Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp372-373

Tilt-Implanted Trench Termination For SiC Power Devices

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Abstract

In this paper, the usage of tilt-implanted trench termination (TITT) device is proposed. The diode contains the potential within the trench insulator without any sacrifice in breakdown voltage. As such, the termination area of the TITT device is 38.7% smaller than that of other devices which use guard rings for the same breakdown voltage. When the trench depth is set to 11um and the width is optimized, a breakdown voltage of 2750V is obtained.

1. Introduction

Silicon carbide (SiC) has received much attention for its usage in power devices due to its wide band gap (3.24eV for 4H-SiC), high critical electric field (2.2×10^5V/cm), and high thermal conductivity (4.5W/cm·K) [1]. The most important aspects of a power semiconductor device are its breakdown voltage and its on-resistance. As such, one of the disadvantages of high voltage devices is their tendency to suffer from electric field crowding which degrades breakdown voltage [2]. Recently, numerous edge termination structures have been adopted to reduce electric field crowding. These structures include guard rings [3], field plates [4] and junction termination extensions (JTE) [5]. However, these structures increase the termination area in order to obtain their high breakdown voltage.

A trench termination structure is used not only to decrease the termination area but also to obtain a high breakdown voltage. Trench termination structures based on silicon (Si) cause holes to develop next to the trench insulator side wall when the reverse blocking mode is operated. All the potential is kept within the trench insulator due to existence of the accumulated holes [6] [7].

When SiC is utilized in power devices, however, the trench side wall is unable to accumulate holes in the reverse blocking mode due to the low intrinsic carrier density (5×10^{-9}cm^{-3}). As such, there are no accumulated holes beside the trench insulator side wall (SiO_2/SiC interface) and the trench insulator is unable to contain all the potential. To solve this problem, a tilt-implanted trench termination (TITT) technique modified for SiC is proposed as a method to keep all the potentials confined in the trench insulator. The trench side wall of the TITT is doped with n+ dopants (1×10^{19}cm^{-3}) via the tilt implantation process. The potentials are kept in the trench oxide insulator without any risk of decreasing breakdown voltage. The breakdown voltage levels are tested under different trench depths and widths.

2. Simulation Method

Figure 1 shows the simulated device structures: (a) a conventional trench termination structure, (b) the TITT structure and (c) a guard rings structure. The Hatakeyama model is used to obtain a breakdown voltage of 4H-SiC [7]. A Sentaurus device simulator is used to analyze the characteristics of the TITT [8]. Table I shows the set device parameters.

3. Simulation Results and Discussion

Figure 2 shows the potential contour of (a) the Si trench termination structure and (b) the accumulated holes beside the trench side wall. The Si trench termination is able to contain all the potential within the trench insulator due to accumulated holes beside the trench side wall [7]. The electric field terminates at the trench side wall. Figure 3 shows the potential distribution of the SiC trench termination. The SiC trench termination structure is unable to contain all the potential beside the trench side wall because the low intrinsic carrier density cannot accumulate holes when the reverse blocking mode is operated. This extends the termination area as shown in figure 3.

Figure 4 shows the potential contour of the TITT with a side wall doping concentration of 1×10^{19}cm^{-3}. With the 1×10^{19}cm^{-3} doping concentration of the side wall, the potential distribution is restricted to the trench insulator as shown in Fig. 4. This means no electric field is able to penetrate into the SiC region.

Figure 5 illustrates the dependence of the breakdown voltage on the trench depth for conventional SiC trench termination and TITT. It is clear from figure that the breakdown voltage is same irrespective of side wall doping. However, as the trench depth increases, so does the breakdown voltage. Thus the trench depth has a significant effect on breakdown voltage.

Figure 6 shows that the breakdown voltage improves with increased trench depth and insulator width. When the trench insulator width is greater than 14um, however, increases in breakdown voltage are marginal.

Figure 7 shows the reverse breakdown voltage of guard rings structures and TITT structures. As illustrated in the graph, the 7-guard rings structure has nearly the same breakdown voltage as the TITT structure. Figure 8 illustrates the potential distribution of the 7-guard rings structure. Though the 7-guard rings and TITT structure have the same breakdown voltage, it is clear in this figure that the potential contour of the guard rings structure extends to 70um while that of the TITT structure extends to just 38um. Therefore, the TITT structure reduces the termination area by 38.7% when compared to a 7-guard rings structure with the same breakdown voltage.

4. Conclusions

A 4H-SiC trench termination structure has been proposed. In this structure, the trench oxide insulator contains all the potential during reverse blocking mode operation. This trench termination implants high doped dopants beside the trench side wall. The breakdown voltage of the TITT structure is 2750V, the same value as that of the conventional trench termination structure. The termination area of the TITT structure is 38.7% smaller than that of the guard rings structure under the same breakdown voltage range. In addition, the breakdown voltage improves when trench depth is increased from 2um to 11um. This technique can be applied to many trench diodes based on SiC, such as Schottky or PiN rectifiers, to isolate potential.

