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Trench IGBT for the Improved Short Circuit Capability by Employing the Curved Junction and Wide Cell Pitch

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1. Introduction

The conduction and switching characteristics of the IGBTs have been considerably improved recently. In addition to the improvement of the performance, the short circuit capability of the IGBT has also significantly increased so that the IGBT has been increasingly used in various motor drive applications.

The trench IGBT exhibits superior performance to the planar one due to the advanced trench process. However, the trench IGBT still shows the weakness on the ruggedness such as the short circuit immunity.

The failure of the IGBT during the short circuit could be classified by two categories such as the activation of he parasitic thyristor and the energy by the self-heating during the short circuit state [1].

The voltage drop of the p-well beneath the n+ emitter turns on the parasitic thyristor. Several methods to suppress the activation of the parasitic thyristor have been reported such as the reduction of the p-well resistance using high-energy implantation [2], the decrease of hole current using p+ diverter [3] and using emitter-ballast resistance (EBR) [4].

In order to reduce the energy dissipated in the short circuit state, the saturation current level should be reduced by the decrease of the channel density. However, this deteriorates the conduction characteristics of the IGBT. To minimize the increase of the saturation voltage, the carrier stored trench-gate bipolar transistor (CSTBT) or high-conductivity IGBT (HiGT) are reported [5][6].

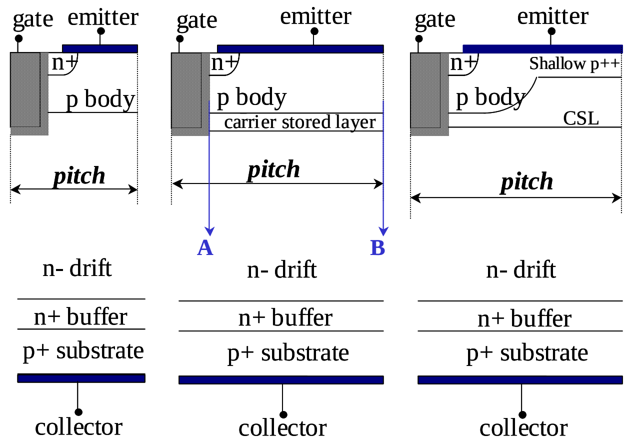
We propose a trench IGBT employing a curved p-well and wide cell pitch which improves the short circuit capability and shows better performance than the conventional IGBT in the conduction characteristics due to the carrier stored layer (CSL). The proposed IGBT is analyzed and verified by the numerical simulation [7].

Table I. The device parameters used in the simulation.

	conventional	CSTBT	proposed	Unit
pitch	3.0	6.0	6.0	μm
trench depth	4.5	4.5	4.5	μm
trench width	0.75	0.75	0.75	μm
gate oxide	1000	1000	1000	Å
p-body depth	3.5	3.5	3.5	μm
conc. of CSL	-	3E16	1E16	cm^{-3}
lifetime	1	1	1	a.u.

2. Device Structures

The cross-sectional view of the conventional and the proposed IGBTs is shown in Fig. 1. We have optimized the pitch of the unit cell to minimize the saturation voltage of the proposed one. And the saturation voltage of the CSTBT is set to be similar to that of the proposed IGBT. The device parameters are listed in Table I.



(a) Conventional (b) CSTBT (c) Proposed
Fig. 1. Cross-sectional View.

3. Saturation Voltage Characteristics

The current-voltage characteristics according to the structure shown in Fig.1 are compared in Fig. 2. The increase of the pitch reduces the channel density so that the saturation current decreases and the saturation voltage increases. In the CSTBT, the carrier stored layer makes the excess carrier profile of the on-state to be similar to that of the p-i-n diode so that the saturation voltage could be maintained in spite of the channel density reduction. From the Fig. 3(a), the left edge is interface between p-well and n-drift layer. Even though the excess carrier of the 6.0μm pitch conventional in the n-drift region is lower than that of 3.0 μm conventional one, the peak value at the p-well interface is slightly high. That is why the current flow only through the channel during the on-state. The holes injected from the collector are concentrated at the channel. From the Fig. 3(b), the excess hole carriers in the n-drift layer of the CSTBT is higher than that of the proposed IGBT. However, the saturation voltage of the CSTBT is slightly higher than that of the proposed IGBT. The hole injected from the collector flow to the emitter perpendicular to the collector electrode. These holes converge to the channel near the surface. Therefore, the high resistive area just below the p-well is appeared, which increases the saturation voltage. This area of the proposed IGBT is smallest than the others. Even if much higher resistive area occurs below the shallow p++ layer in the proposed device as shown in Fig. 3(b), there is little effect on the saturation voltage. Because this high resistive layer is appeared above the p-well junction depth due to the curved shape of the p-well so that there is no current flow during the on-state.

