Analysis of the IGBT with improved trade-off characteristic between conduction and turn-off losses.

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Abstract

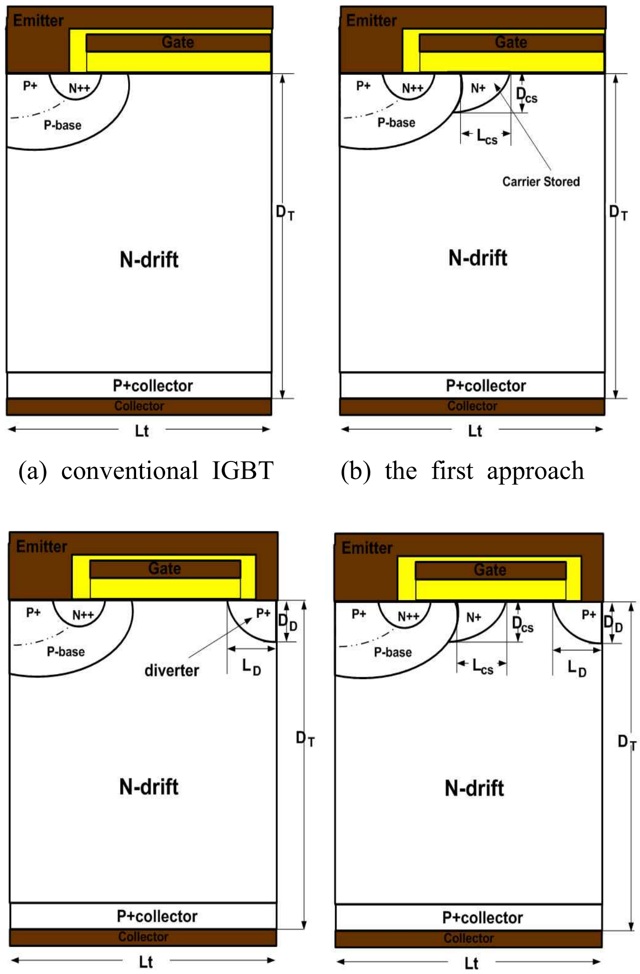
In this paper, we tried different two approach to improve the performance of the IGBT. The first approach is that adding N+ region beside P-base in the conventional IGBT. It can make the conventional IGBT to get faster turn-off time and lower conduction loss. The second approach is that adding P+ region on right side under gate to improve latching current of conventional IGBT. The device simulation results show improved on-state, latch-up and switching characteristics in each structure. The first one was presented lower voltage drop(3.08V) and faster turn-off time(3.4us) than that of conventional one(3.66V/3.65us). Also, second structure has higher latching current(369A/cm^2) that of conventional structure. Finally, we present a novel IGBT combined the first approach with second one for improved trade-off characteristic between conduction and turn-off losses. The proposed device has better performance than conventional IGBT.

1. Introduction

Among the power semiconductor devices, the insulated gate bipolar transistor(IGBT) is the most widely used power device due to its low conduction loss and high switching speed[1]. the IGBT combines both bipolar and MOSFET structures and processes the best features of both device types. so, IGBT has simple MOS gate control, low on-state voltage drop and current carrying capability of a bipolar transistor[2][3]. Nowadays it is finding widespread applications in uninterruptible power supplies, industrial motor drives and domestic and automotive electronics, preferably at medium and higher voltage and in the low and medium frequency. Although it has a good benefit, there are some problems in the planar gate type IGBT such as forward voltage drop(in JFET region) and turn off delay time(due to high level hole injection)[4][5]. So, this paper present a new IGBT for power switching device based on Non Punch Through(NPT) IGBT structure. The proposed structure has adding N+ beside the P-base region and P+ beside On-right side under gate of the conventional IGBT structure. The proposed device has faster turn-off time and lower forward conduction loss than the conventional IGBT structure.

2. Device Description

new structure IGBT for conventional IGBT electrical property improvement is proposed. The proposed IGBTs has method of two type approach. The first approach(Fig 1.(b)) is that adding N+ region beside P-base in the conventional IGBT. It can make the conventional IGBT(Fig 1.(a)) to get faster turn-off time and lower conduction loss. And the features of the second structure(Fig 1.(c)) is adding P+ region on right side under gate. This structure may be effective to improve latching current than conventional Planar type IGBT. The last one of the proposed structure(Fig 1.(d)) has combined the two structure(the first one and second one). The proposed device has faster turn-off time, lower on-state characteristic and higher latching current than conventional IGBT. The device parameters are summarized in the Table 1.



