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A Snapback-Free Reverse-Conducting LIGBT with Embedded MOS Controlled Diode

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Abstract. In this paper, a novel snapback-free reverse-conducting lateral insulated-gate bipolar transistor with embedded MOS controlled diode is proposed and investigated by the numerical TCAD Simulation. The proposed reverse conducting LIGBT features an embedded MOS controlled diode which provides reverse conduction path when the gate voltage of MOS controlled diode is greater than those of threshold voltage. The collector and floating ohmic contact are shorted by the PN junction above the MOS controlled diode gate oxide layer, which provides a current path for carriers in the forward-conducting and turn off modes. Compared with the Separated Shorted-Anode LIGBT (SSA LIGBT), the snapback voltage (ΔV_{SB}) of the proposed LIGBT is not only completely eliminated, but also decreases collector size. The simulation shows that the turn-off loss of the proposed LIGBT, under the same forward voltage drop (V_{on}~1.38 V), reduces 66.4% and 44.2% for the SSA LIGBT and conventional LIGBT (CON LIGBT), respectively. In addition, the short-circuit withstand and reverse recovery capabilities are obviously improved by the MOS controlled diode.

Keywords. RC LIGBT; MOS controlled diode; trade-off V_{on}-E_{off}; short-circuit characteristic; reverse recovery

1. Introduction

The reverse conducting lateral insulated gate bipolar transistor (RC-LIGBT) not only has superior trade-off relationship between the on-state voltage drop (V_{on}) and the turn-off energy loss (E_{off}), but also achieves free-wheeling property, which integrates the LIGBT and a free-wheeling diode (FRD) [1-3]. Therefore, the RC-LIGBT is an extremely promising power device in the smart power integrated circuits and high-power integrated circuits [4-7]. Although the conventional shorted-anode (SA) LIGBT obtains the above abilities, it still exists the unwelcome snapback phenomena, which has seriously affected the application in the parallel operations [8]. In order to suppress and eliminate the snapback phenomena, and further enhance the reliability of the electrical circuit system, many novel structures and technologies are reported in recent years [9,10]. The snapback phenomena can be obviously mitigated by the separated SA (SSA) LIGBT which increases the unipolar on-state resistance for the electronic

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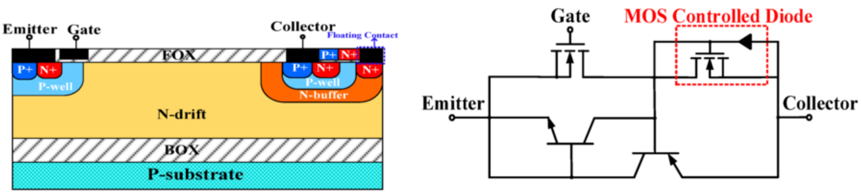
current, but the trade-off V_{on}-E_{off} and free-wheeling capabilities are undesirably deteriorated by the increasing length between N-buffer and N+ collector which reduces the wafer utilization rate [11].

A novel lateral insulated-gate bipolar transistor with embedded MOS controlled diode at the collector side is proposed in this article. The key simulation physics models consist of the EffecticeIntrinsicDensity, Mobility (HighFieldSaturation Enormal PhuMob DopingDependence), Recombination (SRH Auger Avalanche) in the Synopsys Sentaurus TCAD. The proposed LIGBT with embedded MOS controlled diode achieves superior trade-off between forward voltage drop (V_{on}) and turn off loss (E_{off}), as well as excellently short-circuit withstand and reverse recovery characteristics by embedding MOS controlled diode in the collector region.

2. The Device Structure

The previous conventional LIGBT (CON LIGBT) and SSA LIGBT [11] are compared to the proposed LIGBT with embedded MOS controlled diode by the Sentaurus TCAD simulation tools. Figure 1 demonstrates the cross-sectional view of schematic and equivalent circuit for the proposed LIGBT. Additionally, the N-drift doping concentration N_{drift}, length L_D and depth T_D of the structures are 5.0 × 10^{14} cm^{-3}, 50.0 μm and 5.0 μm, respectively. And the BOX thickness T_{BOX} of 2.0 μm, Gate oxide thickness T_{OX} of 0.05 μm, P-well doping concentration $N_{P\text{-}well}$ of 1.0 × 10^{17} cm^{-3}, and N-buffer doping concentration N_{buffer} of 5.0 × 10^{16} cm^{-3} are the same for the three devices. What's more, a longer distance L_A between the N-buffer and the separated N+ collector is 30.0 μm for the SSA-LIGBT, which mainly suppresses the snapback effect. For the proposed LIGBT, the MOS controlled diode is embedded into the right side of collector, and the gate oxide thickness of the MOS controlled diode is 0.05 um, which closely relates to the reverse conductive characteristic [12].



