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Characteristic Enhancement of Trench IGBT by Deep P+ Layer beneath the Trench Emitter Ion Implantation

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Abstract : The Trench Insulated Gate Bipolar Transistor (TIGBT) was invented for lower on-state voltage drop and higher integration due to smaller cell pitch, but TIGBTs suffer from breakdown voltage degradation due to the concentrated electric field at the corner of the trench gate in the forward blocking state. In this paper, we report on a new TIGBT structure that solve this problem.

The proposed structure has a deep P+ layer beneath the trench emitter to distribute the concentrated electric field at the trench gate corners in the forward blocking state. The deep P+ layer of the structure is formed by ion-implantation at the bottom of the trench after partial etching of the P-base region. The electrical characteristics of the proposed IGBT structure are verified by device simulation, namely, MEDICI and TSUPREM. The proposed structure improves the breakdown voltage compared to conventional TIGBTs without changing the threshold voltage and the on-state voltage drop. The distribution of the electric field is also changed by its design parameters. When the depth of the trench gate corner and the deep P+ layer are the same, the breakdown voltage is at the highest point. As the gap distance between the trench the gate corner and the deep P+ layer gets shorter, the breakdown voltage gets higher. The distribution effect operates when the doping level of the deep P+ layer exceeds the appropriate value to prevent punch-through between the metal electrode and the N-drift region.

This structure can be applied easily to various TIGBTs with simple processes addition.

1. Introduction

The Trench Insulated Gate Bipolar Transistor(TIGBT) was invented for lower on-state voltage drop and higher integration due to smaller cell pitch. The main drawbacks of TIGBTs is breakdown voltage degradation due to the concentrated electric field at the bottom of the trench gate in the forward blocking state[1,2,3]. The breakdown voltage of IGBTs is determined by the reverse bias blocking capability of the abrupt junction consisting of P-base and N-drift region[1]. If the electric field distribution is not uniform in the depletion region, the breakdown voltage is decreased compared to the original breakdown voltage which depends on the doping level of the N-drift region. Several researchs have been conducted to solve this problem, but the existing structures have complex processing or changing characteristic of TIGBT like threshold voltage and on-state voltage drops[2,3]. In this paper, we report on a new TIGBT structure that solves the problem of breakdown voltage degradation.

2. Analysis of the Proposed Structure

2.1 The Proposed structure and Process

Figure 1 shows the proposed TIGBT structure.

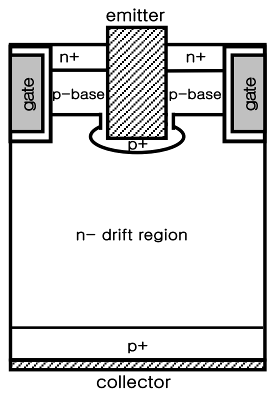


Fig. 1. The Proposed TIGBT structure

The structure has a deep P+ layer beneath the trench emitter to distribute the concentrated electric field at the trench gate corners in the forward blocking state.

The proposed structure mostly follows the conventional TIGBT process flow. First, the TIGBT process is run until the gate and n+ emitter are formed. Then, the next steps are processed to form the deep P+ layer, as shown in Figure 2: (a) the structure formed with the trench gate, p-base, and n+ emitter, (b) the oxide masking process to form the deep P+

layer. (c) etching the trench , (d) P+ ion implantation for the deep P+ layer.

The oxide mask of process in Figure 2 (b) is used both for the trench mask and for the deep P+ layer ion-implantation, so Figure 2's (b) and (c) steps are continuously processed using the same oxide mask. This self-aligned trench process is very efficient because one mask step is eliminated[5].

