A Small Scaling Lateral Trench IGBT with Improved Electrical Characteristics for Smart Power IC

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(Received 18 October 2001, Accepted 21 November 2001)

A new small scaling Lateral Trench Insulated Gate Bipolar Transistor (SSLTIGBT) was proposed to improve the characteristics of the device. The entire electrode of the LTIGBT was replaced with a trench-type electrode. The LTIGBT was designed so that the width of device was no more than 10 ㎛. The latch-up current densities were improved by 4.5 and 7.6 times, respectively, compared to those of the same sized conventional LTIGBT and the conventional LTIGBT which has the width of 17 ㎛. The enhanced latch-up capability of the SSLTIGBT was obtained due to the fact that the hole current in the device reaches the cathode via the p+ cathode layer underneath the n+ cathode layer, directly. The forward blocking voltage of the SSLTIGBT was 125 V. At the same size, those of the conventional LTIGBT and the conventional LTIGBT with the width of 17 ㎛ were 65 V and 105 V, respectively. Because the proposed device was constructed of trench-type electrodes, the electric field in the device were crowded to trench oxide. Thus, the punch through breakdown of LTEIGBT occurred late.

Keywords : Power Integrated Circuit, Forward Blocking Voltage, Latch-up, Trench Electrode

1. INTRODUCTION

Power transistors to be used in Power Integrated Circuits (PICs) are generally required to have low on-resistance, fast switching speed, and high breakdown voltage[1,2]. Silicon-On-Insulator (SOI) Lateral Insulated Gate Bipolar Transistor (LIGBT) enjoys several advantages such as complete dielectric isolation, high packing density and high switching speed. The Lateral Trench Insulated Gate Bipolar Transistor (LTIGBT) is a MOS-controllable device with bipolar action, having trench type electrode. In comparison with conventional LIGBTs, the trench structure offers an increased packing density, an enhanced carrier modulation at the cathode side due to the PIN diode effect, a larger SOA due to a reduced action of the parasitic thyristor in herent in any IGBT structures and a more flexible design and geometry. However, if the size of conventional LTIGBT is small, the electrical characteristics for including latch-up current density is became worse[3-6].

In this paper, we proposed a Small Scaling Lateral Trench IGBT (SSLTIGBT) in which the length of the n-drift layer was no more than 10 ㎛ and the electrodes of SSLTIGBT were replace with trench-type ones. Generally, the convention LTIGBT was over 80 ㎛. Numerical simulations on the latch-up current densities were shown in comparison with those of the same sized conventional LTIGBT. And the characteristics of SSLTIGBT such as forward blocking were investigated by numerical simulations and compared with those of the conventional LTIGBT.

2. DEVICE STRUCTURE AND OPERATION

Fig. 1 illustrates the conventional LTIGBT and the proposed SSLTIGBT. The main difference between the conventional LTIGBT and the proposed SSLTIGBT is the placement of the cathode, the anode electrode. Two-dimensional numerical simulations of the proposed SSLTIGBT and conventional LTIGBT were carried out using MEDICI to verify the device physics and operation[7]. The device parameter used in simulation is shown in Table 1.

As the electrodes of the proposed device are formed of trench structures, they can easily be made to be of small size. This is because the trench-oxide layer plays a role of the mask, and it is effective to form an n+ cathode and a p+ anode junction, as well. In addition, the electric field in this device is centered around the trench-oxide layer so that this device can have a higher blocking voltage in spite of its small size.

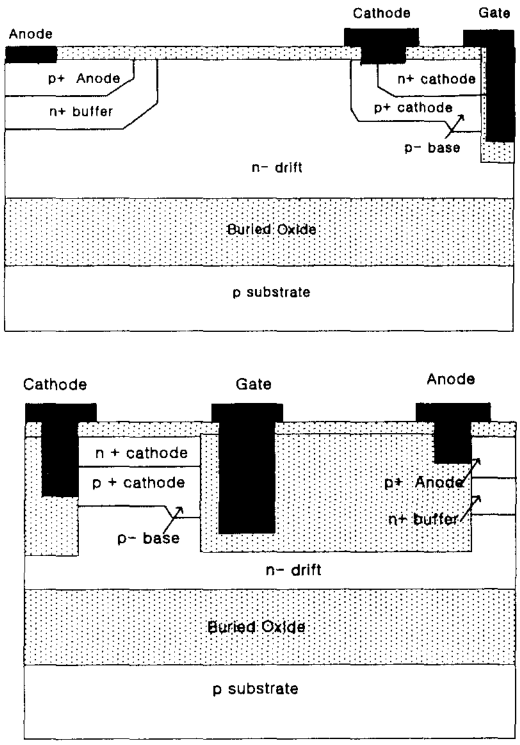


Fig. 1. Cross section of (a) the conventional LTIGBT (b) the proposed SSLTIGBT.

