CURRENT STATUS FOR BIPOLAR-MODE MOSFETs (IGBT)

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1. Introduction

Bipolar-Mode MOSFETs[1] were invented only 6 years ago[2], and evolved rapidly because they revealed significantly low on-resistances[3] and high switching speed[4] in addition to high breakdown voltage[1]. The only serious drawback associated with this device is the parasitic thyristor latch-up and resultant loss of gate controllability. In the early development stage, the device latched-up only in a few hundred amperes. However, a unique design principle[5] for Bipolar-Mode MOSFETs has practically eliminated latch-up problems and attained even greater SOA[6] than for conventional transistors while still retaining all the superior characteristics.

In the present paper, a unique design for Bipolar-Mode MOSFETs will be presented together with electrical characteristics and their applications.

2. Unique Features for Bipolar-Mode MOSFETs

Figure 1 shows the basic structure for Bipolar-Mode MOSFETs. If a positive gate voltage is applied, an induced channel layer beneath the gate electrode allows electrons to flow from the N^+ source into N-base and finally to the P^+-drain. This electron flow induces hole injection from the P^+-drain into the N-base, resulting in conductivity modulation in the N-base and, consequently, low on-resistances.

The source electrode shorts the P-base and the N^+-source, making the parasitic NPN transistor inactive. Thus, if the gate voltage is reduced to zero, electron channel current ceases, leading to device turn-off. However, if current density is excessively high, the parasitic NPN transistor becomes activated and, finally, the parasitic thyristor latches-up. The device cannot be turned-off by the MOS gate, once the parasitic thyristor latches-up.

Bipolar-Mode MOSFETs have successfully achieved non-latch-up characteristics by setting the latch-up current level far above the device saturation current for 15 V gate voltage, based on the following technologies.

(1) Stripe source geometry for preventing local parasitic thyristor latch-up[1][7].

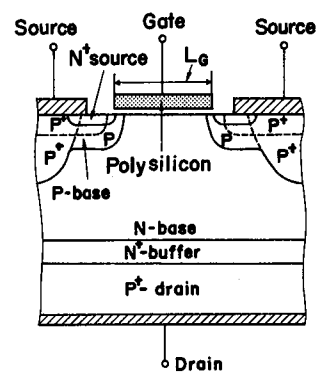

Fig. 1 Cross sectional view of Bipolar-Mode MOSFETs

(2) Triple P-base diffusion for a large latch-up current
(3) Optimized N-buffer for high switching speed[1]. The developed Bipolar-Mode MOSFETs exhibit the following excellent characteristics.
(a) Maximum controllable current is far above the saturation current for 15 V gate voltage[6]. (Non-latch-up characteristics)
(b) Switching speed for 25℃ is comparable to that for power MOSFETs.[4]
(c) No reduction in reverse SOA is caused by a negative gate bias.

3. Trade-off Relation

The trade-off relation between forward voltage and switching-off time are important characteristics from a device design viewpoint. Improvement in trade-off characteristics can be achieved by various methods.

Source-gate geometry optimization is more important for Bipolar-Mode MOSFETs than the conventional power MOSFETs because it influences not only forward voltage but also non-latch-up characteristics. Especially, total channel width and gate polysilicon width, L_G (see Fig. 1 for definition), are to be optimized.

Adopting an N-buffer layer significantly improves forward voltage and fall-time trade-off relation because a narrow N-base can be used for the same breakdown

voltage. Optimally high N-buffer impurity concentration further improves switching speed as well as leakage current since it achieves high switching speed with a high N-base carrier lifetime. Electron irradiation was used for lifetime control with an optimized N-buffer.

Figure 2 shows typical trade-off relations for 500 V and 1000 V devices. Operation current density for 1000 V devices is reduced to almost a half of that for 500 V devices, while still attaining still a good trade-off relation.

4. Safe Operating Area

Non-latch-up characteristics were attained by a unique design principle for Bipolar-Mode MOSFETs. They were attained by setting latch-up current level far above the device saturation current for 15 V gate voltage. Owing to this design principle, maximum current capability is even larger than that for conventional bipolar transistors with the same chip size.

