POWER ELECTRONICS

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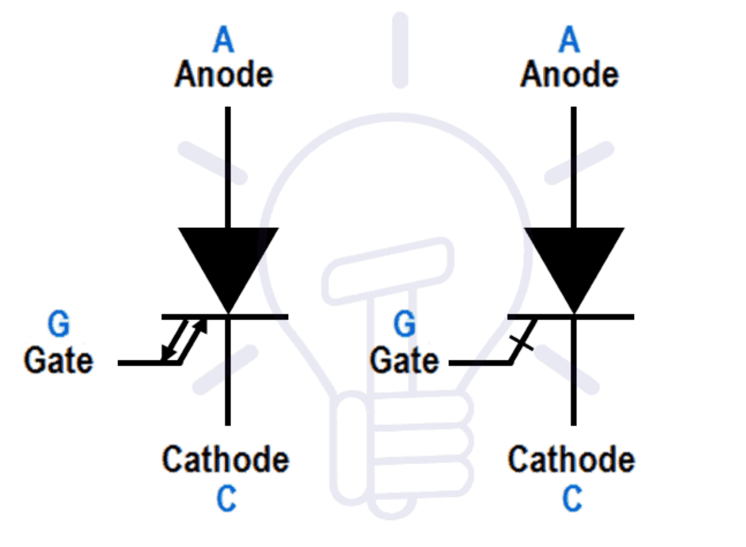
GTO

- Thyristor is a unidirectional semiconductor switch that conducts high current in on-state and blocks high voltages in off-state. It has three terminals Gate (G), Cathode (K) and Anode (A). The cathode and anode terminals are used to conduct the main current while the gate terminal switches the state of the thyristor. It is a semi-controlled switch that can be switched on by applying a positive gate current but it lacks the ability to be turned off using the same gate. The main current must be interrupted to turn off the thyristor using a commutation circuit. To overcome this problem GTO is designed.
- GTO or Gate Turn-Off thyristor is a type of thyristor that offers full control over switching i.e. it can be turned ON as well as turned OFF by using the same gate terminal. GTO has many similarities with a normal thyristor.



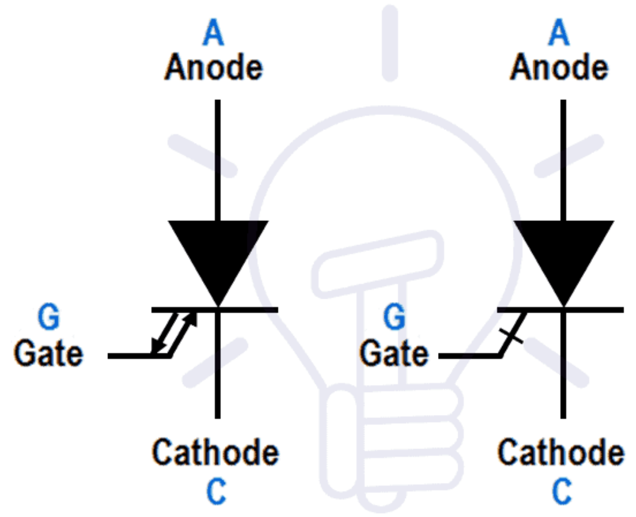
Gate Turn-Off (GTO) Thyristor Symbol

GTO

GTO (aka Gate Turn Off) is a semiconductor based fully controlled unidirectional switching device (thyristor) that has 3 terminals **Gate**, **Cathode**, and **Anode**. It can be switched ON/OFF using the gate terminal.

A positive current pulse at the gate switches ON the GTO while a negative current pulse at the gate switches it OFF. It is unidirectional, therefore, it only allows current from anode to cathode.

Just like a normal thyristor, it can be switched into conduction mode using a positive current pulse at the gate. It has a low on-state voltage drop. However, the turn-off current required at the gate is relatively high. The negative current pulse at the gate is almost one-fourth of the anode current.



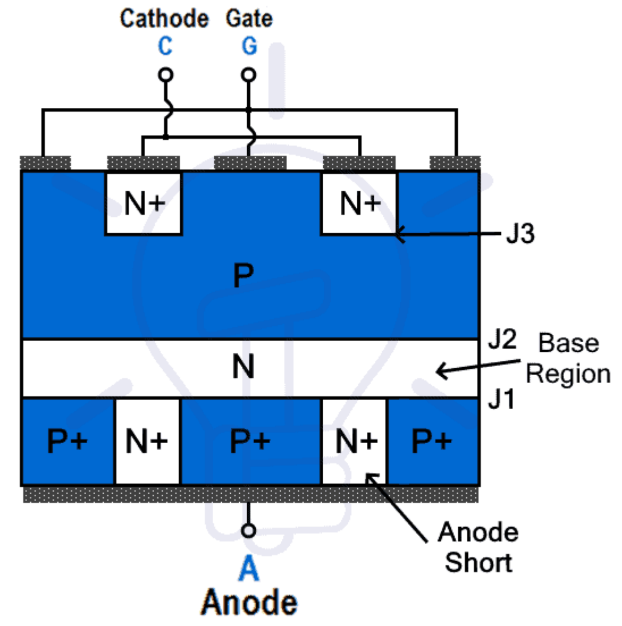
Gate Turn-Off (GTO) Thyristor Symbol

GTO

Structure of GTO

GTO is 4 layer PNPN device having 3 PN junctions and 3 terminals Gate (G), Anode (A), and Cathode (C).

