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著者	Seto Kota, Kamibaba Ryu, Tsukuda Masanori, Omura Ichiro
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Universal Trench Edge Termination Design

Kota Seto, Ryu Kamibaba, Masanori Tsukuda and Ichiro Omura / Kyushu Institute of Technology
Department of Electrical and Electronic Engineering
Kitakyushu-shi, Fukuoka, JAPAN,
E-Mail Address : k349518k@tobata.isc.kyutech.ac.jp, omura@ele.kyutech.ac.jp

***Abstract*—The minimum trench edge termination length for various trench depth is theoretically determined to obtain universal curve for efficient design under considering trade-off relation with trench fabrication difficulty, cost and limitation specially for thin wafer IGBTs and diodes. This study unveils for the first time clear relationship between trench depth and termination length. We present practical design for each trench depth based on design curve considering trench filler material.**

Keywords-component;

I. INTRODUCTION

Reduction of termination area has become a bottleneck in the miniaturization of power devices. Deep trench termination is noteworthy in advance Micro Electro Mechanical System (MEMS) technology and can dramatically reduce the termination area in comparison to conventional guard ring structure.(Fig.1) In terms of process cost, the deep trench structure processing is difficult and limitation specially, for thin wafer IGBTs and diodes. Therefore, design guideline for shallower trench than the current is necessary. Universal design curve for trench edge termination and the design guideline for various trench depth is proposed, for the first time, by simulating over 500 trench termination structure parameters including dielectric constant for filler trench material by 2-dimentional T-CAD. Different from prior art, this study unveil the clear relationship between trench depth and the termination length for appropriate design with the required termination length and/or trench depth. Similarly to theoretical planar termination investigation approach, the P^--layer dose along the trench surface is optimized in the simulation to obtain theoretical minimum termination length for every structure. To propose the general statement, confirmed universality of design curve to simulate the structure of different breakdown voltage. The authors show practical design in case of each trench depth.

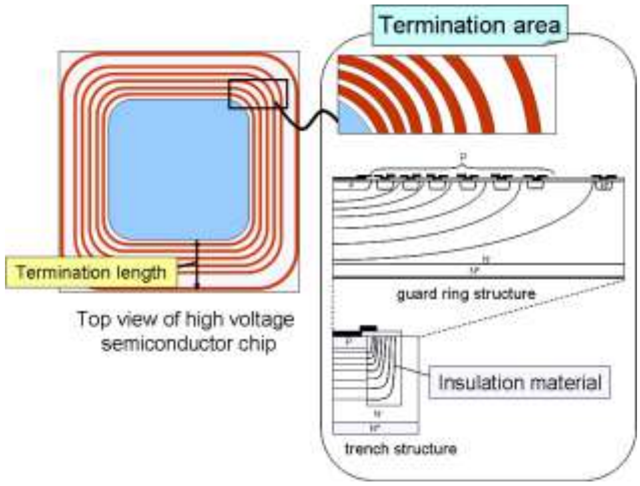

Fig.1 Deep trench structure comparing conventional guard ring structure.

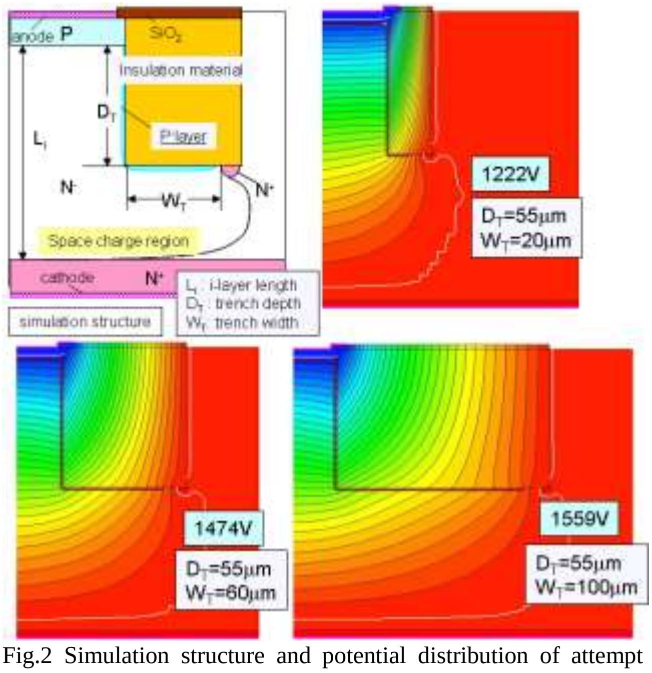

Fig.2 Simulation structure and potential distribution of attempt structure.

