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Design of Trench Termination for High Voltage Devices

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Abstract— **Trench termination technique has been attractive for high voltage power devices design with the possibilities of reducing the chip area and improves the blocking voltage to the level of ideal one, by reducing the termination length and maintaining the ideal electric field uniformity near the chip edge. The authors unveil, for the first time, that positive charges due to the holes accumulated in the trench side wall terminate the high electric field and show the robust design for the trench termination against the avalanche phenomena.**

I. INTRODUCTION

Deep trench structure is one of the candidates for future high voltage power devices edge termination design for reducing the chip area and improves the blocking voltage ([1].[2]). So far, numerous termination structures have been adopted to practical chip design in improving the blocking voltage under the planer technology, for example, guard ring, field plate, semi-insulating polycrystalline silicon (SIPOS), junction termination extension (JTE). The deep trench termination has a possibility to reduce the termination area dramatically comparing to the above conventional structures.

Recently, deep trench structure has become one of the design options for semiconductor devices thanks to the advancement in the Micro Electro Mechanical Systems (MEMS) process technology. In this paper, the deep trench structure is considered for edge termination design based on numerical simulation. The authors unveil, for the first time, that positive charges due to the holes accumulated in the trench side wall effectively terminate the high electric field in chip edge region, which is the key mechanism for the edge termination design with deep trench structure. The authors also show the robust design for the trench termination against the avalanche phenomena.

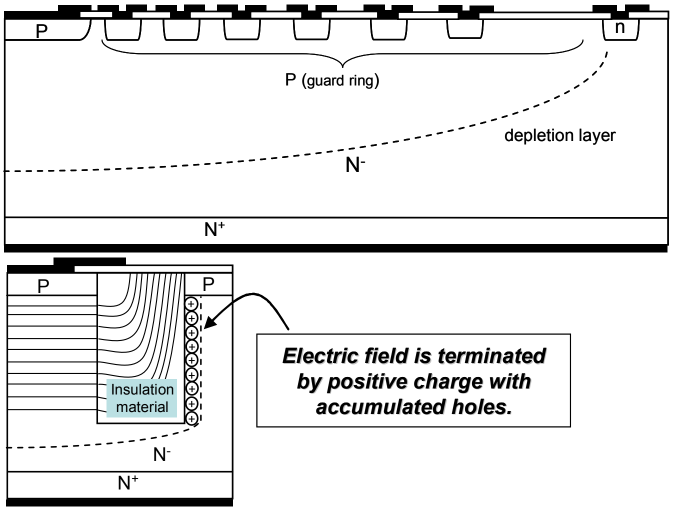

Figure 1. Deep trench termination and conventional guard ring. The high electric field inside the trench is terminated by positive charge with accumulated holes for the deep trench termination structure.

II. BLOCKING VOLTAGE DESIGN

II-1. Electric Field Termination Mechanism

Figure 1 shows deep trench termination structure comparing with conventional guard ring structure. Deep trench termination can dramatically reduce termination length and has a possibility of maintaining the ideal electric field uniformity even near the chip edge. In the proposed termination structure, a deep trench is formed near the chip edge with depth of approaching to the bottom N$^+$-layer. An edge of the deep trench is covered by a field plate.

Figure 1 also shows the mechanism of electric field termination with the deep trench structure. The authors unveil, for the first time, that the high electric field inside the trench is terminated by positive charge with accumulated holes in the other side of deep trench side wall.

This mechanism is confirmed by TCAD simulation with PiN diode structure with deep trench termination. Figure 2 shows the electro-static potential distribution near the trench and hole density near the trench side wall. In the simulation, a field plate width is 40um and the deep trench depth and width are D_{insl}=100um and W_{insl}=70um respectively. The doping concentration of N^--layer is $1.3\times10^{14}cm^{-3}$ and the thickness is 135um. The doping concentration of P^+-layer and N^+-layer are $1\times10^{18}cm^{-3}$ and the thickness is 5um and 10um respectively. Deep trench is assumed to be filled with insulation material with the permittivity of 2.65[1].

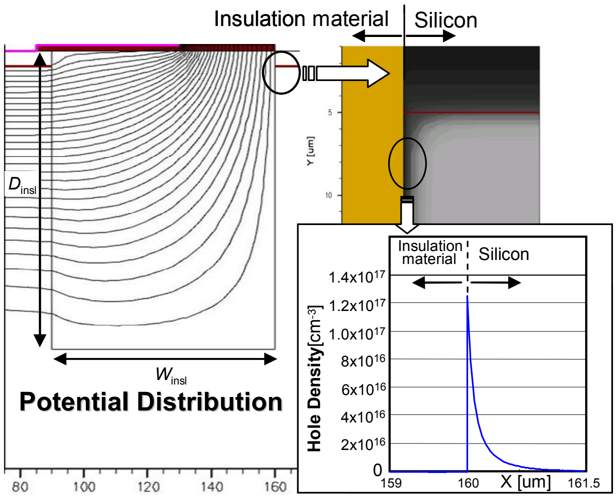

Figure 2. The electro-static potential distribution inside the trench and hole density in the trench surface. Accumulated holes terminate the high electric field inside the trench by their positive charge.

