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A New MOS-Gate Bipolar Transistor with Fast Switching Speed and High Current Capability

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Abstract

A new monolithic integrated power device called the MOS-gate transistor (MGT) which consists of a bipolar transistor for an output stage and two MOSFET's for a driver stage is described. The MGT devices with 400V blocking voltage were fabricated. High current density of $90A/cm^2$ at collector-emitter voltage of 2V, and short turn-off time of less than 1 μs were obtained. This device has no parasitic thyristor, so that the device is free from the latch-up phenomenon.

1. INTRODUCTION

Ideal power switching devices should have characteristics of a low on-state voltage, a fast switching speed and a small gate input power to be supplied by trigger circuit. In spite of many works to approach the ideal power switch, the conventional devices, such as bipolar transistors (BJT), gate turn-off thyristors (GTO), power MOSFET's do not satisfy the requirements completely. Drawbacks of those devices are a low switching speed and a large input power for the bipolar devices (BJT, GTO), and a high on-state voltage for the MOSFET's. Recently, the Insulated Gate Transistor(1) (or COMFET(2) or Bipolar-mode MOSFET(3)) has been proposed. This is regarded as a functionally integrated device which consists of an nMOSFET and a pnp transistor(4). The device structure is similar to that of the vertical MOSFET except for an additional emitter which brings about a low on-state voltage. A drawback of the IGT is latch-up phenomenon inherent to the device structure.

This report presents another bipolar-MOS integrated device MGT, which is free from latch-up phenomenon.

2. DEVICE STRUCTURE

The MGT (MOS-Gated Transistor) is an integrated device which consists of one bipolar transistor and two MOSFET's. The equivalent circuit of the MGT is shown in Fig. 1(a)(5). The output stage is the BJT Q_0. The MOSFET's Q_1 and Q_2 serve for the driver of the BJT Q_0. They turn on alternately, according to their gate voltage signals as shown in Fig. 1(b). The MOSFET Q_1 supplies the base current for Q_0 in order to turn on and keep on-state. On the other hand, the MOSFET Q_2 provides low resistance by-pass between the emitter and the base of Q_0 during the turn-off period T_2. By turning-on of Q_2, turning-off action of Q_0 will be accelerated as a result of shunting a part of the output current through the by-pass Q_2. Besides, blocking voltage of the MGT becomes equal to the collector-base breakdown voltage BV_{CBO} of Q_0, not to the collector-emitter breakdown voltage BV_{CEO}. This allows thiner base width than that of the conventional BJT for the same blocking voltage. Consequently, the MGT can be expected to have a low on-state voltage, a faster switching speed than the BJT, and a high input impedance equal to the MOSFET.

The structure of a unit MGT is shown in Fig. 2. As can be seen in this Fig. 2, the MGT contains no parasitic thyristor. Actual device consists of as many units as required from current specification and termination area. The features of this structure are as follows:

(1) The MOSFET Q_2 is arranged next to Q_0 so that

the n^+ emitter of Q_0 serves also for its source in order to save chip area.

(2) The MOSFET Q_2 is layed out along the periphery of the emitter stripe of the Q_0 in order to avoid current localization during turn-off period.

3. EXPERIMENT

Samples of the unit MGT were prepared by using the fabrication prosesses similar to those of the standard vertical DSA MOSFET. The active area of the devices is 0.038 mm^2, not including edge termination area. Blocking voltage of the samples was designed for 400 V. The gate threshold voltage of the samples was about 2V, both for the MOSFET's Q_1 and Q_2. A typical output characteristics of the MGT is shown in Fig. 3. The gate voltage of about 10V is required for higher current. Current capability of the MGT will be determined by the base current supplied by Q_1 and the current amplification factor h_{FE} of the BJT Q_0. The drivability of Q_1 depends on the area ratio of Q_1 to Q_0, while the h_{FE} can be controlled by the doping level of the base layer of Q_0. In order to determine the best range of device factors, samples of the unit MGT with various Q_1/Q_0 area ratio and base acceptor doping were fabricated. Fig. 4 shows the relation between the Q_1/Q_0 area ratio and the current density of those samples measured at collector-emitter voltage of 2V. It can be seen that the current density reaches maximum for the Q_1/Q_0 area ratio of about 0.4, regardless of the base dose. Considering the effect of base dose to turn-off time, the Q_1/Q_0 area ratio of 0.4 and base dose of 8×10^{13} cm^{-2} were adopted for the samples mentioned below. A forward conduction characteristics of the MGT is shown in Fig. 5. At room temperature, current density of the MGT is 90 A/cm^2 for forward voltage drop of 2V. This current density is about 3 times higher than that of the MOSFET and comparable to that of the BJT designed for the same blocking voltage.

