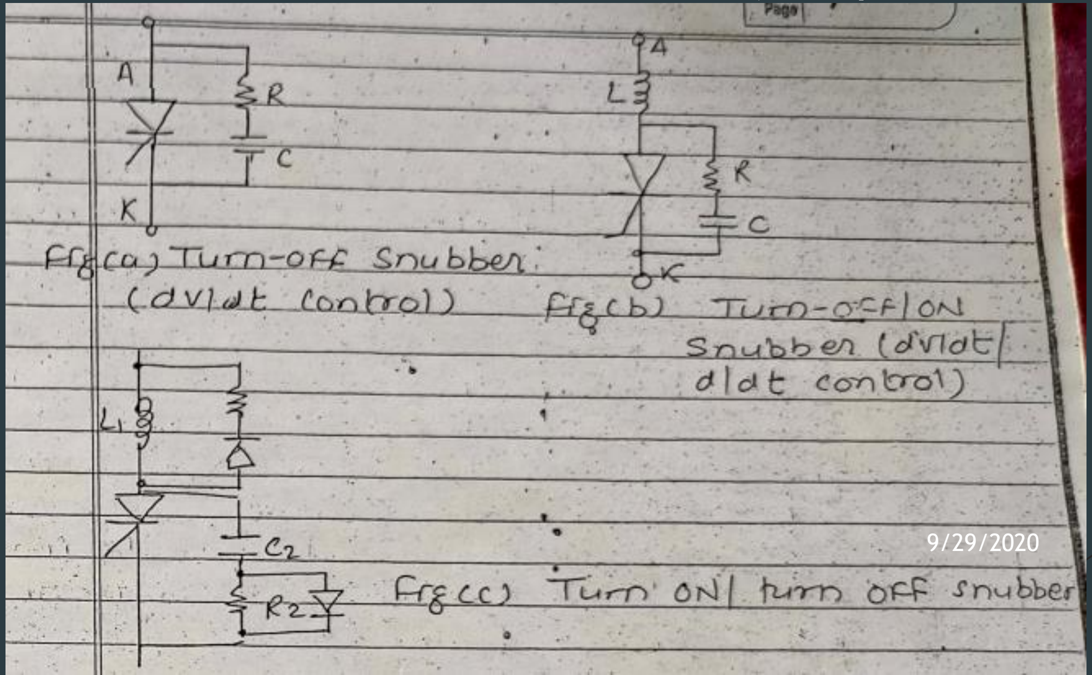
Spurious = apparently but not actually valid

1) di/dt protection:

- For turning on a thyristor, it should be F.B and gate pulse is applied.
- Then conduction begins in the close proximity of the gate-cathode junction and subsequently conduction spread across the whole area of junction quite rapidly in a well design thyristor.
- If rate of rise of anode current i.e. di/dt is large as compared to the spread velocity of carriers.
- Local hot spot will be formed near gate terminal due to heavy current density.
- This heat may destroy thyristor, therefore di/dt should be minimize to specific value.
- This can be controlled by adding small inductor, called di/dt inductor. In series with anode circuit.
- The typical value of di/dt lies within 20-200 A/μ sec.

dv/dt protection:

- For high dv/dt, charging current is high and plays the role of gate current by turing on the thyristor unwantedly, even in the absence of gate current.
- Such turn on is called dv/dt turn on and it result in the false operation of thyristor circuit.
- Hence, dv/dt must be kept blow the rated limit typically 20 to 500 V/µ sec.
- Protection of such circuit is known as snubber circuit.(# imp for short notes)



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Overvoltage protection:

- Thyristor are very sensitive to overvoltage just as other s/c device.
- Transient overvoltage may lead to mal-operation thyristor by permanent breakdown due to reverse breakdown.
- Overvolatge may be due to internal or external overvolatage
    - I) internal overvoltage:
    - large voltage may be generated internally during the commutation of thyristor.
    - When anode current reduce to zero and reverse due to stored charge.
    - This reverse recovery current rise to a peak, and SCRS begins to block. After peaking up rverse recovery currnet try to decay abruptly with large di/dt.
    - Ii) external overvoltage:
    - External overvoltage are caused due to the interruption of current flow in an inductive ckt.

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- Also it may be caused bye lighting stroke on the lines feeding the thyristor circuit.
- Also when thyristor ckt are connected through transformer, voltage transients are likely to occur when the transformer primary is energised or de-energised.
- All this transient may led to thyristor damage(by turning on improperly)

Which can be protected by choosing a thyristor peak voltage rating of 2.5 to 3 times their normal peak working voltage.

This can also overcome by using RC circuits and non linear resistance called voltage clamping device.

Improvement of thyristor characteristics:

- For a thyristor, an improvement of large di/dt as well as dv/dt rating is describe. A boost these rating can be made by doing some structural modification.

a) improvement in di/dt rating:

  - The rate of rise of anode current (di/dt) in thyristor depends primary on the initial area of cathode conduction during rise time.
  - Of initial cathode conduction area is increased, di/dt rating gets improved.
  - Two methods can be used to improve di/dt ratings.
  - i) by using higher gate current
  - Ii) by intermixing the gate cathode region

i) High gate current:

  - At the start of turn on, if higher gate current is applied, turn on area of cathode surface has to be more for handling higher gate current.
  - As consequence initial cathode conduction area for allowing anode current to pass through it increase and this s what is desired.

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ii) Structural modification:

- The di/dt can be improved by modifying the gate cathode geometry.
- This alternation consist of intermixing of gate and cathode region

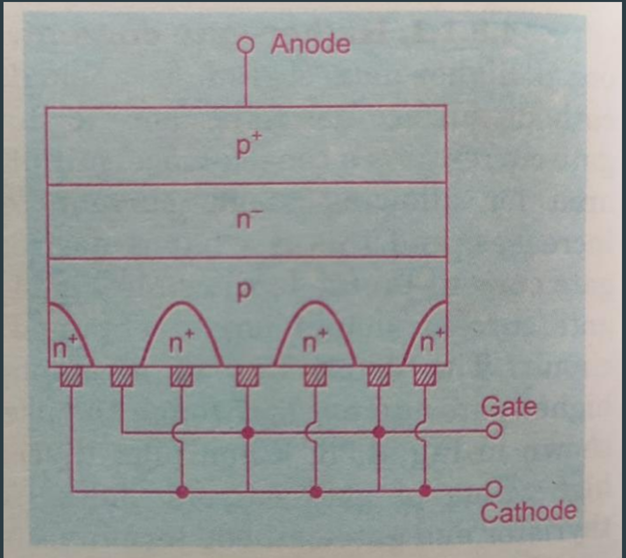

Fig. 4.35. Interdigitating of gate-cathode regions in a thyristor.

