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Comparative Analysis of Power Switches MOFET and IGBT Used in Power Applications

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Abstract:
In this paper, deals with detailed analysis between MOSFET and IGBT. There always a race between MOSFET and IGBT in the power electronics markets. This paper will gives the complete details about them. This paper also discuss how they are used for various applications. By reading this paper any beginners who wants to need detailed analysis between IGBT and MOSGET they can get.

Keywords: MOSFET - Metal Oxide Semiconductor Field Effect Transistor, IGBT- Insulted Gate Bipolar Transistor.

INTRODUCTION:

Past three to four decades, there will be fast revolution in electronics market. All the electronically operated devices are modernised by the developing technology. All the electronic devices are modified in size, operating performance and cost[1]. In olden days thyratron value oscillator bigger in size. Now all the electronics & power electronics devices are in compact in size that too without scarifying its performance. Because of the competitors or more investors per unit cost of the devices are decreased.

Diodes, transistors, Diac, Triac, FET, SCR are the some of electronic switches. Power diodes, power BJT, power MOSFET, IGBT are the some of the power electronic switches [2-4]. All the switches having its unique performance. In paper will gives the details about MOSFET & IGBT[5-6]. Analysis are made as follows, symbols, configuration, and dynamic characteristics and applications.

Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

The MOSFET or metal oxide semiconductor field effect transistor, is a form of FET that offers an exceedingly high input impedance. The gate input has an oxide layer insulating it from the channel and as a result its input resistance is very many MΩ. The MOSFET has a number of different characteristics compared to the junction FET, and as a result it can be used in a number of different areas and it is able to provide excellent performance.

MOSFET circuit symbol

- The circuit symbol for the basic MOSFET (shown Fig.1) indicates that the device has a bulk substrate - this is indicated by the arrow on the central area of the substrate. Depletion mode MOSFETs are generally indicated as shown on the right most section.

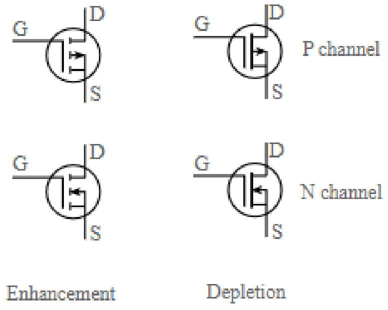


Fig.1 MOSFET symbol

Gate construction:

The gate is physically insulated from the channel by an oxide layer. Voltages applied to the gate control the conductivity of the channel as a result of the electric field induced capacitive across the insulating dielectric layer. Both enhancement and depletion types are available. As the name suggests the depletion mode MOSFET acts by depleting or removing the current carriers from the channel, whereas the enhancement type increases the number of carriers according to the gate voltage

MOSFETs may be characterised as N Channel and P-Channel. Each has different characteristics: Table-1

COMPARISON OF THE KEY FEATURES OF N-CHANNEL AND P-CHANNEL MOSFETS

PARAMETER	N-CHANNEL	P-CHANNEL
Source / drain material	N-Type	P-Type
Channel material	P-Type	N-Type
Threshold voltage V_{th}	negative	doping dependent
Substrate material	P-Type	P-Type
Inversion layer carriers	Electrons	Holes

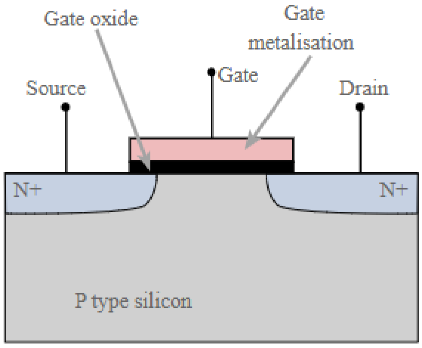
Working of MOSFET:

Like other forms of FET, the current flowing in the channel of the MOSFET is controlled by the voltage present on the gate. As such MOSFETs are widely used in applications such as switches and also amplifiers. They are also able to consume very low levels of current and as a result they are widely used in microprocessors, logic integrated circuits and the like. CMOS integrated circuits used MOSFET technology.

