Research on Dynamic Characteristics of Trench Type Bidirectional IGBT

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Abstract. To improve the switching characteristics of conventional structure IGBT, a new trench type bidirectional insulated gate bipolar transistor (IGBT) is proposed. The main feature of this structure is introducing a cell in collector of conventional trench IGBT. The new type IGBT reduce both turn-on and turn-off losses because double-gate IGBT can accelerate carrier extraction speed. By building the device simulation DC/AC circuit of dynamic characteristics, the turn-on time is 0.12µs and turn-off time is 5.1ns. Compared with conventional IGBT, the new type IGBT's turn-on and turn-off loss have a great reduce.

Introduction

The power semiconductor devices are widely used in switching mode power supply circuits, such as motor control of electric and hybrid vehicle (EV/HEV), smart grid network, etc. IGBT is almost the most popular power component switch in the voltage range from 400V to 4.5kV[1]. Nowadays the improvements in the performance of the IGBT have been mainly based on the following technology: 1) the field stop layer, 2) the trench gate, 3) the injection enhancement effect, 4) the super junction. These mainstream technologies, to some degree, could offer an excellent compromise between the on-state voltage drop and the turn-off switching loss. Nevertheless, the above-mentioned methods may reach a virtual limit in the field of the matrix converter requiring voltage and current switches[2-5]. This paper aimed to explore the feasibility and advantage of the symmetric double-gate IGBT, which can be an alternative method for the monolithically integrated bidirectional switch device.

Device structure and working principle

A conventional trench type IGBT is shown in Fig.1 (a). Trench type bidirectional IGBT is shown in Fig.1 (b). In order to reflect the advantages of the trench type bidirectional IGBT characteristics, both the conventional IGBT and bidirectional IGBT owned the same structure size. The structural parameters of the two devices are shown in Table 1.The gate oxide layer using SiO_2 with the thickness of 0.1µm. The total thickness of the device is 395µm with the width of 20µm. Electrodes are made of aluminum material.
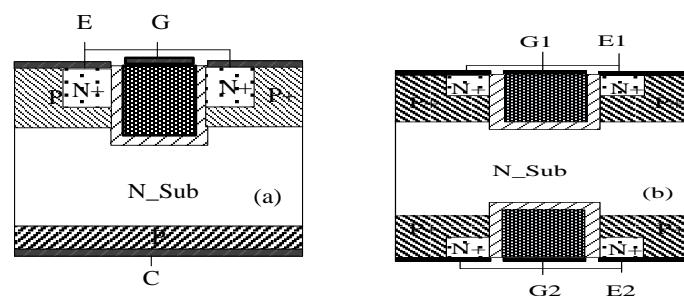

Fig.1 Conventional trench type IGBT(a) and trench type bidirectional IGBT (b) Structures

Table 1 The structure parameters of trench type bidirectional IGBT and conventional trench type IGBT

	Doping (cm^{-3})	depth(μm)	width(μm)	dopant
substrate	3×10^{13}	395	20	P
N+	1×10^{20}	1.5	1.9	P
P+	2×10^{18}	3.5	8	B
Poly-Si	1×10^{20}	4	4	P

There are some different between trench type bidirectional IGBT and conventional trench type IGBT. The electrodes gate, collector and emitter of conventional trench type IGBT is named G, C and E. As shown in Fig.1 (a). Fig.1 (b) shows the trench type bidirectional IGBT have two gate electrodes G1, G2. The other two electrodes named E1, E2.

There are two working statuses in the AC circuit according to the working principle of the device. One is when $V_{G2}=0$; $V_{E1}=0$, $V_{E2}>0$, $V_{G1}>0$. V_{E1}, V_{E2}, V_{G1}, respectively, as the emitter, collector and gate control the switching characteristics of the device. Another is when $V_{G1}=0$; $V_{E2}=0$, $V_{E1}>0$, $V_{G2}>0$. V_{E2}, V_{E1}, V_{G2}, respectively, as the emitter, collector and gate control the switching characteristics of the device. In the states1 when $0V<V_{G1E1}<V_{th}$, the device turn-off. The two sides of the G1 gradually formed an inversion layer when $V_{G1E1}>V_{th}$. Meanwhile, forward voltage make collector E2 hole inject into the substrate region. Then the device conducted. State2 have the same working principle with state1[6.7].

Simulation results and analysis

DC circuit test results and analysis. In the trench type bidirectional IGBT DC circuit test, V2 is a 15V pulse signal applied to the gate G2, as shown in Table 2.

Table 2 Pulse signal of V_2

Time(s)	Voltage(V)
0	0
1×10^{-8}	0
3×10^{-8}	15
1.003×10^{-5}	15
1.005×10^{-5}	0
2×10^{-5}	0

Trench type bidirectional IGBT structure is very special. The double gate structure determines the presence of a plurality of internal resistance inductance capacitance of the device after conducting[8-10]. We get the dynamic characteristics curve of the trench type bidirectional IGBT through simulation as Figure 2 shows. Figure 3 is a simulation waveform of the pulse signal V2 applied to the gate G2. It can be directly observed trench type bidirectional IGBT turn-off voltage and current varies with the voltage on the gate G2.
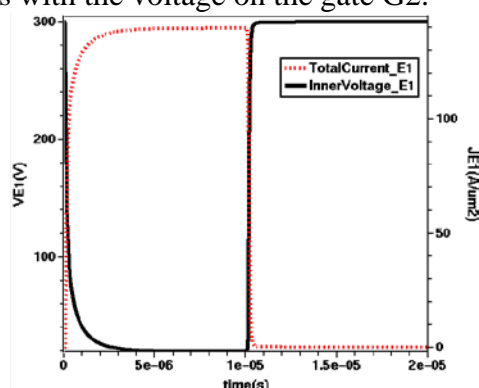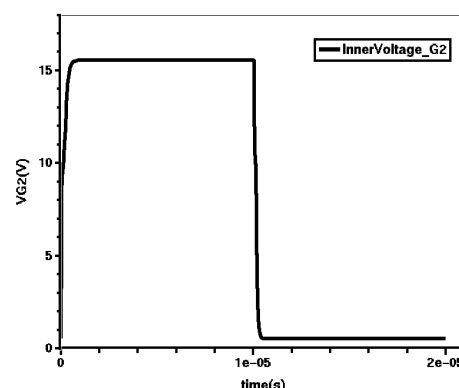

