# Power MOSFET
# Structure and Characteristics

## Description

This document explains structures and characteristics of power MOSFETs.

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# 1. Structures and Characteristics

Since Power MOSFETs operate principally as majority-carrier devices, they are not affected by minority carriers. This is in contrast to the situation with minority-carrier devices such as bipolar transistors where such effects create more serious design problems. Also, the input impedance of power MOSFETs is basically higher than that of junction FETs.

Even though power MOSFETs excel in speed, in the beginning of their development, it was thought that achieving low on-state resistance, high breakdown voltage and high power would be difficult. In recent years, however, we have witnessed major improvement in the performance of power MOSFETs with the prevalence of a planar gate double diffusion structure, followed by trench gate and superjunction (SJ) structures. Power MOSFETs with these new structures deliver higher speed, lower on-state resistance, and higher breakdown voltage. Today, power MOSFETs are widely used as switching devices in commercial, industrial, automotive and other applications.

## 1.1. Structures of Power MOSFETs

Power MOSFETs can be broadly categorized according to their gate and drift structures. Figure 1.1 illustrates the three common structures currently used.

Figure 1.1 (a) shows a double diffusion MOS (D-MOS) structure.

For the fabrication of D-MOS devices, channels are formed in a double diffusion process that provides high withstand voltage. The D-MOS process is well suited to increasing device density, making it possible to realize high performance power MOSFETs with low on-state resistance and low power loss.

Figure 1.1 (b) shows a trench gate structure.

The trench-gate process forms a vertical gate channel in the shape of a U groove in order to increase device density and thereby further reduce on-state resistance. The trench gate structure is employed to fabricate power MOSFETs with relatively low voltage.

Figure 1.1 (c) shows a superjunction (SJ) structure.

This structure has a drift region that consists of alternating p- and n-type semiconductor layers. This process overcomes the inherent limitations of the vertical silicon process used with conventional power MOSFETs and delivers extremely low on-state resistance.

Compared to conventional power MOSFETs, the superjunction process provides significant improvement in the trade-off between $V_{DSS}$ (maximum drain-source voltage) and Ron·A (normalized on-state resistance per specific area), and therefore helps to considerably reduce conduction loss.