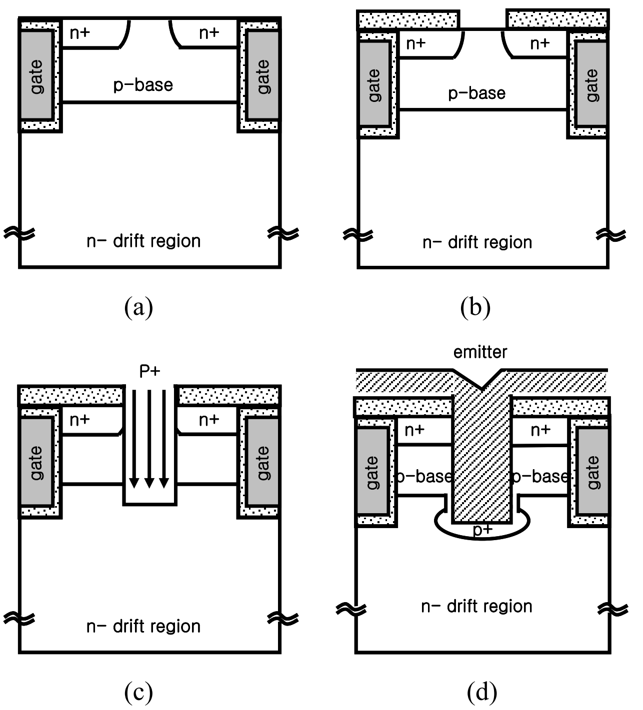


Fig. 2. Process flow for the proposed structure.
(a) form until gate and n+emitter, (b) oxide mask forming,
(c) trench etching and P+ ion implantation, (d) metal forming

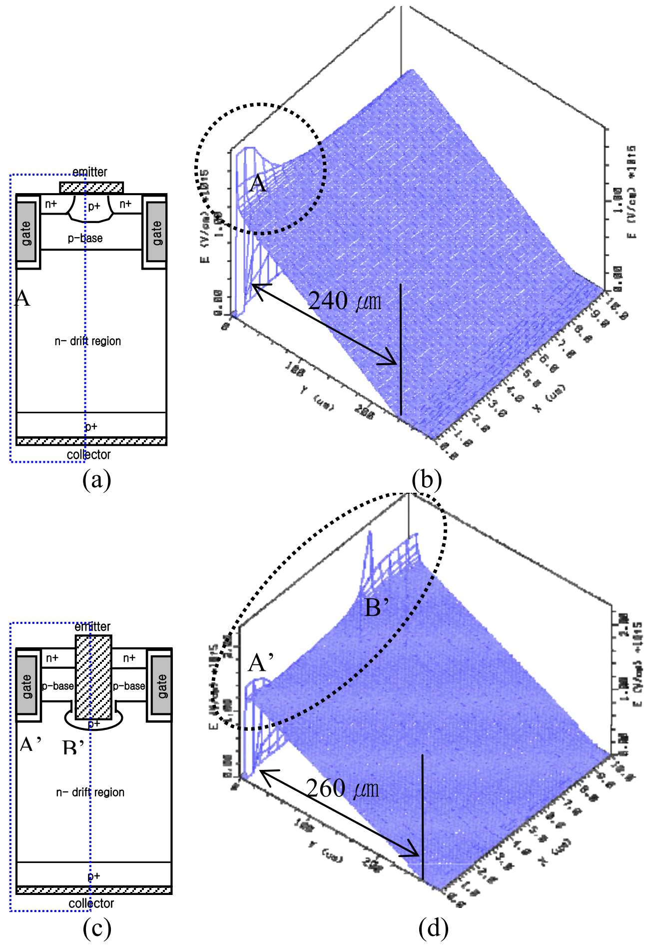


Fig. 3. 3-Diemensional simulation results of electric field distribution enhancement.
(a) the conventional TIGBT, (b) 3-D distribution simulation
(c) the proposed structure, (d) 3-D distribution simulation

2.2 Comparison between conventional and proposed TIGBT

The electrical characteristics of the proposed IGBT structure are verified by device simulation using MEDICI and TSUPREM.

The parameters of the proposed structure are showed in Table 1.

Table 1. Parameters of the proposed structure

Parameters	Depth (㎛)	Doping level(/㎤)	Parameters	Length (㎛)
N^+ emitter junction depth	1.2	4.0×10^{19}	Gate oxide thickness	0.1
P- base junction depth	4.8	1.8×10^{16}	Channel length	1.8
Trench gate Depth	6		Trench gate Width	1
Deep P+ layer depth	2 ~ 7		Deep P+ layer width	2.5

The effect of the electric field distribution is verified by 3-D simulations of the electric field distribution from the trench gate corner to the deep P+ layer. Figure 3 shows the 3-D simulation results: (a) the conventional TIGBT structure and the simulated part(dotted line box); (b) the 3-D simulation of (b)'s electric field distribution; (c) the proposed TIGBT structure and simulation part(dot line box); (d) 3-D simulation of (c)'s electric field distribution. The 3-D simulation of Figure 3(d) has 2 peaks compared to Figure 3(b) and the depletion length of the proposed TIGBT is longer than the depletion length of the conventional structure.

The breakdown voltage of the proposed structure is 1800 V according to the simulation results. This voltage is 30 % higher than 1560 V, the breakdown voltage of the conventional structure.

