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New 1200V Bidirectional FS-IGBT (BFS-IGBT) with Short-Circuit Capability

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Abstract

We propose a new bidirectional FS-IGBT for high voltage applications. Newly developed MOS gate structure with unique N-emitter/P-base and CS/N-buffer layers realize FS-IGBT I-V characteristics for both directions. An optimized N-buffer layer works as CS layer in the cathode and reduces on-state voltage. In result, the device has superior trade-off relationship between on-state voltage and turn-off loss, and even realizes enough short-circuit withstand capability.

1. Introduction

Bidirectional FS-IGBT has conduction and blocking capabilities for both polarities. It realizes AC-AC matrix converters, which achieve much smaller size than DC-linked type converters.

For the matrix converter applications, MBS structures and IGBT structures with reverse blocking capability have been proposed [1-4]. However, in order to adapt the devices to the realistic applications, further loss reduction and ruggedness such as short-circuit withstand capability should be required. In this paper, we propose new bidirectional FS-IGBT structure by using 3D TCAD simulations. It improves the trade-off relationship between on-state voltage drop and turn-off loss by optimizing carrier distribution profiles in the N-base. It also realizes 10us short-circuit withstand capability.

2. Structure and basic operation

Proposed structure is illustrated in Fig. 1. MOSFET cells are symmetrically formed on the front and rear side of the semiconductor wafer.

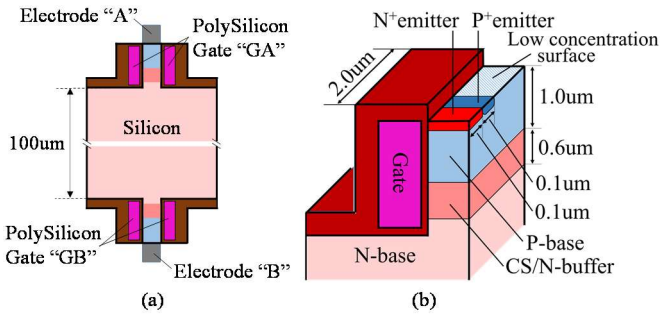

Fig. 1 Proposed bidirectional FS-IGBT structure. (a) Cross sectional view of the whole structure. (b) Schematic view of the cell design. Narrow P+ and N+ emitter segments are formed for depth direction. CS/N-buffer layer is located between P-base and N-base.

The structural parameters of the proposed device are summarized in Table I. Narrow segmented N+/P+ layers and a large low concentration P-base surface are designed. The low concentration P-base surface realizes low hole injection efficiency when it is in the Anode side. A CS/N-buffer layer works as FS(Field Stop) layer and realizes 1500V blocking capability with 100um N-base. It also works as CS layer and achieves high electron injection efficiency from the MOS gate[5] when it is in the Cathode side. Thus, CS/N-buffer layer improves trade-off relationship between on-state voltage drop and turn-off loss. The N+ emitter width is set at 0.1um in order to reduce the saturation current, which affects short-circuit withstand capability. The device is 1.2kV class and the operating gate voltage is 5V.

Table I Device structural parameters.

N-base thickness	100um	Unit half cell pitch for horizontal direction	4.0um
P-base depth	1.0um	Mesa width	2.0um
Trench depth	2.0um	Gate oxide thickness	33nm

The device operation is similar to conventional FS-IGBT. When positive voltages are applied to the electrodes B and GA against A, electrons flow from A to B via MOS channel. Conversely, holes flow from B to A. They cause conductivity modulation in the N-base. It is a unique characteristic feature of this device that the hole injection efficiency can be controlled by the gate bias of the Anode side. When a negative gate bias is applied to the gate GB against B, a P-channel is formed and increases hole injection. When an enough positive gate bias is applied to the gate GB against B and makes short-circuit between N-base and Anode N+ layer by the N-channel, the hole injection is reduced.

3. Results and discussion

Blocking, forward and switching characteristics

Proposed bidirectional FS-IGBT has been analyzed by 3D TCAD simulations. It is shown in Fig. 2 that the breakdown voltage of the proposed device is 1498V. It is shown in Fig. 3 that the proposed device has low on-state voltage drop of 1.26V at 200A/cm^2. The I-V characteristics can be controlled by negative gate bias for the Anode side. It is shown in Fig. 3 that the proposed device achieves flat on-state carrier distribution profiles, compared with conventional device, such as MBS, which does not have the low concentration P-base surface nor CS/N-buffer layer. It is because the hole injection

efficiency in the Anode side is reduced by the low concentration P-base surface (B-side in Fig. 4). The electron injection efficiency in the Cathode side increases by the CS/N-buffer layer (A-side in Fig. 4). It acts as a barrier against holes.

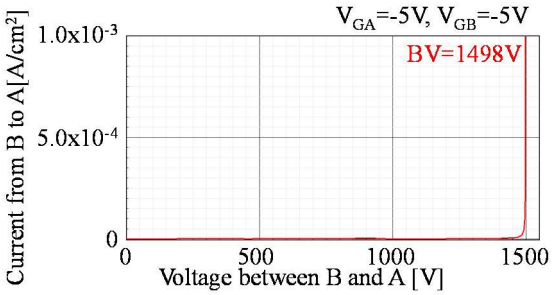

Fig. 2 Breakdown characteristic of the proposed device.