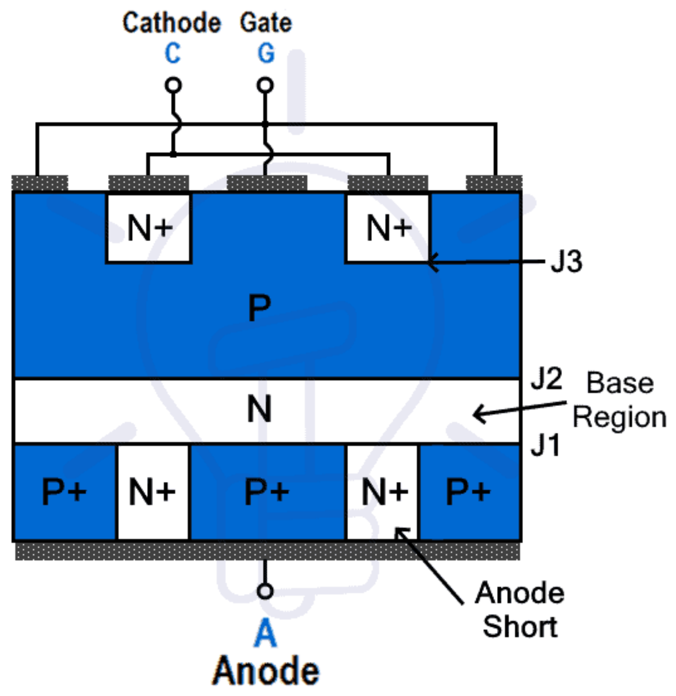
The anode is a metallic electrode attached to the P+ heavily doped region. The doping is kept high to maintain high anode efficiency. Heavy doping decreases the turn-on time but also increases the turn-off time with power loss. To avoid this problem, N+ regions are added into the anode region known as anode shorted structure. It reduces the reverse voltage blocking with better turn-off timing. Therefore, the anode short is designed based on the required performance.



Structre of GTO

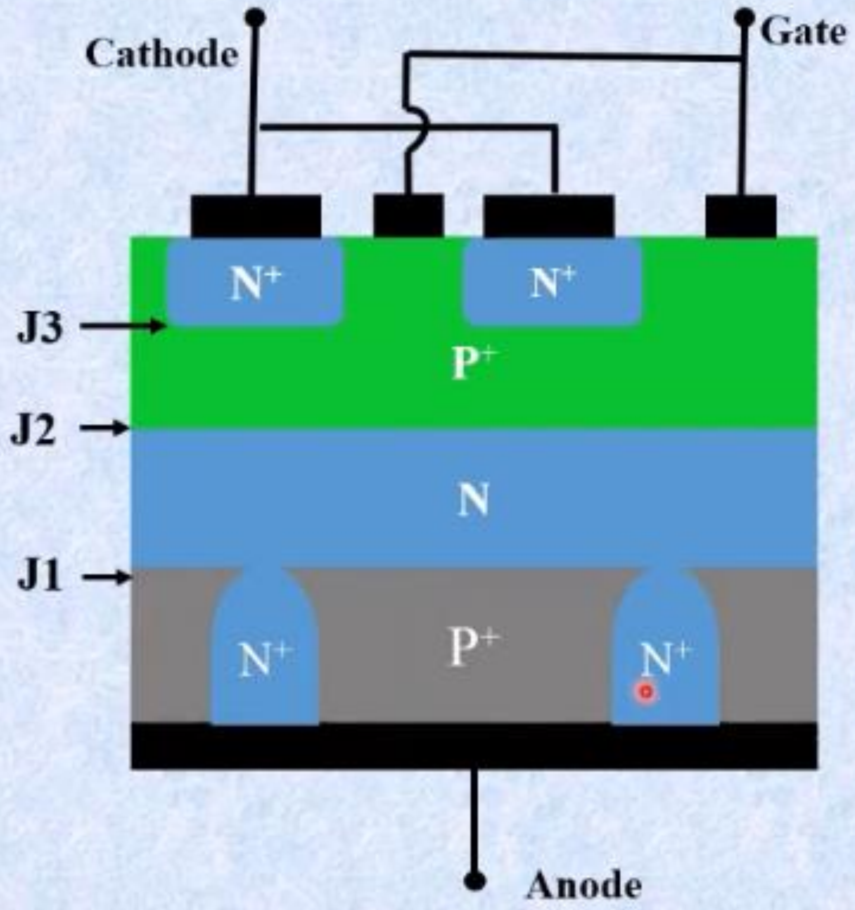
GTO

On top of the anode region, an N-type base region is added forming PN junction J1 where doping and width of this region determines the forward blocking voltage capacity of the device. Low doping level and increased width of this layer increases the forward blocking voltage of the GTO.
The P-type gate region is added on top of the base N layer forming the 2nd junction j2. This region is neither heavily nor lightly doped due to the given reasons. Heavy doping of the gate region causes to have better turn-off time and lightly doping increases the emitter efficiency from the cathode region. This is why the gate P region is moderately doped.
The cathode is attached to a heavily doped N+ layer. It is heavily doped to have higher emitter efficiency but at the cost of reduced breakdown voltage.



