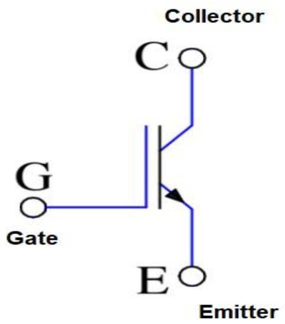
INSULATED GATE BIPOLAR TRANSISTOR

IGBT (Insulated Gate Bipolar Transistor) is a three terminal power switch having high input impedance like PMOSFET and low on-state power loss as in BJT (Bipolar Junction Transistor).

Thus, IGBT is a combined form of best qualities of both BJT and PMOSFET. This is the most popular power switch among the power-electronics engineers and find a great variety of applications.

IGBT is a three-terminal device. The three terminals are Gate (G), Emitter (E) and Collector (C). The circuit symbol of IGBT is shown below.



IGBT is also known as metal oxide insulated gate transistor (MOSIGT), conductivity-modulated field effect transistor (COMFET) or gain-modulated FET (GEMFET). It was initially called Insulated Gate Transistor (IGT).

Construction of IGBT:

An IGBT is constructed on a p+ layer substrate. On p+ substrate, a high resistivity n- layer is epitaxially grown. As in other semi-conductor devices, the thickness of n- layer determines the voltage blocking capability of IGBT. On the other side of p+ substrate, a metal layer is deposited to form the Collector (C) terminal. Now, p regions are diffused in the epitaxially grown n- layer. Further, n+ regions are diffused in p region. A basic construction structure of IGBT is shown in figure below.

