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Improved Latch-Up Characteristics of the LIGBT with the p^+ Cathode Well on the SOI Substrate

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Abstract

A trench-gate SOI LIGBT with the p+ cathode well is proposed to improve the latch-up characteristics and verified by MEDICI simulation. It is found that the latch-up capability of the trench-gate SOI LIGBT is as large as 6 when compared to the conventional devices. The enhanced latch-up capability of the trench-gate SOI LIGBT may be obtained due to the fact that the hole current in the device would bypass the resistance of the p body region which is the source of the latch-up and reach the cathode via the p+ cathode well.

I. Introduction

A Silicon-On-Insulator (SOI) lateral insulated gate bipolar transistor(LIGBT) enjoys several advantages such as the complete dielectric isolation, high packing density and high switching speed over the Junction Isolated(JI) LIGBT[1]. However, the maximum controllable current of the SOI LIGBT is much less than that of the JI LIGBT because the latch-up problem of the SOI LIGBT becomes worse [2].

Although several structures have been proposed to improve latch-up characteristics of LIGBT, the techniques adopted for suppression of the latch-up also bring about the increase of the forward voltage drop considerably.[3-4]

We propose a trench gate SOI LIGBT with p+ cathode well, in which the maximum controllable current could be increased with negligible increase of the forward voltage drop by employing p+ cathode well.

II. The Trench Gate SOI LIGBT with p+ Cathode Well

It is well known that the latch-up of IGBT is caused by a voltage drop in the p body under the n+ cathode. We employ a p+ cathode well and trench gate in proposed SOI LIGBT as shown in Fig. 1. The p+ cathode well provide a bypassing path for holes injected from anode not to pass the p body .

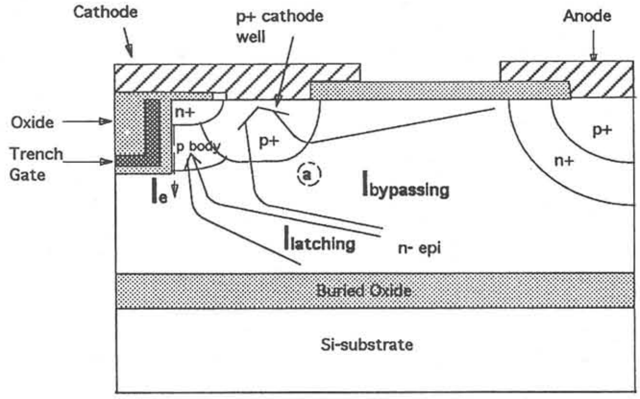


Fig.1 Cross-section of the trench gate SOI LIGBT with the p+ cathode well.

The trench gate helps the electrons from channel flow easily into the n^- epi layer under the p+ cathode well denoted as region ⓐ in Fig. 1. Then, the electron currents would induce the hole currents to flow into the cathode contact via the p+ cathode well without passing through Rp beneath the n+ cathode.

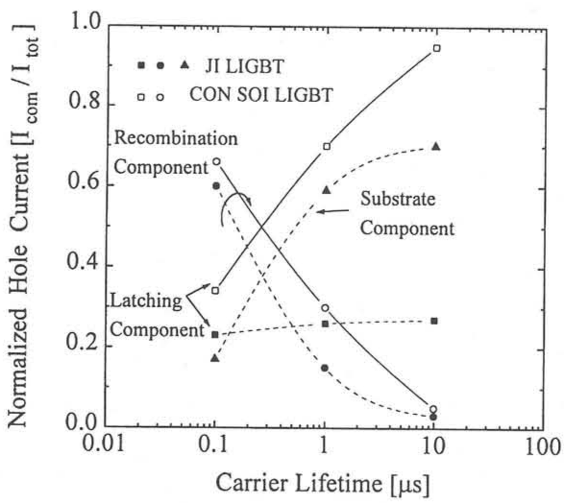
III. Latch-up Characteristics of LIGBT

The maximum controllable current flowing through LIGBT without inducing latch-up may be written as