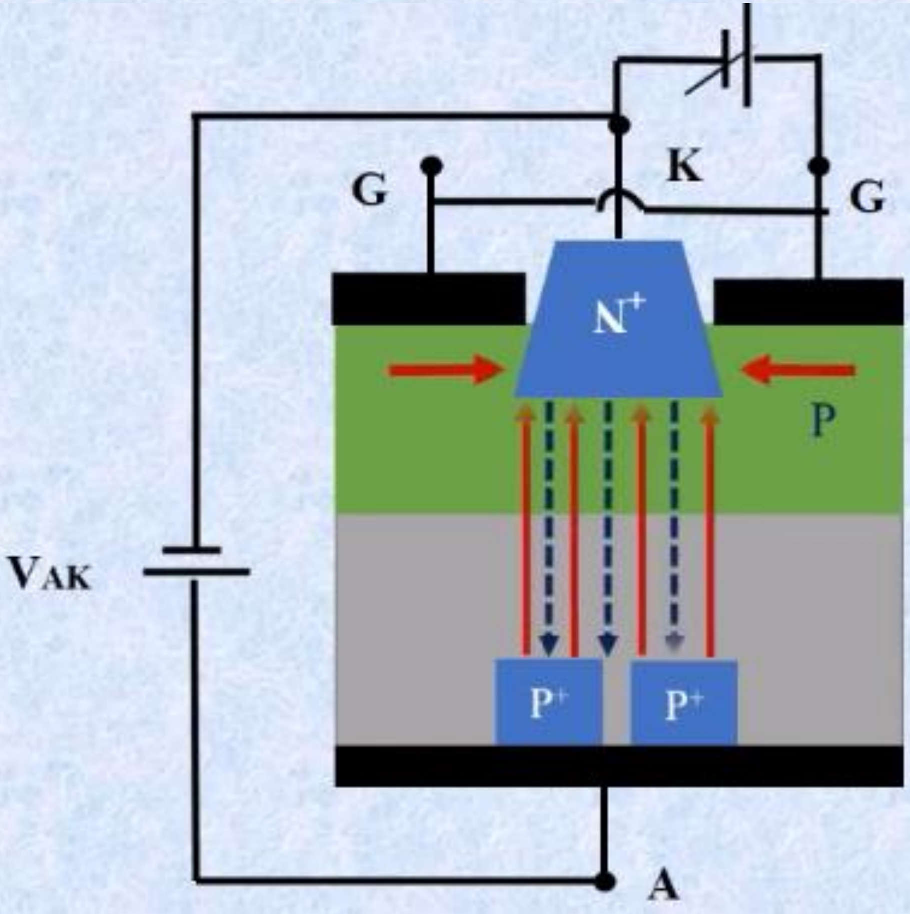
Structre of GTO

CONSTRUCTION OF GTO



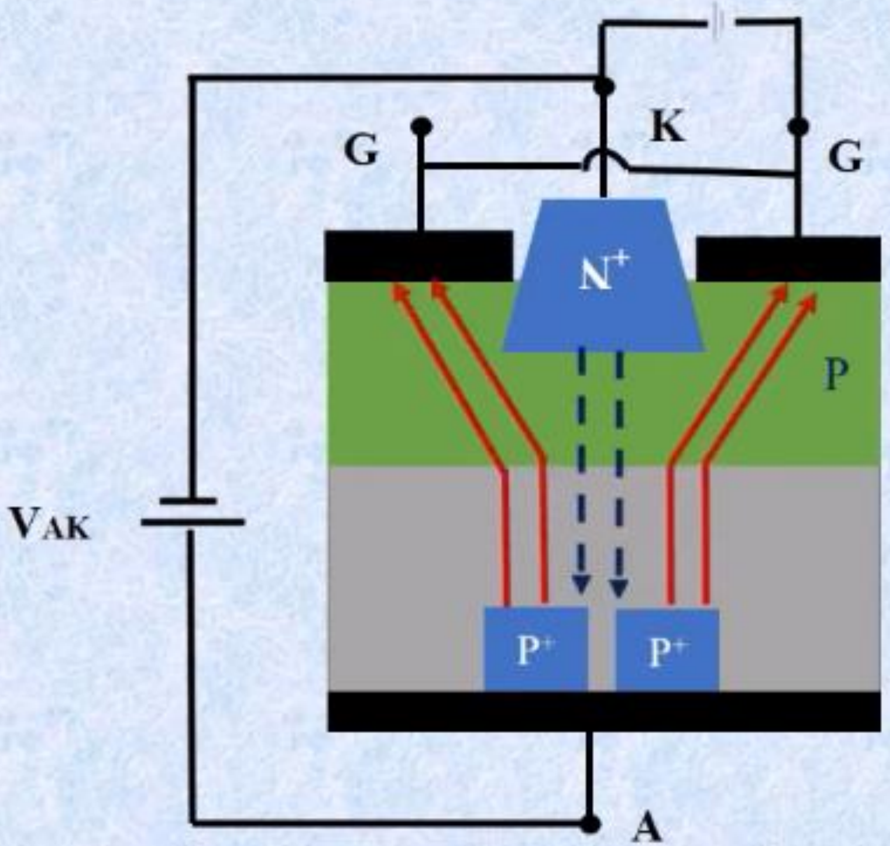
- ✓ It is also a four layer, three junction P-N-P-N device like a standard thyristor
- ✓ In this, the **n+ layer at the cathode end is highly doped to obtain high emitter efficiency.** This result in the low breakdown voltage of the junction J3 which is typically in the range of 20 to 40 volts.
- ✓ For having a good turn OFF properties, doping of the P type gate region should be high
- ✓ A heavily doped P+ anode region is required to obtain the higher efficiency anode junction so that a good turn ON properties is achieved. However, the turn OFF capabilities are affected with such GTOs.
- ✓ This problem can be solved by introducing heavily doped N+ layers at regular intervals in P+ anode layer as shown in figure. So this N+ layer makes a direct contact with N at junction J1.