Figure 3 shows the assured SOA for 1000 V 50A devices. SOA is sufficiently large so that the devices can be used in the same way as conventional transistors.

Figure 4 shows 100 A turn-off waveforms with a 5 μH pure inductive load. 1000 V 50 A devices can turn-off 100 A current even under sustaining mode.

Another important device characteristic is tolerance for sudden external load shortcircuit. If external load is shortcircuited, devices have to withstand a high current and high voltage condition for a short time period until a protection circuit begins to operate. Figure 5 shows experimentally simulated waveforms for sudden load shortcircuit, using a circuit shown in Fig. 6. A 1000 V, 50 A device can withstand more than 400 A drain current and 800 V drain voltage for 10 μsec. These characteristics are sufficient for device protection from sudden load shortcircuit.

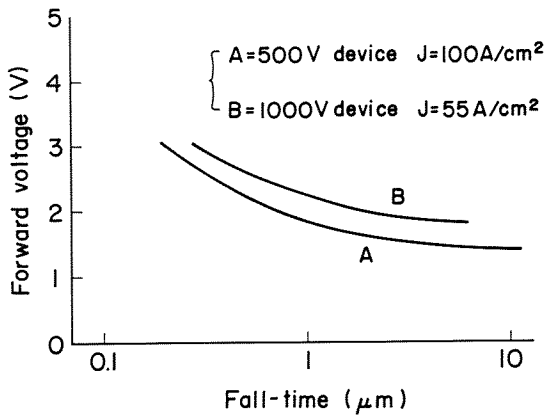

Fig. 2 Typical trade-off relation between voltage and fall-time

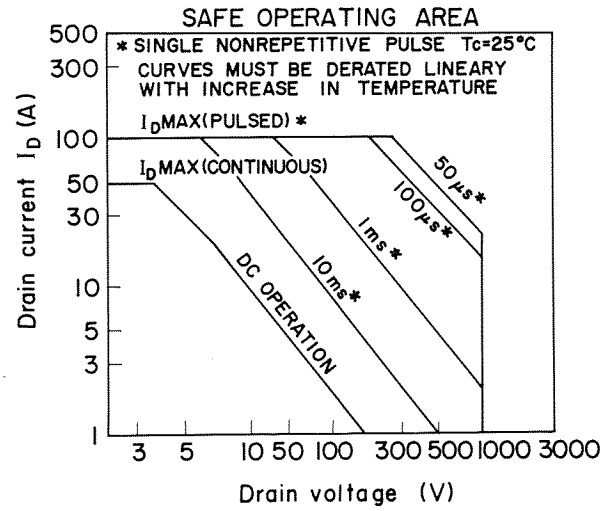

Fig. 3 Assured safe operating area for 1000 V, 50 A devices

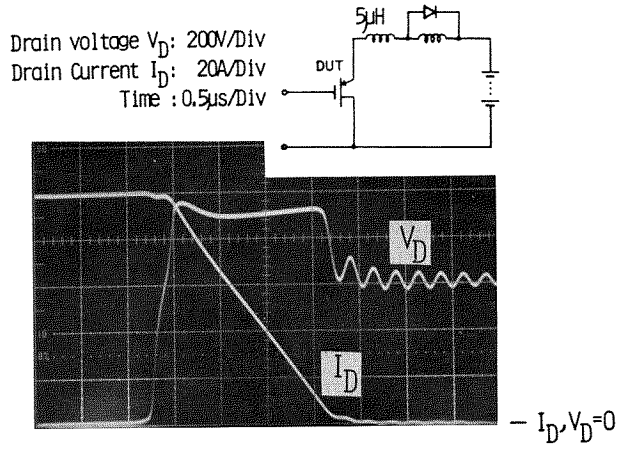

Fig. 4 Typical 100 A inductive turn-off waveforms for a 5 μH inductance load

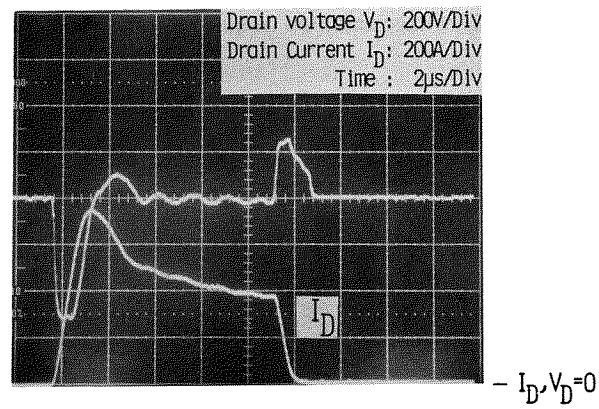

Fig. 5 Experimentally simulated waveform for sudden load shortcircuit. Drain current exceeded 700 A

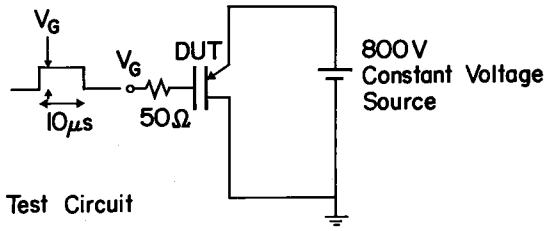

Fig. 6 Experimental circuit for Fig. 5

5. Other Electrical Characteristics and Device Applications for Inverters