Acknowledgements

This research was supported by the MSIP(Ministry of Science, ICT and Future Planning), Korea, under the ITRC(Information Technology Research Center)support program(NIPA-2014-H0301-14-1007) supervised by the NIPA(National IT Industry Promotion Agency)

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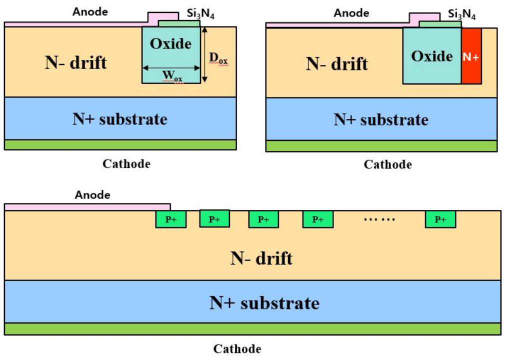

Fig. 1 Edge termination structures: (a) conventional trench termination, (b) tilt-implanted trench termination (TITT), and (c) guard rings

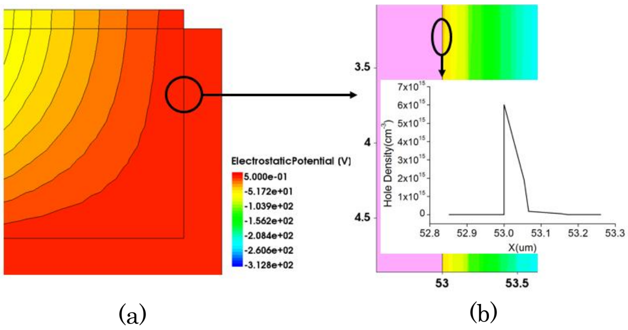

Fig. 2 Potential contour and hole density of Si trench termination insulator: (a) potential contour and (b) side wall hole density

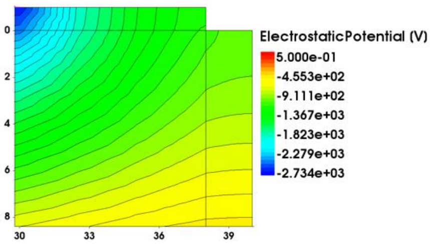

Fig. 3 Potential distribution of conventional SiC trench termination

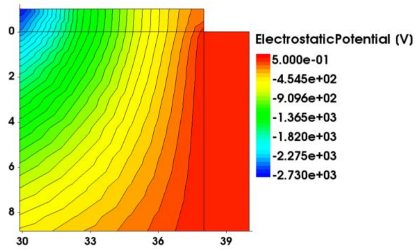

Fig. 4 Potential distribution of TITT with side wall doping concentration

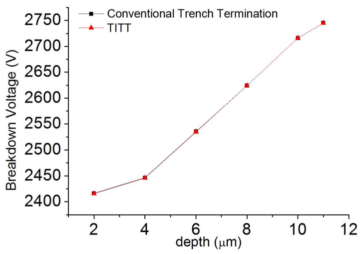

Fig. 5 Breakdown voltage as a function of trench depth

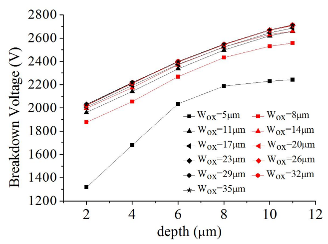

Fig. 6 Breakdown voltage as a function of trench depth with trench width as a parameter

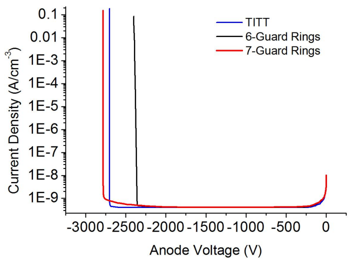

Fig. 7 I-V curves for TITT and guard rings structure

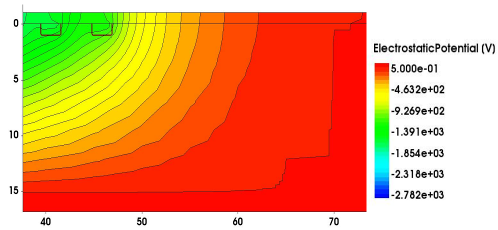

Fig. 8 Potential contour of SiC guard rings structure

Table I Design Parameters

Parameters	TITT	Guard Ring
Epitaxial Width (um)	15	15
Active Length (um)	20	20
Trench Side wall Doping (cm^{-3})	$1x10^{19}$	
Drift Doping (cm^{-3})	$1x10^{15}$	$1x10^{15}$