OPERATION OF GTO



- ✓ When the anode terminal is made positive with respect to cathode by applying a positive gate current, the hole current injection from gate forward bias the cathode p-base junction (J3).
- ✓ This results in the **emission of electrons from the cathode** towards the anode terminal
- ✓ This in turn induces the **hole injection from the anode terminal** into the base region. This injection of holes and electrons continues till the GTO comes into the conduction state.
- ✓ Unlike a thyristor, GTO consists of narrow cathode elements which are heavily interdigitated with gate terminal, thereby initia turn ON area is very large and plasma spreading is small. Hence the GTO comes into the conduction state very quickly.

OPERATION OF GTO



- ✓ To turn OFF a conducting GTO, a reverse bias is applied at the gate by making the gate negative with respect to cathode.
- ✓ A part of the holes from the P base layer is extracted through the gate which suppress the injection of electrons from the cathode.
- ✓ In response to this, more hole current is extracted through the gate results in suppression of electrons from the cathode.
- ✓ Eventually, the voltage drop across the p base junction causes to reverse bias the gate cathode junction and hence the GTO is turned OFF

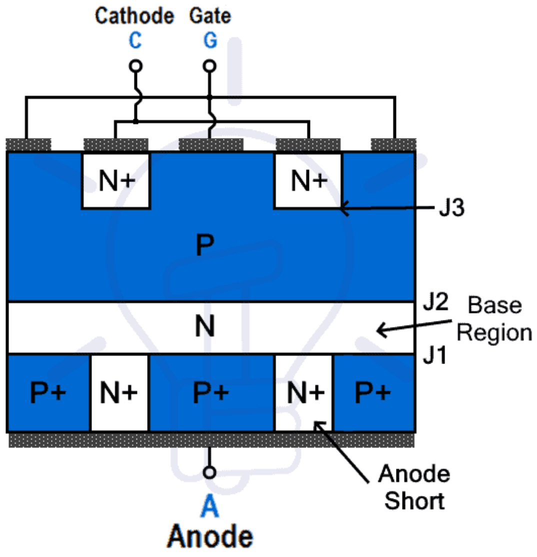
OPERATION OF GTO

Turn-on Mechanism

GTO has the same turn-off operation as a conventional thyristor. It can be turned-on using two methods i.e. increasing forward voltage above break over voltage, applying positive gate current.

When forward voltage is applied to GTO i.e. anode voltage is positive than the cathode, the junction j1 and j3 becomes forward biased while the junction j2 becomes reverse biased. The reversed biased j2 does not allow the current to flow through the device. If the forward is increased above the **forward break over voltage**, an avalanche will occur and the J2 will become forward biased allowing the current flow. this type of switching is destructive and should be avoided.

The proper method of turning a GTO is by applying a positive gate current when forward voltage is applied. Application of positive current at the gate injects holes into the P gate region which makes j3 forward bias. Thus allowing the current flow through it.



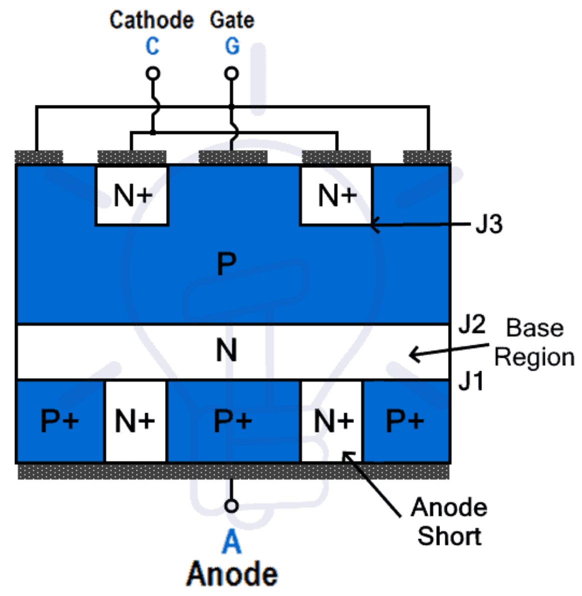
Structre of GTO

OPERATION OF GTO

Turn-off Mechanism

To turn off the GTO, the gate terminal is applied with negative current or negative voltage with respect to the cathode. The holes entering through the anode are extracted through the gate terminal. It makes the junction j3 reverse biased that stops the electron injection from the cathode region.

At this time, there is no cathode current but the anode current is still flowing through the gate terminal which is called "tail current". it reduces exponentially. and once it goes to zero, the device completely turn-off and blocks the voltage at its terminals. The turn-off current required for GTO is dependent on the anode voltage and current but it is usually one-fourth of the anode current.