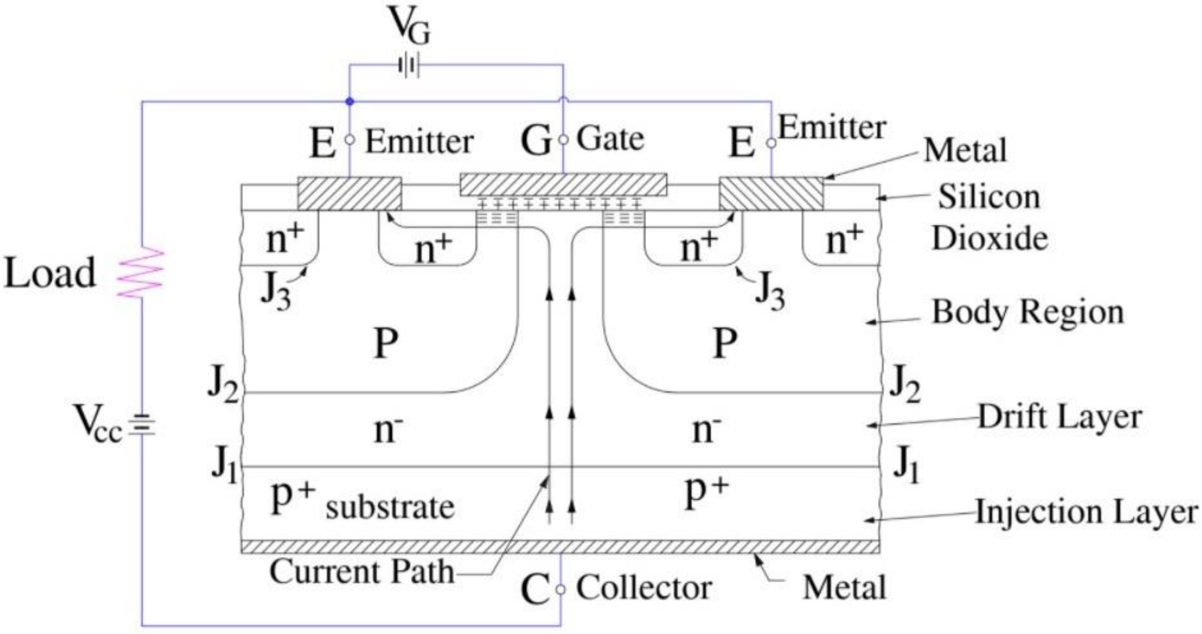


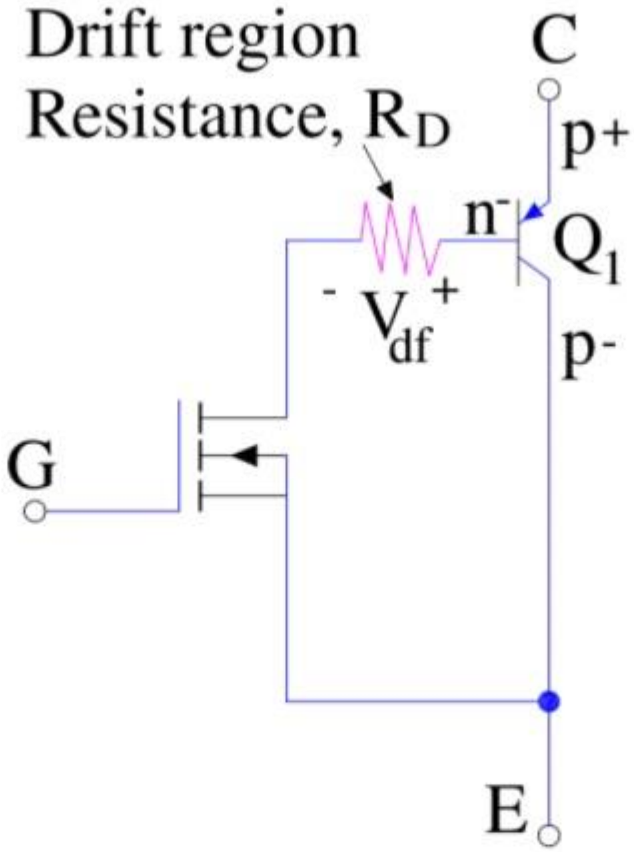
Fig-1

Now, an insulating layer of Silicon Dioxide (SiO_2) is grown on the surface. This insulating layer is etched in order to embed metallic Emitter and Gate terminals.

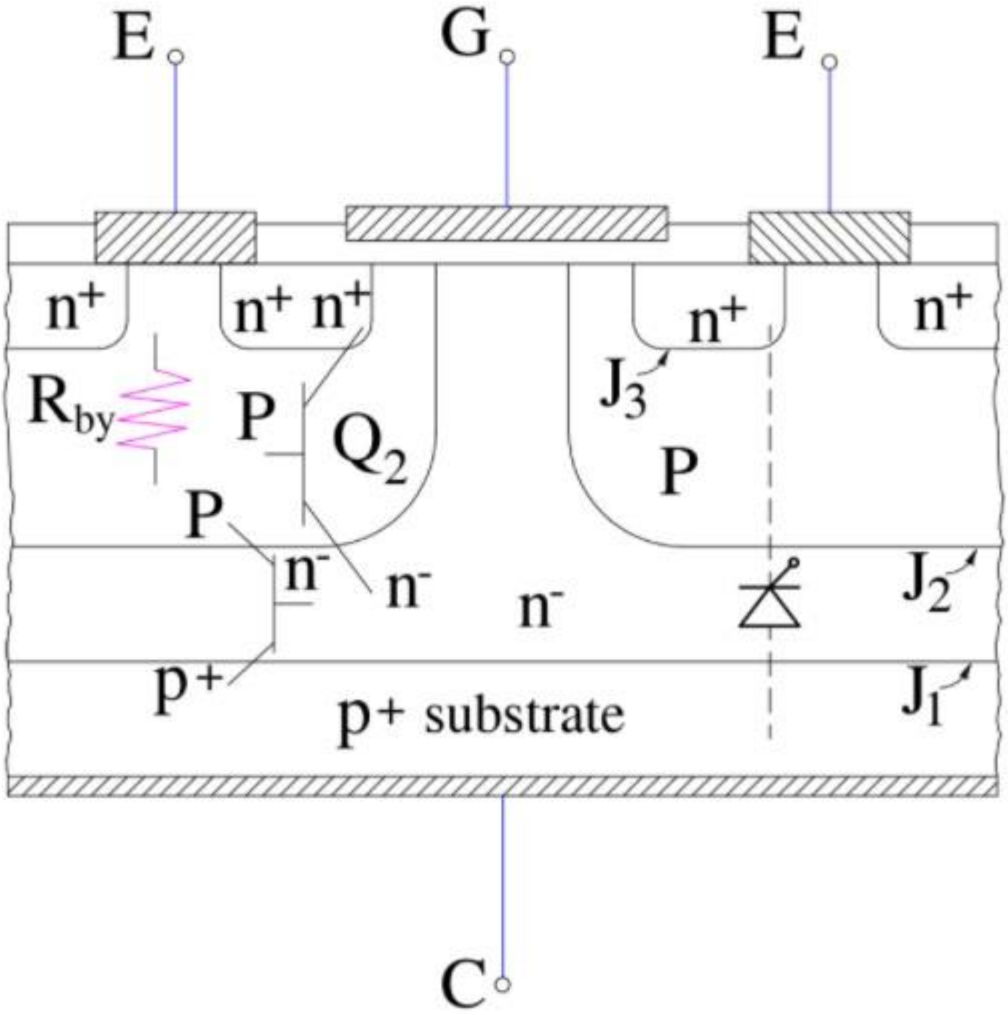
The p+ substrate is also called injector layer because it injects holes into n- layer. The n- layer is called drift region. The next p layer is called the body of IGBT. The n- layer in between the p+ & p region serves to accommodate the depletion layer of pn- junction i.e. J2.