Operation of the SSLTIGBT 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 p-base layer, directly. So they do not cause the latch-up[4].

3. SIMULATION AND RESULTS

The simulated current-voltage (I-V) characteristics of the conventional LTIGBT and the proposed SSLTIGBT are shown in Fig. 2. In this figure, the breakover point from the positive to the negative resistance regime is the latch-up point. The latch-up current densities of the same sized conventional LTIGBT, the conventional LTIGBT which has the width of 17 μm and the proposed SSLTIGBT are 504 A/cm^2, 300 A/cm^2 and 2270 A/cm^2, respectively. The enhanced latch-up capability of the SSLTIGBT was obtained through holes in the current directly reaching the p+ cathode layer beneath the n+ cathode layer.

Table 1. Device parameters used in the simulations.

	Depth/ Thickness (μm)	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	10.0	
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	6.0	5×10^{15}
n+ buffer layer	1.0	10^{17}

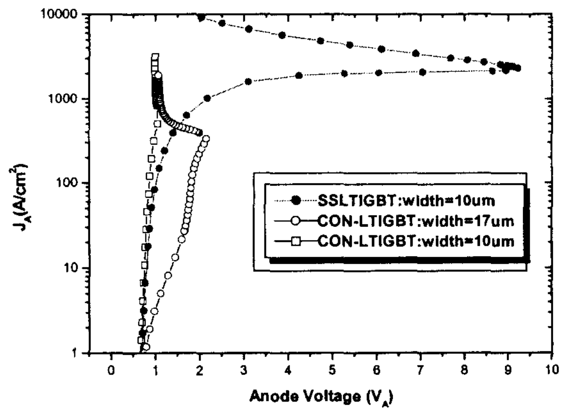
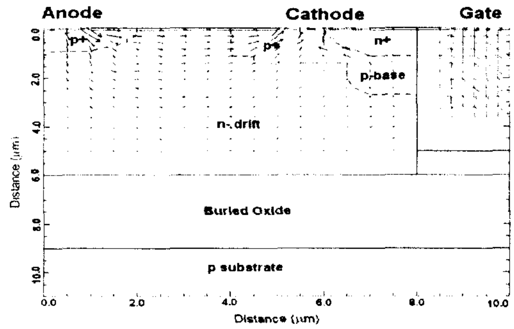


Fig. 2. Forward conduction characteristics of the conventional LTIGBT and the proposed SSLTIGBT.

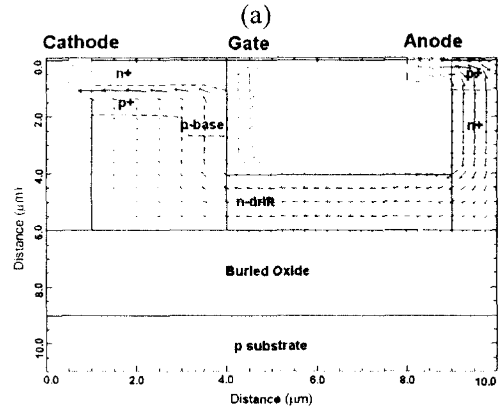
The hole vectors of the proposed device and the conventional at the on state are shown in Fig. 3. Holes of the proposed device flow from the n-drift layer into the p+ cathode layer. The cathode electrode will collect these holes that flow into the p+ cathode without causing latch-up. Thus, the area underneath the n+ cathode layer is found to have many holes, clearly. On the other hand, the conventional LTIGBT is found to have many holes in its p-base layer in comparison with the SSLTIGBT.

Fig. 4 is shown to the forward blocking characteristics.

