MULTI-CHANNEL SOI LATERAL IGBTS WITH LARGE SOA

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Abstract

We report, for the first time, the development of 5 ampere multi-channel lateral IGBTs on SOI. The new LIGBTs are characterized by plural number of parallel stripe poly-silicon gates and resultant plural number of channels, which enhances electron injection and attains a large current capability. The developed LIGBTs conduct the current density over 120 A/cm^2 at the drain voltage of 3V and simultaneously achieve the fall-time below 300ns . The LIGBTs have excellent current capability and short circuit withstanding capability of DC300V with 500 A/cm^2 of drain current even at 200°C.

I. Introduction

Lateral IGBTs fabricated on SOI are attractive devices for use in high voltage power ICs. However, conventional LIGBTs have suffered low current turn-off capability. In this paper, we propose new IGBTs, called "multi-channel LIGBT", for excellent maximum controllable current.

Figure 1 shows the cross-sectional and plane views of a new LIGBT. The new LIGBTs are characterized by two parallel stripe poly-silicon gates and resultant three parallel channels, which enhances electron injection and attains a larger current capability. The forward voltage drop depends on the width, W_{p1} (defined in the Fig.1), of the first p-well diffusion and the width of the second poly-silicon gate, W_{G2}.

Figure 2 compares the calculated current-voltage curves for the conventional and multi-channel LIGBTs. The solid and dotted lines in this figure represent the results for the multi-channel LIGBTs which have two different first p-well width, W_{p1}. It is clear that multi-channel LIGBTs with a smaller W_{p1} value conducts 1.8 times as large a current as the conventional single-gate LIGBT at the forward voltage drop of 3V. The calculated results also indicated that the second gate width should be sufficiently large so that the multi-channel concept effectively works and the IGBT is able to obtain a sufficiently low forward voltage.

To minimize the switching loss, we improved the switching characteristics of the IGBTs. Because the fall time depends on the hole injection from anode side, we adapted a new drain structure which consists of a shallow p-diffusion layer to control the hole injection and a p+ contact diffusion layer to reduce contact resistance with an optimized n-buffer layer.

The present paper also discusses Safe Operation Area of the LIGBTs. The hole current can be removed through the two p-wells during conduction state, thus, significantly increasing the latch-up current density. We further show that an SOA model, we have proposed for the SOI devices [1], agrees with the experimental results.

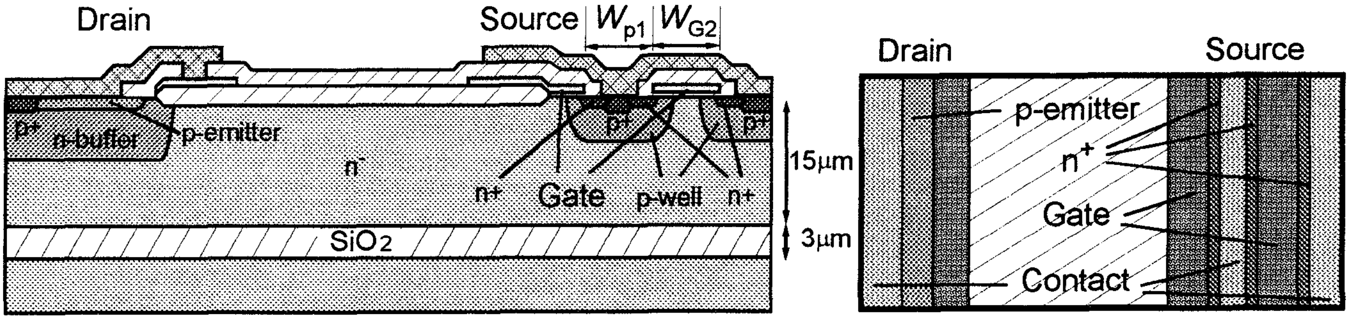

Fig.1 Cross sectional and plain view of a multi-channel lateral IGBT on SOI.