Also like other forms of FET, the MOSFET is available in depletion mode and enhancement mode variants. The enhancement mode is what may be termed normally OFF, i..e when the V_{GS} gate source voltage is zero and requires a gate voltage to turn it on, whereas the other form, deletion mode devices are normally ON when V_{GS} is zero.
There are basically three regions in which MOSFETs Shown in Fig. 2 can operate:

- ***Cut-off region:*** In this region of the MOSFET is in a non-conducting state, i.e. turned OFF - channel current $I_{DS} = 0$. The gate voltage V_{GS} is less than the threshold voltage required for conduction.

- ***Linear region:*** In this linear region the channel is conducting and controlled by the gate voltage. For the MOSFET to be in this state the V_{GS} must be greater than the threshold voltage and also the voltage across the channel, V_{DS} must be greater than V_{GS}.
- ***Saturation region:*** In this region the MOSFET is turned hard on. The voltage drop for a MOSFET is typically lower than that of a bipolar transistor and as a result power MOSFETs are widely used for switching large currents



N- Channel Enhanced mode MOSFET

As already implied the key factor of the MOSFET is the fact that the gate is insulated from the channel by a thin oxide layer. This forms one of the key elements of its structure.

Fig.2

For an N-channel device the current flow is carried by electrons and in the diagram below it can be seen that the drain and source are formed using N+ regions which provide good conductivity for these regions.

In some structures the N+ regions are formed using ion implantation after the gate area has been formed. In this way, they are self-aligned to the gate. The gate to source and gate to drain overlap are required to ensure there is a continuous channel. Also the device is often symmetrical and therefore source and drain can be interchanged.

P-channel FETs are not as widely used. The main reason for this is that the holes do not have as high a level of mobility as electrons, and therefore the performance is not as high. However they are often required for use in complementary circuits, and it is mainly for this reason that they are manufactured or incorporated into ICs

Insulated Gate Bipolar Transistor (IGBT)

The Insulated Gate Bipolar Transistor (IGBT) is a minority-carrier device with high input impedance and large bipolar current-carrying capability

IGBT Circuit Symbol

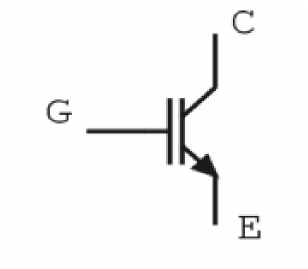


Fig.3 IGBT symbol

The basic schematic of a typical N-channel IGBT based upon the DMOS process is shown in Fig.3. This is one of several structures possible for this device. It is evident that the silicon cross-section of an IGBT is almost identical to that of a vertical Power MOSFET except for the P+ injecting layer. It shares similar MOS gate structure and P wells with N+ source regions. The N+ layer at the top is the source or emitter and the P+ layer at the bottom is the drain or collector. It is also feasible to make P-channel IGBTs and for which the doping profile in each layer will be reversed. IGBT has a parasitic thyristor comprising the four-layer NPNP structure. Turn-on of this thyristor is undesirable.