As the length of the n-drift layer is reduced for the small sized device, the forward blocking voltage is significantly decreased. This is why the small conventional LTIGBT cannot be manufactured. However, as the electrodes of proposed SSLTIGBT are made of trench-type ones, the electric field in the device is centered around the trench-oxide layer. Thus, the punch-through breakdown of the SSLTIGBT occurs late. The forward blocking voltage of the same sized conventional LTIGBT is no more than 65V. And the conventional LTIGBT with 17 ㎛ width is 105V. But forward blocking voltage of the SSLTIGBT is about 125V.



(a)



(b)

Fig. 3. Hole vectors of (a) the conventional LTIGBT (b) the proposed SSLTIGBT Forward.

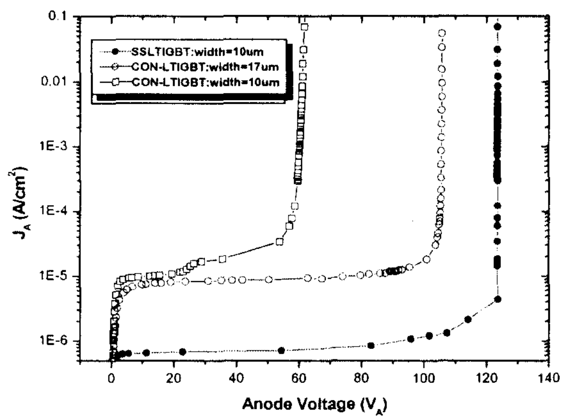


Fig. 4. Forward blocking characteristics of the conventional LTIGBT and the proposed SSLTIGBT.

4. CONCLUSION

A new small size LTIGBT (SSLTIGBT) is proposed to suppress the latch-up which is a key problem to limit the maximum operating current and improve the forward blocking characteristics. The anode, the cathode and the gate electrode of SSLTIGBT are placed to trench-type electrode. The SSLTIGBT is designed so that the width of device is 17 ㎛. The efficiency the proposed device is verified by numerical analysis with MEDICI. The simulation results of the proposed device indicate in significant improvement in latch-up current. The latch-up current densities are improved by 4.5 and 7.6 times, respectively, compared to those of the same sized conventional LTIGBT and the conventional LTIGBT which has the width of 17 ㎛.

The enhanced latch-up capability of the SSLTIGBT is obtained due to the fact that the hole current in the device bypasses 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 the n+ cathode layer. The forward blocking voltage of the SSLTIGBT is 125 V. At the same size, those of conventional LTIGBT and the conventional LTIGBT which has the width of 17 ㎛ are 65 V and 105 V. The size of the n-drift layer of the proposed SSLTIGBT did not related to breakdown voltage in a different way the conventional LTIGBT, clearly. The proposed SSLTIGBT may be used for small power IC system without suffering from the latch up and with the improved forward blocking characteristics.

ACKNOWLEDGMENTS

This work is partially supported by KOSEF(Korea Science and Engineering Foundation) 1999-2-302-017-5 and the Ministry of Science and Technology of Republic of Korea 2000-J-EH-01-B02.

REFERENCES

[1] B. J. Baliga, "Power Semiconductor Devices", PWS Publishing Company, 1996.

[2] B. J. Baliga, "Trends in Power Semiconductor Devices", vol. 43, No. 10, pp. 1717-1731, 1996.

[3] E. G. Kang, S. H. Moon, M. Y. Sung, "LIGBT with Dual Cathode for Improving Breakdown Characteristics", Transactions on Electrical and

Electronic Materials, vol. 1, pp. 16-19, 2000.
[4] E. G. Kang, S. H. Moon, M. Y. Sung, "Simulation of a Novel Lateral Trench Electrode IGBT with Improved Latch-up and Forward Blocking Characteristics", Transactions on Electrical and Electronic Materials, vol. 2, No. 1, pp. 32-38, March 2001.
[5] Jun Cai, "A New Lateral Trench-Gate Conductivity Modulated Power Transistor", IEEE Trans. Electron Devices, vol. 46, No. 8, pp. 1788-1792, 1999.
[6] S. H. Moon, E. G. Kang, M. Y. Sung, Sangsig Kim, "A Latch-Up Immunized Lateral Trench IGBT with p+Diverter Structure for Smart Power", Transactions on Electrical and Electronic Materials, vol. 2, No. 1, pp. 32-38, March 2001.
[7] TMA MEDICI: Two-Dimensional Device Simulation Program, Technology Modeling Associate, Inc., 1993