D-3-03 Extended Abstracts of the 2024 International Conference on Solid State Devices and Materials, Himeji, 2024, pp195-196

Proposal of 1.2kV thin wafer Semi-SuperJunction IGBT (SSJ-IGBT) surpassing Full SuperJunction IGBT

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Abstract

We propose a new Semi-SuperJunction IGBT (SSJ-IGBT) for high voltage applications. The device realizes low turn-off loss as well as low surge voltage by utilizing SSJ structure. Highly doped narrow pillars enable fast extraction of the stored carriers. The relatively slow dI/dt, realized by flat N-base region, suppresses surge voltage. We report, for the first time, that SSJ-IGBT realizes superior Vce(sat)-Eoff trade-off relation, better than that of conventional Full SuperJunction IGBT.

1. Introduction

SuperJunction(SJ) concept is frequently used for middle voltage Power MOSFET. In order to apply SJ concept to higher voltage range, Full SJ-IGBT(SJ-IGBT) and Semi-SJ-IGBT(SSJ-IGBT) have been proposed and discussed[1-6]. However, although the turn-off loss can be considerably reduced, the surge voltage exceeds several hundred voltages in the nominal operating condition[4, 5]. It may affect the endurance of the systems.

In this paper, we propose a new SSJ-IGBT which realizes low turn-off surge voltage together with Vce(sat)-Eoff trade-off relation, which is better than that of conventional SJ-IGBT. The proposed SSJ-IGBT has highly doped N- and P- pillars only in the upper part of the N-base region. The rest of the N-base region acts as a suppressor of the surge voltage.

2. SSJ-IGBT structure and TCAD simulation

TCAD device simulations were performed in order to analyze SSJ-IGBT electrical performances. FS-IGBT and conventional SJ-IGBT were used for the references. For the SSJ-IGBT, P/N pillars were introduced only in the upper part of the N-base. The pillar pitch was set to be 2um. The height of the pillar was set to be 30um. These structures are illustrated in Fig. 1.

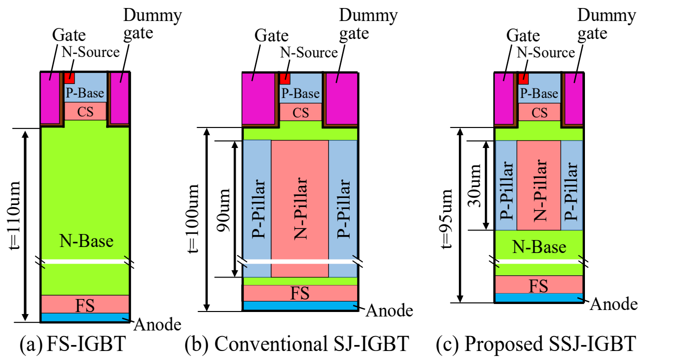

Fig. 1. Cross sectional view of IGBTs.

The structural parameters are summarized in Table I. Switching characteristics were calculated with an inductive load and a parasitic inductance of 100nH.

Table I. Device structural parameters.

	Conv. IGBT	Conv. SJ-IGBT[5]	Proposed SSJ-IGBT
Base thickness	110um	100um	95um
Pillar width	-	2.0um	1.0um
Pillar height	-	90um	30um
Pillar doping concentration	-	$6.0\times10^{15}cm^{-3}$	$2.0\times10^{16}cm^{-3}$
N-base doping concentration	$7.0\times10^{13}cm^{-3}$	$9.0\times10^{13}cm^{-3}$	$1.2\times10^{14}cm^{-3}$

3. Simulation results and discussion

It is plotted in Fig. 2 that SSJ-IGBT shows better Vce(sat)-Eoff trade-off relationship than conventional SJ-IGBT. Also, SSJ-IGBT has quite lower surge voltage of turn-off, compared with that of SJ-IGBT.