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b) Improvement in dv/dt rating:

- When dv/dt is large, high charging current flows in the junction which turn on the thyristor.
- dv/dt can be minimized by using cathode short structure.
- This can be done by overlapping metal on cathode n+ region with a narrow p region in between.
- In cathode short structure, most of the discharge current passed through narrow p channels in between n+ region.
- Junction j_3 shares only negligible amount of dv/dt current.
- Figure below shows the process.

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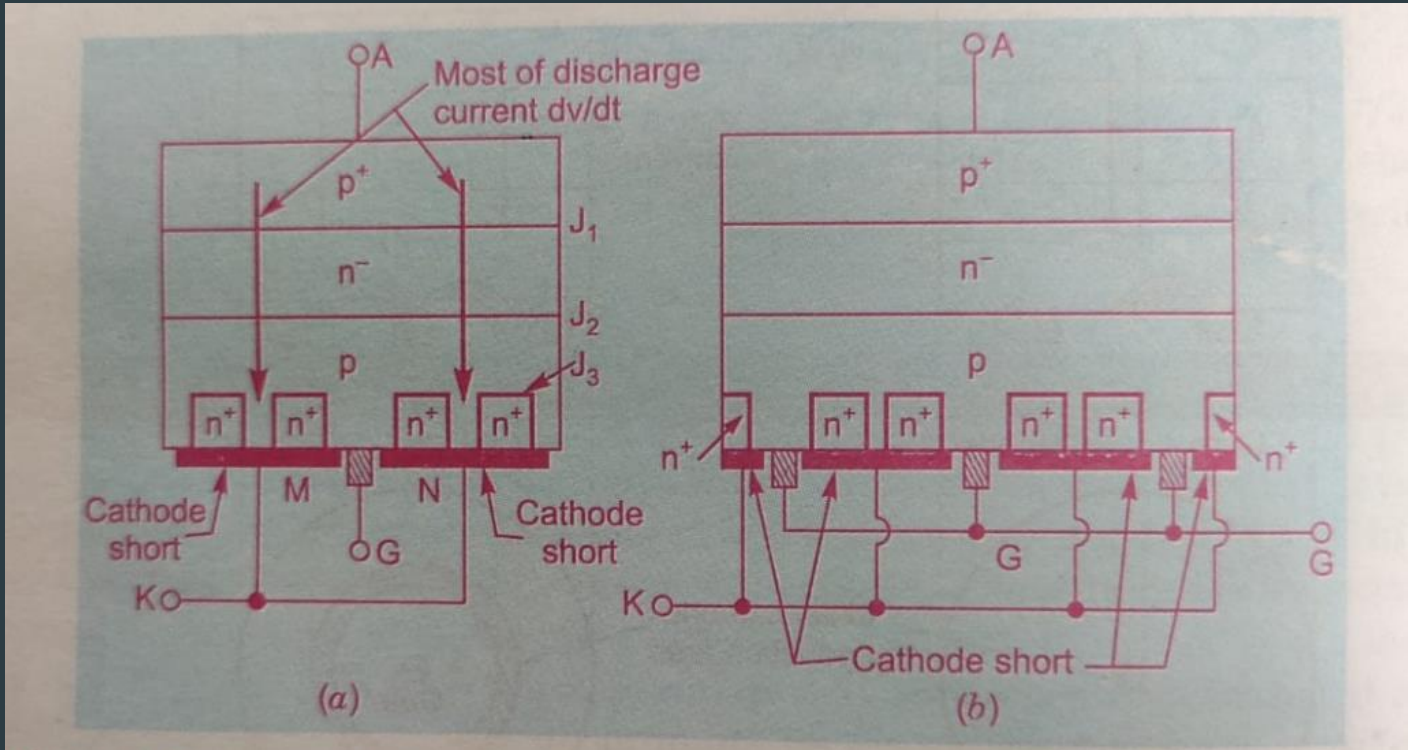

Fig. 4.36. Thyristor cathode-shorts (*a*) elementary intermixing (*b*) advanced intermixing.

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Thyristor commutation technique: (self and force commutation)

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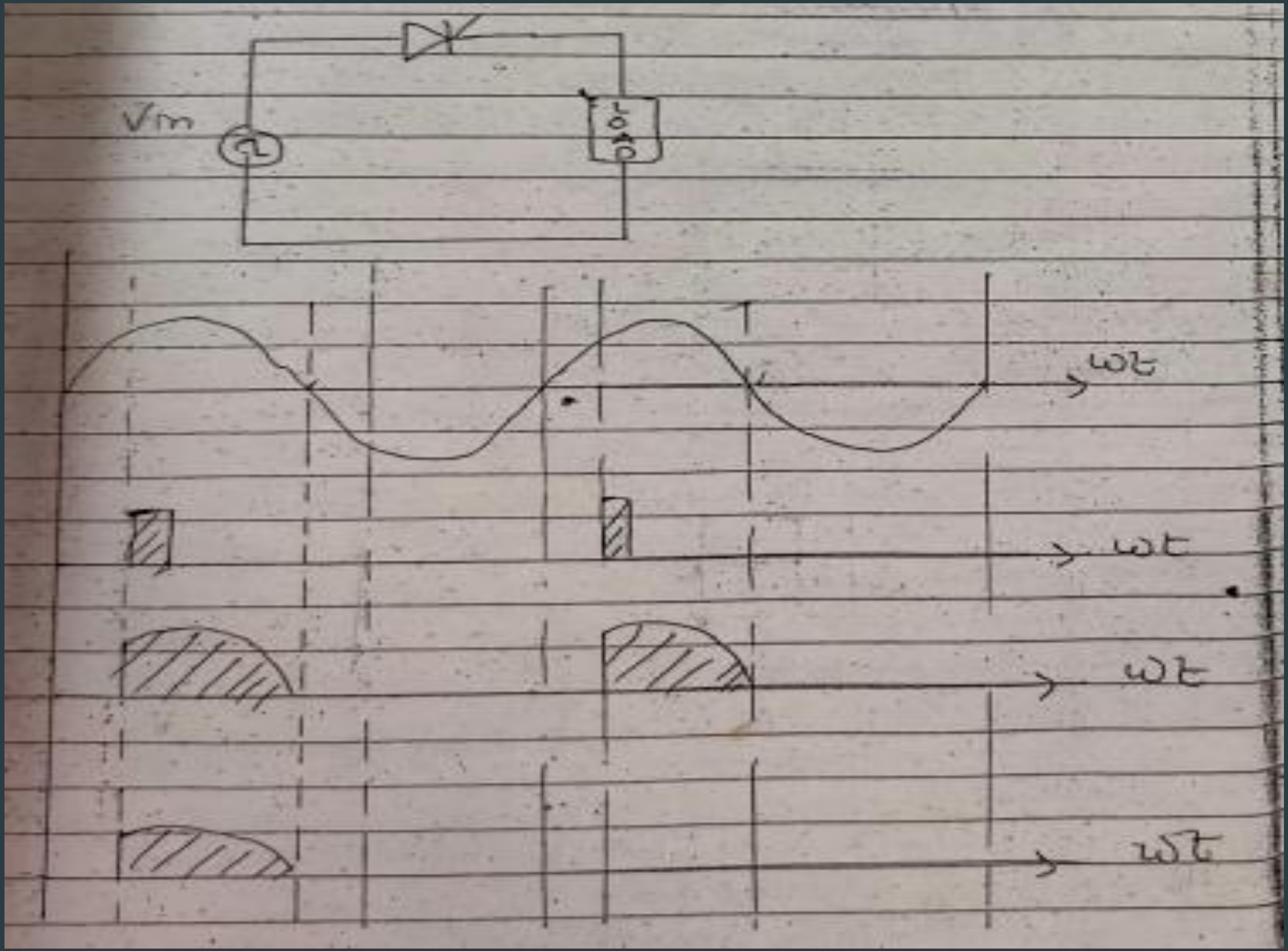
- The process of turning off thyristor i.e. from on state to off state(so the process of switching off a thyristor or SCR is known as commutation)
- The truing off thyristor means bringing it from forward conduction state to forward blocking state.
- It can be achieve by:
  - 1 reducing a anode current fall below the holding current
  - 2. making anode –ve with respect to cathode.