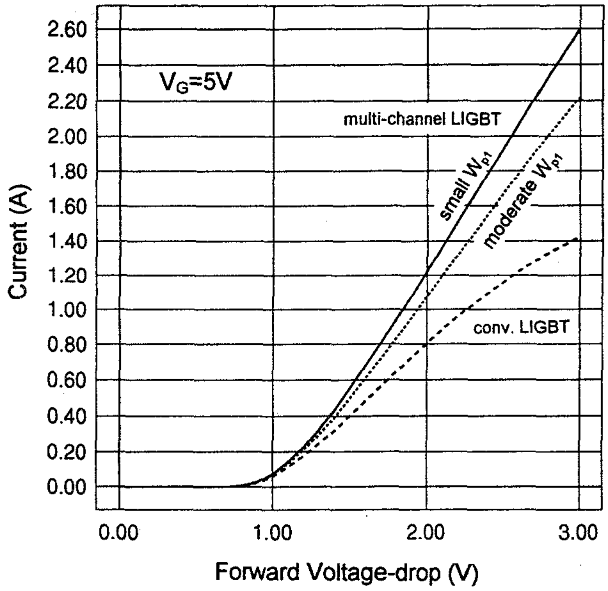

Fig.2 Calculated current-voltage curves for the conventional LIGBT (broken line) and the multi-channel LIGBTs with the two different W_{p1} (solid and dotted lines).

II. Device Fabrication

The devices were fabricated using 1.2 μm design rule CMOS process on SOI of a 10μm or 15μm thick n-type silicon with the 1.0×10^{12} cm^{-2} impurity dose over 2μm or 3μm thick buried oxide. The obtained breakdown voltages ranged from 320V to 520V. The channel of LIGBTs was not formed by using self-alignment processes of DMOS but by using p-well diffusion of CMOS in order to simplify the processes. Since the gate oxide thickness was 25nm, the LIGBTs can be operated at the gate drive voltage of 5V. The two metal electrode layers, of which the thickness were 1μm and 2μm, were used to reduce the inter-connection resistance. Figure 3 shows the top view of the fabricated 2.5A rated device which includes twelve multi-channel LIGBTs.

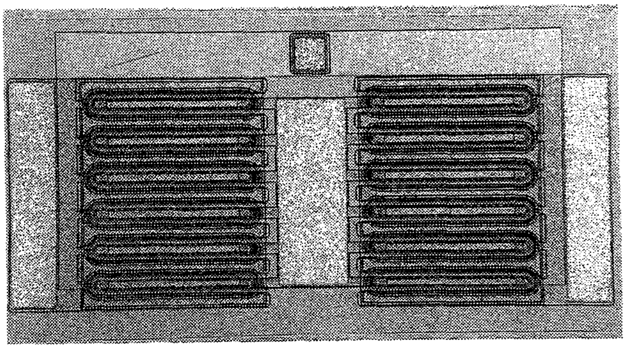

Fig.3 Top view of the fabricated 2.5A rated device which includes twelve multi-channel LIGBTs.

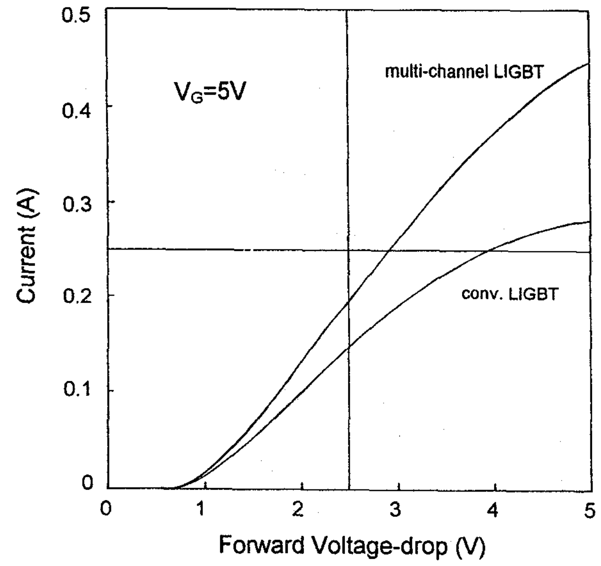

Fig.4 Experimentally obtained current-voltage curves for the conventional and multi-channel LIGBTs.

