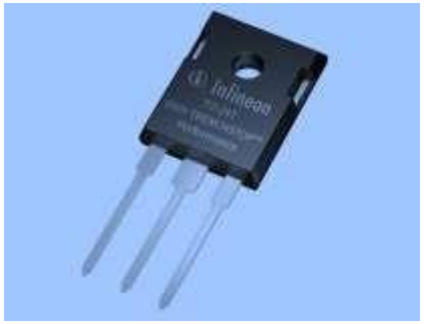
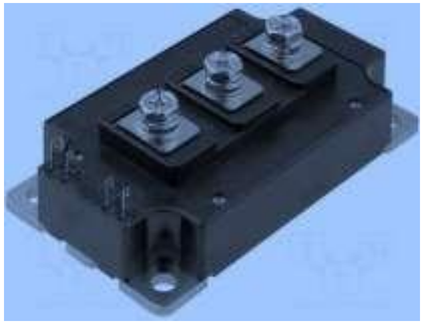
IGBT

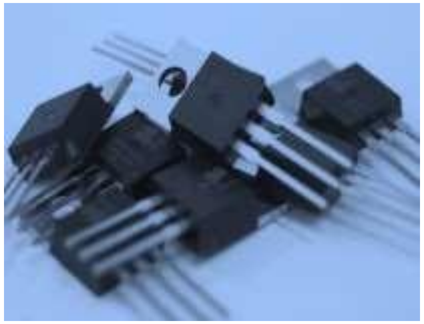
(Insulated Gate Bipolar Transistor)

"Less Losses"

"High Efficiency"







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- Basic structure,
- I-V Characteristics,
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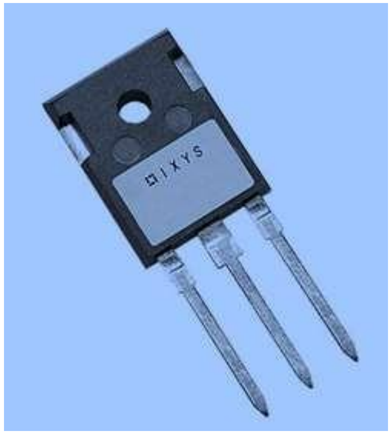
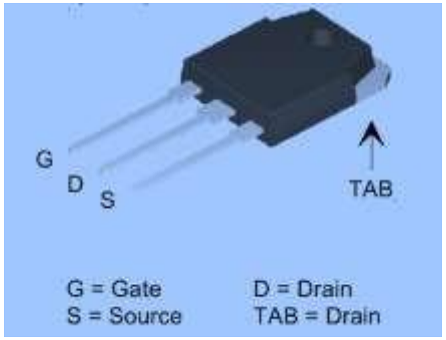
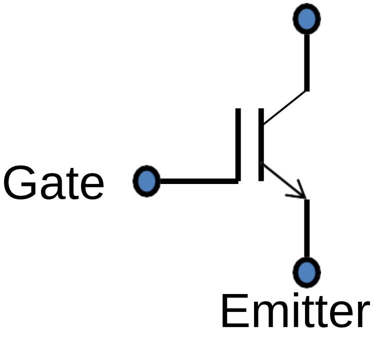
- Device limitations and
- Safe operating area (SOA).





- Combination of BJT & PMOSFET
- High Input Impedance like a PMOSFET.
- Low on state power loss like a BJT.
- In IGBT second breakdown problem is not present.
- Voltage controlled device.
- Three terminal device.



Symbol of IGBT

SOME OTHERS NAME OF IGBT:

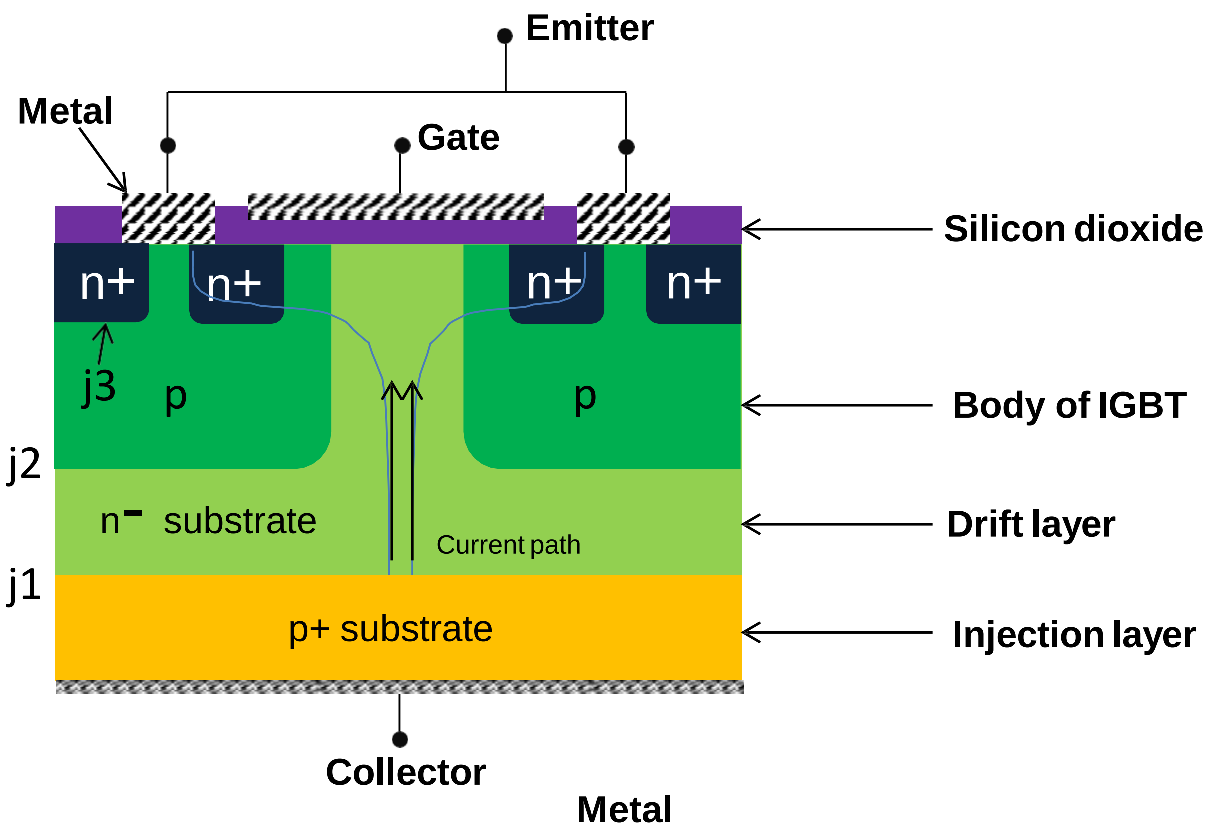
- MOSIGT - metal oxide gate bipolar junction transistor
- COMFET - conductively modulated field effect transistor
- GEMFET – gate modulated field effect transistor

- The IGT device has undergone many improvement cycles to result in the modern Insulated Gate Bipolar Transistor (IGBT).
- These devices have near ideal characteristics for high voltage (> 100V) medium frequency (< 20 kHZ) applications.
- This device along with the MOSFET (at low voltage high frequency applications) have the potential to replace the BJT completely

Basic Structure of IGBT

Do You Know?

- The p+ layer is called injection layer because it inject holes in to n- layer.
- The thickness of n- layer determine voltage blocking capability of IGBT.