Vm
Load
ωt
ωt
ωt
ωt

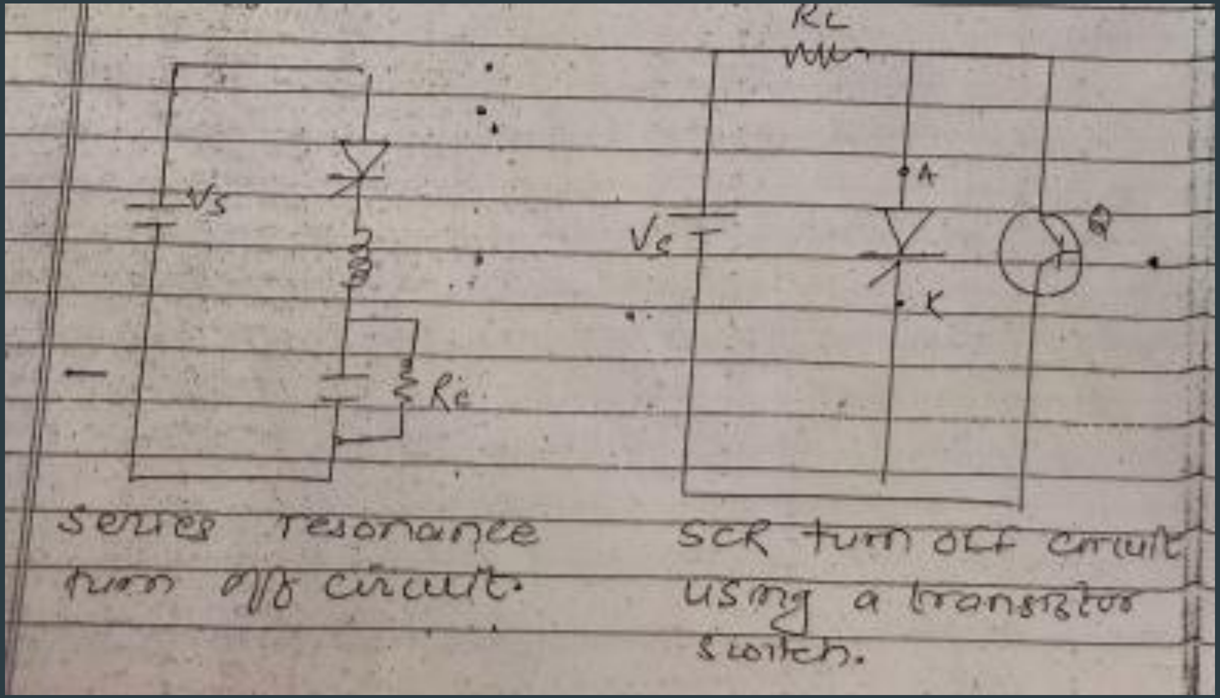
Types of commutation:

1. Natural or line commutation
2. forced commutation

- 1. Natural commutation:
  - The process of turning off a thyristor without using any external circuit is known as natural commutation. This type of commutation is only possible in AC application.
  - If a source(or input) voltage is AC, the thyristor current goes through a natural zero and a reverse voltage appears across the thyristor.
  - This method is only applicable in AC supply. This is not possible to get this w.r.t. DC because SC is unidirectional quantity.
  - a) Holding current:
    - It is define as the minimum value of anode current below which it must fall for turning off the SCR

Continue…

- b) Latching current:
  - It is define as the minimum value of anode current which it must attain during turn on process to maintain conduction. When the gate signal is removed.
- Forced commutation:
  - The process of Turing off thyristor or SCR by using external circuit is known as forced commutation.
  - this type of commutation is only possible in DC application.
  - In some thyristor circuit, the input voltage is DC and forward current of thyristor is forced to zero by an additional circuitry called commutation circuit to turn OFF the thyristor.
  - This is normally applied to DC=DC converter (chopper) and DC-AC(inverter) .
  - Forced commutation is classified as class A, B,C,D and E. this classification is based on the arrangement of commutating components and method to achieve zero current and reverse voltage to across SCR.



RL
Vs
Rc
Vc
A
K
Q
Series resonance turn off circuit.
SCR turn off circuit using a transistor switch.

Class A commutation: Load commutation

- The commutating component L and C are connected, so that the over all circuit becomes underdamped.
- For low value of R,L and C are connected in series with R.
- For high value of R, load R is connected across C.
- The current I first rises to maximum value and then begins to fall.
- At this cond capacitor get fully charged and get reverse, because of this voltage across SCR is zero
- When current decays to zero, and tends to reverse, a reverse voltage is applied across SCR and thyristor T is turned OFF.

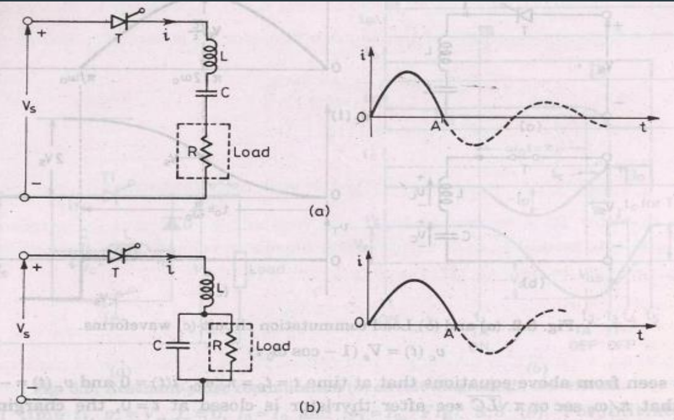


Fig. 5.1. Class A or load commutation (a) series capacitor (b) shunt capacitor.