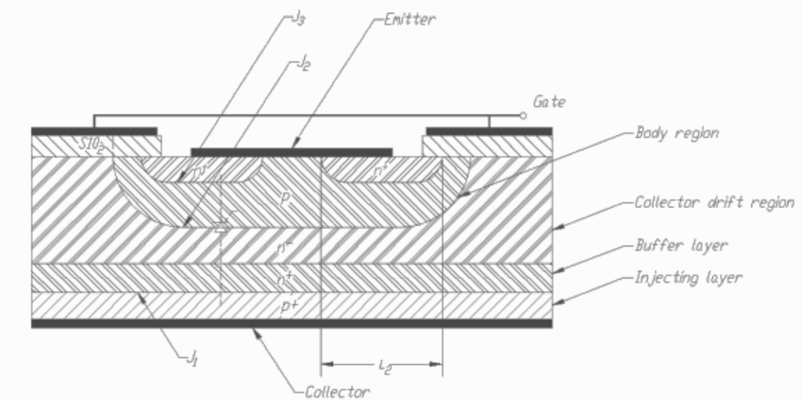


Fig.4 Structure of IGBT

Some IGBTs, manufactured without the N+ buffer layer, are called non-punch through (NPT) IGBTs whereas those with this layer are called punch-through (PT) IGBTs. These are the two types of IGBT's. IGBTs, which have equal forward and reverse breakdown voltage, are suitable for AC applications.

The PT structure Fig.4 has an extra buffer layer which performs two main functions: (i) avoids failure by punch-through action because the depletion region expansion at applied high voltage is restricted by this layer, (ii) reduces the tail current during turn-off and shortens the fall time of the IGBT because the holes are injected by the P+ collector partially recombine in this layer. The NPT IGBTs, which have less reverse breakdown voltage than the forward breakdown voltage, are applicable for DC circuits where devices are not required to support voltage in the reverse direction.

Switching Characteristics of MOSFET

Switching characteristics of an MOSFET during turn-on and turn-off are sketched in fig. Turn-on time is defined as the time between the instant of forward blocking to forward on the state.

The turn ON and OFF times of MOSFET gets affected by its internal capacitance and the internal impedance of the gate drive circuit but it does not affect during steady-state operation.

Turn ON Process:

- The gate voltage is made positive to turn ON the MOSFET. When the gate voltage has applied the gate to source capacitance C_{GS} starts charging.
- When the voltage reached through C_{GS} certain voltage level is called the Threshold voltage (V_{GST}) at the same time drain current I_D begins to increase.
- The time needed to charge C_{GS} to the threshold voltage level is known as a turn-on delay time.
- The C_{GS} charges from threshold to the full gate (V_{GSP}) voltage. The time required for this charging is known as rising time (t_r).

- During this period, the drain current increases to its full value of I_D because of that the MOSFET is fully turned ON.
- MOSFET turn-on time is given by,

$$t_{ON} = t_{[d(on)]} + t_r$$

td(on) – On time delay
tr – rise time

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

Turn OFF Process:

- The MOSFET can be turned off with a negative or zero gate voltage. Due to this, the gate to source voltage decreases from V_I to V_{GSP}.
- C_{GS} discharges from V_I to V_{GSP} gate voltage. The time required for this discharge is called a turn-off delay time, during which the drain current also begins to decrease.
- The C_{GS} continues to discharging and its voltage equals a threshold voltage (V_{GST}).
- The time required to discharge C_{GS} from V_{GSP} to V_{GST} is called fall time (t_f). The drain current will be zero when the voltage $V_{GS} < V_{GST}$ then it is said to have turned off.
- MOSFET turn-off time is given by,

$$t_{OFF} = t_{[d(off)]} + t_f$$

td(off) – Off time delay
tf – fall time

MOSFET switching waveform is shown in the fig.5 below

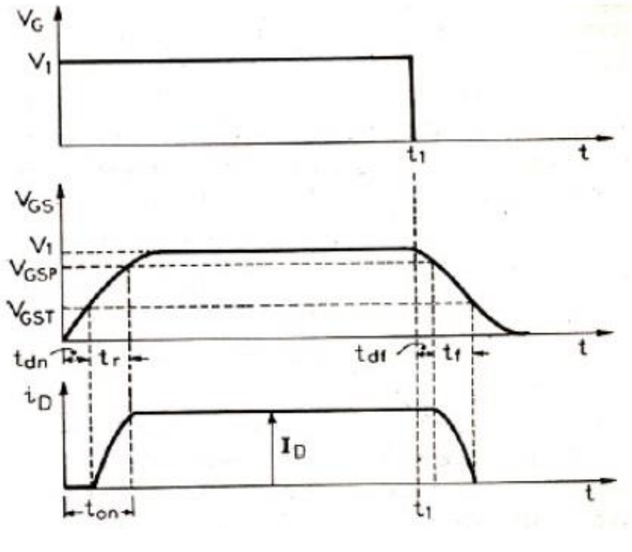


Fig.5. Switching Characteristics of MOSFET

Switching Characteristics of IGBT

Switching characteristics of an IGBT during turn-on and turn-off are sketched in fig.6. Turn-on time is defined as the time between the instant of forward blocking to forward on the state.