Construction of IGBT

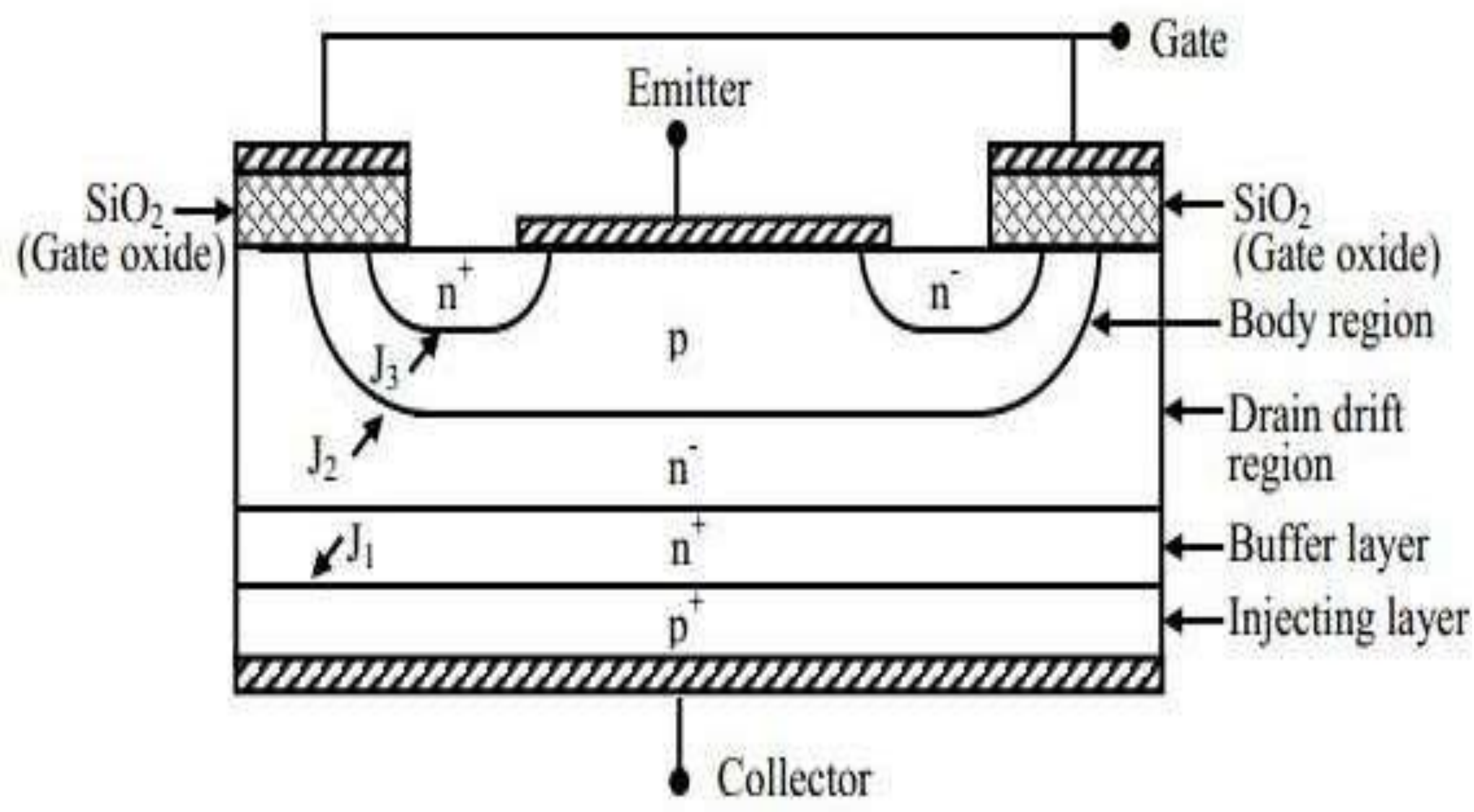


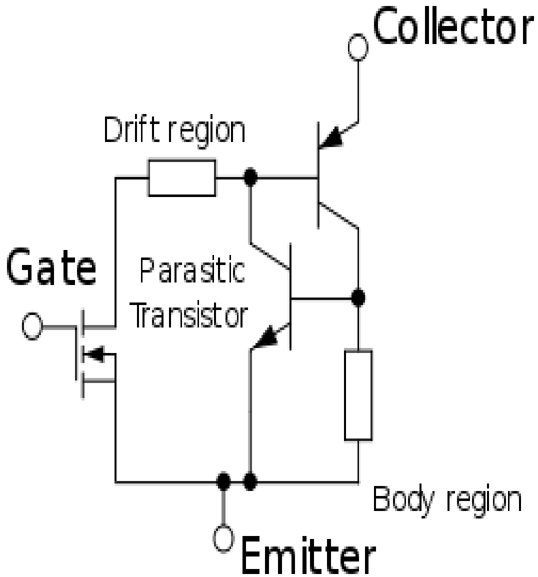
Fig.1

- IGBT & PMOSFET are same in structure but main difference between in the substrate.

- The n+ layer substrate at the drain in PMOSFET is now substitute in the IGBT by a p+ layer substrate is called collector C.