(a) (b)

Figure 1. The cross-sectional view of schematic (a) and equivalent circuit (b) of the proposed LIGBT.

3. Insulator Image Pre-processing

Figure 2 shows the forward conduction characteristics of the former CON LIGBT, SSA LIGBT and proposed LIGBT at the same temperature (~300 K). The SSA LIGBT with the distance between the N-buffer and the N+ collector L_A of 30 μm has the unipolar operation mode when V_{CE} is less than 1.48 V, and the undesier snapback effect is occurred between unipolar conduction mode and bipolar conduction mode, which ΔV_{SB} is 0.26 V. However, the CON LIGBT and proposed LIGBT practically operate the bipolar conductive mode, thus the snapback effect is commendably eliminated. In addition, the V_{on} of the CON LIGBT, SSA LIGBT and proposed LIGBT are 1.36 V, 1.70 V and 1.58 V at the I_{CE} of 100 A/cm^2, respective. The V_{on} of the proposed LIGBT is bigger than those of CON LIGBT due to MOS controlled diode decreasing holes injection efficiency of the collector, thus bipolar conductive characteristic is deteriorated, but the turn off and short-circuit withstand capacities are effectively enhanced as shown figures 3 and 5, respectively.

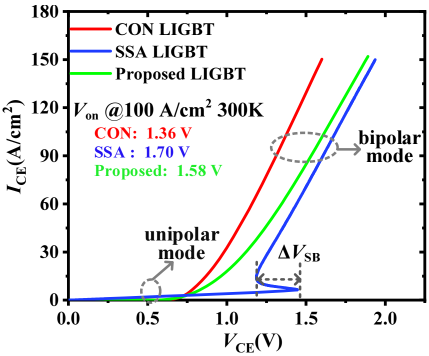


Figure 2. The forward IV characteristic of the CON LIGBT, SSA LIGBT and proposed LIGBT. The $\triangle V_{SB}$ is the snapback voltage.

Figure 3 compares the turn-off characteristics of the proposed and others devices at the same on-state voltage drop V_{on} (~1.8 V), and the turn-off test circuit is also presented. The turn-off time are 530 ns, 520 ns, and 210 ns for the CON LIGBT, SSA LIGBT and proposed LIGBT, respectively. Additionally, the longest tail current is obtained by the CON LIGBT as shown figure 3, but the tail current of the proposed LIGBT is shorted by the MOS controlled diode which provides an electron current extraction path as shown figure 1.

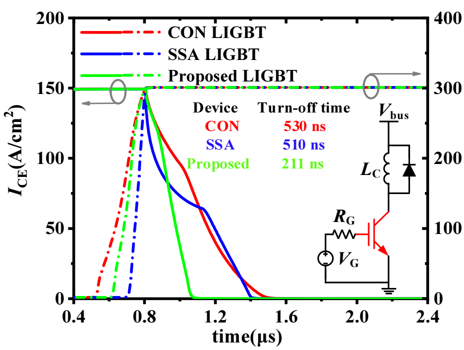


Figure 3. The simulation turn-off characteristics for the CON LIGBT, SSA LIGBT and proposed LIGBT under the same inductive load circuit. The V_{bus}, L_C and R_G are 300 V, 5 μH and 10 Ω, respectively.

Figure 4 shows the trade-off relationship between the turn-off loss (E_{off}) and on-state voltage drop (V_{on}) of the three different structures at the same load current density (~100 A/cm^2). The E_{off} of the proposed LIGBT, at the same V_{on} of 1.38 V, decreases by 66.4% and 44.2% in the comparison with the CON LIGBT and SSALIGBT, respectively. Hence, the proposed LIGBT with embedded MOS controlled diode offers a desirable V_{on}-E_{off} trade-off relationship compared with the others.

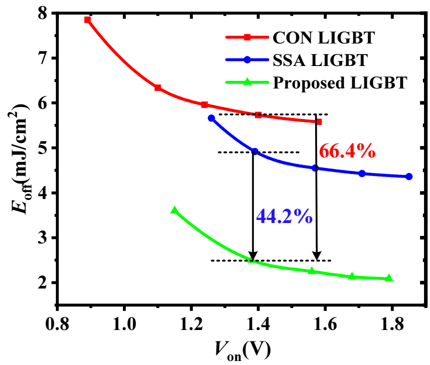


Figure 4. The trade-off relationship between the E_{off} and V_{on} of the three different devices at the same load current density (100 A/cm^2).