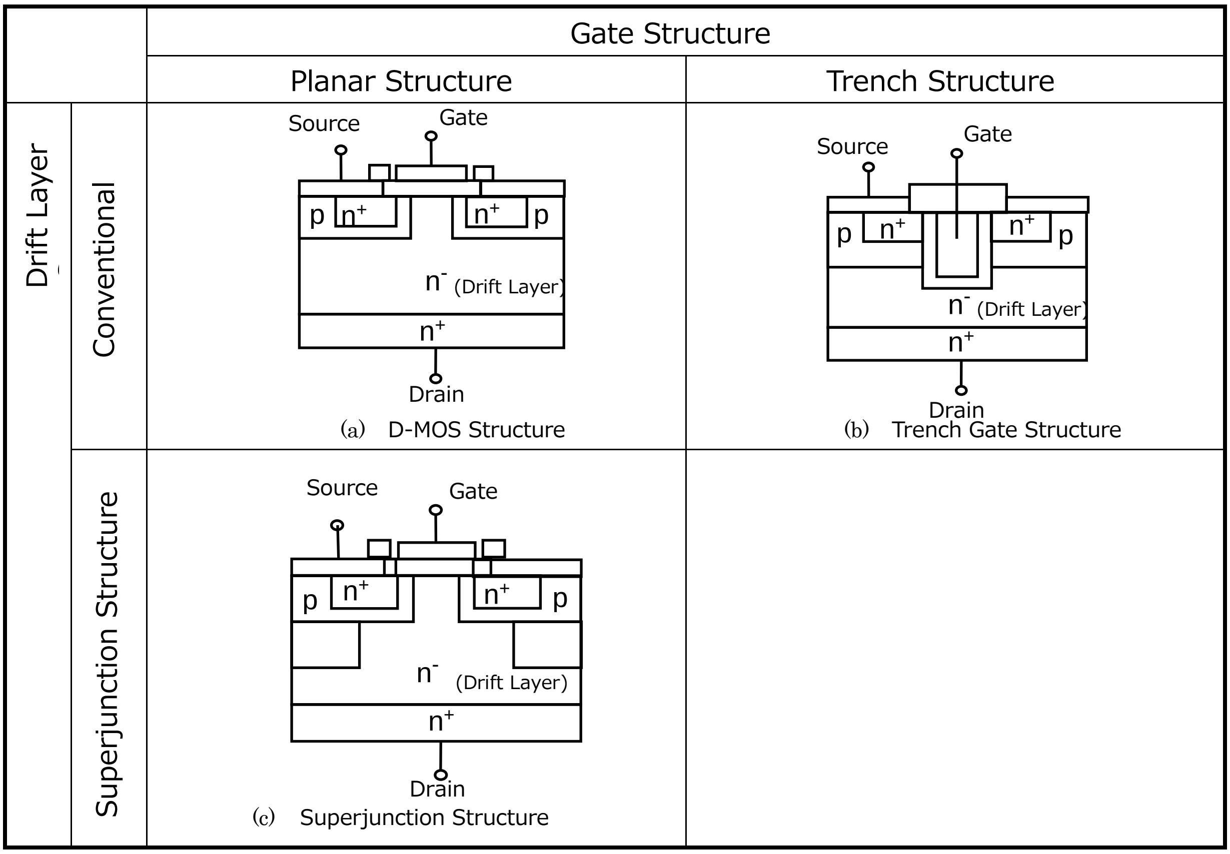


**Figure 1.1 Power MOSFET Structures**

**Table 1.1 Comparison of Power MOSFETs**

| Toshiba Product Series | High Voltage | Low On-State Resistance | High Current | High Speed |
|---|---|---|---|---|
| π-MOS (DMOS) | Excellent (up to 900 V) | Moderate | Moderate | Good |
| U-MOS (Trench-gate MOS) | Good (up to 250 V) | Excellent | Excellent | Good |
| DTMOS (SJ-MOS) | Excellent (500 V or higher) | Excellent | Excellent | Excellent |

## 1.2. Characteristics of Power MOSFETs

The general characteristics of power MOSFETs are listed below.

(1) Basically, MOSFETs are majority-carrier devices and operationally different from bipolar transistors that are minority-carrier devices.

(2) While bipolar transistors are current-controlled devices, MOSFETs are voltage-controlled devices that are controlled by gate-source voltage.

(3) Since MOSFETs are majority-carrier devices, they do not suffer delay due to the carrier storage effect, making high frequency switching possible.

(4) In bipolar transistors, current concentrates in the high voltage region, making them vulnerable to junction destruction due to secondary breakdown. Operating conditions are de-rated as necessary to prevent junction destruction. In contrast, power MOSFETs are much more immune to secondary breakdown and therefore more rugged. However, the electrical characteristics of recent MOSFET devices should be carefully examined as some of them are vulnerable to secondary breakdown.

(5) Since power MOSFETs have a positive temperature coefficient of on-state resistance, $R_{DS(ON)}$ at high temperatures should be considered during thermal design.

Table 1.2 compares bipolar power transistors and power MOSFETs.

**Table 1.2 Comparison of Bipolar Power Transistors and Power MOSFETs**

| | Bipolar Power Transistor | Power MOSFET |
|---|---|---|
| Drive circuit | Drive conditions are difficult to determine because switching time varies with drive current conditions. Also, the drive circuit suffers high power loss. | The drive circuit for the voltage control of a power MOSFETs is simpler and offers lower power loss than that of a bipolar resistor. |
| Switching time | Due their structure, bipolar transistors have a storage time $t_{stg}$ and therefore a longer switching time than MOSFETs. | Power MOSFETs are much faster than bipolar power transistors. Power MOSFETs have no storage time and are less affected by temperature. |
| Safe operating area (SOA) | Restricted due to the risk of secondary breakdown. | Restricted mainly by power dissipation (equal power lines). |
| Breakdown voltage (Collector-emitter, drain-source) | Bipolar power transistors are often used with a reverse current between the base and emitter. Sometimes, both $V_{CES}$ and $V_{CEX}$ ($V_{CBO}$) are rated. | The withstand voltage is limited by $V_{DSS}$ except for trench MOSFETs operating in a reverse gate bias condition (during which the withstand voltage is restricted by $V_{DSX}$). |
| On-state voltage | Even high voltage bipolar power transistors have very low on-state voltage and generally have a negative temperature coefficient. | Low-voltage power MOSFETs have an extremely low on-state voltage. High voltage devices have a slightly higher on-state voltage. Power MOSFETs have a positive temperature coefficient, which is beneficial in connecting multiple devices in parallel. |
| Parallel connection | It is necessary, but difficult, to equalize the current flowing through multiple transistors connected in parallel. | Multiple power MOSFETs can be connected in parallel, but it requires a bit of attention to prevent oscillation and match the switching times of the parallel devices. |
| Temperature stability | A certain amount of care is required because an increase in temperature causes $h_{FE}$ to increase and $V_{BE}$ to decrease. | Various characteristics exhibit outstanding temperature stability. |

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