II. SIMULATION

A. Trade-off curve of trench depth and termination length

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The most important factor in trench edge termination design is the relationship trench depth (D_T) and termination length (W_T). This study unveils clear this relationship by simulation using a 1200V class PiN diode. The simulation PiN diode structure has a trench and P^--layer along with the trench side wall and bottom is shown in Fig.2. The N^+ field stopper at the bottom corner of the trench is suppresses the depletion layer expansion outside the trench. W_T is determined by this N^+ stopper position. The trench depth, the termination length and P^--layer dose are variables. As fixed values, P-layer concentration and N-layer concentration, i-layer concentration and width are $3x10^{17}[cm^{-3}]$ and $1x10^{18}[cm^{-3}]$, $7x10^{13}[cm^{-3}]$, 110[mm], respectively and using Benzocyclobutene (BCB) with dielectric constant is 2.65 for trench filler material. The potential distribution of structures were attempted are shown in Fig.2. Optimized P-layer dose is significant point in breakdown voltage design. Breakdown voltage is the highest value in specific dose and the optimum dose is different for every structure.

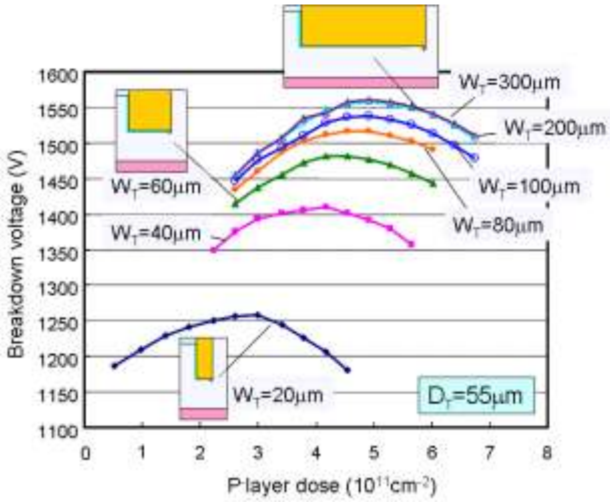

Fig.3 The relationship between P^-dose and breakdown voltage each structure.(D_T=55µm)

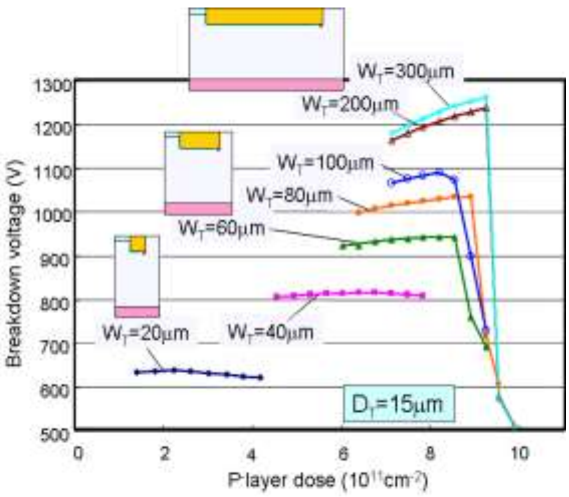

Fig.4 he relationship between P^-dose and breakdown voltage each structure.(D_T=15µm)

Similarly to theoretical planar termination investigation approach, the P-layer dose along the trench surface is optimized in the simulation to obtain theoretical minimum termination length for every structure. Fig.3and4 shows P^- layer dose effect for breakdown voltage (at D_T=55µm and 15µm). The relationship between W_T and breakdown voltage is shown in Fig.5. Drabe's planar junction termination result [5] is put on the same graph. The ideal breakdown voltage (1526V) is the breakdown voltage of one dimensional PiN diode with same i-layer length (110um). The minimum termination length and/or trench depth is determined by the length with 90% of ideal breakdown voltage reached. For shallow trench, extend the tangent from linier variable part each curve.