- The p layer is called body of IGBT.

Equivalent & Working circuit of IGBT



Equivalent circuit of IGBT

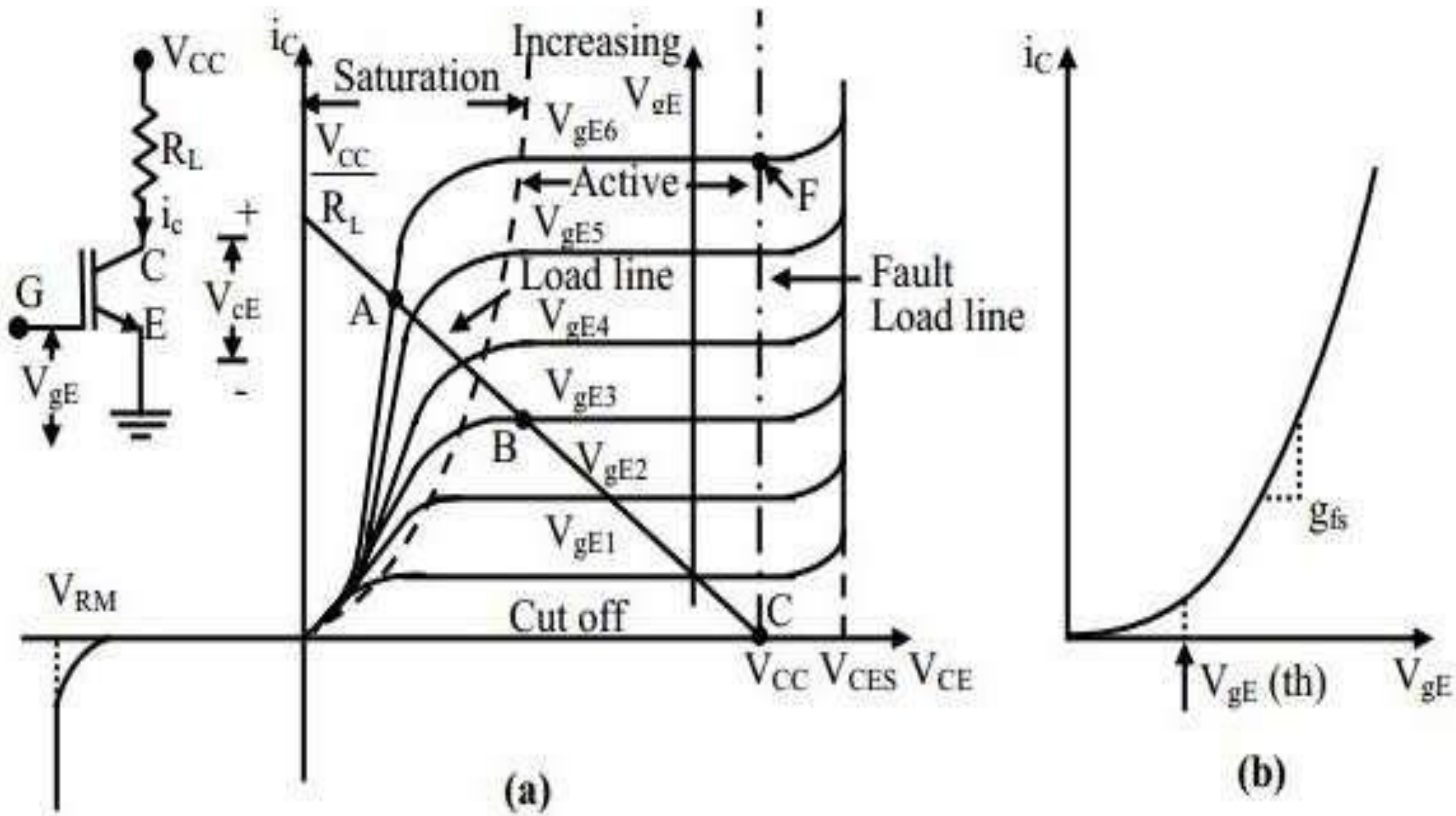
Operating principle of IGBT

- Operating principle of an IGBT can be explained in terms of the schematic cell structure and equivalent circuit of Fig.2(a) and (c).
- From the input side the IGBT behaves essentially as a MOSFET.
- Therefore, when the gate emitter voltage is less then the threshold voltage no inversion layer is formed in the p type body region and the device is in the off state.
- The forward voltage applied between the collector and the emitter drops almost entirely across the junction J2.

