Simulation of a Novel Lateral Trench Electrode IGBT with Improved Latch-up and Forward Blocking Characteristics

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A new small sized Lateral Trench Electrode Insulated Gate Bipolar Transistor(LTEIGBT) was proposed to improve the characteristics of conventional Lateral IGBT (LIGBT) and Lateral Trench gate IGBT (LTIGBT). The entire electrode of LTEIGBT was replace with trench-type electrode. The LTEIGBT was designed so that the width of device was no more than 19 ㎛. The Latch-up current densities of LIGBT, LTIGBT and the proposed LTEIGBT were 120A/cm^2, 540A/cm^2, and 1230A/cm^2, respectively. The enhanced latch-up capability of the LTEIGBT was obtained through holes in the current directly reaching the cathode via the p+ cathode layer underneath n+ cathode layer. The forward blocking voltage of the LTEIGBT is 130V. Conventional LIGBT and LTIGBT of the same size were no more than 60V and 100V, respectively. Because the the proposed device was constructed of trench-type electrodes, the electric field moved toward trench-oxide layer, and punch through breakdown of LTEIGBT is occurred, lately.

Keywords: Trench Electrode, Power Integrated Circuit, Latch-up, Forward Blocking Voltage, Turn-off, SOI Thickness, Power Transistor

1. INTRODUCTION

Power transistors used in Power Integrated Circuits (PIC's) are generally required to have low on-resistance, fast switching speed, and high breakdown voltage. Silicon-On-Insulator (SOI) Lateral Insulated Gate Bipolar Transistor (LIGBT) has several advantages such as complete dielectric isolation, high packing density and high switching speed. However, one of the biggest problems of LIGBT is the latch-up of a parasitic thyristor. IGBTs have an inherent thyristor structure that is composed of p+ anode – n- drift region – p- base – n+ cathode. A MOS gate does not control the electron currents when latch-up occurs. Latch-up due to the parasitic thyristor limits the maximum operating current of IGBTs [1]. Therefore, the prevention of latch-up is very important when designing power transistors with wide SOA (Safe Operating Area).

In order to increase latch-up current density, several IGBT structures such as deep p+ implantation under the n+, reverse channel and p+ diverter have been proposed. Previous studies could reduce the voltage drop due to hole currents in the p-base region and increase the latch-up current density. In spite of previous efforts the latch-up of parasitic thyristor remains a key problem that limits the maximum operating current of LIGBTs.

Recently, a Lateral Trench-gate IGBT (LTIGBT) with improved the latch-up characteristics was proposed. LTIGBT is an effective structure to increase the latching current density as the p base length under n+ cathode layer is controlled [2-6]. However the LTIGBT is not driven in scaling down because that the length of n-drift layer cannot be reduced due to rating voltage.

In this paper, we proposed a Lateral Trench Electrode IGBT(LTEIGBT) in which the length of the n-drift layer was no more than 19 ㎛. Currently, the length of the n-drift layer of the conventional LIGBT and LTIGBT was over 80 ㎛, and the electrodes of LTEIGBT were replace with trench-type ones. Numerical simulations on the latch-up current densities were shown in comparison with those of the same sized conventional LIGBT and LTIGBT. And the characteristics of LTEIGBT such as forward blocking, turn-off and on state were investigated by numerical simulations and compared with those of the conventional LIGBT and LTIGBT. Moreover, we investigated how the length of p+ cathode layer, SOI thickness and buried oxide thickness affected the latch-up current density, forward blocking voltage and forward voltage drop of the LTEIGBT.

2. DEVICE STRUCTURE AND OPERATION

Fig. 1 illustrates the conventional LIGBT, LTIGBT and the proposed LTEIGBT. The main difference between the conventional LIGBT and LTIGBT is the placement of the MOS gate region and the p+ cathode. And the main difference between the conventional LTIGBT and the proposed LTEIGBT is the placement of the cathode and anode electrode. As the electrodes of the proposed device are formed of trench structures, it can easily be made into a small size. This is because the trench oxide layer play a role of mask, it is effective in forming an n+ cathode and p+ anode junction, as well. In addition, the electric field in this device centers on the trench oxide layer so that this device can have a higher blocking voltage in spite of its small size.

