Proceedings of 1995 International Symposium on Power Semiconductor Devices & ICs, Yokohama 7.3

A Trench-Gate Injection Enhanced Lateral IEGT on SOI

Tomoko Matsudai, Mitsuhiko Kitagawa and Akio Nakagawa
Materials and Devices Labs., Research and Development Center, Toshiba Corp.
1, Komukai Toshiba-cho, Saiwai-ku, Kawasaki 210, Japan
Phone: 044-549-2139, Fax: 044-549-2259

Abstract

This paper reports, for the first time, that lateral IGBTs with an injection enhanced multiple trench gate structure (LIEGT) on SOI successfully achieved both a low forward voltage drop and a high switching speed. The current density of LIEGTs with two trench gates is more than twice as large as that of conventional lateral IGBTs on a 10 μm SOI. Closely spaced deep trench gates result in carrier storage under the trench gates and enhance lateral carrier flow. Although the switching speed of 10 μm SOI LIEGTs is as fast as that of LIGBTs, its switching loss can be reduced. Thus, the electrical characteristics of lateral trench gate IEGTs on SOI is quite good.

1. Introduction

High voltage SOI technology has been attracting interest because high voltage devices can be integrated with control and protection circuits, even with an MPU, at low cost. High voltage lateral IGBTs have already been developed for such applications. Furthermore, it has been theoretically [1] and experimentally [2] shown that lateral IGBTs fabricated on a thin SOI exhibit high switching speed. However, they have low current capability in comparison with vertical IGBTs because conventional lateral IGBTs have only a surface channel and the voltage drop along the channel is large for a large current. Recently, the development of lateral IGBTs with trench gates, which successfully increased the latch up current level, has been reported [3,4]. However, the forward voltage drop was unexpectedly worse.

On the other hand, for vertical discrete devices, the injection enhanced trench gate device (IEGT) was successful in maintaining a low forward voltage drop, even for 4500 V devices, by achieving a thyristor-like carrier distribution [5].

The present paper reports, for the first time, that the same structure works as well for lateral trench gate IGBT structures (LIEGTs). The forward voltage drop and the turn-off characteristics of an LIEGT on SOI is also discussed, using the simulation results.

2. Forward current-voltage characteristics

2-1. Device structure

Figure 1 shows a cross section of the proposed trench gate structure in a lateral IEGT on SOI (structure a). The structure of the anode region is the same as that of conventional LIGBTs. The SOI layer thickness was 10 μm on a 2 μm thick bottom oxide film. The high resistivity drift regions were 55 μm in length and were uniformly doped by blanket implants. The impurity dose was chosen to be

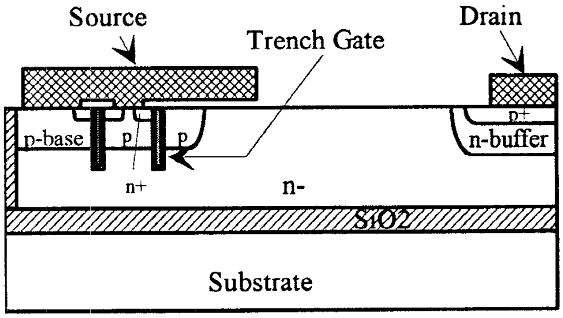

Fig. 1 (structure a)
Trench-gate lateral IEGT structure on 10 μm SOI with two trench gates

$1.0\times10^{12}cm^{-2}$ for a high breakdown voltage. The concentration of the drift region was $1.0\times10^{15}cm^{-3}$. Two trenches for the gate electrode were formed parallel to the edge of the p^+ drain region. The trench width and depth were 1 μm and 5 μm, respectively. The three channel regions were formed on the three out of four sidewalls of the two trenches.

2-2. Forward characteristics

Simulations were carried out for the LIEGT and a conventional LIGBT on 10 μm SOI using a device simulator TONADDE 2C program. Figure 2 shows the calculated current-voltage characteristics. The applied gate voltage was 12 V, and the source and the substrate were set to ground potential. The curve (a) shows the current-voltage relation of the proposed IEGT shown in Fig. 1. It was found that the proposed LIEGT (Fig. 1) conducts a drain current twice as large as that of the conventional LIGBT for the same forward voltage drop of 3 V. The latch up current level is also increased due to a decreased p-base resistance in the vertical trench structure.

