Experimental Verification of Large Current Capability of Lateral IEGTs on SOI

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Abstract

This paper reports, for the first time, the experimentally obtained electrical characteristics of lateral injection enhanced insulated gate bipolar transistors (LIEGTs) on SOI. It is shown that optimized LIEGTs have twice as large a current capability as LIGBTs and attain the same turn-off characteristics. These results show that LIEGTs are attractive for the output devices of high voltage power ICs.

Introduction

High voltage power ICs with dielectric isolation have been a focus of great interest in recent years[1][2]. SOI technology combined with trench isolation is especially attractive because it can integrate high voltage devices with control and protection circuits in the same chip at reasonable cost. Lateral IGBTs (LIGBTs) are frequently used output devices for such power ICs because of the easiness of their gate control. It has been shown that LIGBTs on a thin SOI exhibit high switching speed.

However, current handling capability of LIGBTs is insufficient for use in large power equipment. Recently, new device, injection enhanced insulated gate bipolar transistors (IEGTs) were proposed and reported to have good conduction characteristics as compared with conventional IGBTs[3]. They realize low on-resistance by achieving a thyristor-like carrier distribution. It was shown by numerical simulations that the IEGT principle is also applicable to lateral devices[4]. The present paper reports, for the first time, the experimentally obtained characteristics of lateral IEGTs (LIEGTs) on SOI. It is verified that LIEGTs have large current conduction capability and good turn-off characteristics, which were predicted by the numerical simulation results.

Device structures

Fig.1 shows the cross-sectional view and the plane view of the main part of fabricated LIEGTs. 10 μm thick n-type SOI layers on 2 μm thick buried silicon dioxide layers were used. The SOI layers have the (100) surface. The impurity concentration of the high resistivity n-layer is about $1\text{x}10^{15}\text{cm}^{-3}$. LIEGTs have plural number of trench MOS gates instead of a surface MOS gate. The width and the depth of the trenches are 1 μm and 5 μm, respectively. The depth of the p-base is about 3 μm. The trench gates penetrate through the p-base region and reach the high resistivity n-layer. The structure of the anode region is the same as that of conventional LIGBTs with an n-buffer region. The drift region length is 55 μm. LIEGTs with various trench gate layouts were fabricated. Fig.1 shows an LIEGT, having three trenches, where channels are formed on one

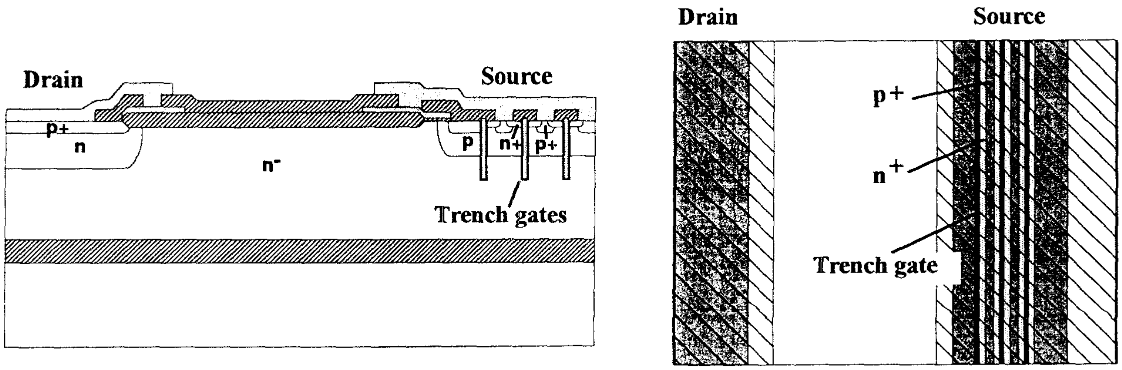

Fig. 1 Cross-sectional and plane views of fabricated LIEGTs

side of the first trench and both sides of the second and the third trenches. The fabrication process was similar to that of LIGBTs. Only trench gate formation processes were added.

Experimental results

A. Breakdown voltage

Fig.2 shows the breakdown characteristics of an LIEGT. The forward blocking voltage of the LIEGTs was 310 V, which was the same as that of LIGBTs fabricated on the same wafer. This value is limited by the one-dimensional vertical structure around the drain region, because the vertical electric field between the n-buffer layer and the substrate is the highest at the off-state. The measured breakdown voltage is in good agreement with the theoretical value calculated by one-dimensional model. Higher blocking voltage is expected by using a thicker buried dioxide layer or a thicker SOI layer. For example, a 14 μm thick SOI layer on a 3 μm thick buried silicon dioxide layer is sufficient for blocking voltage of 500 V.

B. Forward current-voltage characteristics

Threshold voltage for LIGBTs was about 1.3 V and that for LIEGTs was about 2.6 V. Fig.3 compares the current-voltage characteristics of two LIEGTs with different trench gate structures. The applied gate voltage was fixed at 14 V. Fig.4 and Fig.5 show the cathode region of these LIEGTs. The on-resistances of these LIEGTs were higher than predicted. The reason is assumed to be that the trench channel mobility is lower than that of the surface channel because the trench gate formation process is not yet established.