Operation of the LTEIGBT is identical to that of the conventional LTIGBT. In the forward active mode of operation, a positive voltage is applied to the anode relative to the cathode. Anode current starts to flow at gate voltages higher than the threshold voltage and an anode voltage higher than one diode drop. At a higher anode voltage, the anode pn junction starts to turn on and injects holes into the n-drift of the transistor. Some of these holes will recombine with the electrons flowing from the vertical channel, and some of them will flow from the n-drift to the p+ cathode without flowing through the p-base layer, directly. So they do not cause latch-up.

3. SIMULATION AND RESULTS

To analyze the on-state, latch-up performance, turn off and breakdown characteristics of LTEIGBT, numerical simulations were performed using the two-dimensional device simulator MEDICI. The device geometry for numerical simulation is shown in Table 1.

The simulated current-voltage (I-V) characteristics of the LIGBT, LTIGBT and LTEIGBT are shown in Fig. 2. The Latch-up current densities of LIGBT, LTIGBT and LTEIGBT are 120A/cm^2, 540A/cm^2 and 1230A/cm^2, respectively. The latch-up current density of the LTEIGBT exhibits a 10 times higher than that of LIGBT and a 2.3 times higher than that of LTIGBT. In this situation, the electron injection from the channel will be significant and conductivity modulation in the n-epi will be much stronger than that in the LIGBT and LTIGBT structure.

At an on-state current density of 147A/cm^2 and at a gate bias of 20V, the forward voltage drop of the LIGBT, LTIGBT and LTEIGBT are approximately 1V, 2V, and 5.5V, respectively.