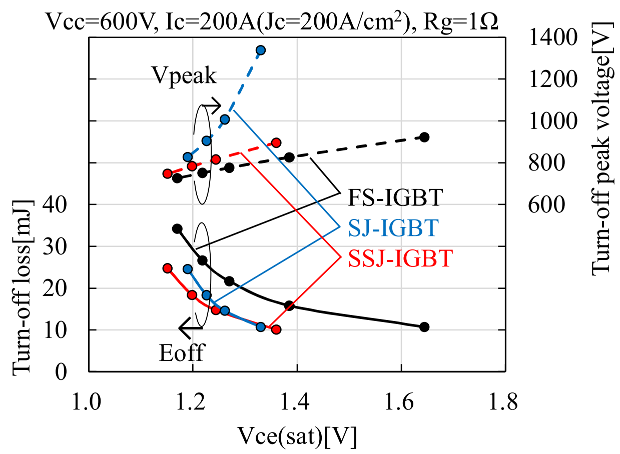

Fig. 2. Eoff and turn-off surge voltage are shown as a function of Vce(sat).

Turn-off waveforms are compared in Fig. 3. The surge voltage of SSJ-IGBT is well suppressed than that of SJ-IGBT. It is because SSJ-IGBT has a small tail current and, thus, the dI/dt is reduced. This good characteristic is maintained even for smaller current density, as shown in Fig. 4.

The turn-off mechanism of SSJ-IGBT can be explained by following three steps. In the first step, the gate charge is extracted via gate resistance and the channel electron current is stopped. In the second step, high electric field is applied in the SJ region. In SSJ-IGBT, the electric field in the SJ region has more rapidly risen than that of conventional full SJ-IGBT as shown in Fig. 5. Then, the stored carriers are extracted immediately from the SJ region as is also shown in Fig. 5. These phenomena can be explained by the magnitude of the minority carrier densities in the on-state. Fig. 6 shows that the stored minority carriers in SSJ-IGBT are quite lower than those of SJ-IGBT. It enables fast extraction of excess carriers from SJ regions, similar to unipolar SJ-MOSFET. In the third step, the electric field in the N-base is expanded towards the field-stop(FS) layer. The excess carriers are extracted gradually, and it realizes relaxed slope of the current waveform. This is because the electric field does not reach the FS layer and there is a region of very small electric field, remaining as shown in Fig. 7. The tail current suppresses surge voltage, which is quite smaller than that of full SJ-IGBT.

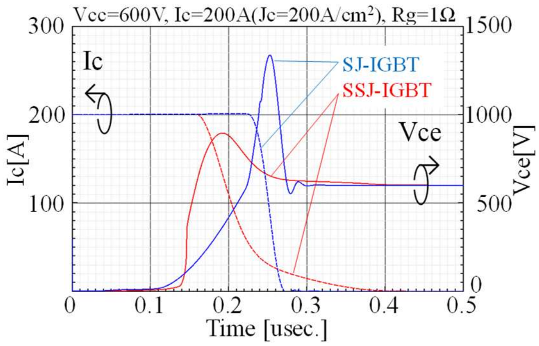

Fig. 3. Turn-off waveforms.

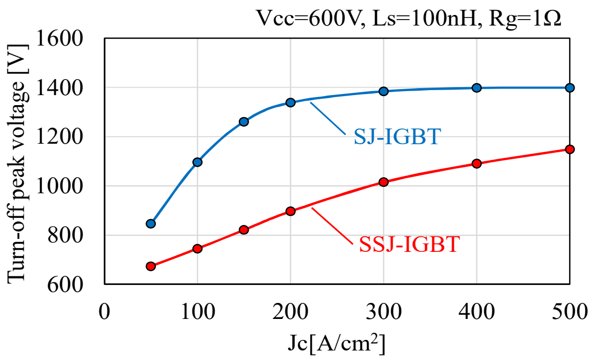

Fig. 4. Turn-off peak voltage versus turn-off current. Device active area is assumed as $1cm^2$.

