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Power MOSFET

Construction and Characteristics

2. Construction and Characteristics

Since Power MOSFETs operate principally as majority carrier devices, adverse influences are relatively small magnitude or importance. This is in contrast to the situation with minority carrier devices, bipolar transistors, where such effects create more serious design problems. Also, the input impedance of power MOSFETs is basically higher than that of junction type FETs.

Even though the power MOSFETs have high speed, at the beginning of their development it was thought to be difficult to make devices characterized by low resistance, high breakdown voltage and high power. However, in recent years power MOSFETs from 60 V/70 A to 1000 V/12 A become available and are widely used as ideal switching devices.

2.1 Power MOSFET Construction

Power MOSFETs are classified into three major types as shown in Figure 2.1.

Figure 2.1 (a) shows a type of construction which is an extension of the small-signal MOSFET and with which high breakdown voltage is obtained using ion junction technology and the offset gate construction. However, this approach is disadvantageous from the viewpoint of the long channel required and the consequent loss in efficiency of surface area utilization.

Figure 2.1 (b) shows the product of a method called D-MOS (double diffusion MOS) which is used to form the channels by using double diffusion. High breakdown voltage can be obtained by using this technology.

This D-MOS construction uses double diffusion on a high-resistance drain substrate, which diffuses the gate area and the source area. The difference in depth of diffusion between the gate and the source area is used as the channel. When the gate-drain junction is formed in this way, there are fewer impurities on the drain side.

When drain voltage is applied, the depletion area extends considerably to the drain side but cannot easily extend to the channel side; therefore, breakdown voltage drop due to punch-through is prevented, and this structure makes possible high breakdown voltage even with an extremely short channel.

D-MOS takes the drain electrode from the back surface of the substrate, achieving high integration and high power. In addition, the cascade connection of a power MOSFET and a junction FET makes it possible to reduce the reverse transfer capacitance of the power MOSFET.

High breakdown voltage and large current are easier to achieve with this D-MOS construction than with the former two methods Figure 2.1 (a) and (c). Mass production at low cost is also possible; therefore, the technique portrayed in Figure 2.1 (b) is now widely used as the basic construction for power MOSFETs for ordinary power amplification applications.

Figure 2.1 (c) is the trench power MOSFET structure. High-integration is achieved by connecting channel vertically and this structure is capable of low ON-resistance.
Low-voltage power MOSFETs use this structure.

(a) Lateral construction (b) Double diffusion construction (c) Trench construction

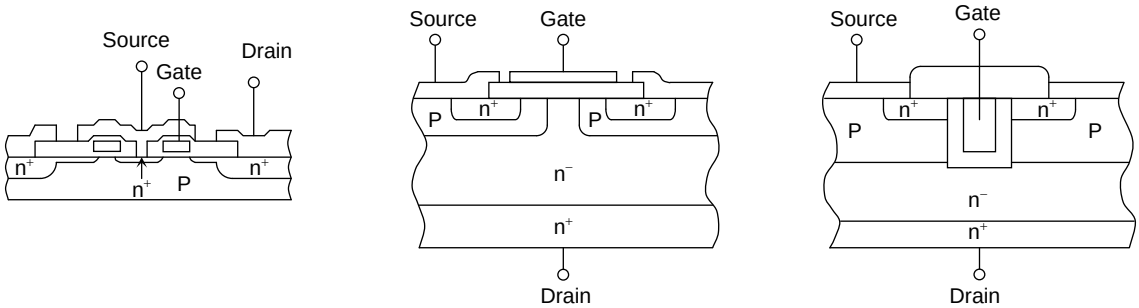


Figure 2.1 Power MOSFET Construction

2.2 Power MOSFET Features

Main features of power MOSFETs are shown as follows:

a) MOS type FETs are basically majority carrier devices; consequently, they differ greatly from bipolar transistors which are minority carrier devices.

b) MOS type FETs are not current controlled devices as are bipolar transistors. They are voltage controlled devices and are controlled by the voltage applied between the gate and source.

c) Since they are majority carrier devices, high-frequency switching operation is possible because there is no storage time-lag due to the carrier storage effect.

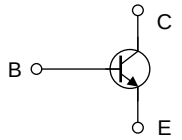
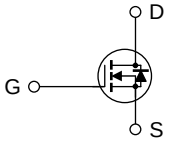
d) With bipolar transistors, current concentration occurs in the high-voltage area and junction failure occurs due to secondary breakdown. Therefore, bipolar transistors require considerable derating. Power MOSFETs, on the other hand, have a negative temperature coefficient which makes it difficult for secondary breakdown to occur, making these devices highly resistant to failure and thus enabling use right up to the maximum rating.

e) When power MOSFETs are used for switching operations, their switching times, that is, the rise and fall times, of power MOSFETs are one order of magnitude faster than those of bipolar transistors; therefore, turn-ON and turn-OFF loss are much smaller than those of bipolar transistors.

Incidentally, the ON resistance of power MOSFETs has a positive temperature coefficient; therefore, heat sink and thermal expansion design is necessary, taking into consideration the $R_{DS\ (ON)}$ at high temperatures.

Table 2.1 shows a comparison between bipolar transistor and MOSFET as to drive method, switching time, safe operation area, breakdown voltage, ON voltage, parallel connection and temperature stability.

Table 2.1 Comparison between Bipolar Power Transistors and Power MOSFETs

	Bipolar Power Transistor	Power MOSFET
Symbol		
Products in use	Very numerous	Growing rapidly
Product cost	Construction is relatively simple, an advantage in the long term.	Construction is more complex than that of bipolar transistors. This and the slightly larger chip size increases cost.
Drive	Fairly complex due to current drive. Also it influences switching time and makes selection of drive conditions difficult.	Voltage drive, so extremely simple. Load current and safe operation range are unrelated.
Switching time	Minority carrier device, therefore slow.	Much faster than bipolar transistors. No storage time and no influence from temperature.
Safe operation area	Restricted due to risk of secondary breakdown.	Basically restricted by power dissipation (equal power lines).
Breakdown voltage (collector-emitter, drain-source)	Determined by V_{CEX} (V_{CBO}) for most circuits. Rating is 1.2 to 2.0 × V_{CE}.	Limited by V_{DSS} except when the gate of a trench-structure MOSFET is inversely biased with V_{GS} (limited by V_{DSX})
ON voltage	Extremely low, even for high breakdown voltage devices. Temperature coefficient is normally negative.	Can be extremely low for low breakdown voltage devices, but is somewhat higher for high breakdown voltage devices. Positive temperature coefficient.
Parallel connection	Difficult due to current balance relationship.	Some caution required, including equalization of oscillation or switching time, but parallel connection is possible.
Temperature stability	h_{FE} rises and V_{BE} falls along with temperature rise, so some caution is required.	Extremely high stability in relation to the temperatures of various parts.

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