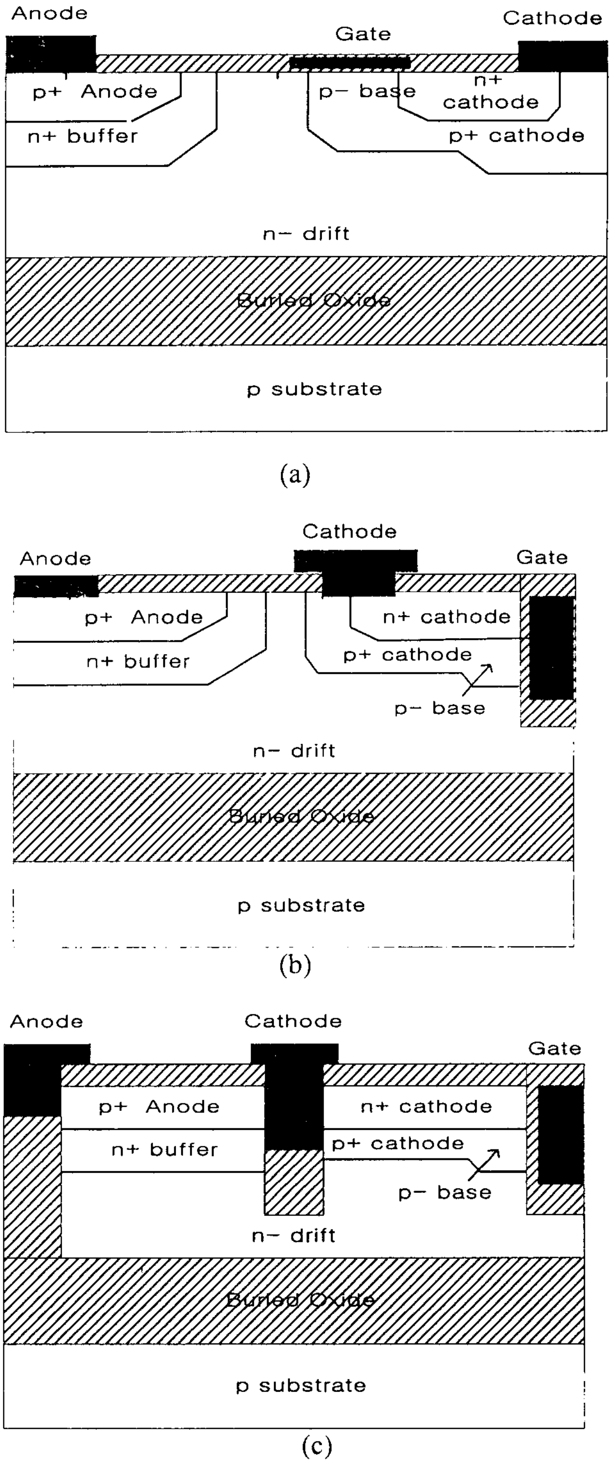


Fig. 1. Cross-section of the conventional (a) LIGBT (b) LTIGBT (c) the proposed LTEIGBT.

Table 1. Device parameters used in the simulations.

	Depth/ Thick -ness (㎛)	Concen -tration (cm^{-3})
Gate oxide thickness	0.5	
Trench depth of gate	4.5	
Trench depth of cathode	4.5	
Trench depth of anode	6.0	
Cell width	19.0	
n+ cathode layer	0.5	10^{21}
p+ cathode layer	1.5	10^{18}
p+ anode layer	0.5	10^{21}
p- base layer	2.0	10^{16}
n drift region	17.0	5×10^{15}
n+ buffer layer	1.0	10^{17}

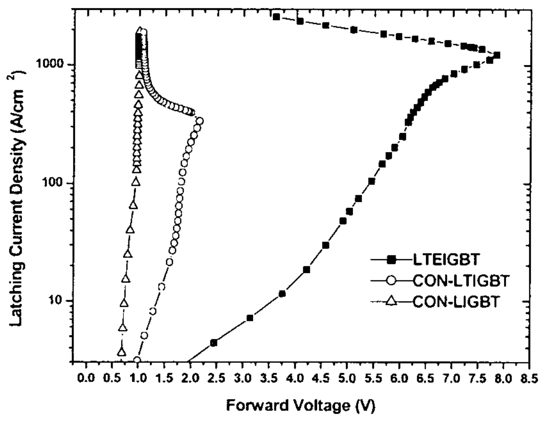


Fig. 2. Forward conduction characteristics of the conventional LIGBT, LTIGBT and the proposed LTEIGBT.