III. Electrical Characteristics

A. On-State Characteristics

We first fabricated multi-channel LIGBTs with a moderate W_{p1} value. Figure 3 shows the experimentally obtained current-voltage curves for the conventional LIGBT and the multi-channel LIGBTs. The fabricated multi-channel LIGBTs have attained 1.5 times as large a current as the conventional single-gate LIGBT. It was found that the device current increased linearly with the width of the second poly-silicon gate (W_{G2}). The current at 200°C decreased by 20% than that at room temperature. The on-state characteristics did not mainly depend on the thickness of SOI.

B. Switching Characteristics

The multi-channel IGBTs had the switching characteristics similar to the conventional ones. Figure 5 shows the measured 5A turn-off waveforms of 2.5A rated devices (see Fig. 3). The waveform for the applied voltage of 200V had the terrace shape tail current because of the induced p-channel on the buried oxide. The switching fall-time for the multi-channel IGBT with a conventional drain structure was 900 nsec at 150°C.

The switching fall-time for multi-channel IGBTs with the new drain structure changed 200ns to 600ns according to the impurity dose of the shallow p-emitter and its layout as well as the n-buffer layer dose. Figure 6 shows the measured typical turn-off waveforms of a LIGBT with the shallow p-emitter.

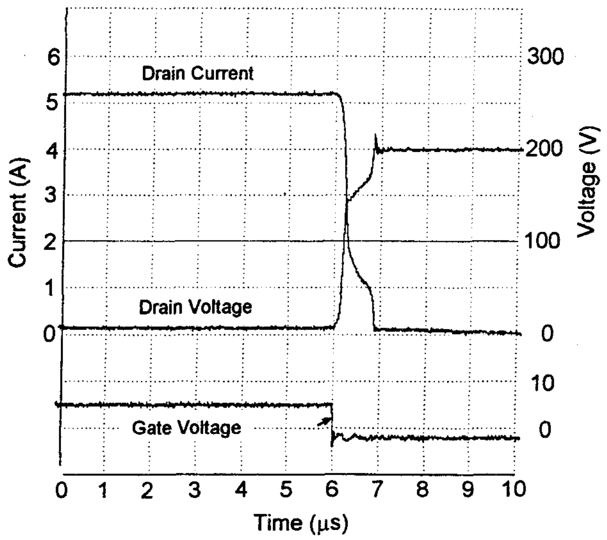

Fig.5 Measured 5A turn-off waveforms of 2.5A rated device under 200V and 40Ω resistive load.

C. Improvement of Trade-Off

The trade-off curves for the conventional LIGBTs (open triangles) and the multi-channel LIGBTs with the shallow p-emitter (open squares) was shown in Fig.7. Adopting the shallow p-emitter improved the switching characteristics, however, decreased the current density for the fall time below 500ns.

We adopted new designs in order to increase the current density. As an example of them, we adopted the overlap source structure in which the second gate was shared by the two neighboring IGBTs. Figure 9 shows the cross sectional view of the improved structure of multi-channel LIGBTs. Owing to the overlap source structure, the current density was improved by 30%. We also optimized the drain structure and finally obtained the LIGBTs which has current density of 120 A/cm^2 and the fall-time of 300ns at V_D=3V and V_G=5V (open circles in Fig.7).

IV. Safe Operating Area

We have already proposed Reverse Safe Operating Area model for double injection devices on SOI [1]. In this section, we show that the model is valid for IGBTs. Figure 9 shows a typical short-circuit withstanding waveforms of 1A rated device at 200°C, where devices were directly connected to 300V DC source. The arrow in this figure shows the hole current after turn-off. The dynamic breakdown voltage during turn-off transients depends on the amount of the hole current because the net positive charge in the depletion layer exceeds the optimum charge determined by Resurf principle.