Equivalent Circuit:

The approximate equivalent circuit of IGBT comprises of MOSFET and p+n-p transistor (Q_1). To account for resistance offered by the n- drift region, resistance R_d has been incorporated in the circuit. This is shown below.



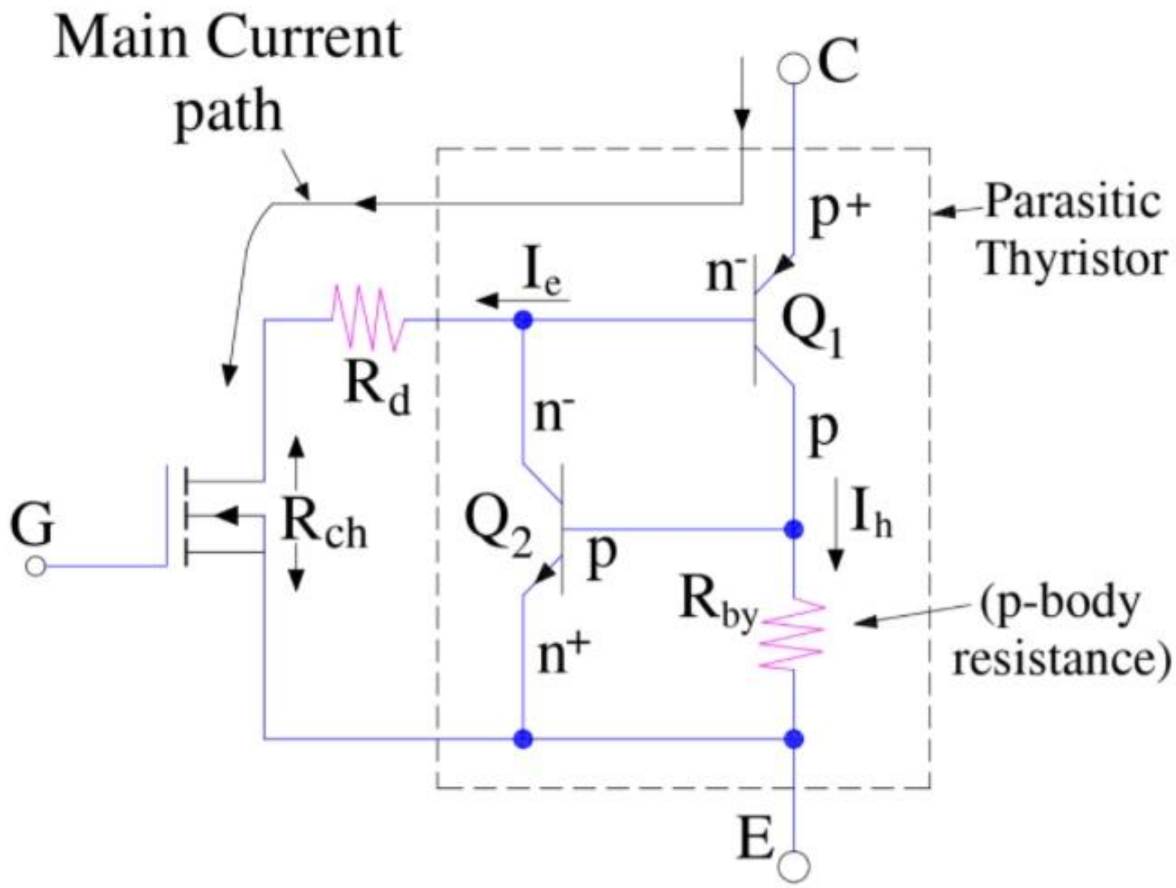
This equivalent circuit may be arrived at by a careful examination of basic structure of IGBT. The basic structure is shown below.