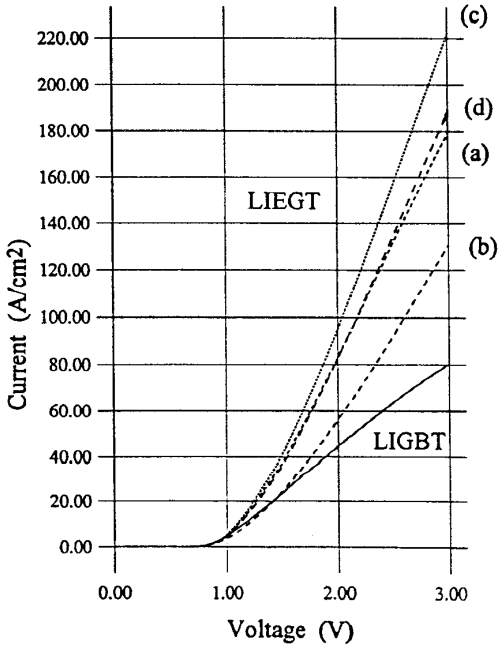

Fig. 2
Current-voltage characteristics of the LIEGTs and the conventional surface gate LIGBT on a 10 μm SOI

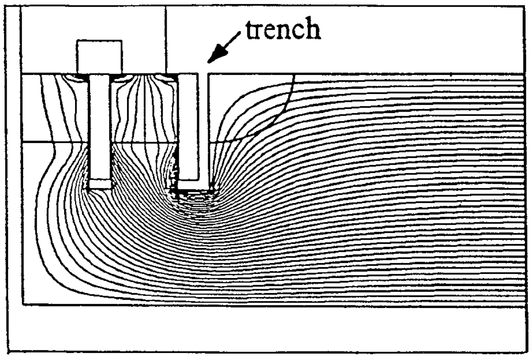

Fig. 3
Calculated current flow lines for the source region of Fig. 1

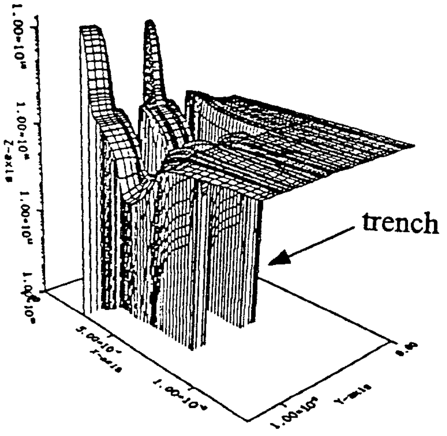

Fig. 4
Calculated three-dimensional hole density distribution for the source region of Fig. 1

Figure 3 shows the calculated current flow lines for the source region of an LIEGT (Fig. 1). It was found that all three channels are effectively active. Figure 4 shows the calculated three-dimensional hole density distribution for the source region. It is seen that the hole density is accumulated beneath the trench gates. Figure 5 compares the two-dimensional hole density distributions for the drift regions of the simulated LIEGT and LIGBT. The hole carrier concentration were slowly decreased in the drift region from the drain towards the source for both structures. However, it was found that the hole density does not decrease completely, but stays above $1\times10^{16}cm^{-3}$ even at the front of the source region in

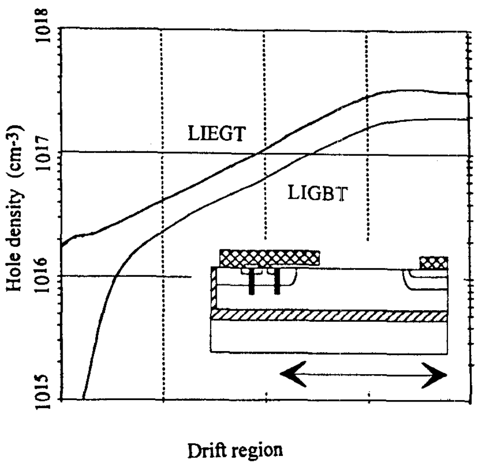

Fig. 5

Calculated two-dimensional hole density distribution for the drift region of Fig. 1

the case of LIEGTs, whereas the hole density rapidly decreases to a very low value in LIGBTs. Closely spaced trench gates result in carrier storage under the trench gates and enhance lateral carrier flow. Thanks to the enhanced carrier storage under the trenches, multiple trench gates, which are placed in parallel, contribute equally to the injection of electrons into the n-drift layer, thus reducing the forward voltage drop.

Several modified LIEGTs were also examined. Figure 6 shows a modified LIEGT (structure b) where an additional source contact is formed to the p-base in front of the first trench gate. As most of the hole current is collected without flowing beneath the trenches, for this structure, the latch up current is expected to be increased. In addition, the drain current is still 1.6 times larger than in conventional LIGBTs for the same drain voltage because of the two narrowly spaced trench gates.