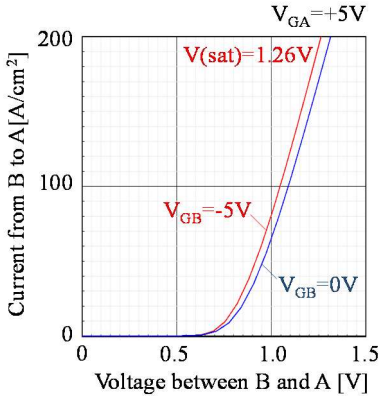

Fig. 3 Forward I-V characteristics of the proposed device. The on-state voltage drop can be reduced by applying a negative gate bias to the Anode side.

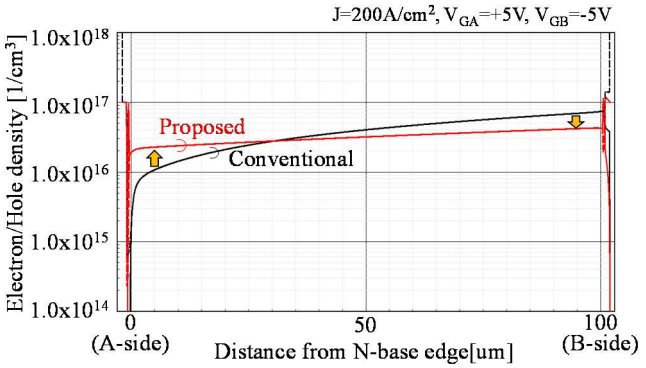

Fig. 4 On-state carrier distribution in the N-base. Proposed device achieves lower hole injection efficiency from the Anode side (B-side) and higher electron injection efficiency from the Cathode side (A-side), than conventional device such as MBS.

The turn-off waveforms are shown in Fig. 5. In the turn-off, it is found that, in the case where the gate bias of the Anode side changes from zero to +5V, the switching speed becomes faster, compared with the case where the gate bias changes from -5V to +5V. Thus, it is important to set the gate voltage at zero before turn-off because the excess carriers are reduced by removing the P-channel prior to the turn-off. It is also shown in the inlet of Fig. 5 that the proposed bidirectional FS-IGBT improves the trade-off relationship between on-state voltage drop and turn-off loss.

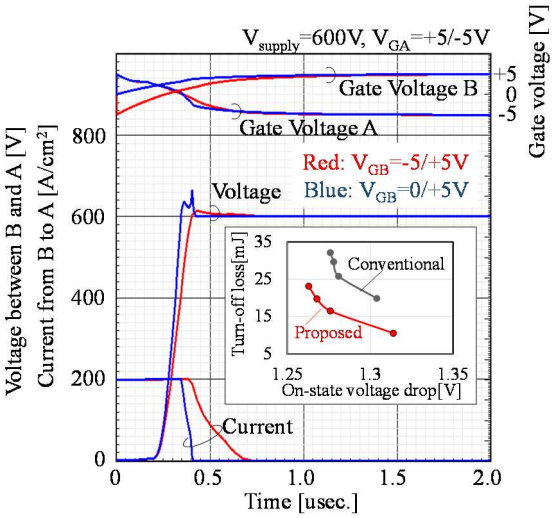

Fig. 5 Turn-off switching waveforms of inductive load circuit. The initial gate voltage of the Anode side affects the turn-off speed. Trade-off relationship between on-state voltage drop and turn-off loss is also shown. Proposed device improves on-state voltage drop as well as turn-off loss by introducing low concentration P-base surface and CS/N-buffer layers.

Short-circuit withstand capability

It is shown in Fig. 6 that the proposed bidirectional FS-IGBT has 10us short-circuit withstand capability. The saturation current during the operation is restricted less than 700A/cm^2 by the narrow segmented N+ emitter. The temperature increase is successfully suppressed below 630K.

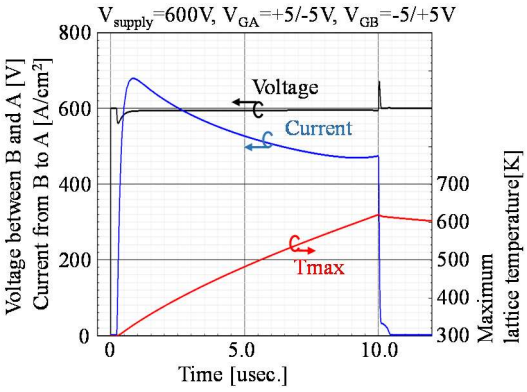

Fig. 6 Short-circuit waveforms. The device is successfully turned off after 10us.

3. Conclusions

A new bidirectional FS-IGBT was proposed. Carrier injection efficiencies and saturation current are optimized by narrow P+/N+ emitters, low concentration P-base surface and CS/N-buffer layers. We also confirmed that the proposed device has enough short-circuit withstand capability.

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