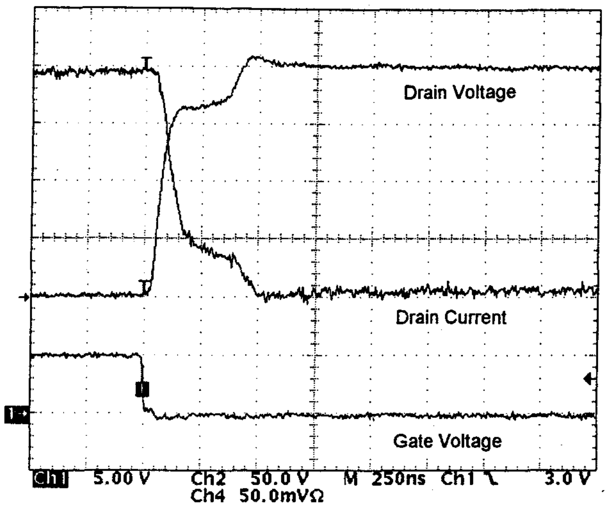

Fig.6 Measured turn-off waveforms for a multi-channel IGBT with the shallow p-emitter layer. (time: 250ns/div, drain current: 50mA/div, drain voltage: 50V/div)

The maximum current can be estimated by considering that the SOI device is designed so that 7.0×10^{11} cm^{-2} positive charge is reserved for the hole current. The calculated maximum hole current for the device of 1cm channel width is 1.1A, which agreed with the experimental results.

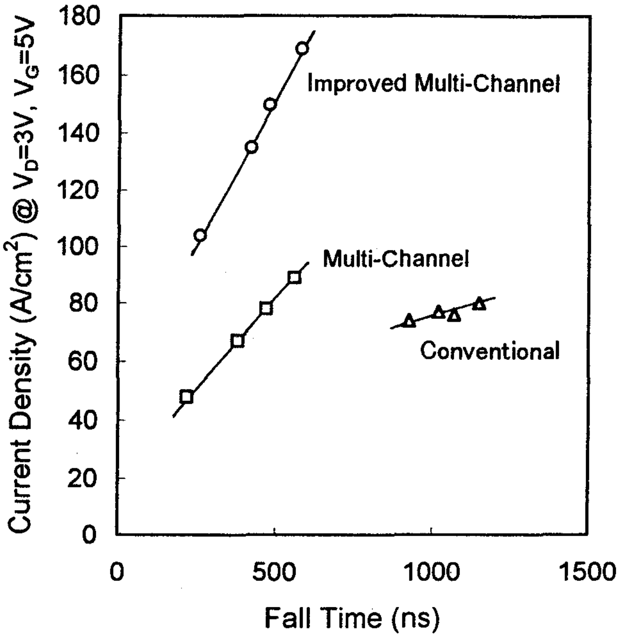

Fig.7 Trade-off curves of the fabricated LIGBTs for conventional (open triangles), multi-channel with the shallow p-emitter (open squares), and improved multi-channel structures (open circles).

Figure 10 shows the current-voltage curves for the region of an extreme high current density of 500A/cm^2 and a high voltage of 300V, which were measured under the short-circuit configuration with a gate voltage as a parameter. The figure shows that the multi-channel LIGBT has extremely good current saturation characteristics even for a high gate voltage of 7V without parasitic thyristor latch-up. The maximum controllable current capability is more than 5A (500A/cm^2) for 1A rated devices at the applied voltage of 300V.

V. Conclusion

We proposed multi-channel lateral IGBTs which are characterized by plural number of parallel stripe poly-silicon gates and resultant plural number of channels. The new LIGBTs have attained 1.5 times as large a current as the conventional single-gate LIGBT. We reported the development of LIGBTs which has the current density over 120 A/cm^2 and the fall time below 300ns at V_D=3V and V_G=5V. The IGBTs have also excellent controllable current capability of 500 A/cm^2. We obtained 5A large current LIGBTs on SOI with 300V short circuit withstanding capability even at 200°C.

Acknowledgment

The authors would like to thank General Manager Makoto Azuma and Dr. Yasuo Ikawa for their support.