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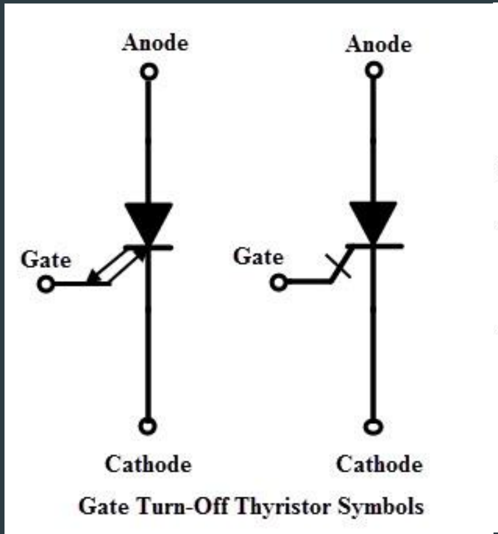
Continue…

- Load commutation is possible in DC ckt but not in AC ckt.
- It is also called **resonant commutation or self commutation**.

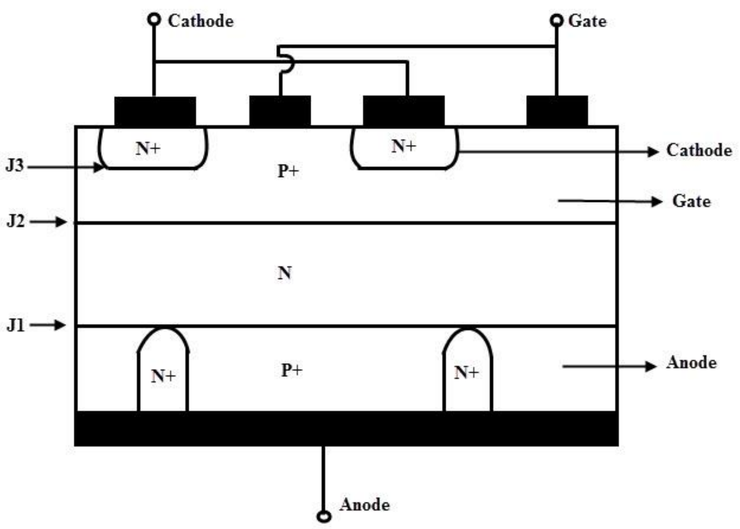
- Assignment 2:
- What is thyristor(SCR) commutation explain all(A,B,C,D & E)
- Why series and parallel connection of thyristor required, explain ii with neat figure.
- Each question hold 7 marks

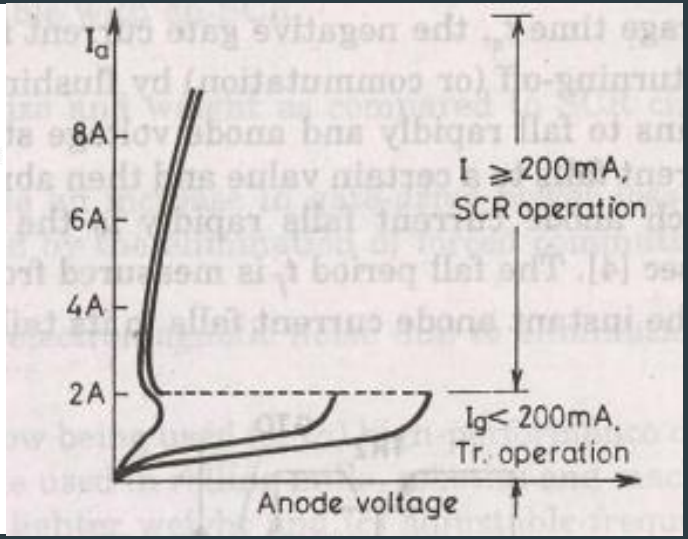
GTO(gate turn off):

- A GTO is a pn device that can be turn on by a positive gate current and turn off by negative gate current.



Gate Turn-Off Thyristor Symbols





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- At early age, due to some unavoidable circumstances GTO was not able to find its commercial use, but nowadays due to modern technology its performance has improved and being used in several commercial inverter.
- Since, there is no forced commutation circuitry is required for GTOs, inverter using such device are compact and cost less.

Structure difference between thyristor and GTO:

- Both thyristor and GTO are four layer device. However there are some difference between two devices.

Gate Turn Off Thyristor (GTO)	Silicon Controlled Rectifier (SCR)
GTO is a four-layer, three terminal pn pn device. The anode is made up of n+ fingers diffused into p+ layer.	SCR is also a four-layer, three terminal pn pn device. However, the anode is only made up of p+ layer. This is the basic structural difference between the two.
It is represented by the either circuit symbol (i) or (ii) shown below.	The circuit symbol of SCR is shown below.
Commutation circuit is not required and hence, it can be used beyond 1 kHz application.	Requirement of bulky and costlier commutation circuit limits its use up to about 1 kHz.
The V-I characteristics is similar to that of an SCR. But the value of latching current is much more (of the order of 2 A).	The value of latching current is comparatively less (of the order of 100-500 mA).
The reverse voltage blocking capability is less as compared to SCR. It is typically 20 to 30 V.	Reverse voltage blocking capability is comparatively more.
Turn off time comprises of storage time, fall time and tail time.	Turn of time can be divided into reverse recovery time and gate recovery time.
Due to multilayer structure, the value of gate triggering current is higher.	Gate triggering current is comparatively lower.
Due to elimination of commutation circuit, the commutation losses are eliminated and hence, the efficiency of GTO circuit is more.	Efficiency is comparatively low.

Apart from the above tabulated differences, the on stage voltage drop and associated losses are more in GTO. Its gate drive losses are also on higher side as compared to SCR. However, GTO has faster switching speed and more di/dt rating at turn on.