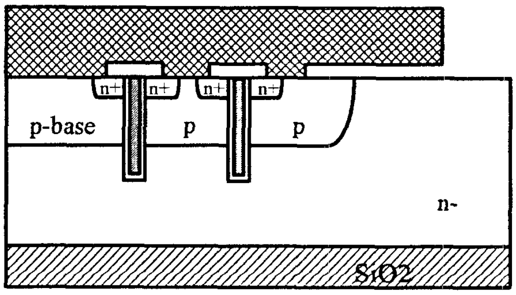

Fig. 6 (structure b)

Trench-gate lateral IEGT structure on 10 μm SOI with a contact to the p-base in front of the first trench gate

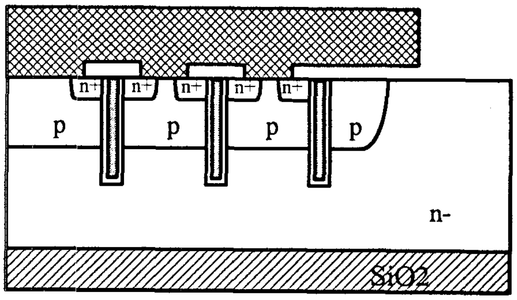

Fig. 7 (structure c)

Trench-gate lateral IEGT structure on 10 μm SOI with three trench gates

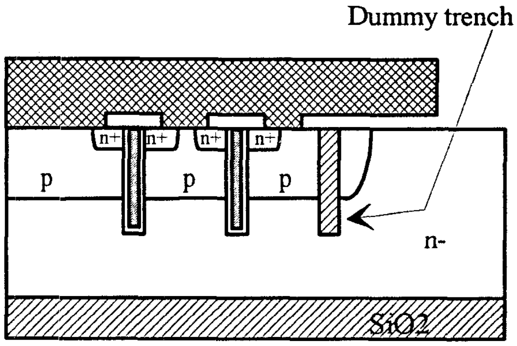

Fig. 8 (structure d)

Trench-gate lateral IEGT structure on 10 μm SOI with two trench gates and dummy trench

Figure 7 shows another LIEGT (structure c) with three trench gates and five channel regions. This LIEGT can handle 2.7 times higher current than conventional LIGBTs for the same device area. The calculated current-voltage curve for this LIEGT is shown in Fig. 2 as curve (c).

Figure 8 shows the fourth LIEGT (structure d) with two trench gates and one dummy trench. The dummy trench was filled with silicon dioxide. Figure 9 shows the calculated current flow lines for the source region of Fig. 8. This structure has four channel regions and a source contact to the p-base in front of the first trench gate. However, the dummy trench effectively reduces the collection of the hole current directly flowing into the source electrode. Therefore, the calculated forward current-voltage characteristic was quite good (see curve (d) in Fig. 2).

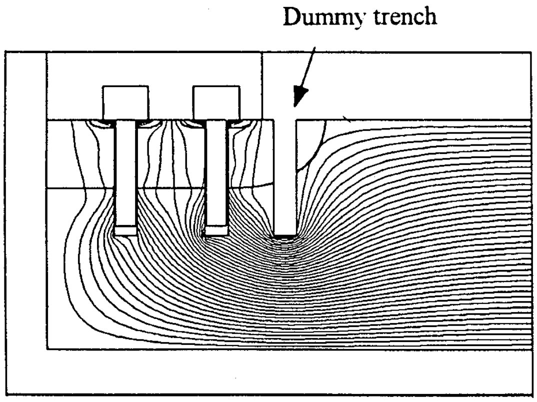

Fig. 9
Calculated current flow lines for the source region of Fig. 8

3. Turn-off characteristics

In this section, switching waveforms for the LIEGT shown in Fig. 8 and a conventional LIGBT are compared. Figure 10 shows the simulated circuit. The initial drain currents for the LIEGT and the LIGBT were 188 A/cm^2 and 80 A/cm^2, respectively, at 3 V forward voltage drop. The lifetimes of both the electron and hole were 1 μsec. A surface recombination velocity of 1000 cm/sec was assumed for the silicon dioxide interfaces. The turn-off simulations were carried out under a resistive load.