Turn-on time is composed of delay time t_{dn} and rise time tr

$$\mathbf{t_{on} = t_{dn} + t_r.}$$

- The delay time is defined as the time for the collector-emitter voltage to fall from V_{CE} to 0.9 V_{CE}. Here V_{CE} is the initial collector emitter voltage.
- Time t_{dn} may also be defined as the time for the collector current to rise from its initial leakage current I_{CE} to 0.1 I_c. Here I_c is the final value of collector. The rise time t_r is the time during which collector-emitter voltage falls from V_{CE}.
- It is also defined as the time for the collector current to rise from 0.1 I_C to its final value I_C. After time t_{on}, the collector current I_C is and the collector-emitter voltage fall to a small value called conduction drop is said to be V_{CES} where subscript S denotes saturated value.
- The turn-off time is somewhat complex.
- It consists of three intervals: (i) delay time , (ii) initial fall time and (iii) final fall time.

$$\mathbf{t_{off} = t_{df} + t_{f1} + t_{f2}.}$$

- The delay time is the time during which gate voltage fall forms V_{GE} to threshold V_{GET}.
- As V_{GE} falls to V_{GET} during t_{df}, the collector current falls from I_c to 0.9 I_c . At the end of t_{df}, the collector-emitter voltage begins to rise.
- The first fall time t_{f1} is defined as the time during which collector current fall from 90 to 20 % of its initial value of current I_C, or the time during which collector-emitter voltage rise from V_{CES} to 0.1 V_{CE}.
- The final fall time t_{f2} is the time during which collector current fall from 20 to 10% of I_c or the time during which collector-emitter voltage rise from 0.1 V_{CE} to final value.

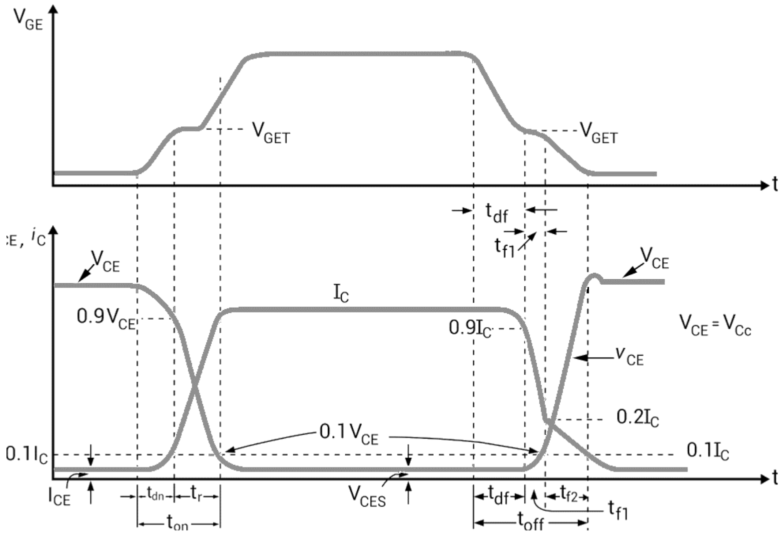


Fig.6. Switching Characteristics of IGBT

Performance Analysis of IGBT and MOSFET

Similarities

- MOSFET and IGBT both are solid-state semiconductor devices integrated on a single piece of Silicon.
- Although a BJT is a current controlled device, but both IGBT and MOSFET are voltage controlled device.
- Both can be used as a Static electronic Switch.
- Both devices have insulation between Gate and other terminals and also have high input impedance.