References

(1) H. Funaki, N. Yasuhara and A. Nakagawa, "High Voltage Lateral MOS Thyristor Cascode Switch on SOI -Safe Operating Area of SOI-Resurf Devices-," *Proc. of 8th ISPSD*, 1996, p.101.

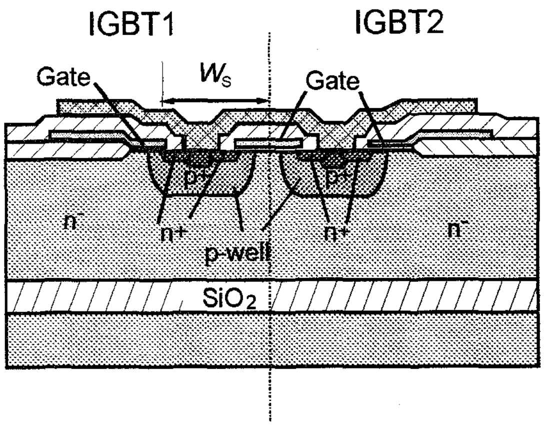

Fig.8 Cross sectional view of the overlap source structure of multi-channel LIGBTs.

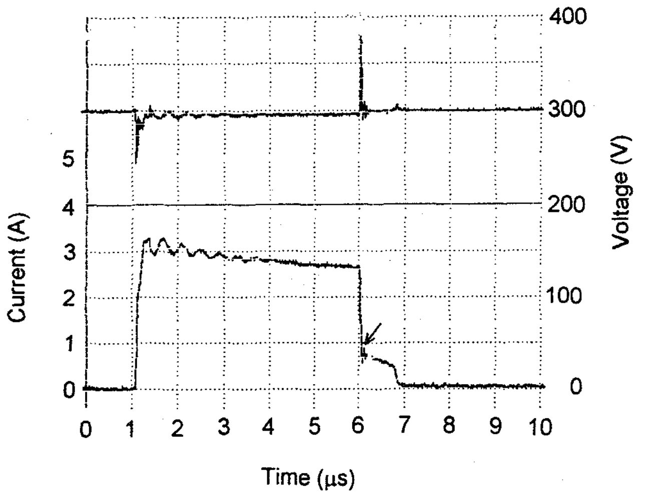

Fig.9 Typical short-circuit withstanding waveforms for 5 μsec duration at 200°C, where devices were directly connected to 300V DC source. The arrow in this figure shows the hole current after turn-off.

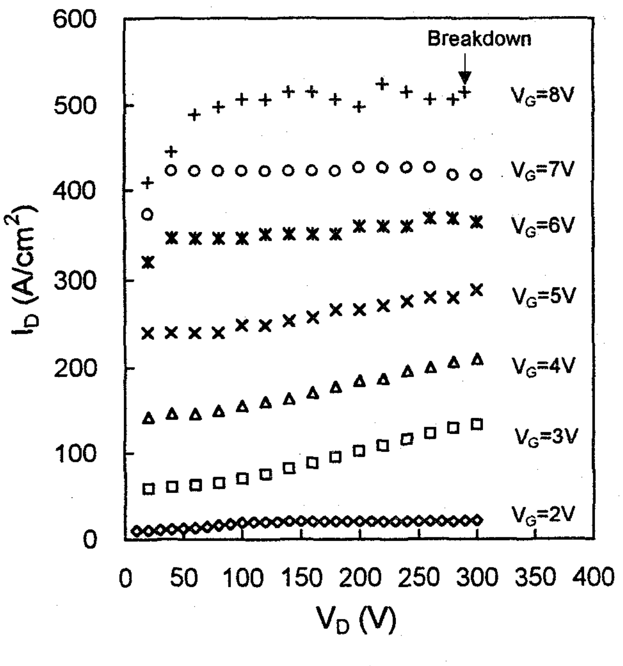

Fig.10 Current-voltage curves of 320V, 200mA rated device under the short circuit configuration with a gate voltage as a parameter.