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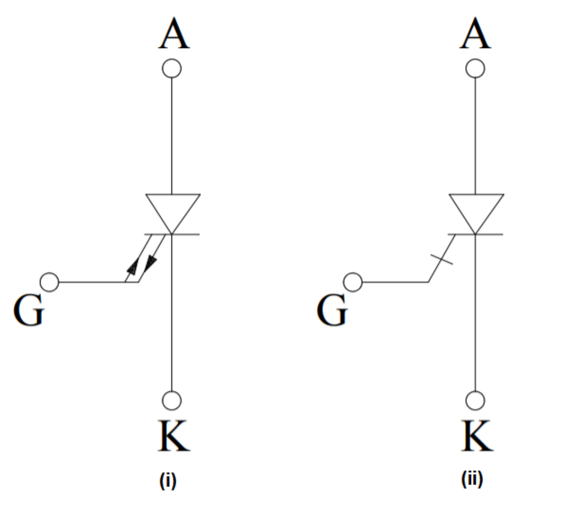
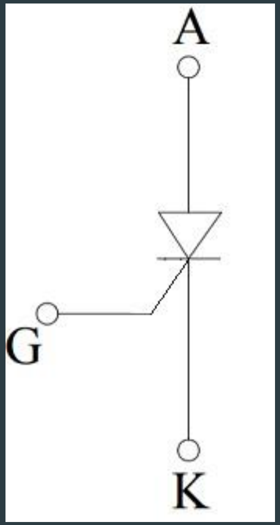
GTO



SCR



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Members of Thyristor family:

- There are two members of thyristor family which are given below.
  - a) TRIAC:
  - b) DIAC

POWER BJT

- Power transistors are devices that have controlled turn-on and turn-off characteristics.
- These devices are used a switching devices and are operated in the saturation region resulting in low on-state voltage drop.
- They are turned on when a current signal is given to base or control terminal.
- The transistor remains on as long as the control signal is present.
- The switching speed of modern transistors is much higher than that of Thyristors

- **APPLICATIONS:**

  - Used extensively in dc-dc and dc-ac converters.
  - voltage and current ratings are lower than those of thyristors and are therefore used in low to medium power applications.

Characteristics	Transistors	Thyristors
switching speed	faster	lower
switching loss	lower	higher
voltage & current ratings	lower	higher
on-state conduction loss	higher	lower
applications	low-to-medium power applications	high power applications

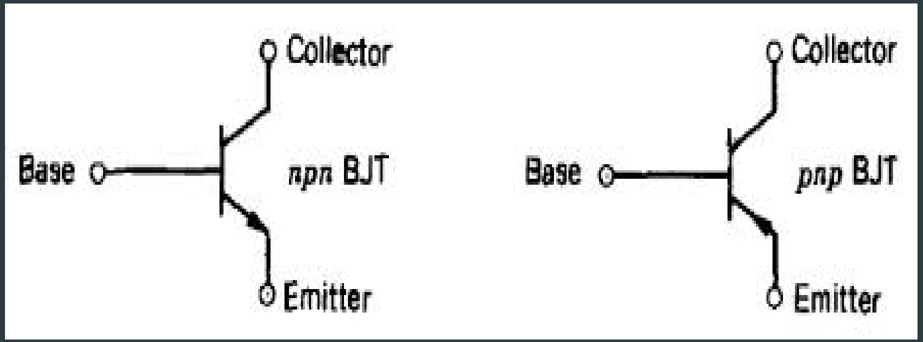
Power transistors are classified as follows:

- Bipolar junction transistors(BJTs)
- Metal-oxide semiconductor filed-effect transistors(MOSFETs)
- Static Induction transistors(SITs)
- Insulated-gate bipolar transistors(IGBTs)

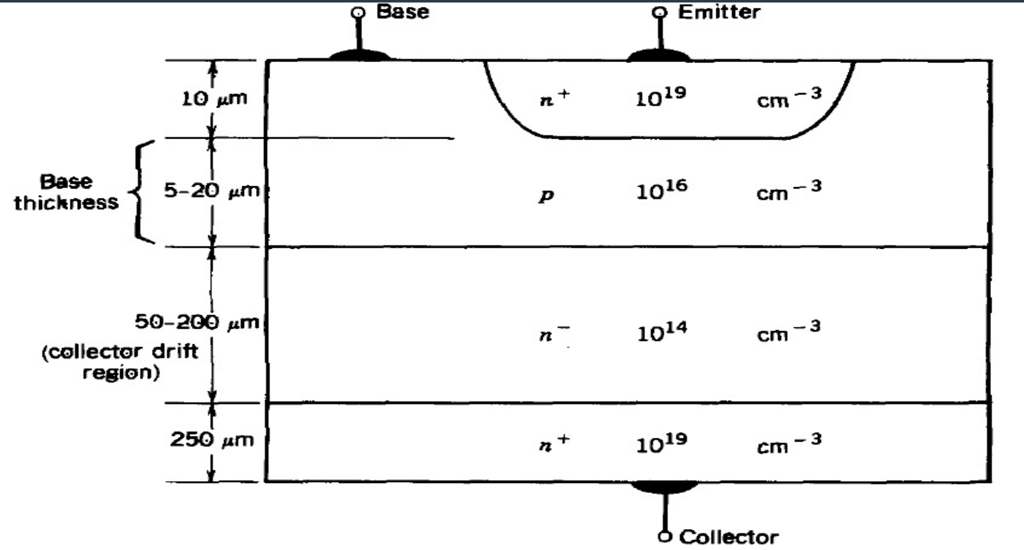
Continue…

- The BJT are of two types npn and pnp
- BJT has collector (C) , base (B) and emitter (E).
- In npn transistor, when the base-emitter junction is forward biased to saturation, the transistor turns ON and the current flows from collector to emitter.
- When the BJT turns ON, the collector emitter drop becomes negligible.
- When the base-drive is removed, BJT turns-off.
- Similar is the operation for pnp transistor.
- Thus, the drive has full control over the conduction of BJT.
- No commutating components are required by BJT for turn-off.

Symbol of power BJT



Structure of power BJT



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A power transistor is a vertically oriented four layer structure of alternating p-type and n- type.

The vertical structure is preferred because it maximizes the cross sectional area ,through which the current is flowing.

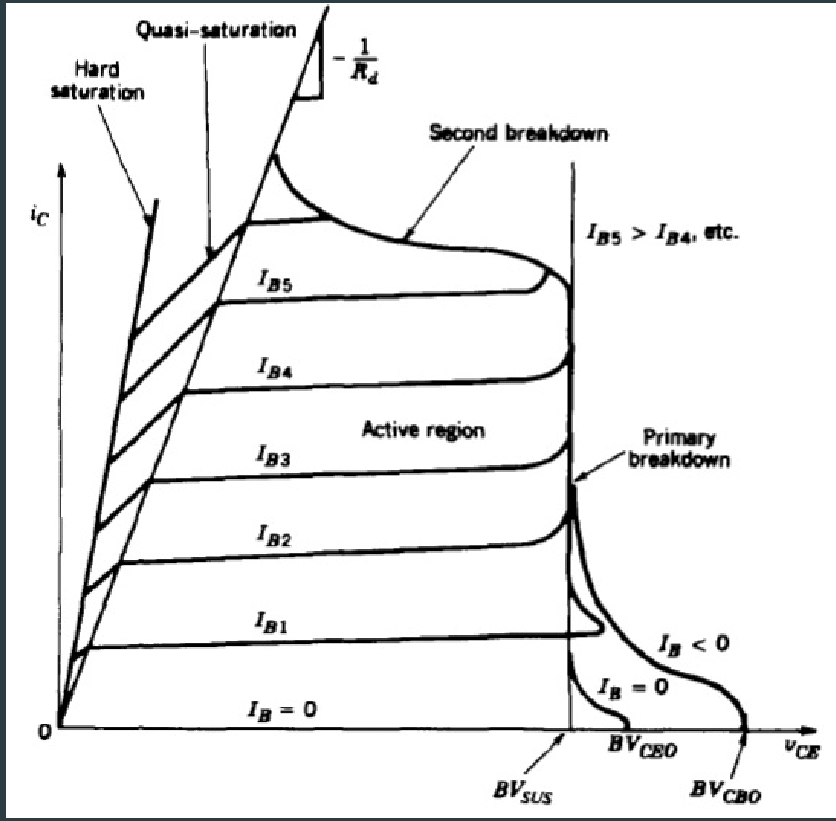
This also minimizes on-state resistance and thus power dissipation in the transistor.