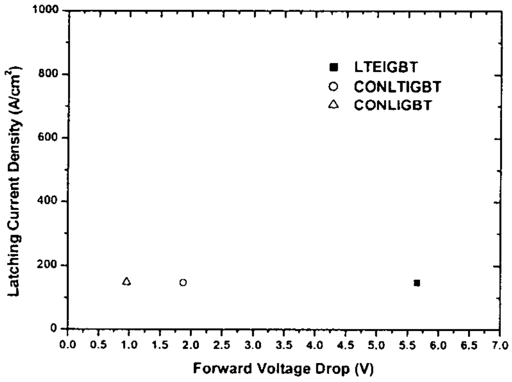
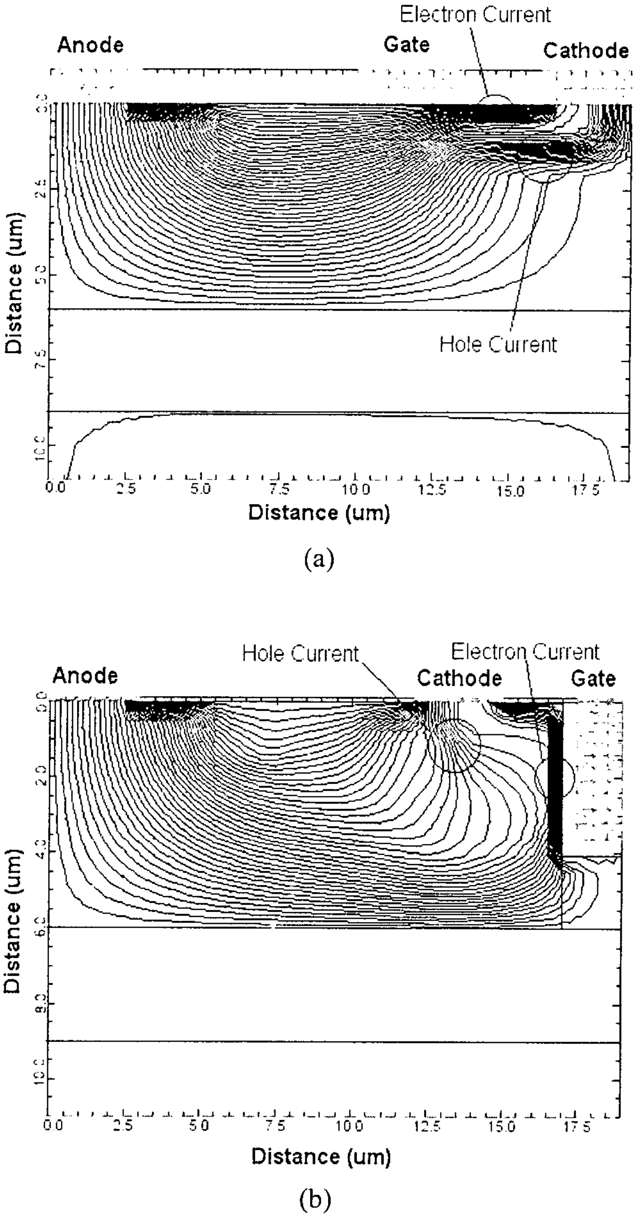


Fig. 3. Forward voltage drop of the conventional LIGBT, LTIGBT and the proposed LTEIGBT.

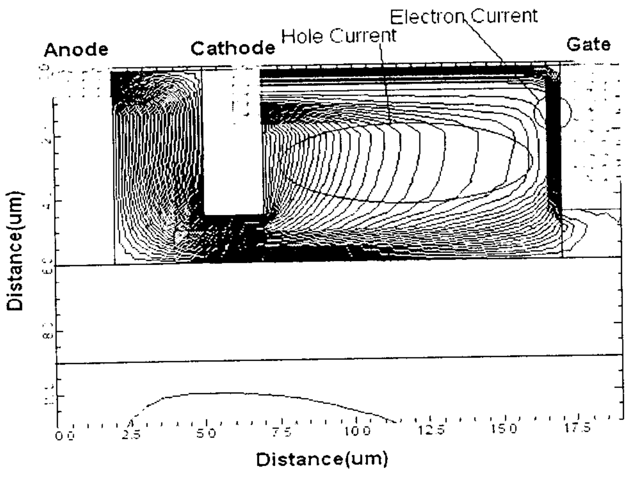
The current flow lines of the devices at the on state are shown in Fig. 4. It is observed that electrons are flowing from the vertical channel to the n-drift region, and holes are injected from the p+ anode into n-drift region at LTEIGBT.

Part of the holes flow from the n-drift layer into the p+ cathode layer. And part of them recombines with electrons flowing in from the channel. The cathode electrode will collect these holes that flow into the p+ cathode layer without causing latch-up. Thus, the area underneath the n+ cathode layer is found to have many holes. On the other hand, the conventional LIGBT and LTIGBT are found to have many holes in its p-base layer in comparison with the LTEIGBT.



(a)

(b)



(c)

Fig. 4. Current flow line in conventional (a) LIGBT (b) LTIGBT (c) the proposed LTEIGBT.