(a) conventional IGBT (b) the first approach

(c) The second approach (d) proposed IGBT(b+c)

Fig 1. Cross-section of conventional IGBT and proposed IGBT

Table 1. The device parameters used for simulation

L_D	-	diverter electrode length (um)	2
L_T	-	total length (um)	23
L_{cs}	-	carrier stored region length (um)	3
t_{ox}	-	oxide thickness (Å)	1000
D_T	-	total depth(um)	390
D_D	-	diverter region depth (um)	1.5
D_{cs}	-	carrier stored region depth (um)	1.5
Pb	-	P-base region doping (cm^3)	3.5e17
P^{++}	-	p++ emitter region doping (cm^3)	3e19
N^{++}	-	n++ emitter region doping (cm^3)	3e19
P^+	-	p+ diverter region doping (cm^3)	1e15
N^+	-	n+ carrier stored doping (cm^3)	1e16
P^+c	-	p+ collector region doping (cm^3)	1e19

3. Simulation Results and Discussion

We used the process simulator of Tsuprem4 and device simulator of medici to MEDICI to verify the electrical characteristics of proposed IGBT. Fig.1(a) and (d) show the structures of proposed IGBT and convention IGBT respectively. And Fig. 1(b),(c) show different two approaches to improve the performance. In the first approach, highly doped N+ region is added beside P-base region. This added N+ region interrupt the flow of hole current, which flow through P-base, injected from P-collector. And, the holes is stored around N+ region. These stored holes decease the On-resistance and turn-off loss. However, added N+ region can reduce the breakdown voltage due to its high doping concentration. The optimum value for high breakdown voltage, low conduction loss and fast switching speed is required. In the simulation result, it is confirmed that the optimum doping concentration of added N+ region is of 1e16(atoms/cm^3). At this value, the IGBT has lowest saturation voltage of 3.04V and similar breakdown voltage of 2951V with conventional IGBT of 2952V. And the optimized value of depth and width of added N+ region is 1.5um and 3um respectively. In the second approach, P+ region is added on the right side of structure under poly gate. This structure is well known as IGBT with diverter. This device can improve the latching current due to the reduction of the current via P-base under N+ emitter. However, the added P+ region(P+ diverter) increased the resistance due to the JFET action. It is required to optimize the design parameter and the process parameter for improvement of trade-off characteristic

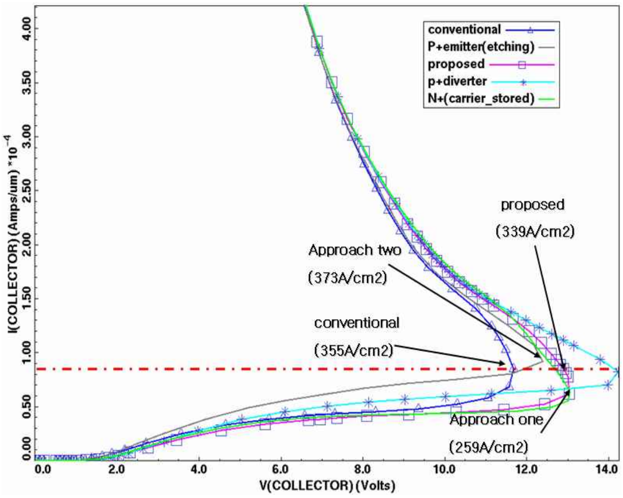


Fig 2. Latch-up characteristics of the conventional and proposed IGBT. (@gate bias=15V)

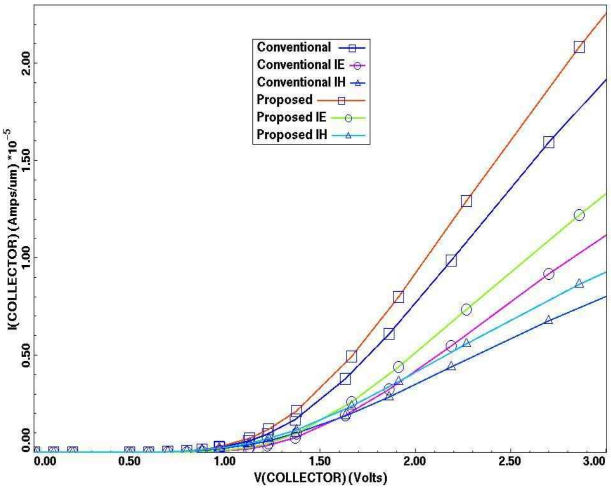


Fig 3. I-V characteristics of the conventional and proposed IGBT. (@gate bias=15V)