Structre of GTO

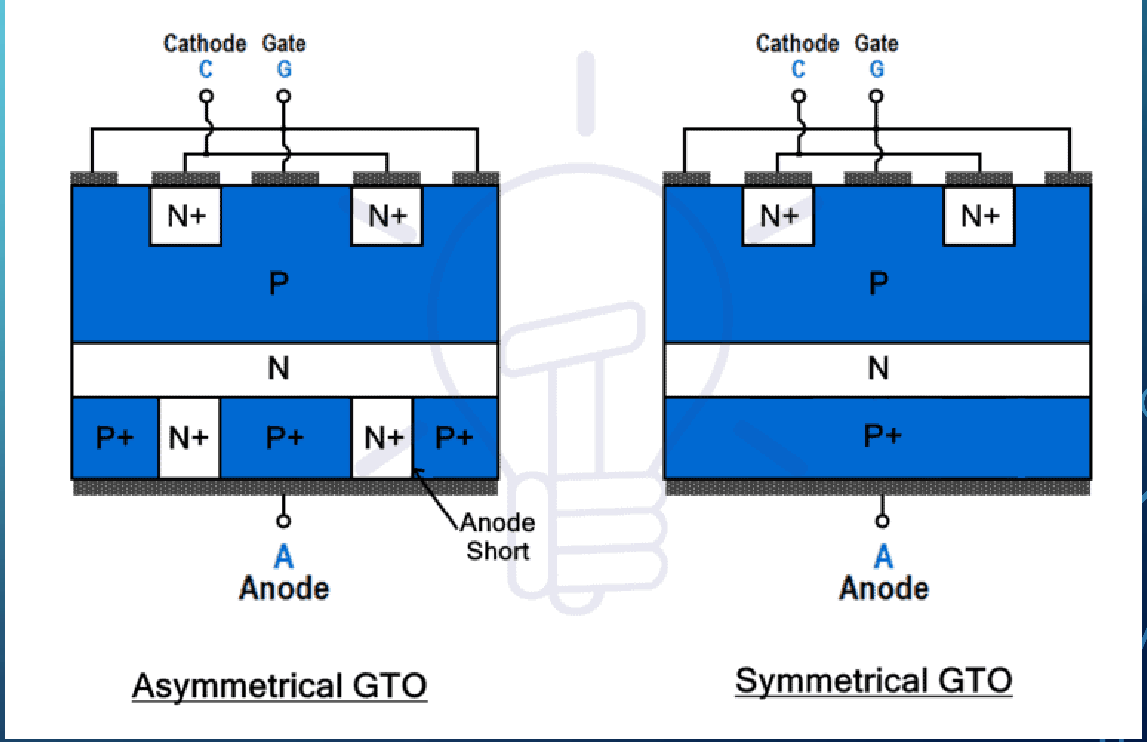
TYPES OF GTO

Asymmetric GTO

Asymmetric GTOs are the most common type of GTOs also known as “shorted anode GTO”. They have asymmetric voltage blocking capabilities i.e. forward blocking voltage is not equal to reverse blocking voltage. The reverse blocking voltage is very less than forward blocking voltage. They are usually used with a diode in anti-parallel

Symmetric GTO

The symmetric GTO has symmetric voltage blocking capabilities. The reverse blocking voltage is as high as forward voltage. It does not have a “shorted-anode” structure instead anode is made of pure P+ region.



MODES OF OPERATION OF GTO

Forward Blocking Mode

When the applied anode-to-cathode voltage is positive but there is no gate current. The device does not conduct and blocks the forward current unless the anode voltage increase over the break over voltage or the gate current is applied. This mode is called forward blocking mode.

