Compact Trench Floating Field Rings Termination for 10kV+ Rated SiC n-IGBTs

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Abstract. This work presents the design methodology and performance of a compact edge termination structure aiming 10kV+ rated Silicon Carbide (SiC) devices. Standard Floating Field Rings (FFRs) for such high voltage rating SiC devices are not favored because they are inefficient in terms of the achievable breakdown voltage as a percentage of the 1D maximum, consume large chip area, require high implantation energies and small gaps between rings which can violate fabrication limits. We show that the implantation of Aluminium at the bottom of carefully positioned trenches can be analogous to deep Aluminium implantation in terms of performance, thus annulling the need for small gaps between rings and MeV ion implantation. We optimize the distribution of trenches by placing them in multiple zones of different expansion coefficient. The proposed multi expansion ratio Trench FFR termination was utilized to terminate the active area of a 10kV rated Punch Through n-IGBT having 0.8 μm p-body and 100 μm, 3×10^{14} cm^{-3} drift region. We found the 0.6 – 0.8 μm to be the most optimum trench depth, achieving over 10 kV within less than 500 μm of termination length.

Introduction

Edge termination for 10 kV+ devices is an area of intense research. Floating Field Rings (FFRs) for such high voltage rating SiC devices are not favored because they are inefficient in terms of the achievable breakdown voltage as a percentage of the 1D maximum, consumes large chip area, require high implantation energies and small gaps between rings which can violate fabrication limits. We show that the implantation of Aluminium at the bottom of carefully positioned trenches can be analogous to deep Aluminium implantation in terms of performance, thus annulling the need for small gaps between rings and MeV ion implantation. We optimize the distribution of trenches by placing them in multiple zones of different expansion coefficient. The proposed multi expansion ratio Trench FFR termination was utilized to terminate the active area of a 10kV rated Punch Through n-IGBT having 0.8 μm p-body and 100 μm, 3×10^{14} cm^{-3} drift region. We found the 0.6 – 0.8 μm to be the most optimum trench depth, achieving over 10 kV within less than 500 μm of termination length.
concentration, the number of rings, the expansion ratio in each zone, the width and the depth of the trenches. Accurate and appropriate physics models and parameters have been used [12] to optimize the design with TCAD simulations. The results are discussed in the following section.

**Fig. 1:** Trench Rings edge termination design.

**Results**

The doping profile of the implanted p rings resulted from calibrated process simulations using Synopsys Advanced TCAD Sentaurus Process (SProcess). Fig. 2 depicts the final. The peak doping is at the bottom of the trench; it is near constant for 0.4 μm and then reduces with depth to achieve an effective p body/drift junction of depth ~0.8 μm. The selected profile helps avoid punch through and keeps the space charge at least 0.4 μm from the SiO2. Any micro-trenches or small variations in the sidewall etching angle will be hidden/buried by the highly doped portion of the p ring, hence having very small or no impact. Device simulations were then conducted with Synopsys Advanced TCAD Sentaurus Device (SDevice) to optimise the distribution of rings and to assess the impact of trench depth and width in the achievable blocking voltage (BV). This multi-parameter, single objective optimisation procedure revealed that 65 rings implanted through trenches 0.6 – 0.8 μm deep and 2.5 – 5 μm wide can achieve 10.3 – 10.9 kV (~84 – ~89 % efficiency; 1D PNP breakdown voltage ~12.3 kV) when distributed in 4 expansion zones (Fig. 1), with a wide initial gap of 2 μm. A smaller initial gap, and the addition of rings and Al implantations can increase the blocking ability. The dependency of BV on the trench depth for trench widths of 2.5 μm and 5 μm can be seen in Fig. 3.

**Fig. 2:** Aluminium distribution of implanted Trench FFRs with calibrated SProcess simulations.

The impact of trench depth on the electric field profile is shown in Fig. 4. Shallow trenches and thus shallow FFR junctions result in a spike in the electric field close to the active area as the electric field pressure cannot be alleviated by the superficial p-ring junction for the same p-rings spacing; this can be solved only by reducing the initial distance and adding more rings. Deeper trenches result in an electric field spike at the edge of the termination because lower potential drop takes place in-between the p-rings; again, this can be addressed by adding more rings hence increasing the termination area.
While adding more rings is not a challenge, reducing the initial gap is limited by the processing capabilities of the foundry. Fig. 5 depicts the electric field distribution and electrostatic potential of an optimised arrangement (trench depth $0.8\,\mu m$ and width $2.5\,\mu m$) at 10 kV, whereby the electrostatic potential is fully dissipated within $450\,\mu m$ (4.5× the drift region width). The peak electric field remains less than 2 MV/cm throughout, and less than 1.7 MV/cm at the surface (the SiO$_2$ interface).

![Electric field distribution and electrostatic potential](image)

**Fig. 5:** Electric field distribution and electrostatic potential of an optimised arrangement at 10 kV.

**Summary**

FFRs are widely used in power devices due to their reliability and effectiveness. However, for 10kV+ rated SiC devices, they require deep junctions, or can consume large area and pose a challenge towards the fabrication of small ring spacing. By implanting aluminium at the bottom of trenches we show that the effective junction of FFRs in the edge termination region increases without the need to consult in MeV ion implantation. Trench FFRs placed in multiple zones of different expansion ratio, can be optimised to achieve over 10 kV, 84% – 89% efficiency and as little as 4.5× termination length to drift width ratio; while the required implantation energy is be kept low (< 300keV), the gaps between rings and trench dimensions are kept large (> 2μm and 2.5μm respectively) to enhance manufacturability. To achieve the same result with conventional FFRs, the implantation energy required is over 1 MeV which results in excessive damage and the requires thick masks.
**Fig. 5:** Top image – Plot of electric field and electrostatic potential along a Y-cut passing through the peak E-field value (C1) and a Y-cut at the surface of the semiconductor (C2). Bottom image – Electrostatic potential contours depicting the smooth 2D distribution of the electrostatic potential in the termination area. Trench depth is 0.8μm, width is 2.5μm. All dimensions are in μm.

**Fig. 6:** Initial experimental results (left) compared to simulations (right) on Trench FFRs devices with (non-optimal) fixed expansion ratio. Therefore, the proposed trench rings compare well with equivalently rated JTE structures [3, 4]. Furthermore, as with standard FFRs, the rings are expected to be of highly reliable due to the low electric field in the trenches oxide and to be largely independent of dose variations.

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