Fig.2 DC dynamic characteristic curve   Fig.3 The simulation waveform of V2

Figures 2 and Figures 3 show the trench type bidirectional IGBT switching characteristics. When the forward voltage of trench type bidirectional IGBT V_{G2} increased from 0V to 15V at 3×10^{-8}s, both sides of the gate G2 formed on a conductive channel, E1 emitter gradually emerge the current at 6.075×10^{-8}s; when $V_{G2} = 15V$, I_{E1} shows a stable value and V_{E1} declined from 300V to a little value. When V_{G2} declined from 15V down to 0V at 1.005×10^{-5}s, I_{E1} declined to a minimum value with V_{G2} declining. The time from V_{G2} falling to the collector current begins to falling last almost 0s. Then V_{E1} returned to 300V. According to the definition of trench type bidirectional IGBT turn on-time and turn-off time, after the final calculation, the trench type bidirectional IGBT turn-on time is 0.5593μs, off-time is 0.1127μs. It shows that trench type bidirectional IGBT has a high turn-on and turn-off speed, especially in turn-off speed.

AC circuit test results and analysis. We make a test in AC circuits when V_{E2}=0. The pulse signal in G1 and G2 controlled the device conduction and shutdown. There is a $\pm$300V pulse signal applied to E1electrode. V3 is a pulse signal applied to the E1 side, as shown in Table 3. V2 is a 15V pulse signal applied to G2, as shown in Table 2. When G2 electrode is conduction, V_{E1}=-300V as the collector. Before G2 shutdown, G1 is opening and controls the conduction and shutdown of the device.V_{E1}=-300V as the emitter of the device. V1 is the pulse signal applied to the gate G1 as shown in Table 3.

Table 3 Pulse signal of V1

Time(s)	Voltage(V)
0	0
1.0028×10^{-5}	15
1.0048×10^{-5}	15
2×10^{-5}	0

Table 4 Pulse signal of V3

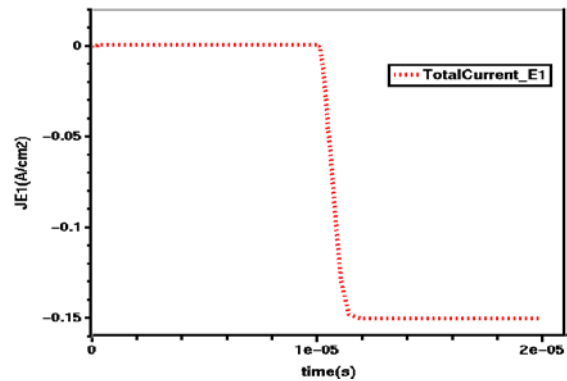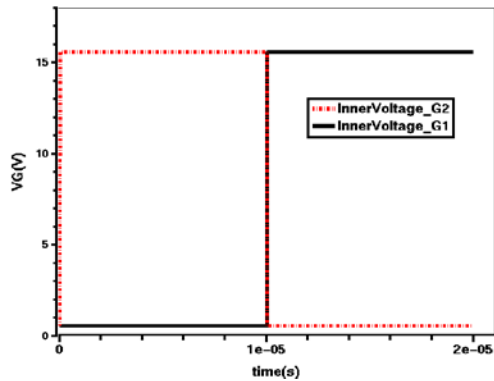| Time(s)	Voltage(V)
0	300
1.0048×10^{-5}	300
1.0068×10^{-5}	-300
2×10^{-5}	-300

Fig.4 The simulation waveform of V1 and V2   Fig.5 Current dynamic characteristic curve

Trench type bidirectional IGBT V1 and V2 pulse signal is shown in Figure 4. It can be seen from Figure.4 that V_{G1} reach peak before V_{G2} declined. As table 4 shows, at the peak of the G1 electrode V_{E1} convert from -300V to 300V. It can be seen from Figure 5 shows, with the rise of V_{G2}, E1 began to appear current. Then the current tends to be stable. When G2 turn-off and G1 turn-on. The current in E1 reverse rise. It is much larger than the forward current. After calculation, compared with conventional IGBT trench type bidirectional IGBT in AC circuit turn-on time is 0.12μs and turn-off time is 5.1ns. Its turn-on and turn-off loss have a great reduce.

Summary

In this paper a new trench type bidirectional insulated gate bipolar transistor (IGBT）is proposed. We make a test in DC/AC circuits, and find conventional IGBT and new type IGBT Dynamic characteristics have a certain similarity. Through the analysis of trench type bidirectional IGBT in DC/AC circuits simulation. The trench type bidirectional IGBT turn-on time is 0.5593μs, off-time is 0.1127μs. It shows that trench type bidirectional IGBT has a high turn-on and turn-off speed. Also the trench type bidirectional IGBT can accelerate the speed of carrier extraction, reduce the tail current and turn-off time.

Acknowledgment

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