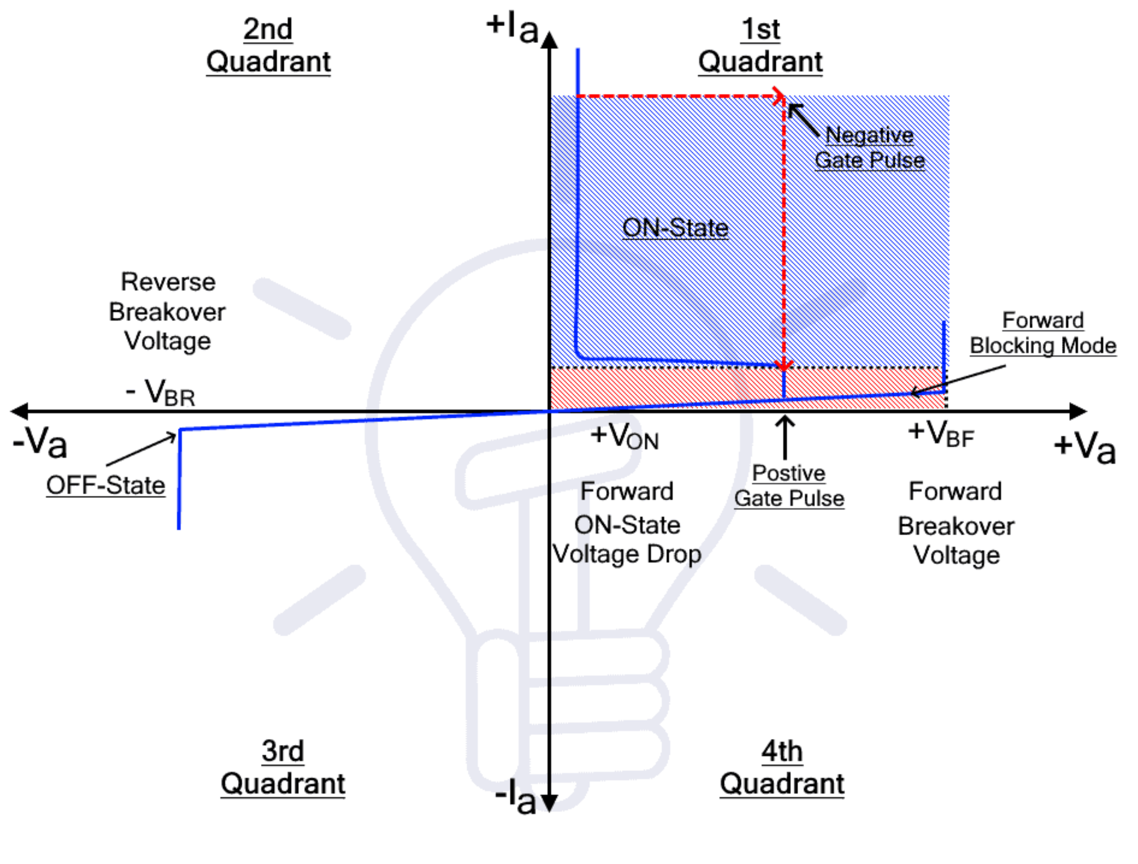
Forward Conduction Mode

In this mode, the GTO in is conduction-state and since its unidirectional. It conducts current from anode to cathode. The GTO just like thyristor can be triggered into conduction by either applying gate current which is the proper way or increasing the anode voltage above the break over voltage.

Reverse Blocking Mode

When the anode voltage is made negative with respect to the cathode, it blocks the current flow. it is a unidirectional device, it does not allow current is reverse direction. But if the reverse voltage exceeds the reverse break over voltage, it will start conduction

V-I CHARACTERISTICS OF GTO



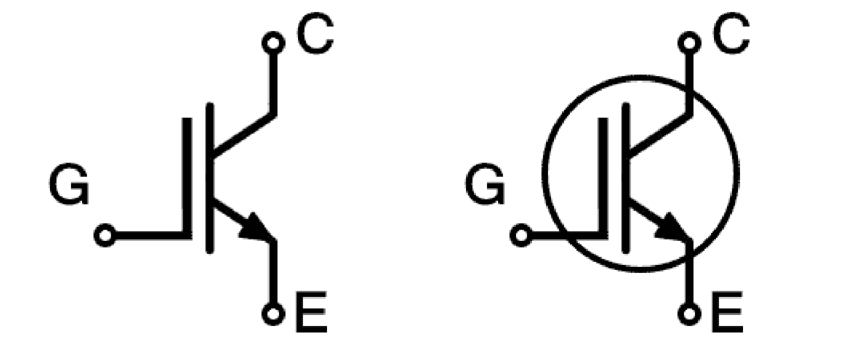
V-I Characteristics of GTO

IGBTs do not require a continuous gate signal to remain in the on-state.

IGBT

Thyristors are the most used components in modern electronics and logic circuits are used for switching and amplification. BJT and MOSFET are the most used types of the transistor where each of them has its own advantage over the other and some limitations. The IGBT (Insulated Gate Bipolar Transistor) takes the best parts of both BJT and MOSFET into a single transistor. It takes the input characteristics (high input impedance) of MOSFET (Insulated Gate) and the output characteristics of BJT (Bipolar nature).

The **IGBT or Insulated Gate Bipolar Transistor** is the combination of BJT and MOSFET. Its name also implies the fusion between them. "Insulated Gate" refers to the input part of MOSFET having very high input impedance. It does not draw any input current rather it operates on the voltage at its gate terminal. "Bipolar" refers to the output part of the BJT having bipolar nature where the current flow is due to both types of charge carriers. It allows it to handle very large currents and voltages using small voltage signals. This hybrid combination makes the IGBT a voltage-controlled device.



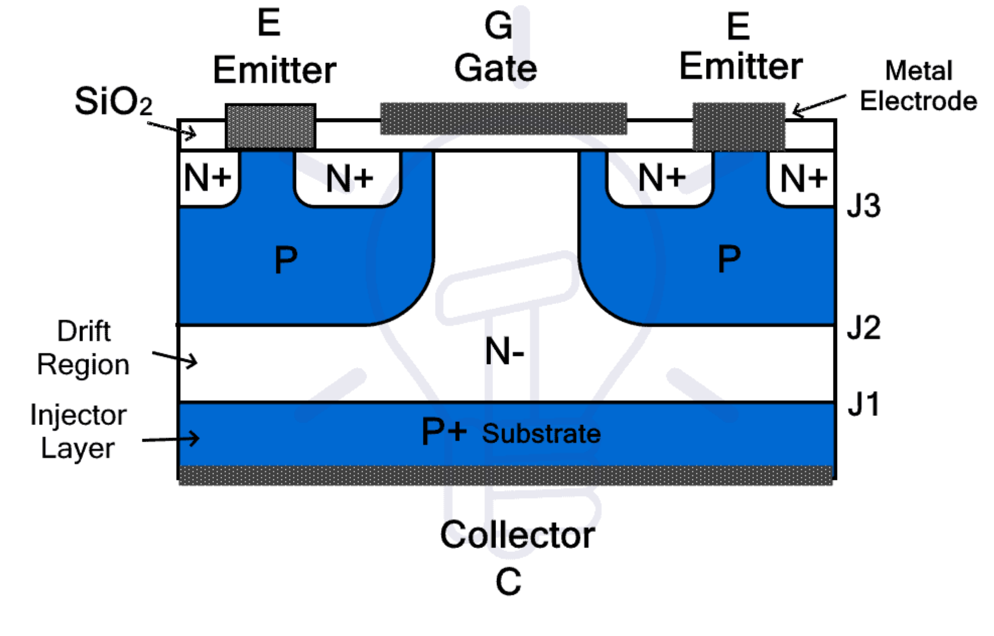
IGBT - Insulated-Gate Bipolar Transistor Symbol

IGBT

It is a four-layer PNPN device having three PN junctions. It has three terminals Gate (G), Collector(C) and Emitter (E). The terminal's name also implies being taken from both transistors. Gate terminal as it is the input part, taken from MOSFET while the collector and emitter as they are the output, taken from the BJT

Construction of IGBT

IGBT is made of four layers of semiconductor to form a PNPN structure. The collector (C) electrode is attached to P layer while the emitter (E) is attached between the P and N layers. A P+ substrate is used for the construction of IGBT. An N- layer is placed on top of it to form PN junction J1. Two P regions are fabricated on top of N- layer to form PN junction J2. The P region is designed in such a way to leave a path in the middle for the gate (G) electrode. N+ regions are diffused over the P region as shown in the figure.