- Very small leakage current flows through the device under this condition.
- In terms of the equivalent current of Fig.2(c), when the gate emitter voltage is lower than the threshold voltage the driving MOSFET of the Darlington configuration remains off and hence the output **p-n-p** transistor also remains off.
- When the gate emitter voltage exceeds the threshold, an inversion layer forms in the **p** type body region under the gate.

- This inversion layer (channel) shorts the emitter and the drain drift layer and an electron current flows from the emitter through this channel to the drain drift region.
- This in turn causes substantial hole injection from the p+ type collector to the drain drift region.
- A portion of these holes recombine with the electrons arriving at the drain drift region through the channel.
- The rest of the holes cross the drift region to reach the p type body where they are collected by the source metallization.

I-V Characteristics of IGBT

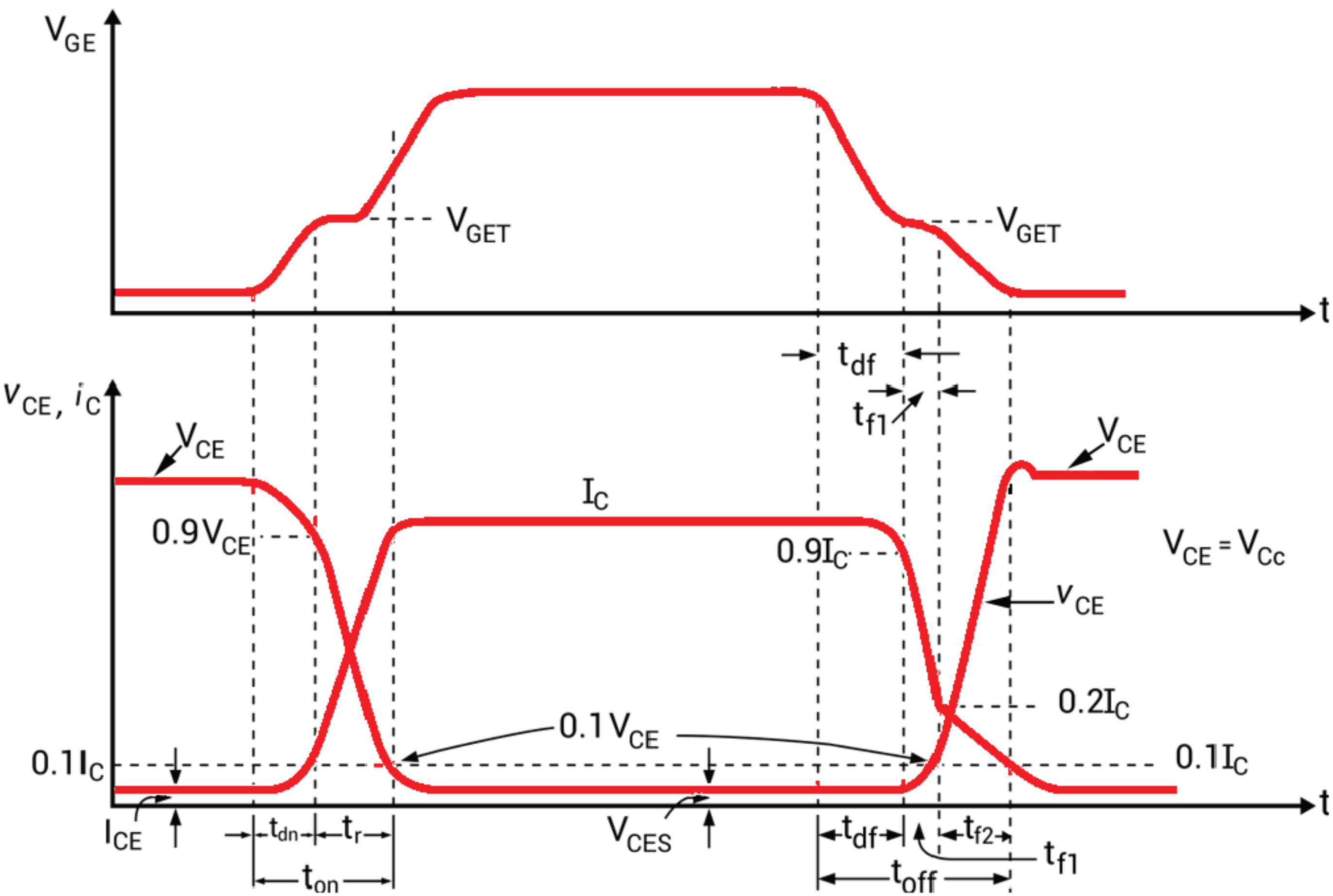


(a)

(b)

- They appear qualitatively similar to those of a logic level BJT except that the controlling parameter is not a base current but the gate-emitter voltage.
- When the gate emitter voltage is below the threshold voltage only a very small leakage current flows though the device while the collector – emitter voltage almost equals the supply voltage (point C in Fig).
- The device, under this condition is said to be operating in the cut off region.

Switching Characteristics



Typical Switching Characteristic of IGBT

Switching Characteristics

Turn on time t_{on} is composed of two components as usual, delay time (t_{dn}) and rise time (t_r). Delay time is defined as the time in which collector current rises from leakage current I_{CE} to 0.1 I_C (final collector current) and collector emitter voltage falls from V_{CE} to $0.9V_{CE}$. Rise time is defined as the time in which collector current rises from 0.1 I_C to I_C and collector emitter voltage falls from $0.9V_{CE}$ to 0.1 V_{CE}.

The turn off time t_{off} consists of three components, delay time (t_{df}), initial fall time (t_{f1}) and final fall time (t_{f2}). Delay time is defined as time when collector current falls from I_C to 0.9 I_C and V_{CE} begins to rise. Initial fall time is the time during which collector current falls from 0.9 I_C to 0.2 I_C and collector emitter voltage rises to 0.1 V_{CE}. The final fall time is defined as time during which collector current falls from 0.2 I_C to 0.1 I_C and $0.1V_{CE}$ rises to final value V_{CE}.

$$t_{off} = t_{df} + t_{f1} + t_{f2}$$