Typical inductive turn-off storage-time and fall-time are 0.6 μs and 0.3 μs, respectively. These high speed switching characteristics are suitable for inverter applications. Figure 7 shows a typical circuit diagram for voltage source inverters. Bipolar transistors cannot attain high frequency switching because of their long storage times. Bipolar-Mode MOSFETs realized 15 or 20 kHz operation for PWM control, successfully improving inverter output characteristics, for example, reducing output current ripples. Thus, inverter systems equipped with Bipolar-Mode MOSFETs attained low noise motor control. Figure 8 compares two noise frequency spectra, each of which was generated from the same synchronous motor driven by an inverter with Bipolar transistors or driven by an inverter with Bipolar-Mode MOSFETs. Switching frequencies were 5 kHz and 15 kHz for Bipolar transistors and for Bipolar-Mode MOSFETs, respectively. Noises due to motor-driving current ripples were significantly reduced by adopting Bipolar-Mode MOSFETs for an inverter.

6. Conclusion

Bipolar-Mode MOSFETs successfully achieved high current, high voltage and high frequency switching capabilities together with practical non-latch-up characteristics. They even have a sufficiently large safe operating due to protect themselves from sudden external load short-circuit. Bipolar-Mode MOSFETs are suitable for use in inverters to realize low noise motor control.

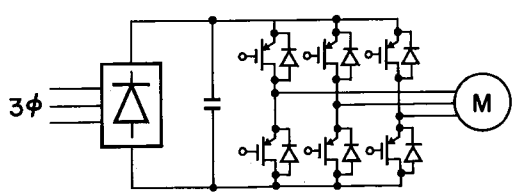

Fig. 7 Typical circuit diagram for voltage source inverters

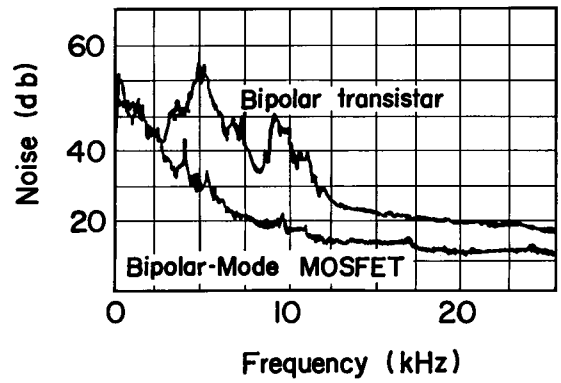

Fig. 8 Comparison in noise frequency spectra

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