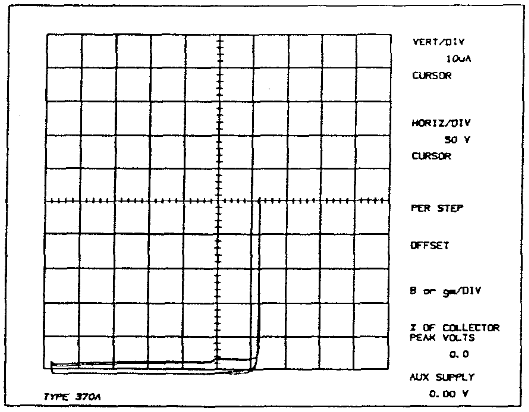

Fig. 2 Forward blocking waveform for the fabricated LIEGT

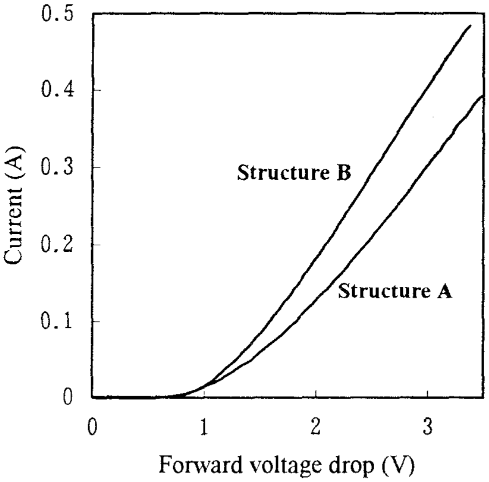

Fig. 3 Current-voltage characteristics for LIEGTs shown in Fig.4 and Fig.5

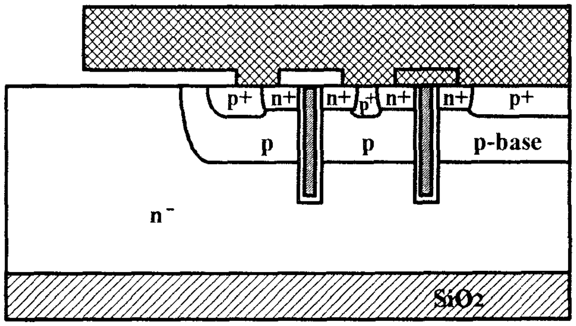

Fig. 4 Cathode region of LIEGT with structure A

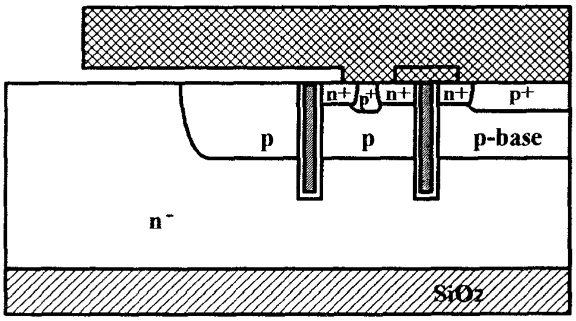

Fig. 5 Cathode region of LIEGT with structure B

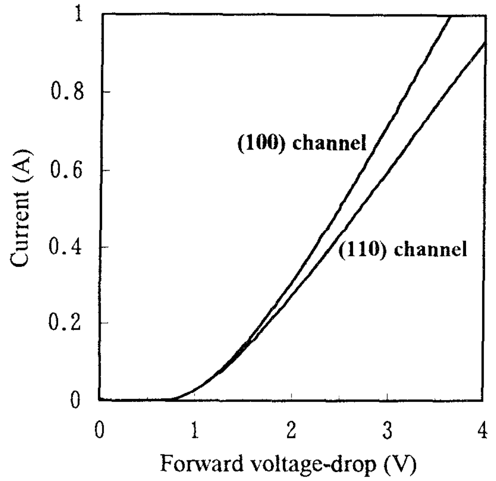

Fig. 6 Current-voltage characteristics for LIEGTs with different channel directions

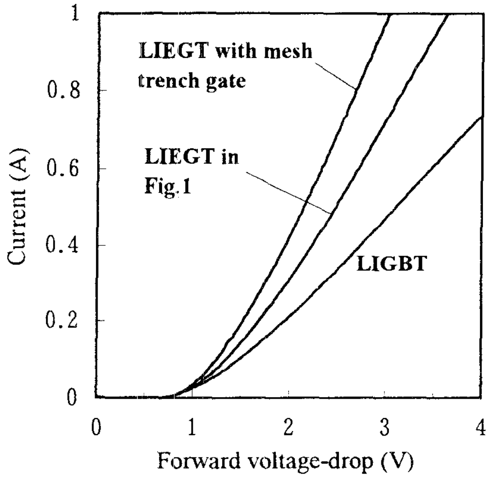

Fig. 7 Current-voltage characteristics for several kinds of LIEGTs and a conventional LIGBT

It was found that that the device with structure B has better characteristics than the device with structure A. This agrees well with the results of the numerical simulation. In the device with structure B, as the source channel contact is not formed in front of the first trench gate, there are a smaller number of channels than in the device with structure A. The hole current cannot flow directly into the source electrode and must go beneath the trenches. This induces the large carrier accumulation or conductivity modulation under the trenches and helps the electron injection from the inner trench gates.