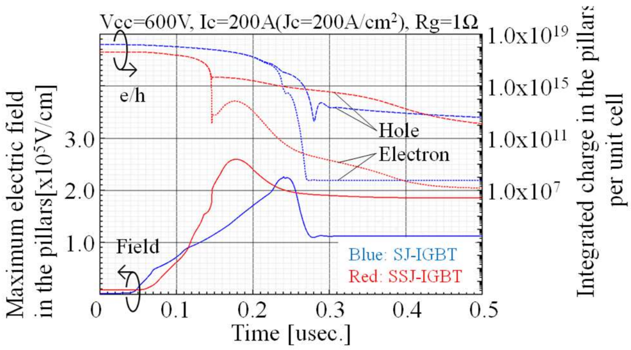

Fig. 5. Maximum electric field and integrated charges in the pillars are plotted as a function of time during turn-off.

The doping concentration and the width of the pillars influences process margin for the charge imbalance. Fig. 8 compares the relationship between the charge imbalance and the breakdown voltage. SSJ-IGBT has the same level of the tolerance for the charge imbalance as conventional SJ-IGBT, in spite of the highly doped narrow pillars.

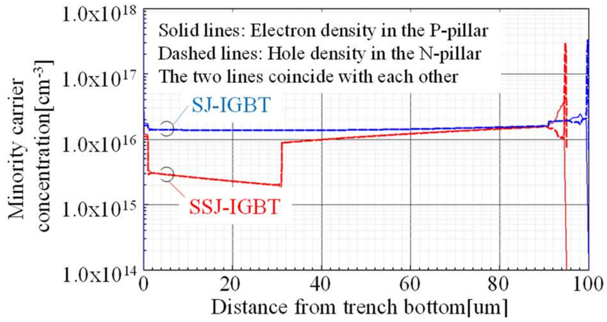

Fig. 6. Minority carrier distributions in the on-state ($Jc=200A/cm^2$).

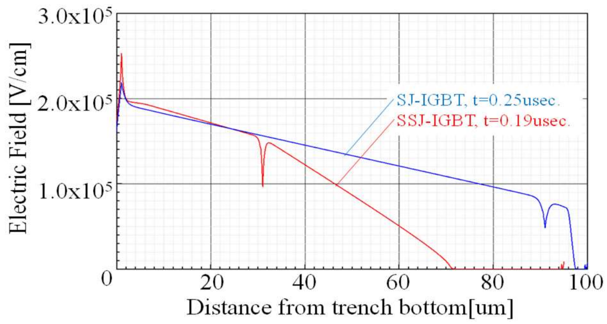

Fig. 7. Electric field distributions in the N-pillar and N-base, as snapshots of t=0.19usec (SSJ-IGBT) and t=0.25usec (SJ-IGBT).

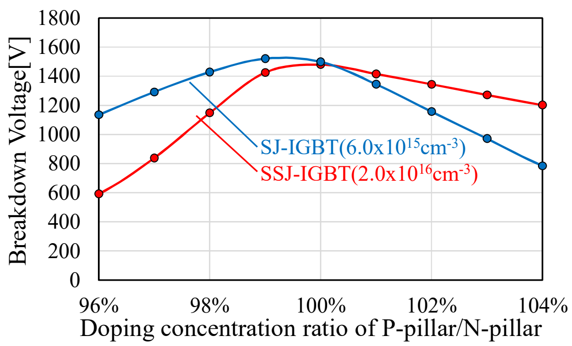

Fig. 8. Relationship between charge imbalance and breakdown voltage.

4. Conclusions

We propose a new SSJ-IGBT, which realizes superior Vce(sat)-Eoff trade-off relation, better than that of conventional full SuperJunction IGBT. The higher pillar concentration enables faster depletion of the SJ region. The device further realizes low turn-off surge voltage owing to the remaining small tail current.

References

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