The thickness of the drift region determines the breakdown voltage of the transistor.

The base thickness is made as small as possible in order to have good amplification capabilities.

The doping and thickness levels are shown in the figure.

Steady state characteristics of BJT



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There are four regions namely:

Cutoff region, Active region, quasi saturation and hard saturation.

In cutoff region , base current is almost zero. Hence no collector current flows and transistor is said to be in off state.

In the quasi saturation and hard saturation, the base drive is applied and transistor is said to be on. Hence collector current flows depending upon the load.

The power BJT is never operated in the active region (i.e. as an amplifier) it is always operated between cutoff and saturation.

The B VSUS is the maximum collector to emitter voltage that can be sustained when BJT is carrying substantial collector current.

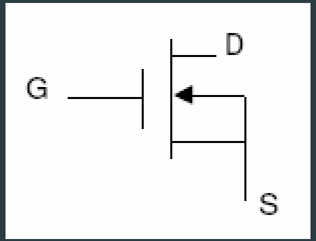
The BVCEO is the maximum collector to emitter breakdown voltage that can be sustained when base current is zero and BVCBO is the collector base breakdown voltage when the emitter is open circuited.

The primary breakdown is because of avalanche breakdown of collector base junction. Large power dissipation normally leads to primary breakdown.

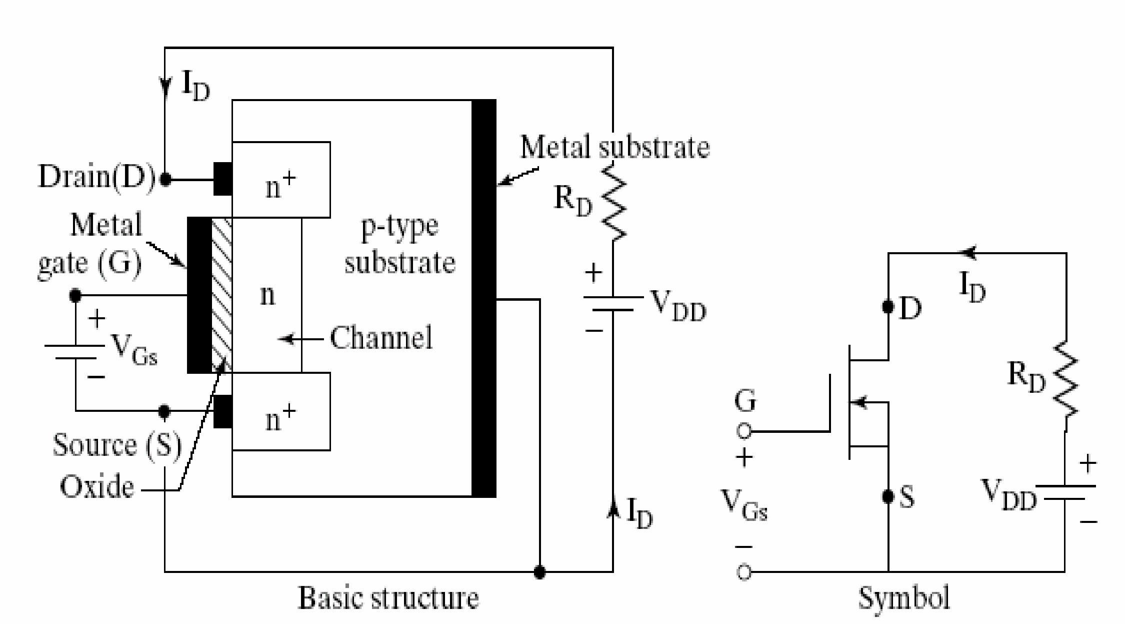
Power mosfet:

- **POWER MOSFET:**
- MOSFET stands for metal oxide semiconductor field effect transistor. There are two types of MOSFET
- • Depletion type MOSFET • Enhancement type MOSFET

- **Depletion Type MOSFET**



- It consists of a highly doped p-type substrate into which two blocks of heavily doped n-type material are diffused to form a source and drain.
- n-channel is formed by diffusing between source and drain.
- A thin layer of SiO_2 is grown over the entire surface and holes are cut in SiO_2 to make contact with n-type blocks.
- The gate is also connected to a metal contact surface but remains insulated from the n-channel by the SiO_2 layer.
- SiO_2 layer results in an extremely high input impedance of the order of 1010 to 1015 Ω for this area.



(a) n-Channel depletion-type MOSFET

- When VGS = 0V and VDS is applied and current flows from drain to source similar to JFET.

When $V_{GS} = -1V$, the negative potential will tend to pressure electrons towards the p-type substrate and attracts hole from p-type substrate.

Therefore recombination occurs and will reduce the number of free electrons in the n-channel for conduction.

Therefore with increased negative gate voltage I_D reduces.

For positive value of Vgs , additional electrons from p-substrate will flow into the channel and establish new carriers which will result in an increase in drain current with positive gate voltage.

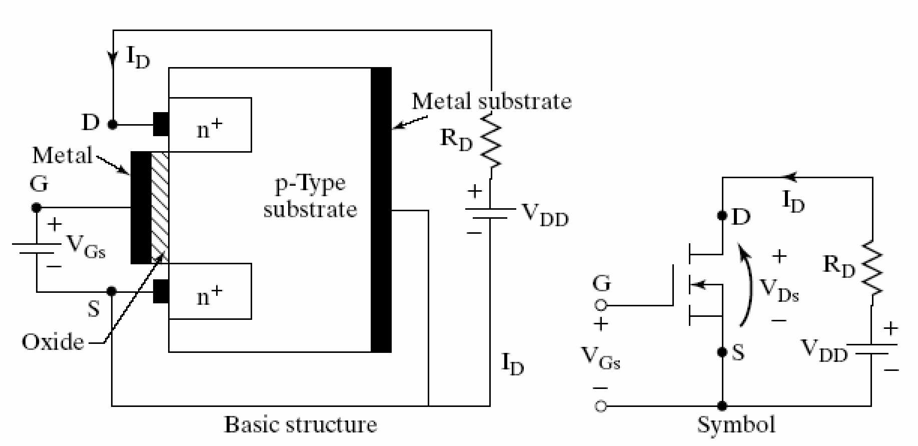
Enhancement Type MOSFET

The current control in an n-channel device is now affected by positive gate to source voltage rather than the negative voltages of JFET's.