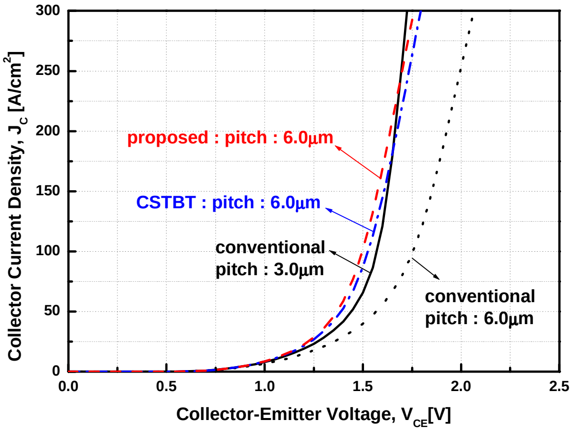
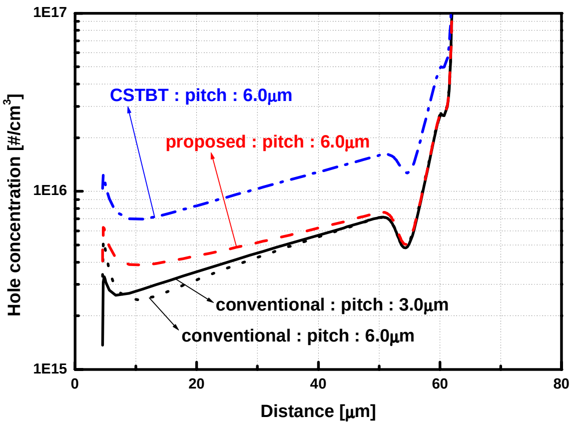
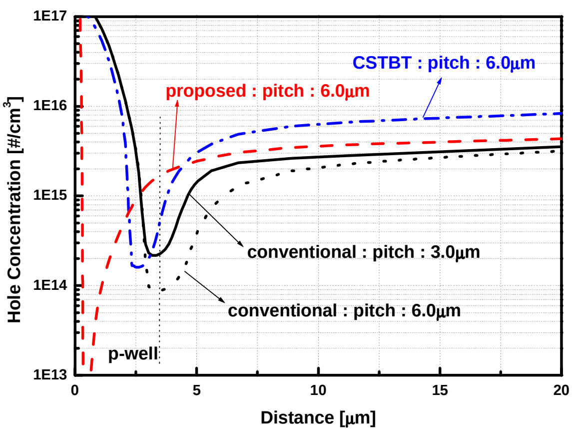


Fig. 2. I-V characteristics.



(a) according to the cut-line A



(b) according to the cut-line B

Fig. 3. Hole carrier profile at collector current density 200[A/cm^2].

4. Short Circuit Capability

The structures shown in Fig. 1 have the same peak concentration of the p-well. The latch-up characteristics are similar to each other. In general, the shallow p++ layer is also adopted in conventional and the CSTBT while that layer does not affect on the threshold voltage so that there is little difference in the resistance of the p-well. Therefore, the short circuit capability is considerably dependent on the saturation current level, which causes the increase of the temperature due to the self-heating. Our simulation results of the Fig. 4 show the short circuit capability of the proposed IGBT is higher than that of CSTBT, while the saturation voltage of the proposed IGBT and the CSTBT is almost same as the 3.0µm pitch conventional IGBT.

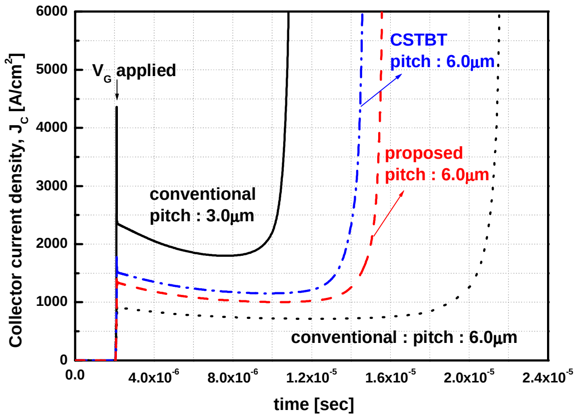


Fig. 4. Short circuit capability.

4. Conclusion

We propose the new trench IGBT employing the curved junction and wide cell pitch, which improves the short circuit immunity by the reduction of the energy dissipated by the self-heating during the short circuit state. The reduced channel density does not increase the saturation voltage by the shift of the high resistive area to the surface due to the carrier stored layer and the curved p-well junction. The short circuit capability of the proposed IGBT could be increased 1.6 times larger than that of the 3.0µm pitch conventional IGBT while the saturation voltage is almost identical. The proposed IGBT is suitable for the motor drive applications.

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