As shown in Figure 2, the electric field in the trench is terminated at the side wall of the trench and no electric field penetrates into silicon region. The accumulated hole at side wall was calculated about $3.04\times10^{-8}cm^{-2}$ from the simulation result which is equivalent to the counter charge ($Q=\varepsilon_{insl}E_{insl}=\varepsilon_{insl}V/W_{insl}$) to terminate the electric field inside the trench. Therefore, it can be confirmed that the high electric field inside the trench is terminated by positive charge with accumulated holes in the trench side wall surface.

II-2. Hole Supply to Trench Side Wall during Turn-off Transient

Under turn-off transient, supply of holes to the trench side wall is needed to terminate the increasing electric field in the deep trench. Figure 3 shows the simulation results with / without hole supply path to the trench side wall. In case of the trench termination without hole supply path, simulation result shows that the structure can not terminate the high electric field inside the deep trench because of lack of the counter charge with accumulated holes and the depletion layer expands outside of the trench. In case with hole supply path, the electric field is successfully terminated with the holes in the trench side wall supplied through the hole supply path structure even under high dV/dt condition of 1000V/us.

The hole supply path structure has an N^+-layer formed next to the P^+-layer with an electrode connected the layers each other so that the P^+-layer is electrically connected to the cathode. Figure 4 shows the hole current flow along the trench surface with hole path structure. Large hole current flows along the side wall to supply the counter charge, while without hole supply path structure, no hole current is observed. It is concluded that a hole supply path is required for terminating electric field with deep trench under high dV/dt conditions.

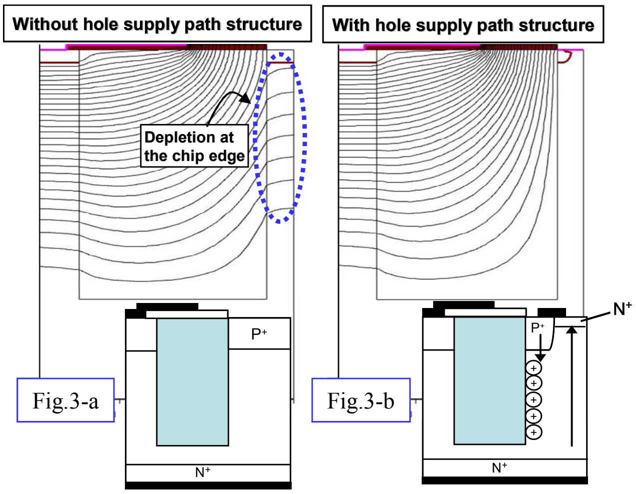

Fig.3-a

Fig.3-b

Figure 3. Potential distribution during turn-off transient at 1000V with/without hole supply path structure. With hole supply path structure, the electric field is terminated even during high dV/dt turn-off, while the depletion layer expands outside of the trench without hole supply path structure.

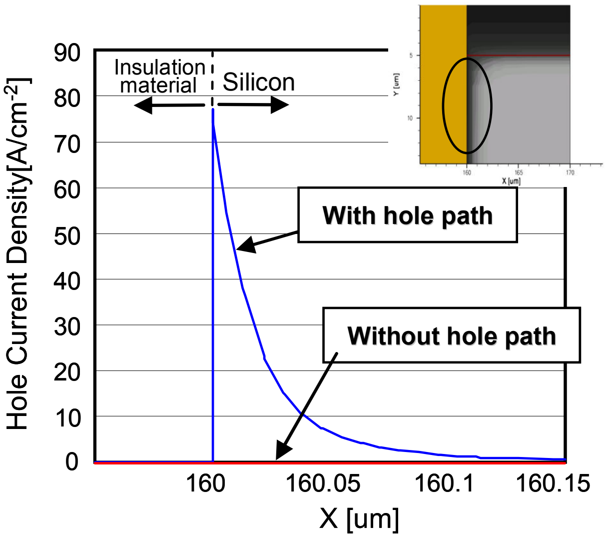

Figure 4. Hole current flow along the trench side surface for shielding the increasing electric field during turn-off.