Fig. 5. is shown to forward blocking characteristics. As length of n-drift layer is reduced, forward blocking voltage is greatly decreased. This is why a small power device cannot be made such as memory device. However, as the electrodes of the proposed device are formed of trench type, the electric field in the device centers toward the trench-oxide layer. Thus, the punch through breakdown is occurred, lately. the forward blocking voltage of same size conventional LIGBT and LTIGBT are no more than 60V and 100V, respectively. But forward blocking voltage of LTEIGBT is 130V. The forward blocking voltage of LTEIGBT increased 2 and 1.25 times more than those of the conventional LIGBT and LTIGBT. Fig. 6 is shown the electric field distribution of the conventional LIGBT, LTIGBT and the proposed LTEIGBT when the breakdown is occurred.

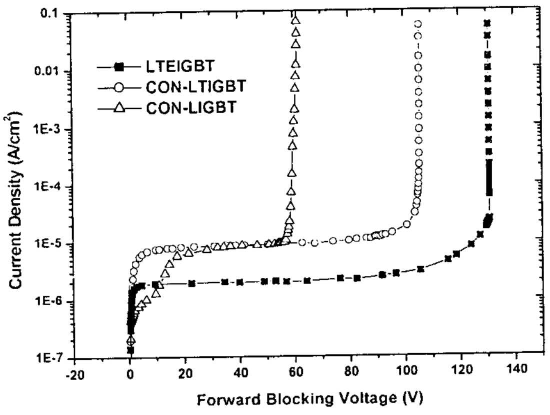
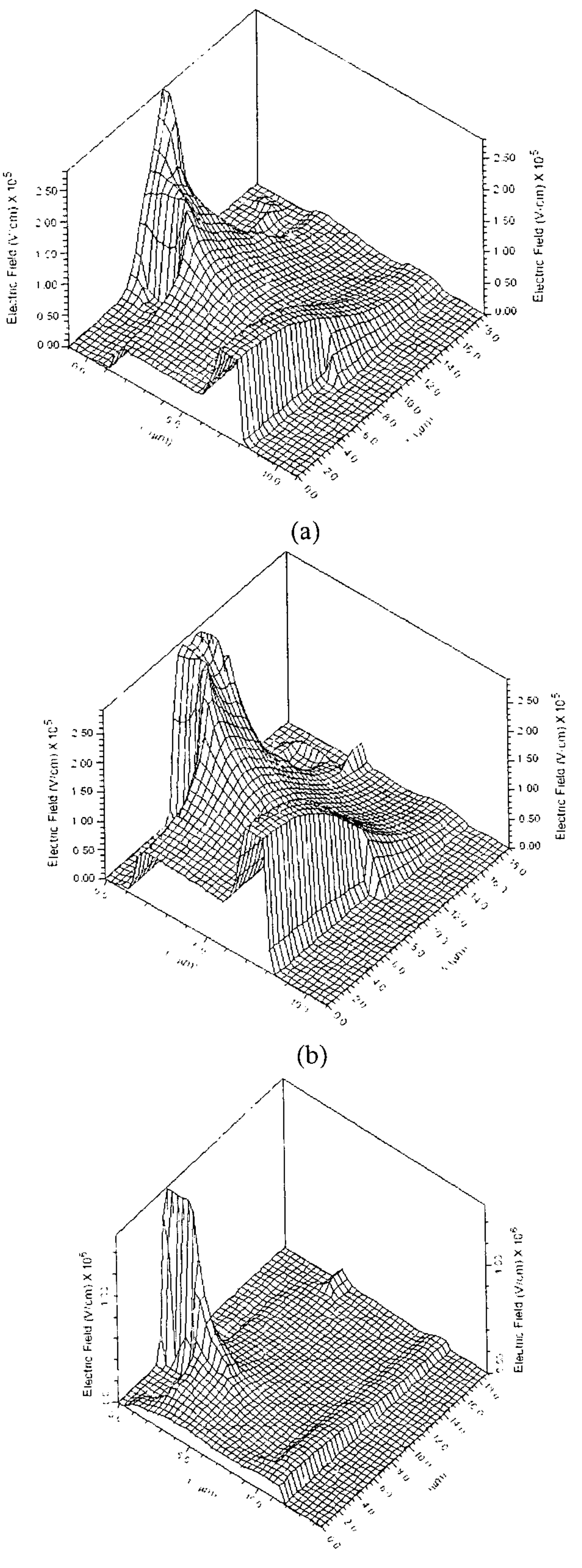