- Both are three terminal devices.

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Difference:

- IGBT is suitable for medium to very high current conduction and controlling whereas the MOSFET is suitable for low to medium current conduction and controlling.
- IGBT is not suitable for high-frequency applications, it can perform well up to a few Kilo Hz frequency. But MOSFET is most suitable for very high-frequency applications, it can perform well at Mega Hz frequencies.
- The switching speed of an IGBT is very low, whereas MOSFET provides very fast switching.
- IGBT can handle very high voltage and high power but MOSFET only suitable for low to medium voltage and power applications.
- IGBT is extremely tolerant to electrostatic discharge and overloads whereas MOSFET are vulnerable to ESD as the high impedance technology won't allow for voltage dissipation.
- MOSFET used in a condition of high light-load efficiency, dv/dt on the diode is a limited and wide line and load conditions where IGBT used in full load efficiency, high dv/dt handled by a diode and high power levels around 3 kW.
- IGBT produces a lower forward voltage drop when it conducting current, but MOSFET produces a more forward voltage drop compared to IGBT.
- IGBT has a larger turnoff time whereas MOSFET has a smaller turnoff time
- IGBT has three terminals named Emitter, Collector, and Gate whereas the MOSFET has also three terminals named as Source, Gate, and Drain.
- IGBT has PN Junction in its construction but MOSFET has not any PN Junction.
- IGBT can handle any transient voltage and current, but the operation of a MOSFET got disturbed when transient voltage occurs.
- MOSFET has a long history than IGBT.
- MOSFETs are low-cost devices whereas IGBTs are high-cost devices.
- IGBT modules are their higher voltage and current handling capability as compared to a comparable price of MOSFET.
- IGBT has a better power handling than MOSFET.
- IGBTs are most suitable for high power AC applications whereas MOSFETs are most suitable for low power DC applications.

Salient Features of IGBT

- It is capable to handle and conduct medium to ultra-high voltage and high current.
- Its operation no got disturbed when a surge voltage occurs.
- It provides a very high gate insulation feature.
- It produces a very low forward voltage drop during current conduction.

Limitations of IGBT

- It is not suitable for high-frequency applications.
- Its switching speed is slow compared to others such as SCR, MOSFET, etc.
- IGBT has a larger turnoff time.

Salient Features of MOSFET

- It is most suitable for high-frequency applications.
- It provides a very fast switching facility.
- It is capable to handle noise signals.
- It is a compact and easily available low-cost device.

Limitations of MOSFET

- It is not capable to handle high current, voltage, and power.
- Its operation got disturbed if surge voltage occurs.
- It produces a more forward voltage drop compared to IGBT.

Applications

IGBT:

- IGBTs are used for low frequency, high power applications such as Industrial Inverters, UPS, Power controllers, etc.
- IGBT also used in three-phase inverters, VFDs which work with high voltage and high current.
- IGBT is mainly designed for use in Power Electronics applications.

MOSFET:

- MOSFETs are used for high frequency, low power applications such as Pulse Width Modulation (PWM) circuits, single-phase inverters, High-frequency amplifier circuits, Digital electronic circuits, etc.
- MOSFET is designed for use in power electronics as well as digital electronics circuits.

CONCLUSION

MOSFETs and IGBTs are fast replacing a large majority of older solid-state and mechanical devices. It’s a movement that doesn’t look like it’s going to slow down any time soon either, especially with the development of silicon carbide (SiC) material quality. SiC power devices are showing developers advantages like less loss, smaller size, and improved efficiency. Innovations like this will continue to push the limits of MOSFETs and IGBTs into higher-voltage and higher-power applications. As a result, trade-offs and overlaps are likely to continue in many applications

The choice of IGBT or MOSFET will vary from application to application, depending on the exact power level, the devices being considered, and the latest technology available for each type of transistor.

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