II-3. N^--layer Doping Influence

N^--layer impurity concentration influence to the termination mechanism is investigated. The authors compared the blocking voltage of PiN diodes with trench termination structure for variety of impurity concentration of N^--layer. And the simulation results are compared with ideal PiN diode blocking voltage (a PiN diode with 1-dimensional structure) Figure 5 shows simulation results of the simulated blocking voltages as functions of doping concentration of the N$^-$-layer. Here, blocking voltages are determined at the voltage where the reverse current exceeds 10uA/cm^2. In higher doping concentration range of the N$^-$-layer, both ideal PiN diode structure and the trench termination structure shows same blocking characteristics, i.e. the deep trench termination structure can realize almost 100% of blocking voltage of that for ideal PiN diode structure in high doping range. According to the decrease in the doping concentration, the simulated blocking voltage curve starts to decline toward 0 V from the point of 7x10^{13}cm^{-3}. Figure 6 explained the decline of the blocking voltage. In high doping concentration case, the potential barrier appears at the trench bottom due to un-depleted region next to the bottom part of the trench so that the accumulated holes remain at the trench side wall and no hole current flows beneath the trench bottom. While in low doping concentration case, depletion layer reached to entire region near the trench bottom and hence holes start to flow beneath the trench bottom which is, in other word, equivalent to the punch-through phenomena to the accumulated holes in the trench side wall.

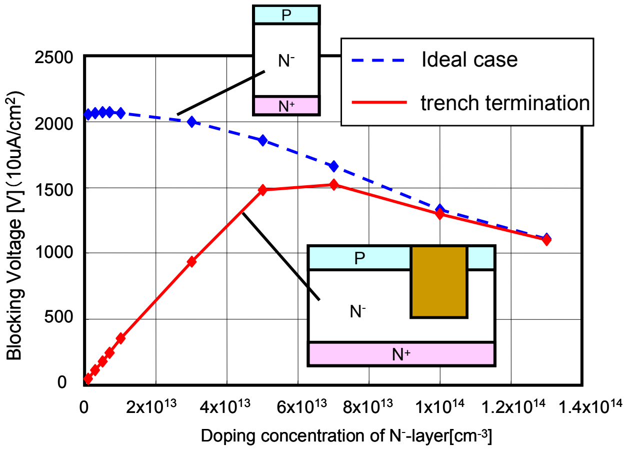

Figure 5. Blocking voltages of trench termination in comparison with ideal 1-dim PiN structure as function of doping concentration of N$^-$-layer.

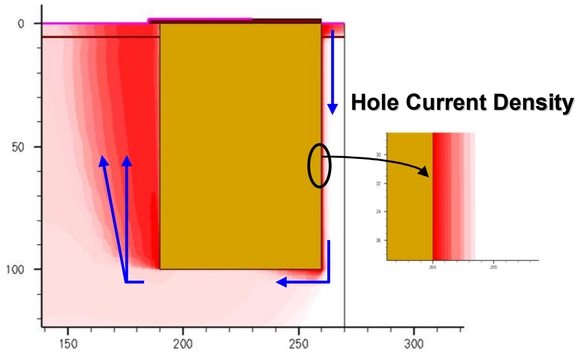

Figure 6. Hole current density with doping concentration of 5x10^{13}cm^{-3}

III. ROBUST DESIGN

The authors verified the robust design for avalanche phenomena with the proposed structure. Figure 7 shows avalanche phenomena at the edge termination with impact ionization. The chip destruction may occur with the generated heat by avalanche current flow along trench side wall [1].

We proposed the robust design for the trench termination against the avalanche phenomena. Figure 8 shows electron current density under avalanche condition for trench termination with additional P$^-$-layer along trench side wall. The avalanche current flows apart from the trench to prevent destruction at the edge termination, i.e. avalanche current flows chip center area which can improve robustness of the chip against avalanche energy since the generated heat spreads wider area of the chip.

Figure 9 also confirms the effect of the additional P$^-$-layer. The blocking voltages at the chip edge (corner/side) are higher than that of the center portion with P$^-$-layer while the edge corner has lowest blocking voltage without P$^-$-layer.

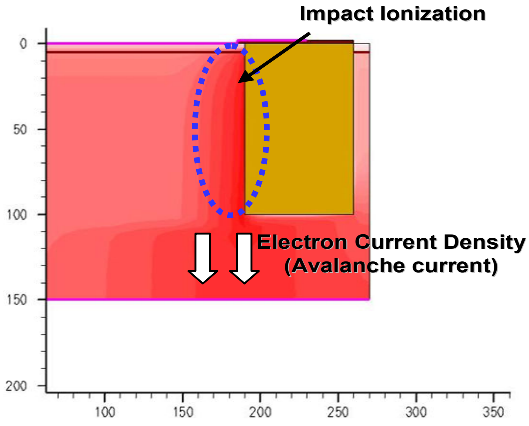

Figure 7. Electron current density under avalanche condition for deep trench termination. The avalanche current flows along the trench side wall.