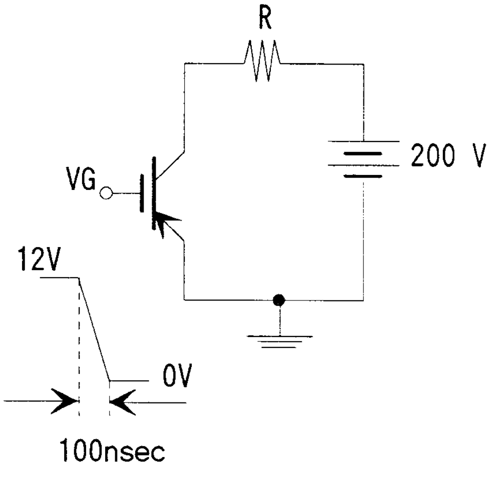

Fig. 10
Turn-off simulation circuit of LIEGT

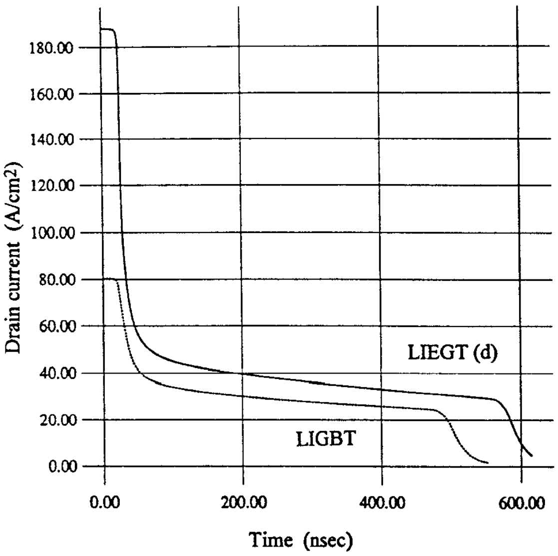

Fig. 11
Simulated turn-off waveforms of LIEGT and LIGBT

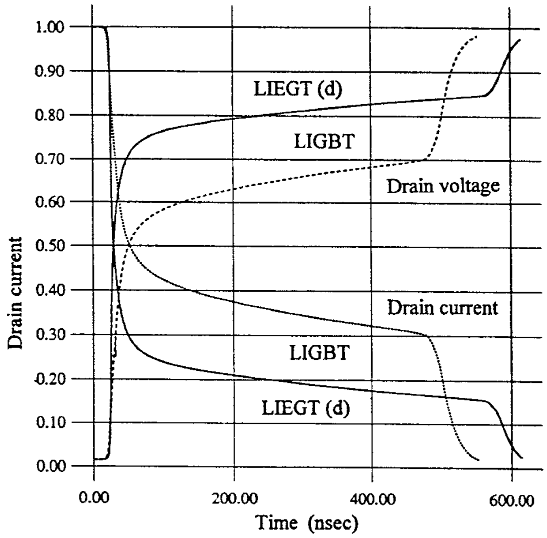

Fig. 12
Normalized turn-off waveforms of Fig 11

Figure 11 shows the calculated turn-off waveforms for the two devices. The turn-off waveforms of the devices on SOI were characterized by a terrace tail current [1]. The calculated fall time for the LIEGT was 560 nsec and that for the LIGBT was 500 nsec. Because of the large initial drain current, the fall time for the LIEGT was a little long. However, if the two devices are compared, with the same current rating of 1 A, the LIEGT shows superior characteristics in terms of lower switching loss. Figure 12 compares the turn-off waveforms for two 1 A devices.

Conclusion

We have numerically verified that the electrical characteristics of the lateral trench gate IEGT achieved lower forward voltage drop than conventional LIGBTs. Forward voltage drop for an LIEGT with two trench gates is only 2.2 V at 100 A/cm^2 current density. Closely spaced deep trench gates result in carrier storage under the trench gates and enhance lateral carrier flow. Furthermore, the turn-off characteristics of these LIEGTs were shown to be quite good. The fall time of the LIEGT was 560 nsec and the turn-off loss was shown to be smaller than that of conventional LIGBTs.

Acknowledgments

The authors are grateful to General Manager Makoto Azuma, Dr. Yasuo Ikawa and Mr. Hiroshi Mochizuki for their continuous interest in this work.

References

[1] Ichiro Omura, Norio Yasuhara, Akio Nakagawa and Yoshie Suzuki, "Numerical analysis of SOI IGBT switching characteristic --Switching speed enhancement by reducing the SOI thickness", 1993 ISPSD, p.248

[2] Norio Yasuhara, Tomoko Matsudai and Akio Nakagawa, "SOI layer thickness and buried oxide thickness dependencies of high voltage lateral IGBT switching characteristics", 1993 SSDM, p.270

[3] Byeong Hoon Lee, Chong Man Yun, Dae Seok Byeon, Min Koo Han, and Yearn Ik Choi, "Improved Latch-Up Characteristics of the LIGBT with the p+ Cathode Well on the SOI Substrate", 1994 SSDM, p.289

[4] D.R.Disney, H.B.Pein, and J.D.Plummer, "A Trench-Gate LIGBT structure and Two LMCT Structure in SOI Substrates", 1994 ISPSD, p.405

[5] M.Kitagawa, Ichiro Omura, Shigeru Hasegawa, Tomoki Inoue and Akio Nakagawa, "A 4500 V Injection Enhanced Insulated Gate Bipolar Transistor (IEGT) Operating in a Mode Similar to a Thyristor", 1993 IEEE IEDM Tech. Digest, p.679