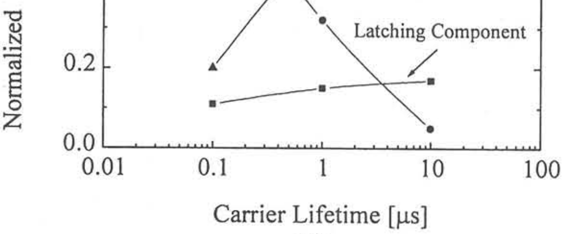
$$I_{MAX} = I_e + I_h \cong \left(\frac{1}{\beta}+1\right)\cdot\frac{0.7}{R_p}\cdot\frac{1}{\gamma_{LAT}} \qquad \text{-------- (1)}$$

where $\gamma_{LAT} = {}^{I_{lat}}/_{I_h}$ is the ratio of the latching component to total hole current injected from the anode, R_p is the p body resistance, and $\beta = {}^{I_h}/_{I_e}$ is the current gain in LIGBT. Eq.(1) indicates that it is important not only to reduce the p body resistance but also to decreases γ_{LAT} for a large maximum controllable current.

We have simulated the conventional and trench gate SOI LIGBT, and JI LIGBT to analysis the latch-up. It is shown in Fig.2(a) that the latching component to total hole current is less than 30% in JI LIGBT because substrate current is above 50% in the case of the large carrier lifetime and the recombination current in n- epi layer becomes dominant in the case of the small lifetime. In conventional SOI LIGBT, the substrate current component is zero because substrate is completely isolated from SOI layer, and the latching current component be as high as 70 to 95% of the total hole current except only the case of very small lifetime. However, The latching current component in the proposed trench-gate SOI LIGBT with p+ cathode well can be restricted within 20% of the total hole current due to the bypassing current component as shown in Fig. 2(b).



(a)



(b)

Fig.2 Normalized current components as a function of the lifetime, (a) in JI and conventional SOI LIGBT, (b) in Trench gate SOI LIGBT.

IV. Numerical Simulation Results

The latch-up current and forward voltage drop is evaluated in the case that the SOI thickness is 6μm and 10μm. As shown in Fig.3, it is found that the latch-up current density of the trench-gate(TG) SOI LIGBT is larger than conventional (CON) SOI LIGBT for both 6μm and 10μm of the SOI thickness, and the latch-up current decreases slightly as the carrier lifetime is increased. In conventional device, the latch-up current is almost identical for 6μm and 10μm of the SOI thickness, while the trench-gate device with the 6μm SOI thickness has larger latch-up current than the device with 10μm thickness. This may be understood as follows: Because the electrons from vertical channel move vertically toward the buried oxide at first and flow laterally to anode, the

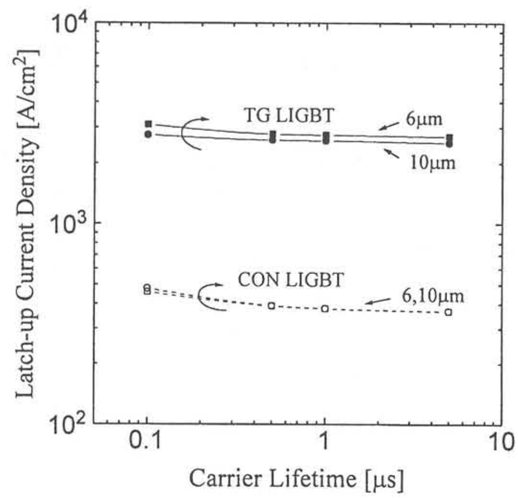


Fig.3 Latch-up current density of the trench-gate and conventional SOI LIGBT as a function of the lifetime at 10V of the gate voltage.

electrons, which is deeply diffused into the n- epi region, induce more holes to reach the p body as the SOI thickness becomes larger in the trench gate SOI LIGBT.

The I-V curves of both devices are shown in Fig .4 as an example. In the Figure, the breakover point from the positive to negative resistance regime is the latch-up point.