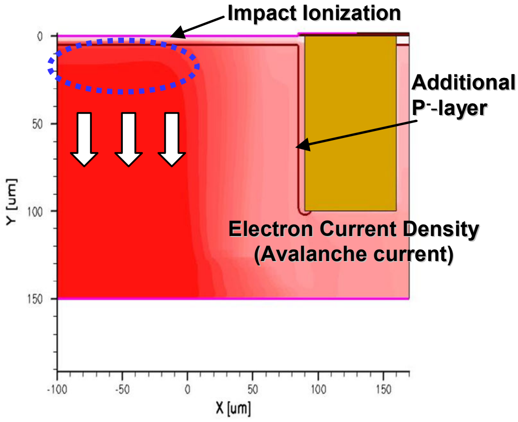

Figure 8. Electron current density under avalanche condition for deep trench termination with additional P$^-$-layer along trench side wall. The avalanche current flows apart from the trench to prevent destruction at the edge termination.

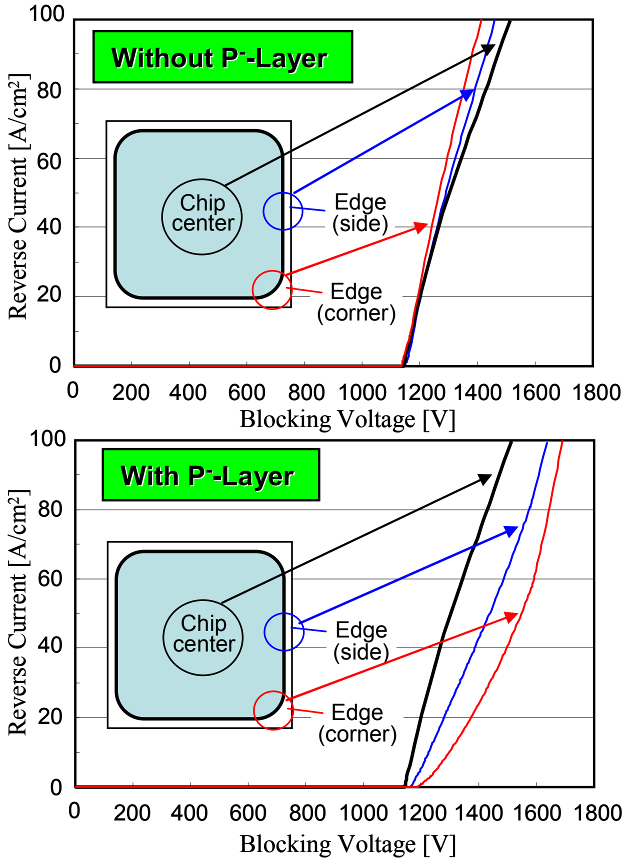

Figure 9. The blocking voltages at the chip edge (corner/side) are higher than the center portion with the P$^-$-layer, while the edge corner has lowest blocking voltage without P$^-$-layer which can cause current concentration to destruction.

IV. CONCLUSION

The deep trench structure is considered for edge termination design based on numerical simulation. The authors unveil, for the first time, that positive charges due to the holes accumulated in the trench side wall effectively terminate the high electric field in chip edge region, which is the key mechanism for the edge termination design with deep trench structure.

The authors proposed the hole path structure to supply holes to the side wall even during high dV/dt turn-off transient. The hole supply path is required for terminating electric field with deep trench under high dV/dt conditions.

The proposed structure can realize almost 100% of blocking voltage of that for ideal PiN diode structure in high doping range. In low doping concentration case, on the other hand, a kind of punch-through phenomena occurs and the blocking voltage declines. We proposed the robust design for the trench termination with the P$^-$-layer in the trench side wall against destruction with avalanche phenomena.

REFERENCES

[1] L. Theolier et al. “A new junction termination technique : the Deep Trench Termination (DT2),” Proc. of ISPSD’2009, pp. 176-179, 2009.

[2] S. Yanagisawa et al. “Semiconductor Device,” Japan Patent Application 2004-217640, 2004..

[3] N. Tokuda et al. “An ultra-small isolation area for 600V class Reverse Blocking IGBT with Deep Trench Isolation Process (TI-RB-IGBT),” Proc. of ISPSD2004, pp. 129-132, 2004.

[4] C. Park, “A New Junction Termination Technique Using ICP RIE for Ideal Breakdown Voltages,” Proc. of ISPSD2002, pp. 257-260, 2002.