Fig. 5. Forward blocking characteristics of the conventional LIGBT, LTIGBT and the proposed LTEIGBT.



(c)

Fig. 6. Electric field distribution of the (a) conventional LIGBT (b) conventional LTIGBT (c) proposed LTEIGBT.

The turn-off characteristics of LTEIGBT, conventional LIGBT and LTIGBT are shown Fig. 7. The turn-off times of LTEIGBT, conventional LIGBT and LTIGBT are 0.2 μs, 4 μs and 4 μs, respectively. The proposed LTEIGBT has fastest switching speed. This is reason that LTEIGBT accumulated little minor carriers in n-drift layer because trench oxide layer occupy a part of n-drift region.

For the purpose of improving performance of LTEIGBT, latching current density, forward voltage drop and forward blocking characteristics were analyzed according to SOI thickness, buried oxide thickness and the length of p+ cathode layer. Fig. 8, 9 and 10 are shown. It is shown in Fig. 8, 9 and 10 that the latching current density and forward blocking voltage increase with SOI thickness, length of p+ cathode layer and buried oxide thickness. But the forward voltage drops decrease with them. Especially, when SOI thickness is 12 μm, forward voltage drop is 1.1V and latching current density is 1475 A/cm^2.

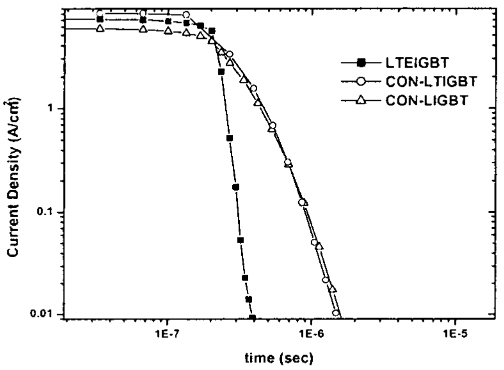
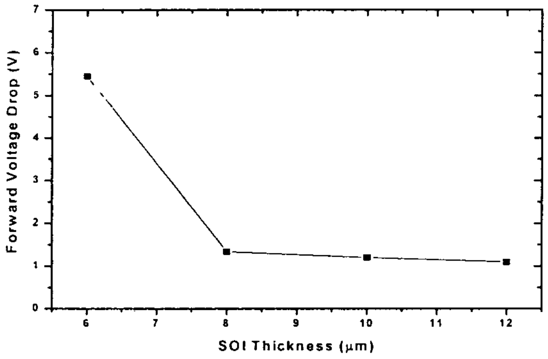
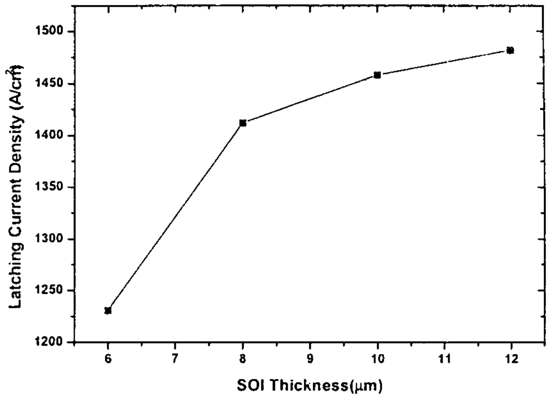


Fig. 7. Turn-off characteristics of the conventional LIGBT, LTIGBT and the proposed LTEIGBT.