From the above figure, it is clear that as we move vertically up from collector to emitter, we come across p+, n-, p layers. This means that IGBT can be thought of as the combination of MOSFET and p^+n^-p transistor (Q_1). This is the basis for approximate equivalent circuit.

Now, carefully observe the basic structure of IGBT shown above. You will notice that there exists another path from collector to emitter; this path is collector, p+, n^-, p (n-channel), n+ and emitter. There is, thus, another transistor Q_2 as n^-pn+ in the structure of IGBT. Thus, we need to incorporate this transistor Q_2 in the approximate equivalent circuit to get the exact equivalent circuit.

The exact equivalent circuit of IGBT is shown below.



R_{by} in this circuit is the resistance offered by p region to the flow of hole current.

Working Principle of IGBT:

The working principle of IGBT is based on the biasing of Gate to Emitter terminals and Collector to Emitter terminals. When collector is made positive with respect to emitter, IGBT gets forward biased. With no voltage between Gate and Emitter, two junctions between n-region & p region i.e. junction J2 are reversed biased. Therefore, no current flows from collector to emitter. You may refer figure-1 for better understanding.

When Gate is made positive with respect to Emitter by some voltage V_G (this voltage should be more than the threshold voltage V_{GET} of IGBT), an n-channel is formed in the upper part of the p-region just beneath the Gate. This n-channel is called the *inversion layer*. This n-channel short circuits the n- region with n+ emitter region. Electrons from n+ emitter begins to flow to n- drift region through n-channel.

As IGBT is forward biased with collector positive and emitter negative, p+ collector region injects holes into n- drift region. Thus, n- drift region is flooded with electrons from p-body region and holes from p+ collector region. With this, the injection carrier density in n-drift region increases considerably and subsequently, conductivity of n- region enhances. Therefore, IGBT gets turned ON and begins to conduct forward current I_C.

Current I_C or I_E comprises of two current components:

- Hole current I_h due to injection of holes from collector p+, p^+n^-p transistor Q_1, p-body region resistance R_{by} and emitter.
- Electronic current I_e due to injected electrons flowing from collector, injection layer p+, drift region n-, n-channel resistance R_{ch}, n+ and emitter.

Therefore, the collector, or load current
I_C = Emitter Current
= I_E
= $I_h + I_e$

Major current of collector current is electronic current I_e i.e. main current path for collector, or load, current is through p+, n-, drift resistance R_d and n-channel resistance R_{ch}. This is shown in exact equivalent circuit.

The voltage drops in an IGBT during its ON condition consists of voltage drop in n-channel, voltage drop across drift n- region, voltage drop across forward biased p+n- junction J1. The voltage drop across junction J1 is very small of the order of 0.7 to 1V. The ON state voltage drop

APPLICATION

- switching devices in the inverter circuit (for DC-to-AC conversion) for driving small to large motors.

IGBTs for inverter applications are used in home appliances such as

- Air conditioners
- Refrigerators
- Industrial motors
- Automotive main motor controllers to improve their efficiency.

Advantages of IGBT :

- Simple drive circuit
- Low on-resistance
- High voltage capacity
- Fast switching speed
- Easy of drive
- Low switching loss
- Low on stage power dissipation
- Low gate drive requirement
- High switching speed
- High input impedance
- Voltage control device
- Smaller snubber circuit requirement
- It has Superior current conduction capability
- It is easy to turn ON and OFF
- It has excellent forward and reverse blocking capabilities
- Switching frequency is higher than the BJT
- Enhanced conduction due to bipolar nature
- IGBT has a very low on-state voltage drop due to superior on-state current density and conductivity modulation. So the cost can be reduced and a smaller chip size is possible

Disadvantages of IGBT :

- Latching up problem
- It can't block high reverse voltage
- High turn off time
- Cost is high
- The speed of the switching is lower to a power MOSFET and higher to a BJT. So the collector current following due to the minority charge carriers root the turnoff speed to be very slow. There is a chance of latch-up due to the internal structure of the PNPN thyristor device
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