Switching characteristics of the sample MGT's were measured with a resistive load. Fig. 6 shows temperature dependence of the turn-on times of the MGT. The turn-on time t_{on} of the sample was less than 0.3 μs at temperature range of 25∼150°C. Fig. 7 shows typical waveforms of the sample MGT with and without driving Q_2. The turn-off time t_{off} of the MGT with Q_2 driving is 0.3 μs, whereas that without Q_2 driving is 1.5 μs. This shows clearly that Q_2 is effective to speed up turn-off action of the device. The temperature dependence of turn-off times of the MGT is shown in Fig. 8. Turn-off time t_{off} of the MGT was less than 0.8 μs even at 150°C.

4. CONCLUSION

A new MOS-gate transistor MGT which integrates one bipolar transistor for the output stage and two MOSFET's for the driver on a silicon wafer was proposed. Basic characteristics of the MGT have been revealed by experimental studies using the unit MGT with blocking voltage of 400V. It has been confirmed that the MGT has characteristics of a high current density equal to the BJT and a shorter turn-off time than the BJT designed for the same blocking voltage. This characteristics are brought about by turning-on the MOSFET Q_2 connected between the emitter and the base of the BJT Q_0 during the turn-off period. The MGT can be used for an output stage in power IC's as well as for a discrete power switch.

5. ACKNOWLEDGEMENTS

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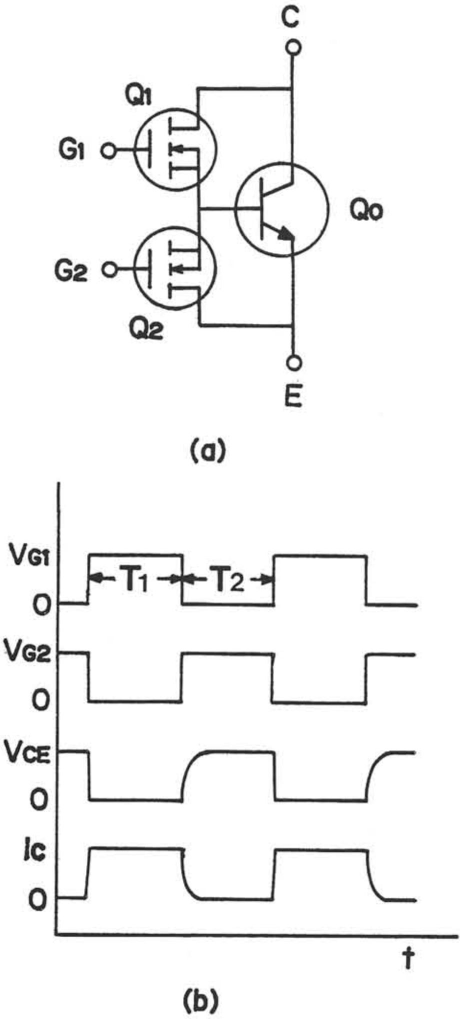

Fig.1 Equivalent circuit and operational time sequence of an MGT.
(a) Equivalent circuit.
(b) Time sequence.

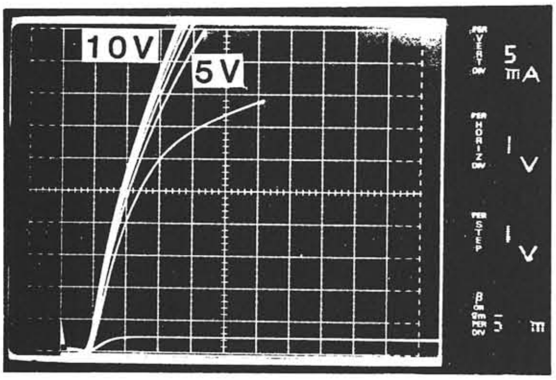

Fig.3 Static output characteristics of an MGT.