The main advantages of IGBT over a Power MOSFET and a BJT are:

1. It has a very low on-state voltage drop due to conductivity modulation and has superior on-state current density. So smaller chip size is possible and the cost can be reduced.
2. Low driving power and a simple drive circuit due to the input MOS gate structure. It can be easily controlled as compared to current controlled devices (thyristor, BJT) in high voltage and high current applications.
3. Wide SOA. It has superior current conduction capability compared with the bipolar transistor. It also has excellent forward and reverse blocking capabilities.

The main device limitations (drawbacks) are:

1. Switching speed is inferior to that of a Power MOSFET and superior to that of a BJT. The collector current tailing due to the minority carrier causes the turnoff speed to be slow.
2. There is a possibility of latchup due to the internal PNPN thyristor structure.

Safe operating Area (SOA)

- The safe operating area (SOA) is defined as the current-voltage boundary within which a power switching device can be operated without destructive failure.
- For IGBT, the area is defined by the maximum collector-emitter voltage VCE and collector current IC within which the IGBT operation must be confined to protect it from damage.
- The IGBT has the following types of SOA operations:

✓ **forward-biased safe operating area (FBSOA)**,

✓ **reverse-biased safe operating area (RBSOA)** and

✓ **short-circuit safe operating area (SCSOA).**

Forward-Biased Safe Operating Area (FBSOA)

The FBSOA is an important characteristic for applications with inductive loads. It is defined by the maximum collector-emitter voltage with saturated collector current. In this mode, both electrons and holes are transported through the drift region, which is supporting a high collector voltage. The electron and hole concentrations in the drift region are related to the corresponding current densities by:

$$n = \frac{J_n}{qV_{sat,n}} \qquad (3)$$

$$p = \frac{J_p}{qV_{sat,p}} \qquad (4)$$

where $V_{sat,n}$ and $V_{sat,p}$ are the saturated drift velocities for electrons and holes, respectively. The net positive charge in the drift region is given by,

$$N^+ = N_D + \frac{J_p}{qV_{sat,p}} - \frac{J_n}{qV_{sat,n}} \qquad (5)$$

This charge determines the electric field distribution in the drift region. In steady-state forward blocking condition, the drift region charge is equal to N_D. In FBSOA, the net charge is much larger because the hole current density is significantly larger than the electron current density.