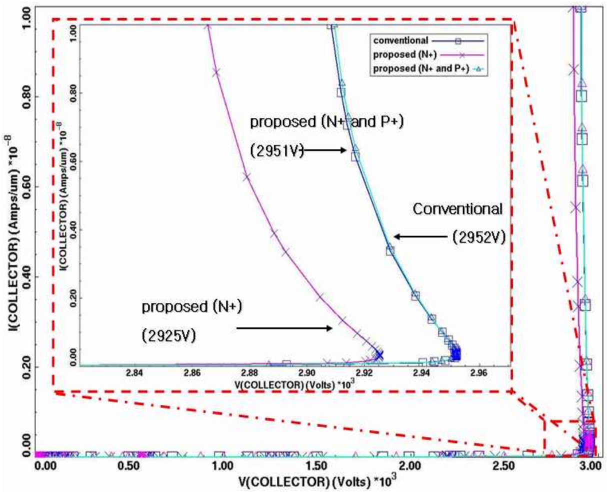


Fig 4. Forward blocking characteristics of the conventional and proposed IGBT.

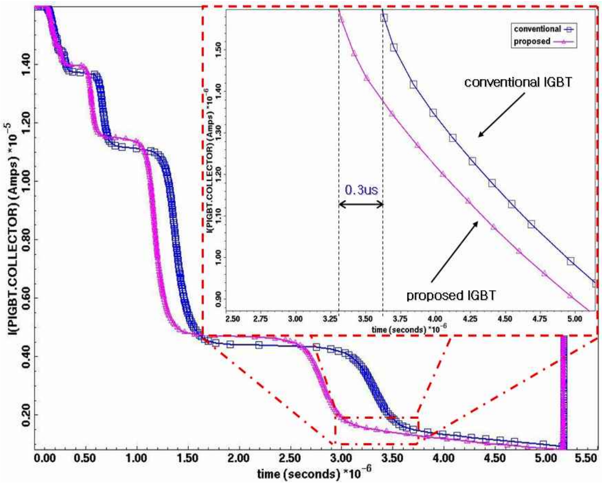


Fig 5. Turn-off characteristics of the conventional and proposed IGBT.

between latching current and conduction losses. In the simulation result, the latching current of the IGBT with adding p+ region is 372(A/cm^2). It is higher than that of conventional IGBT(355(A/cm^2). But the IGBT with adding p+ region has higher saturation voltage of 3.9V than that of conventional one(3.66V). Figures 2, 3 shows latching current and on-state characteristics for proposed IGBT and conventional IGBT. As shown in this figure, the proposed IGBT(339A/cm2 / 3.15V) have latching current and on-state characteristic than approach one(259A/cm2/3.66V). Turn-off waveforms of the proposed and conventional IGBTs shown in Figure 5. proposed IGBT(3.34us) were shown superior turn-off characteristics more than conventional IGBT(3.65us). So this structure can get higher on-state voltage(3.15V) and faster Turn-off time(3.34us) than conventional one(3.66V/3.65us).

Table 2. Comparison of the results of the conventional IGBT and proposed IGBT.

	Vce,sat	Turn-off	Latch-up	B.V
conventional	3.66V	3.65us	355A/cm^2	2952V
proposed	3.15V	3.34us	339A/cm^2	2951V

Conclusion

In this paper, two types of new structural planar type IGBT are presented. the first structure has N+ region beside P-base to get faster turn-off time and lower conduction loss. And features of the second structure is p+ region on right side under gate. This structure effective to latching current. So this structure can get higher latching current than conventional planar IGBT. The device simulation results represent the improved on-state, latching current and switching characteristics in each structure. The first one was presented lower on-state voltage drop(3.08V) and faster turn-off time(3.4us) than that of conventional one(3.66V/3.65us). Also, second structure has higher latching current(373A/ cm^2) than that of conventional structure(355A/cm^2). Finally, In this paper, the last one of the proposed structure has combined the two structure (the first one and second one). This structure has superior electric characteristics than conventional structure about forward voltage drop, turnoff characteristics. The results are summarized in the Table 2.

Acknowledgement

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