Structure of IGBT

The emitter and gate are metal electrodes. The emitter is directly attached to the N+ region while the gate is insulated using a silicon dioxide layer. The base P+ layer inject holes into N- layer that is why it is called injector layer. While the N- layer is called the drift region. Its thickness is proportional to voltage blocking capacity. The P layer above is known as the body of IGBT.

The N- layer is designed to have a path for current flow between the emitter and collector through the junction using the channel that is created under the influence of the voltage at the gate electrode.

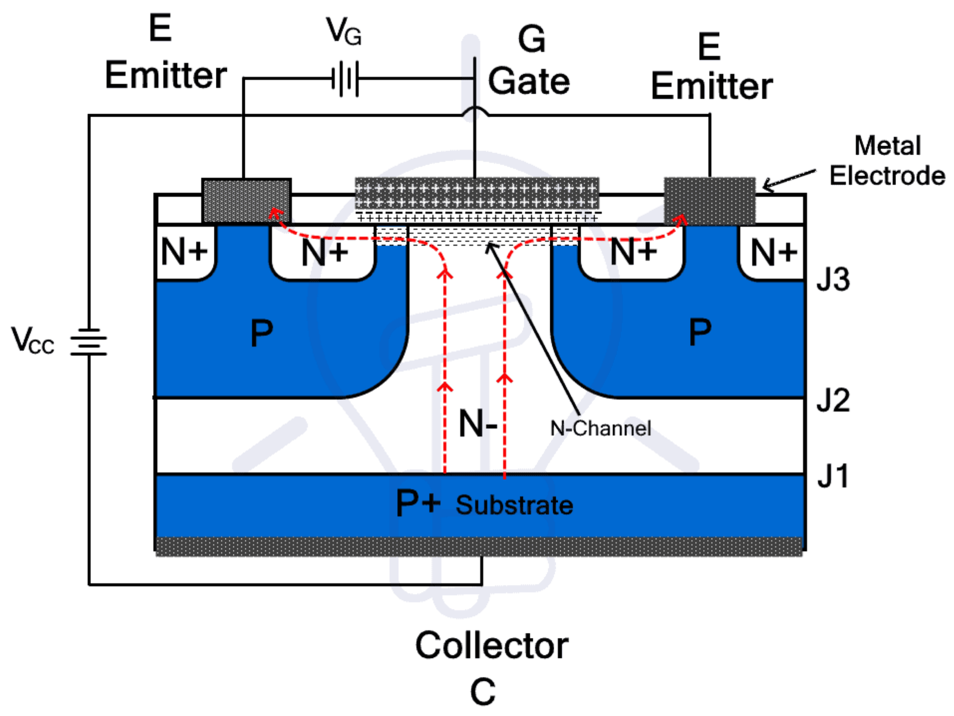
IGBT

Working of IGBT

The two terminals of IGBT collector (C) and emitter (E) are used for the conduction of current while the gate (G) is used for controlling the IGBT. Its working is based on the biasing between Gate-Emitter terminals and Collector-Emitter terminals.

The collector-emitter is connected to Vcc such that the collector is kept at a positive voltage than the emitter. The junction j1 becomes forward biased and j2 becomes reverse biased. At this point, there is no voltage at the gate. Due to reverse j2, the IGBT remains switched off and no current will flow between collector and emitter.

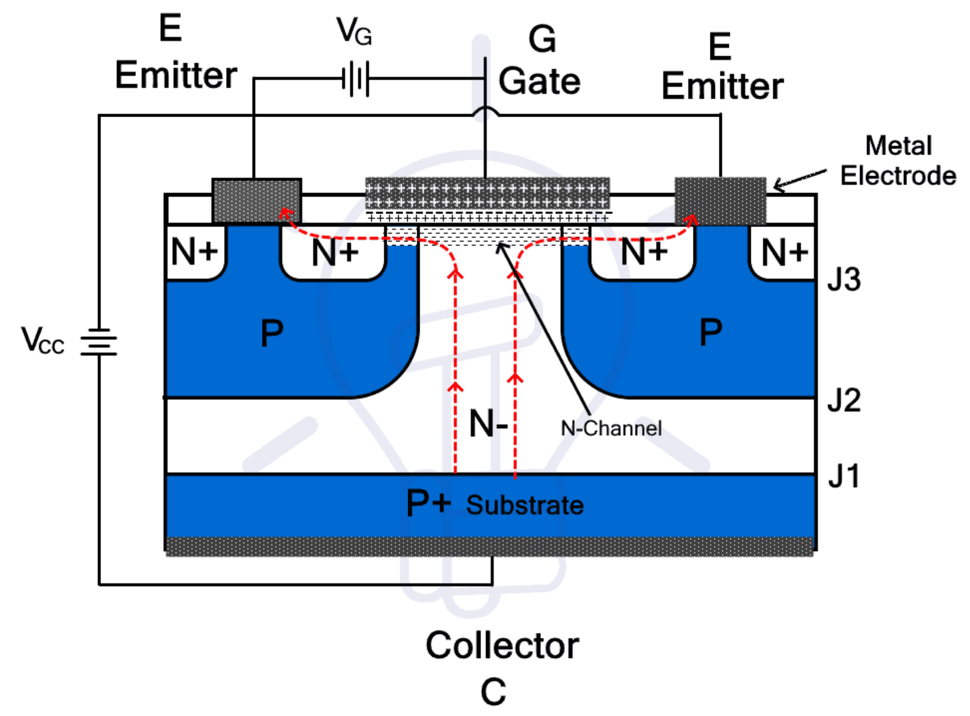
Applying a gate voltage V_G positive than the emitter, negative charges will accumulate right beneath the SiO_2 layer due to capacitance. Increasing the V_G increases the number of charges which eventually form a layer when the V_G exceeds the threshold voltage, in the upper P-region. This layer form N-channel that shorts N- drift region and N+ region.