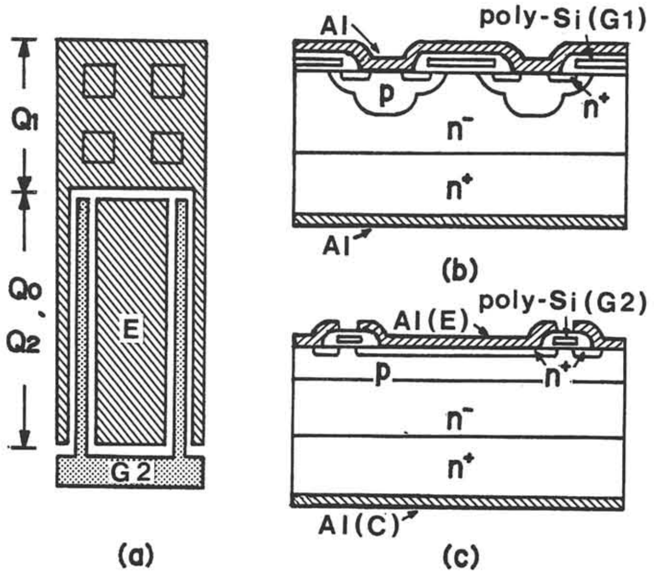

Fig.2 Structure of a unit MGT. (a) Top view.
(b) Cross section of the MOSFET Q_1.
(c) Cross section of the BJT Q_o and MOSFET Q_2.

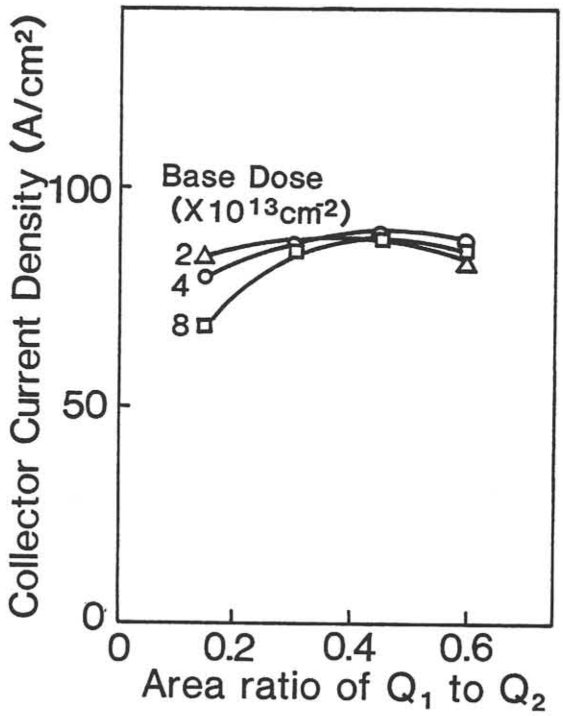

Fig.4 Conduction current density vs area ratio of Q_1 to Q_o. Gate voltage of the Q_1 is 10 V.

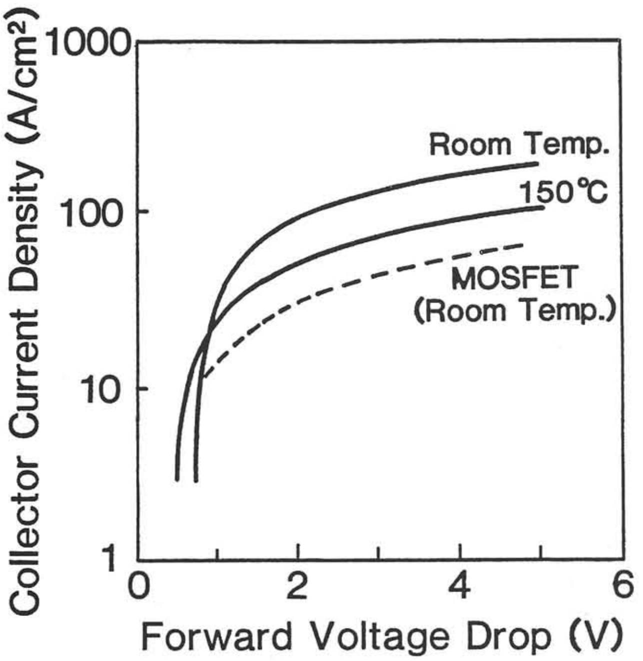

Fig.5 Forward conduction characteristics of an MGT with a blocking voltage of 400 V. Gate voltage of the Q_1 is 10 V.