The breakdown voltage limit in the FBSOA is defined by

$$BV_{SOA} = \frac{5.34x10^{13}}{(N^+)^{3/4}} \qquad (6)$$

Reverse-Biased Safe Operating Area (RBSOA)

The RBSOA is important during the turn-off transient. The current which can be turned-off is limited to twice the nominal current of the IGBT. This means a 1200A IGBT is able to turn-off a maximum current of 2400A. The maximum current is a function of the peak voltage which appears between collector and emitter during turn-off. The peak value of V_{CE} is the sum of the DC link voltage and the product of $L_\sigma dI_C / dt$ where L_σ is the stray inductance of the power circuit. The relation between maximum I_C and V_{CE} can be seen in the RBSOA diagram in Figure 11 for the IGBT [IXSH30N60B2].

In this mode, the gate bias is at zero or at a negative value thus the current transport in the drift region occurs exclusively via the holes for an n-channel IGBT. The presence of holes adds charge to the drift region, resulting to the increase in the electric field at the P-base/N drift region junction. The net charge in the space charge region under the RBSOA condition is given by:

$$N^+ = N_D + \frac{J_C}{qV_{sat,p}} \qquad (7)$$

where Jc is the total collector current. The avalanche breakdown voltage for RBSOA is given by:

$$BV_{SOA} = 5.34x10^{13}(\frac{J_C}{qV_{sat,p}}) \qquad (8)$$

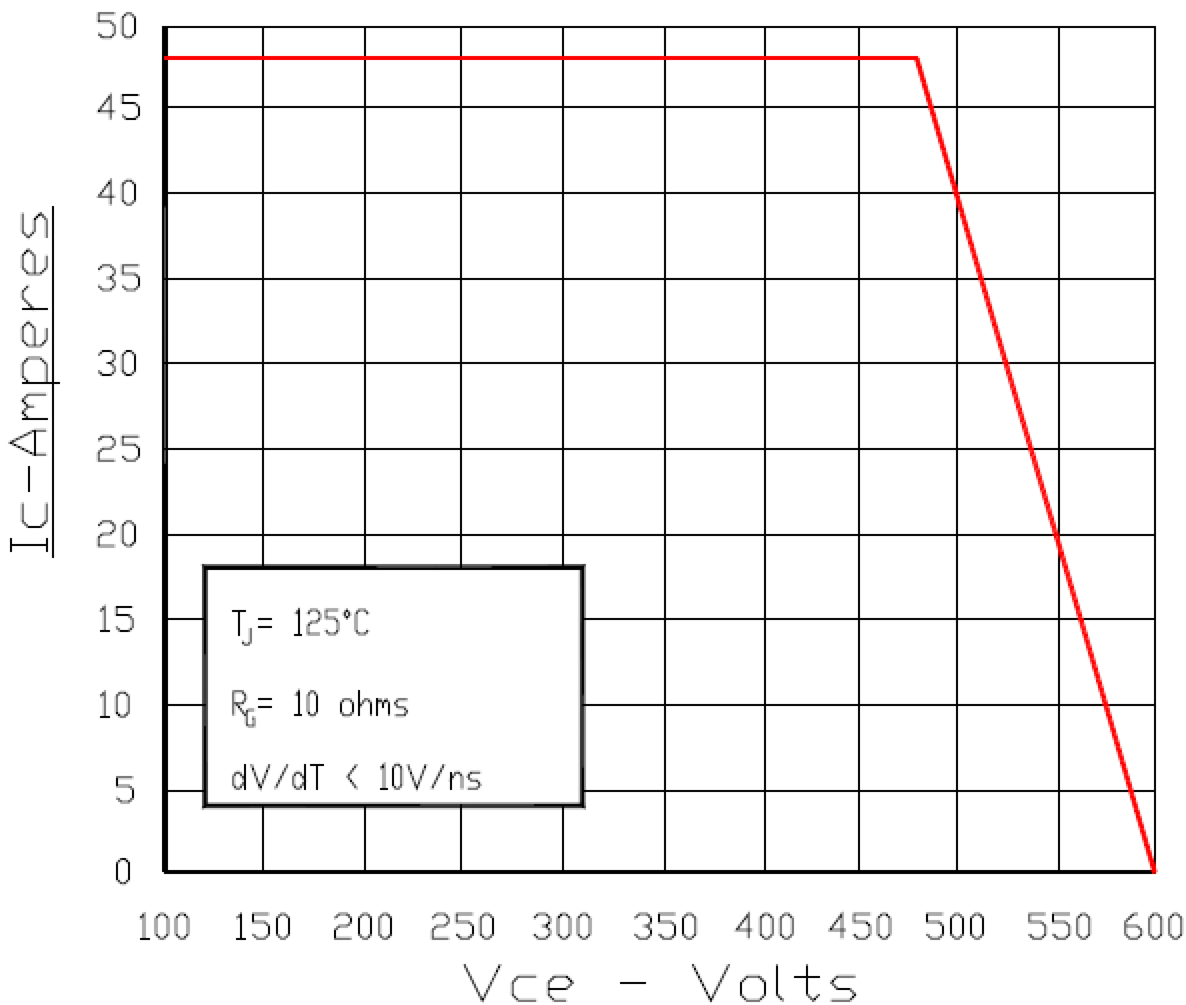
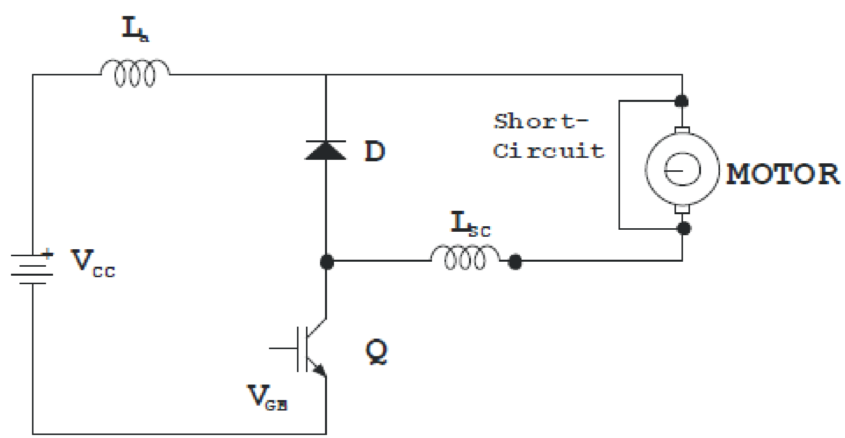


Figure 11: RBSOA of IGBT [IXSH30N60B2]

Short-Circuit Safe Operating Area (SCSOA)