(a)



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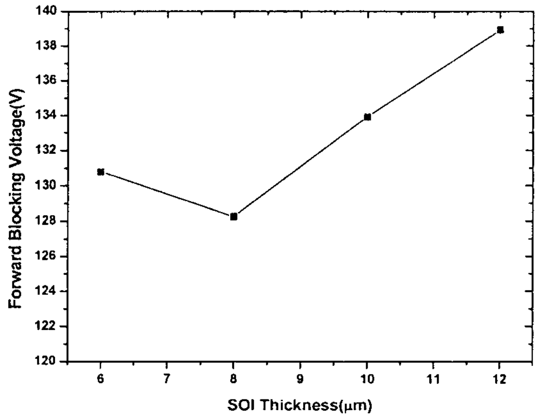

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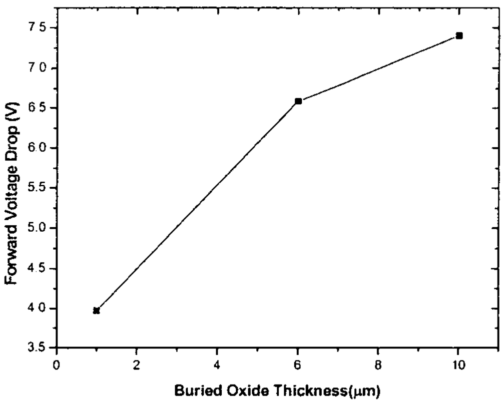
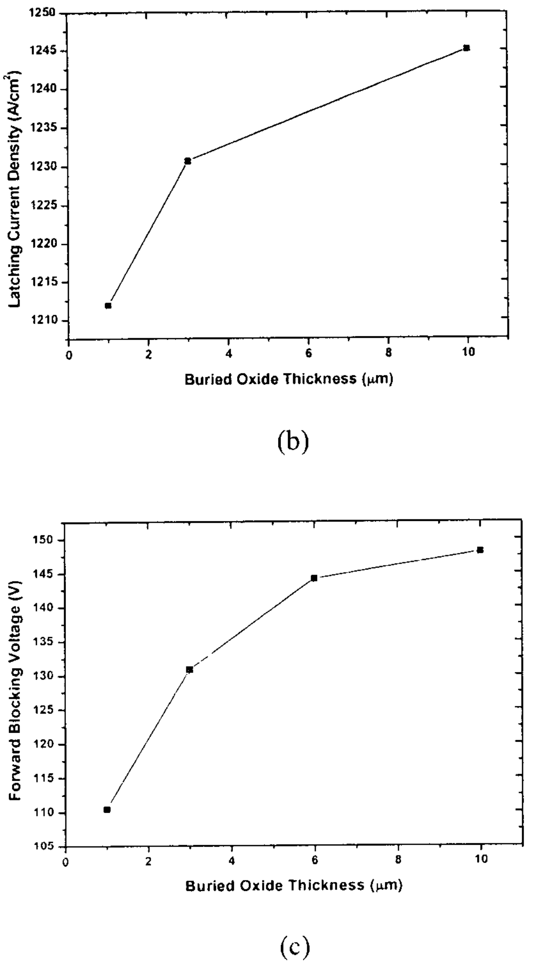
Fig. 8. (a) Forward voltage drop (b) latching current Density (c) forward blocking voltage with SOI thickness in LTEIGBT.