A slab of p-type material is formed and two n-regions are formed in the substrate.

The source and drain terminals are connected through metallic contacts to n-doped regions, but the absence of a channel between the doped n-regions.

The SiO_2 layer is still present to isolate the gate metallic platform from the region between drain and source, but now it is separated by a section of p-type material.



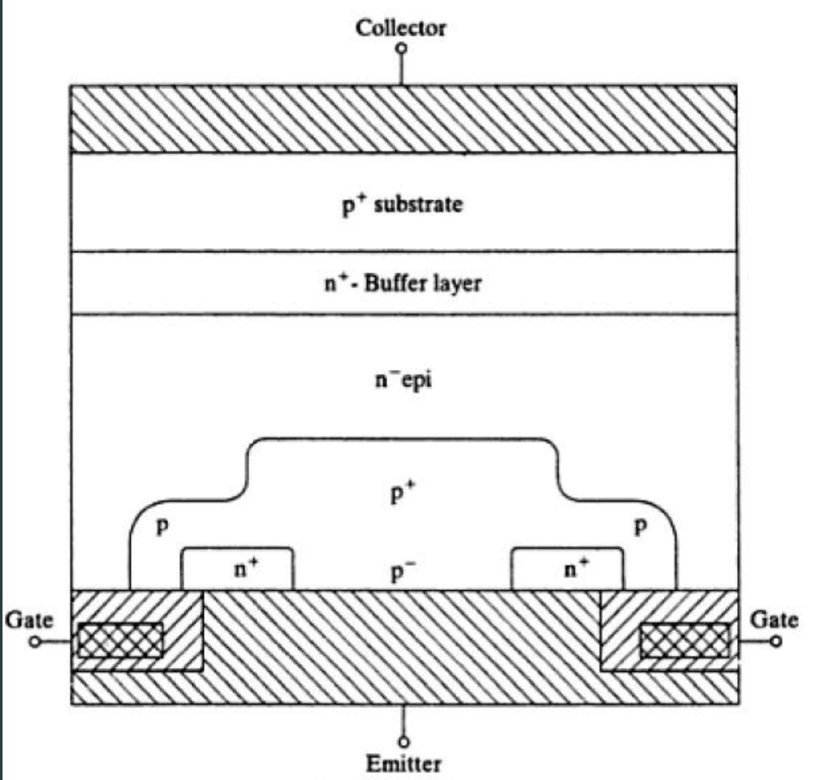
(a) n-Channel enhancement-type MOSFET

- If VGS = 0V , a voltage is applied between the drain and source, the absence of a n-channel will result in a current of effectively zero amperes.
- When VDS is set to some positive voltage and VGS set to 0V, there are two reverse biased p-n junction between the n-doped regions and p substrate to oppose any significant flow between drain and source.

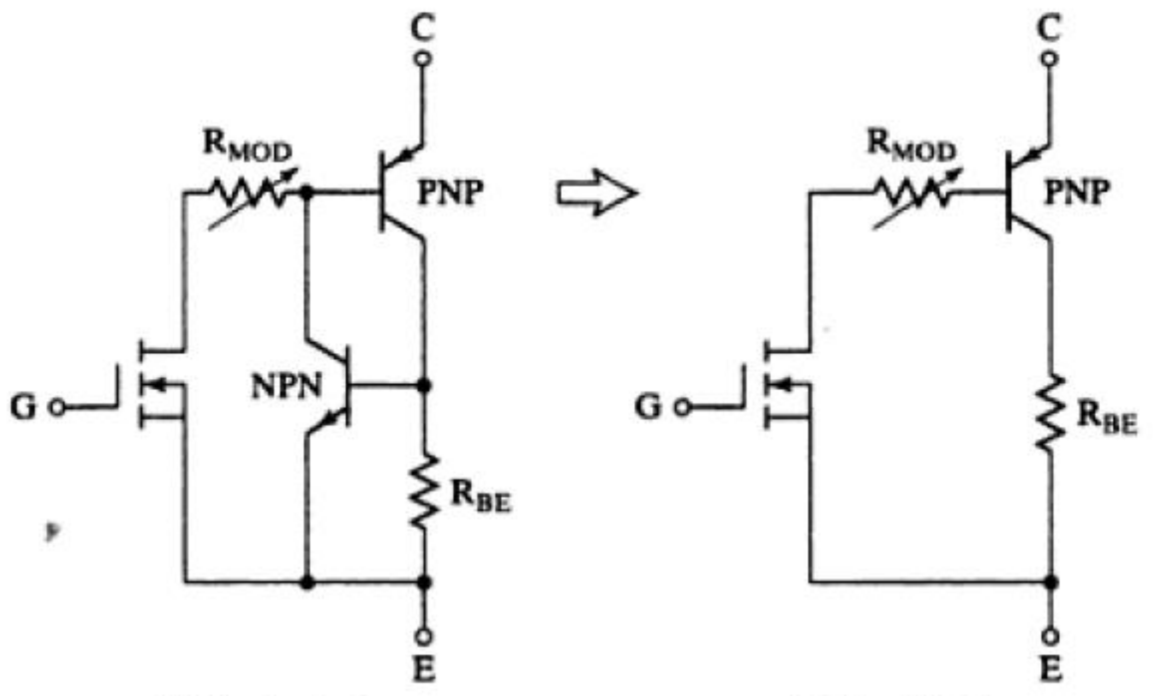
IGBT

- An IGBT combines the advantages of BJTs and MOSFETs.
- An IGBT has high input impedance (like MOSFETs), and low on-state conduction losses (like BJTs).
- There is no second breakdown problem as with BJTs.
- The silicon cross section of an IGBT is shown in Figure which is identical to that of an MOSFET except for the p^+ substrate.
- However, its performance is closer to that of a BJT than an MOSFET.
- This is due to the p^+ substrate, which is responsible for the minority injection into the n-region.