It is thought that the good conduction capability is realized if the channel resistance is well reduced. Choosing appropriate trench wall surface crystal orientation and a larger number of trench channels are practical means for this purpose. Fig.6 shows the comparison between LIEGTs with different trench wall surface crystal orientation, which were fabricated on the same wafer in order to investigate the effect of channel mobility. The orientations of the fabricated trench sidewalls are (100) and (110). The structures of these LIEGTs are the same as that shown in Fig.1. The LIEGT with (100) channel conducts about 20 % larger current than the LIEGT with (110) channel. It is shown that choosing the appropriate channel crystal surface is effective in improving conductance of LIEGTs.

Fig.7 shows the current voltage curves of the LIEGT shown in Fig.1 and the LIEGT which has a mesh-like trench gate layout as seen in Fig.8. Both LIEGTs have (100) channels. The LIEGT with mesh trench gates has about 1.5 times as long a channel width as the LIEGT of Fig.1. Adopting the mesh type trench gate improves current conductance by 35 %. Fig.7 also compares forward current voltage curves of LIEGTs and a conventional LIGBT. The LIEGT with mesh-like trench gates conducts twice as large a current as the LIGBT. The current density per unit device area reaches 490 A/cm^2 for the forward voltage-drop of 3 V.

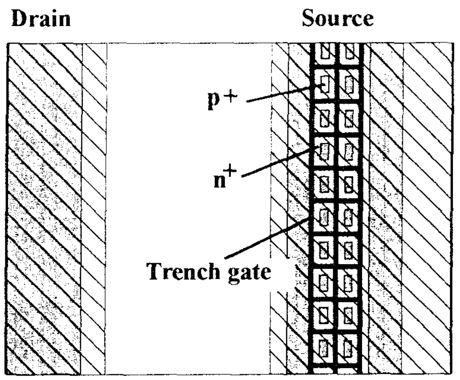

Fig. 8 Plane view of mesh-like trench gate layout

C. Turn-off characteristics

Fig.9 and Fig.10 show the turn-off waveforms for an LIGBT and an LIEGT, respectively. This LIEGT, which has the structure in Fig.1 with (100) channel, can conduct a 55 % larger current than the LIGBT, and attains the same turn-off time. The reason is assumed to be that the increase in conductance is attained mostly by the decrease in channel resistance for electrons, which causes only a little increase of stored carriers.

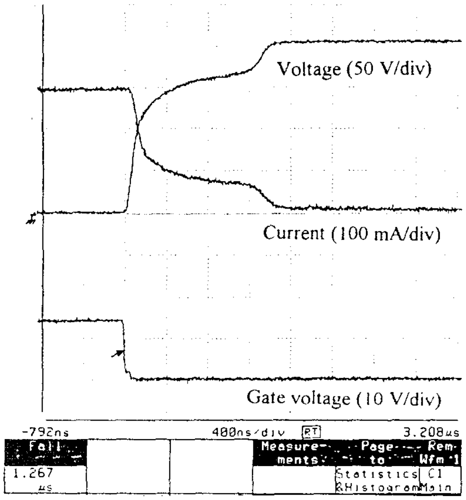

Fig. 9 Turn-off waveforms for an LIGBT

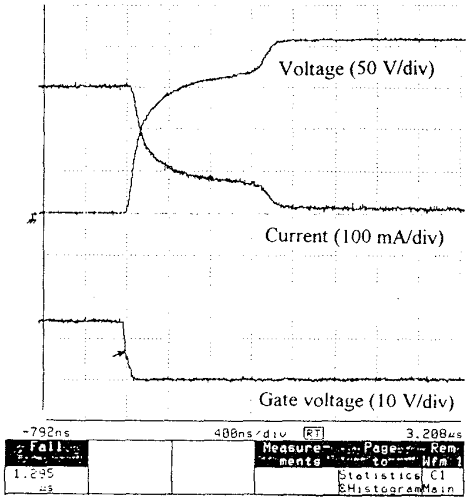

Fig. 10 Turn-off waveforms for an LIEGT

Conclusion

The excellent current capability of LIEGTs was experimentally verified. It was also shown that LIEGTs exhibit switching characteristics as good as those of conventional LIGBTs. These results show that LIEGTs are attractive as output devices of power ICs. They open up the possibility of shrinking power device area, which occupies a large portion of a power IC chip.

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