The forward voltage drop of simulated structures is compared in Fig .5 at 10V of the gate voltage and 200 A/cm^2 of the forward current density. When the SOI thickness is 6μm, the forward voltage drop of the trench gate SOI LIGBT is increased by about 25% compared with that of the conventional devices due to the electron current crowding between the p body and the buried oxide. However, the increase of the forward voltage drop in trench-gate device is negligible in the SOI thickness of 10μm. We has also evaluated the turn off time under resistive load condition. The resistance value adopted as the load in our simulation is 1MΩ/μm. The simulated turn off time is almost identical in the conventional and trench-gate devices, and 3.5 μs and 50ns when the lifetime is 1μs and 0.1μs , respectively.

The simulated breakdown voltage of the trench gate and conventional SOI LIGBT are both about 240 V, where the thickness of the buried oxide is 3μm and lateral length of the n$^-$ epi is 40μm.

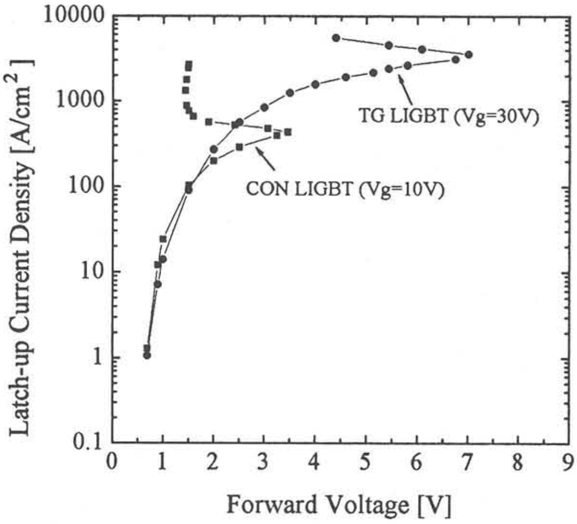


Fig.4 Latch-up curves of the trench gate and conventional SOI LIGBT at 0.1 μs of the lifetime.

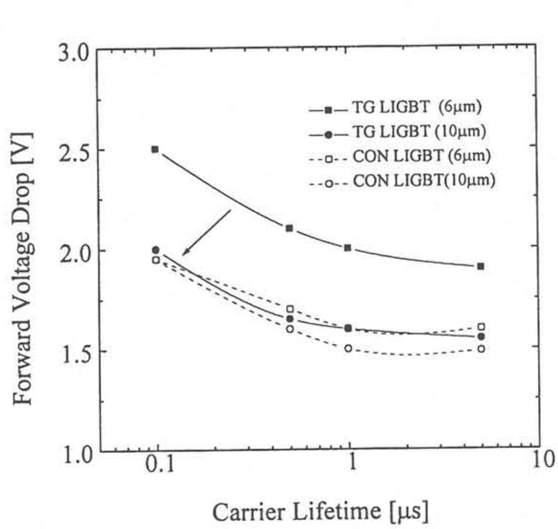


Fig.5 Forward voltage drop of the trench gate and conventional SOI LIGBT as a function of the lifetime when the gate voltage is 10V and the current density is 200A/cm^2 .

V. Conclusion

We have proposed the trench gate SOI LIGBT with the p+ cathode well and verified the improved latch-up characteristics of the device by MEDICI simulation to enhance the latch-up capability in SOI LIGBT. The new SOI LIGBT exhibits at least 6 times larger latch-up capability than the conventional device. It has been found that the improved latch-up characteristics of the trench gate SOI LIGBT was attributed to the p+ cathode well which provides the direct path irrelevant to the latch-up for the hole current. Turn off time and breakdown voltage of the trench gate device are almost same with the conventional devices. The forward voltage drop in the trench gate device increases slightly due to the electron current crowding between the buried oxide and the p body. However, the increase of the forward voltage drop is negligible. The trench gate SOI LIGBT with p+ cathode well may be utilized for the power integrated circuits(PICs) without suffering from latch-up.

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