Working of IGBT

IGBT

The electrons from the emitter flow from N+ region into N- drift region. While the holes from the collector are injected from the P+ region into the N- drift region. Due to the excess of both electrons and holes in the drift region, its conductivity increase and starts the conduction of current. Hence the IGBT switches ON.



Working of IGBT

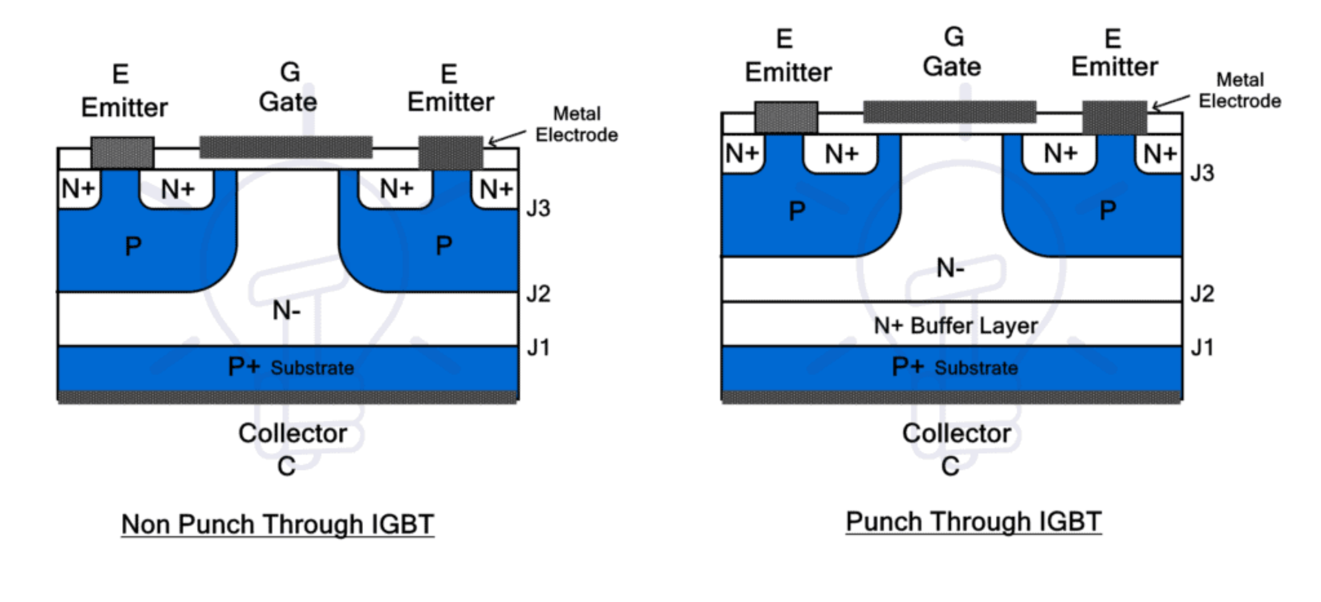
TYPES OF IGBT

Punch through IGBT

The Punch through IGBT includes N+ buffer layer due to which it is also known as an asymmetrical IGBT. They have asymmetric voltage blocking capabilities i.e. their forward and reverse breakdown voltages are different. Their reverse breakdown voltage is less than its forward breakdown voltage. It has faster switching speed. Punch through IGBTs is unidirectional and cannot handle reverse voltages. Therefore, they are used in DC circuits such as inverters and chopper circuits.

Non Punch through IGBT

They are also known as symmetrical IGBT due to the absence of extra N+ buffer layer. The symmetry in structure provides symmetrical breakdown voltage characteristics i.e. the forward and reverse breakdown voltages are equal. Due to this reason, they are used in AC circuits.



IGBT

Characteristic	Power BJT	Power MOSFET	IGBT
Voltage Rating	High < 1kV	High < 1kV	Very High > 1kV
Current Rating	High < 500 A	Low < 200 A	Very High > 500 A
Input Parameter	Base Current, I_b	Voltage, V_{GS}	Voltage, V_{GE}
Input Drive	Current gain (hfe) 20-200	Voltage, V_{GS} 3-10V	Voltage, V_{GE} 4-8V
Input Drive Power	High	Low	Low
Input Drive Circuitry	Complex	Simple	Simples
Input Impedance	Low	High	High
Output Impedance	Low	Medium	Low
Switching Loss	High	Low	Medium
Switching Speed	Low	Fast	Medium
Cost	Low	Medium	High

IGBT

IGBT

Thank You!