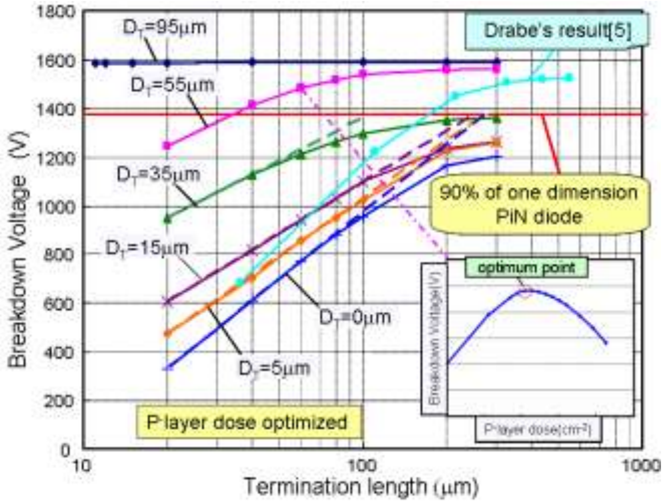

Fig.5 The relationship between termination length and breakdown voltage with trench depth as a parameter. Drabe's planar junction termination result [5] is put on the same graph.

The trade-off curve of trench depth and termination length is shown in Fig.6. This curve shows that even shallower trench is sufficiently reduction effect for termination length. Specialy, even a trench with half depth of conventional deep trench termination design dramatically reduces the termination length. In addition, N^+ stopper is mechanism point in this structure for dramatically reduce the termination length.

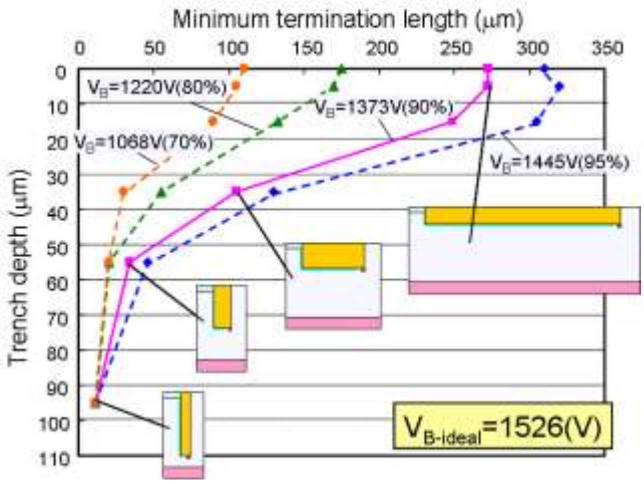

Fig.6 Trade-off curves between trench depth and minimum termination length with breakdown voltage as a parameter.

B. *Universality of design curve*

To investigate universality of the design rule, we also simulated structures of deferent sizes (Li=55um and Li=220um). Universality of the trench termination design is shown in Fig.7. These curves are relationship between trench depth and termination length breakdown voltage becomes 90% of ideal one. It notes that the design curve is universality and can be applied to any structure. In terms of reduction effect of termination length and process, the half depth trench is the most effective structure in any size. By this rule, required termination length is automatically determined by the trench depth.

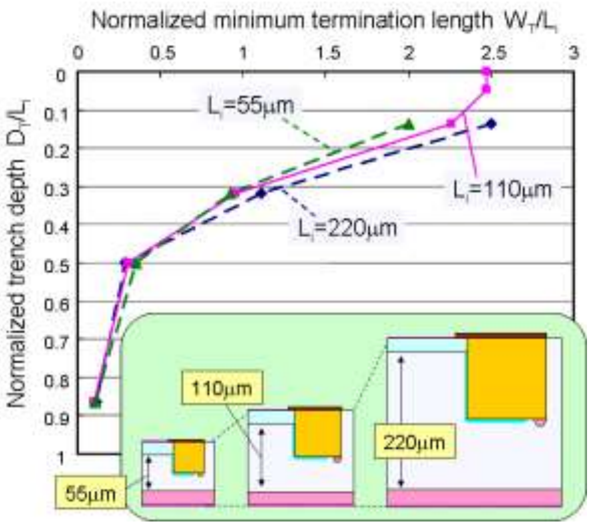

Fig.7 Universality of trench termination design.

C. *Dielectric constant (εr) of trench filler material*

Dielectric constant (εr) of trench filler material significantly affects the design curve as shown in Fig.8, so that the filler material selection is key point in trench termination design. For example, high dielectric constant filler materials are suitable to shallower trench and low dielectric constant filler materials are suitable to deeper trench for effective reduction in termination length.