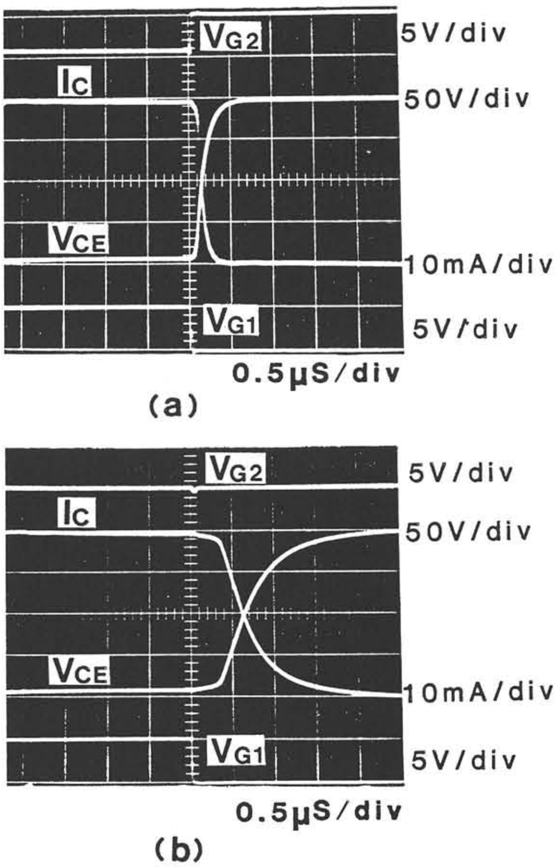

Fig.7 Turn-off waveforms of an MGT.
(a) With driving the MOSFET Q_2.
(b) Without driving the MOSFET Q_2.

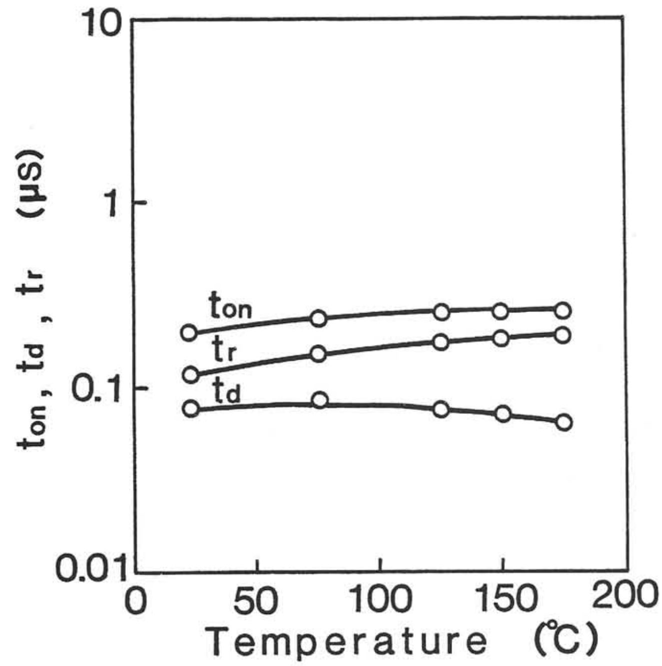

Fig.6 Temperature dependence of turn-on times t_{on}, t_d, t_r of an MGT.

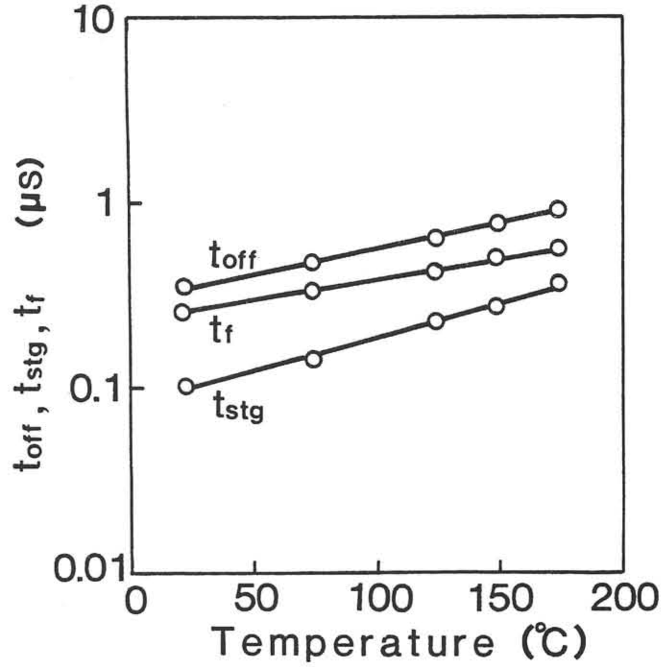

Fig.8 Temperature dependence of turn-off times t_{off}, t_{stg}, t_f of an MGT.