A very important requirement imposed on the power switching device, when used in motor control applications is that be able to turn-off safely due to a load or equipment short circuit. When a current overload occurs, collector current rises rapidly until it exceeds that which the device can sustain with the applied gate voltage. The key to survivability for the power device is to limit the current amplitude to a safe level for a period of time that is sufficiently long to allow the control circuit to detect the fault and turn the device off.

The IGBT collector current I_C is a function of the gate-emitter voltage V_{GE} and the temperature T. The transfer characteristic of a 600V/55A IGBT in Figure 6 shows the maximum collector current I_C vs. the gate-emitter voltage V_{GE}. For V_{GE} of 15V the current is limited to a value of 80A, which is about 1.5 times the nominal value. This is very low value compared to the short circuit current which is typically 6-7 times the nominal value.



A circuit diagram for SCSOA test is shown in Figure 12. The short-circuit inductance value determines the mode of operation of the circuit. When it is in the range of uH, the operation is similar to normal switching of inductive load. When IGBT is turned on, V_{CE} drops to its saturation voltage. The IGBT is saturated and I_C is increasing with a dIc/dt of Vcc/Lsc. It is not allowed to turn-off the IGBT from the saturation region at a collector current higher than 2 times rated current because this is an operation outside the RBSOA. In case of short-circuit; it is necessary to wait until the active region is reached. The IGBT must be turned-off within 10 us to prevent destruction due to overheating.