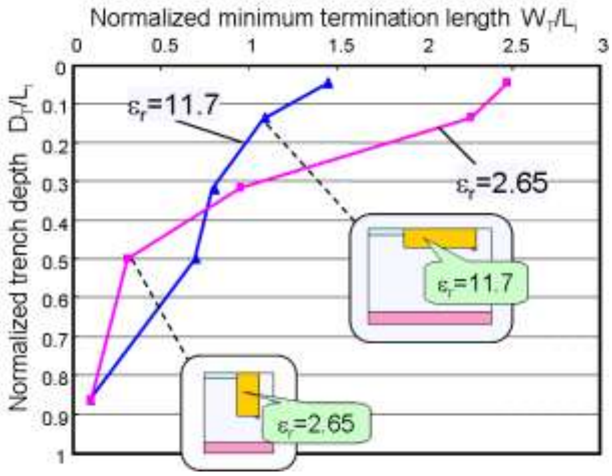

Fig.8 Trade-off curves between trench depth and termination length with dielectric constant of the insulation material as a parameter.

III. PRACTICAL DESIGN

We present practical trench termination structures based on the design curve considering dielectric constant for trench filler material. The practical structures for each depth are shown in Fig. 9.

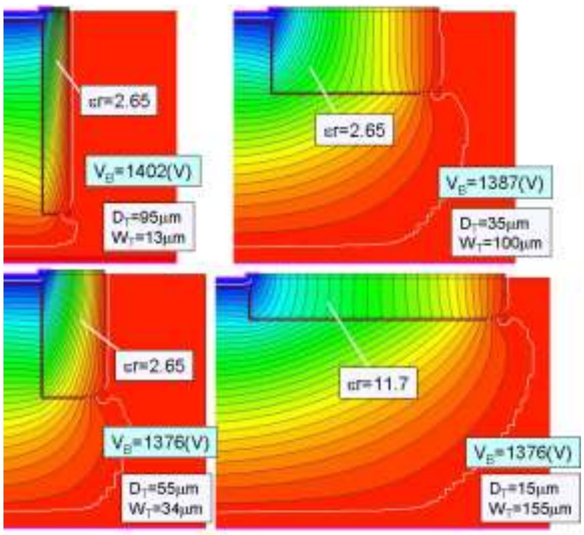

Fig.9 Practical trench termination structures for each depth.

These structure successfully show the breakdown voltage which is more than 90% of ideal breakdown voltage and suppresses the depletion layer expansion outside the trench. The shallow trench structure used the high dielectric constant filler material. This implies that field stopper design is the other important issue to reduce the termination length including lateral expansion of the depletion layer outside trench. Deep trench structure and half depth structure are successfully realize dramatically reduce termination length. On the other hand, electric field concentration is increasing in insulator and the trench filler material is limited. Maximum value of electric field in insulator each practical design is show in Fig.10.

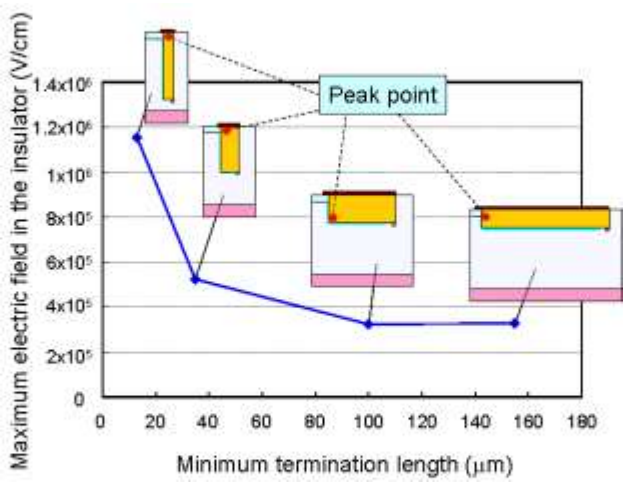

Fig.10 Maximum electric field in the insulator material in practical design.

The breakdown electric field of BCB used in simulation is 5.3×10^6 (V/cm) and can be applied well to deep trench structures.

IV. CONCLUSION

Universal design curve for trench edge termination and the design guideline for various trench depth is proposed, for the first time. This study unveils clear relationship between trench depth and termination length and even shallower trench is sufficiently reduction effect for termination length. Specially, even a trench with half depth of conventional deep trench termination design dramatically reduces the termination length. We shown for universality of design curve and also considered trench filler materials. We present practical trench termination structures for each depth based on the design curve considering dielectric constant for trench filler material.

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