Figure 5 demonstrates the short-circuit withstand capabilities of the three different devices under the same test condition. The short-circuit withstand time are 5.468 μs, 5.654 μs and 6.818 μs for the CON LIGBT, SSA LIGBT and proposed LIGBT, respectively. The desirable short-circuit characteristic, compared to the CON LIGBT and SSA LIGBT with a longer distance L_A (~30 μm) between the N-buffer and the separated N+ collector, is directly obtained by the proposed LIGBT with the MOS controlled diode which the hole injection efficiency is effectively adjusted. When V_{CE} is bigger than 0.6 V, the PN junction above the above the MOS controlled diode gate oxide layer is opened, providing an electron current conductive path, and the hole injection efficiency of the P+ collector is suppressed, thus the short-circuit withstand capability of the proposed LIGBT will be significantly improved.

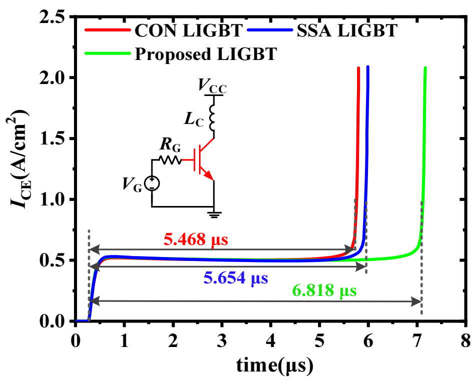


Figure 5. The short-circuit characteristics for the three different LIGBTS. The V_{CC}, L_C and R_G are 300 V, 5 nH and 10 Ω, respectively.

Figure 6 compares reverse conductive characteristics for the conventional lateral PIN (CON LPIN), SSA LIGBT and proposed LIGBT at the same temperature (~300 K). The reverse conducting voltage drop (V_R) are 0.89 V, 0.96 V and 1.65 V for the CON LPIN, SSA LIGBT and proposed LIGBT at the same I_R (~100 A/cm^2), respectively. The biggest V_R is achieved by the proposed LIGBT due to connecting an MOS controlled diode in series through floating ohmic contact.

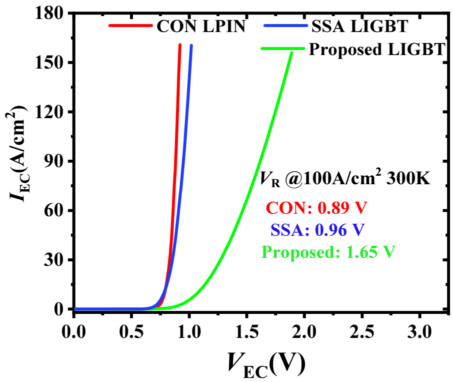


Figure 6. Simulation reverse conductive characteristics for the three different structures at the temperature 300 K.

Figure 7 shows the reverse recovery characteristics of the three-difference structure. The reverse recovery time (t_{rr}) are 0.650 μs, 0.995 μs and 0.457 μs, the reverse recovery peak current (I_{RRM}) are -302.589 A/cm^2, -214.643 A/cm^2 and -219.694 A/cm^2, and the reverse recovery charge (Q_{rr}) are 101.117 μC/cm^2, 89.934 μC/cm^2 and 55.372 μC/cm^2. The SSA LIGBT achieves the biggest t_{rr} due to the longer distance L_A between the N-buffer and the separated N+ collector, but the least t_{rr} is gained by the proposed LIGBT. Moreover, the I_{RRM} of the proposed LIGBT and SSA LIGBT is lower than those of the CON LPIN, and the superior reverse recovery abilities can be achieved by the proposed LIGBT which introduces into the MOS controlled diode at the collector region.

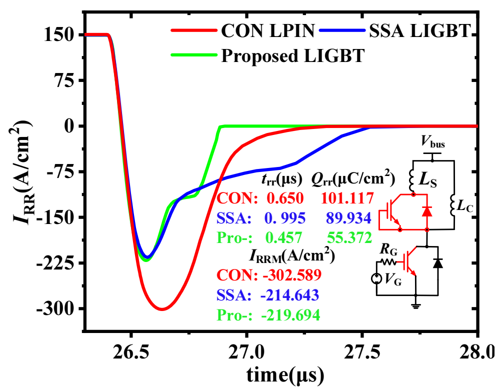


Figure 7. The reverse recovery characteristics for the CON LPIN, SSA LIGBT and proposed LIGBT under the same load circuit. The V_{bus}, L_S, L_C and R_G are 300 V, 5 nH, 5 μH and 10 Ω, respectively.

4. Conclusion

A novel snapback-free Reverse-conducting lateral insulated-gate bipolar transistor with embedded MOS controlled diode is proposed and investigated in this article. The MOS controlled diode not only eliminates the snapback effect, but also achieves superior trade-off between V_{on} and E_{off}, as well as excellent reverse recovery characteristic, and enhances short circuit withstand capacity. Under the same conditions, the E_{off} of the proposed LIGBT reduces by 66.4 % and 44.2% compared to the CON LIGBT and SSA LIGBT, respectively.

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