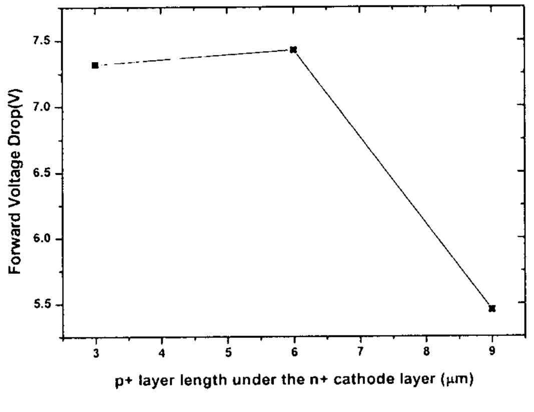
(a)



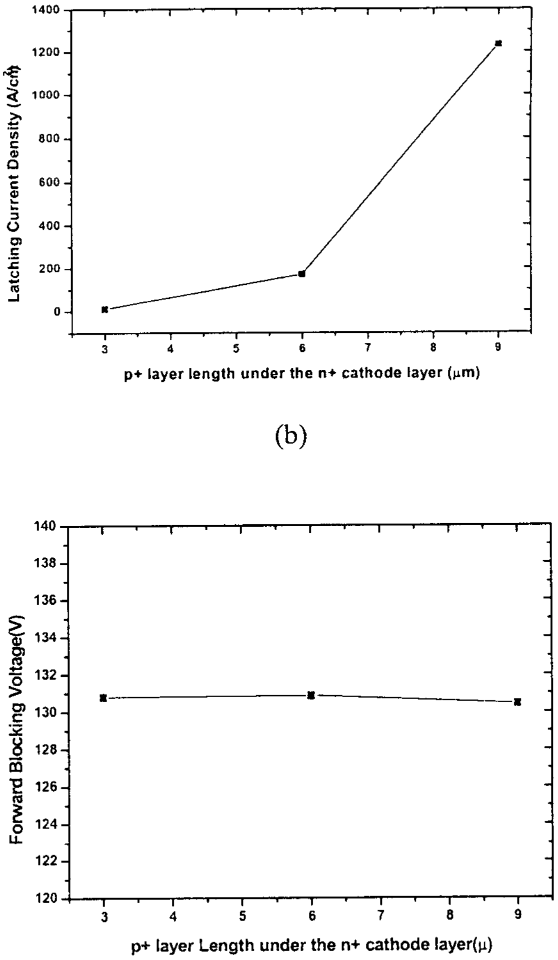
(b)

(c)

Fig. 9. (a) Forward voltage drop (b) latching current Density (c) forward blocking voltage with buried oxide thickness in LTEIGBT.



(a)



(b)

(c)

Fig. 10. (a) Forward voltage drop (b) latching current Density (c) forward blocking voltage with length of p+ cathode layer in.

4. CONCLUSIONS

A new small sized LTEIGBT (Lateral Trench Electrode Insulated Gate Bipolar Transistor) was proposed to suppress latch-up which was a key problem in limiting the maximum operating current and improve the forward blocking and turn-off characteristics. The LTEIGBT was designed so that the width of device was 19 ㎛. The anode, cathode and gate electrodes of LTEIGBT were replaced with trench-type electrodes. The efficiency of the proposed device was verified by numerical analysis with MEDICI. The simulation results of proposed device indicated in significant improvement in latch-up current. Latch-up current densities increased by 10 and 2.3 times more than those of the conventional LIGBT and LTIGBT. The enhanced latch-up capability of the LTEIGBT was obtained due to the fact that the hole current in the device bypassed the resistance of the p base region which is the source of the latch-up and reaches the cathode via the p+ cathode layer underneath n+ cathode layer. Forward blocking voltage of the LTEIGBT was 130V. Those of conventional same sized LIGBT and TIGBT were 60V and 100V, respectively. Turn off time of the LTEIGBT was 0.2 μs. those of conventional LIGBT and LTIGBT were 4 μs and 4 μs, respectively. The proposed LTEIGBT had fastest switching speed. Optimal parameter for LTEIGBT was 12 μm of SOI thickness, 9 μm of p+ cathode layer and 10 μm of buried oxide thickness. The LTEIGBT may be utilized for a small sizing of power integrated circuits.

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