Structure:



(a) Cross section



(b) Equivalent circuit

(c) Simplified circuit

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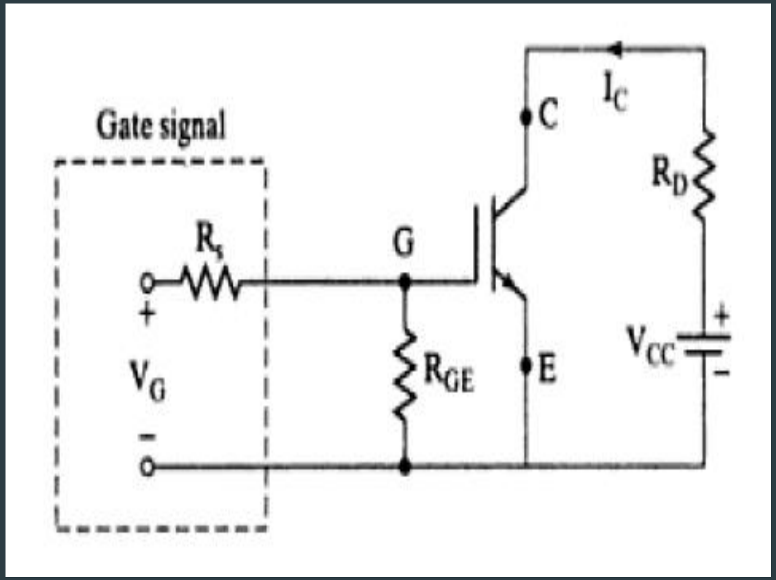
- The equivalent circuit is shown in Figure(b), which can be simplified to Figure(c).
- An IGBT is made of four alternate PNPN layers, and could latch like a thyristor given the necessary condition: $(\alpha_{npn} + \alpha_{pnp}) > 1$.
- The n^+ buffer layer and the wide epi base reduce the gain of the NPN terminal by internal design, thereby avoiding latching.
- IGBTs have two structures: punch-through (PT) and nonpunch-through (NPT).
- In the PT IGBT structure, the switching time is reduced by use of a heavily doped n buffer layer in the drift region near the collector.

Continue…

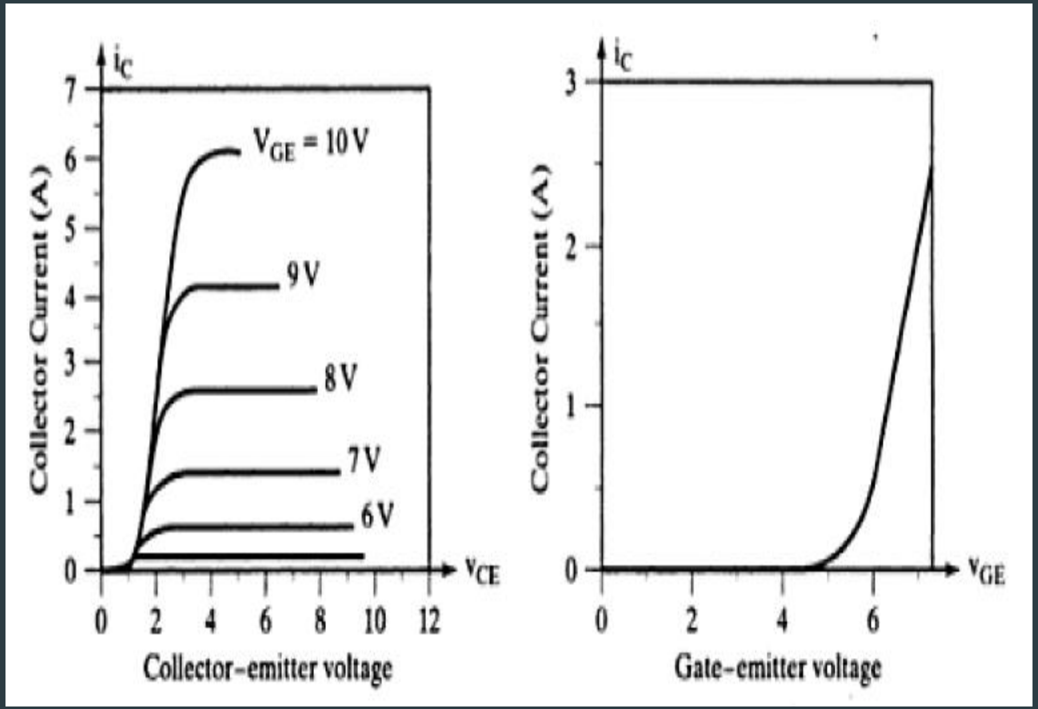
- In the NPT structure, carrier lifetime is kept more than that of a PT structure, which causes conductivity modulation of the drift region and reduces the on-state voltage drop.
- An IGBT is a voltage controlled device similar to a power MOSFET.
- Like a MOSFET, when the gate is made positive with respect to the emitter for turn-on, *n* carriers are drawn into the *p*-channel near the gate region; this results in a forward bias of the base of the NPN transistor, which thereby turns on.

Continue…

- The symbol and circuit of an IGBT switch are shown in Figure.
- The three terminals are gate, collector and emitter.
- The typical output characteristics of i_C versus v_{CE} are shown in Figure(a) for various gate-emitter voltage, v_{GE}.
- The typical transfer characteristics of i_C versus v_{GE} is shown in Figure(b).
- The parameters and their symbols are similar to that of MOSFETs.



Symbol and circuit for an IGBT



Typical output and transfer characteristics of IGBTs

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- The current rating of a single IGBT can be up to 6500 V, 2400 A and the switching frequency can be up to 20 kHz.
- IGBT are finding increasing applications in medium-power applications such as dc and ac motor drives, power supplies, solid-state relays and contractors.
- As the upper limits of commercially available IGBT ratings are increasing, IGBTs are finding and replacing applications where BJTs and conventional MOSFETs were predominantly used as switches.

Comparison between IGBT and MOSFET

S.No	MOSFET	IGBT
1.	THREE TERMINALS ARE GATE,SOURCE AND DRAIN	THREE TERMINALS ARE GATE,EMITTER AND COLLECTOR
2.	HIGH INPUT IMPEDANCE	HIGH INPUT IMPEDANCE
3.	VOLTAGE CONTROLLED DEVICE	VOLTAGE CONTROLLED DEVICE
4.	RATINGS AVAILABLE UPTO 500V,140A	RATINGS AVAILABLE UPTO 1200V,500A
5.	OPERATING FREQUENCY IS UPTO I MHz	OPERATING FREQUENCY IS UPTO 50KHz
6.	WITH RISE IN TEMPERATURE,THE INCREASE IN ON-STATE RESISTANCE IN MOSFET IS MORE PRONOUNCED THAN IGBT.SO, ON-STATE VOLTAGE DROP AND LOSSES RISE RAPIDLY IN MOSFET THAN IN IGBT ITH RISE IN TEMPERATURE.	
7.	WITH RISE IN VOLTAGE,THE INCREMENT IN ON-STATE VOLTAGE DROP IS MORE DOMINANT IN MOSFET THAN IT IS IN IGBT.THIS MEANS IGBTs CAN BE DESIGNED FOR HIGHER VOLTAGE RATINGS THAN MOSFETs.	

Thank You