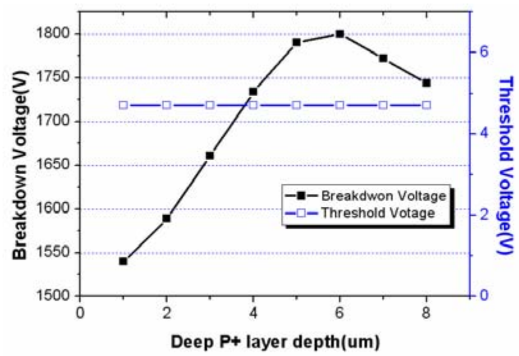
The breakdown voltage of an IGBT is determined approximately by the reverse biased characteristics(depletion length and maximum electric field) of the abrupt junction that consists of the highly doped p-base and the lowly doped N-drift junction[1].

If an abrupt junction is formed with highly doped p-type silicon and lowly doped n-type silicon, the breakdown voltage of this junction is determined by Equation (1)[1].

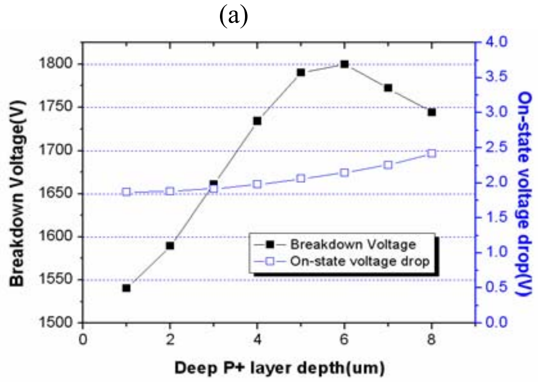
$$V_{Breakdown} = 5.34 \times 10^{13} N_D^{-3/4} \quad - (1)$$

If the conventional TIGBT has an N-drift concentration $4.5 \times 10^{13} cm^{-3}$,its breakdown voltage is ideally 2332 V following Equation (1). However the breakdown voltage of conventional the TIGBT is 1560 V according to the simulation because the concentrated electric field at the gate corner creates a depletion layer unbalance that reduces the breakdown voltage as shown in Figure 3. However the proposed structure distributes the concentrated electric field as shown in Figure 3(d), so the proposed structure has an improved breakdown voltage compared to the conventional TIGBT. From Figure 3, we can clearly see the difference of depletion layer length and the maximum electric field.

2.3 Analysis of the influences of the design parmeters on the device characteristics



(a)



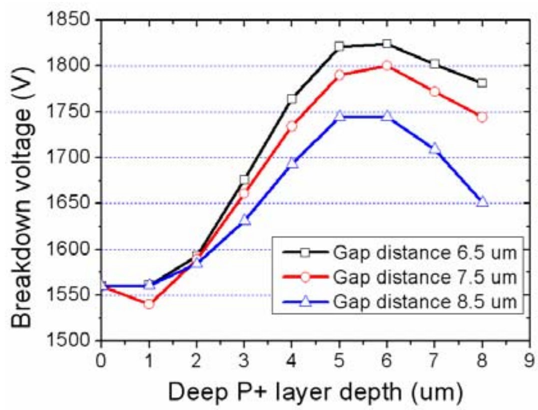
(b)

Fig. 4. Change of breakdown voltage compared to threshold voltage depending on the deep P+ layer depth
(a) change of breakdown voltage compared to threshold voltage
(b) change of breakdown voltage compared to on-state voltage drop.

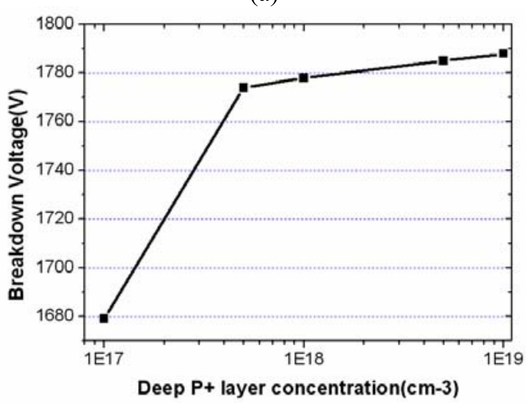
The threshold voltage is determined by the gate oxide thickness and the channel doping level. The on-state voltage drop is also determined by doping level of the channel and N-drift region. The proposed structure does not change the doping level of these regions.

Because the deep P+ layer is away from the channel and the current path, the improvement of the breakdown voltage is affected by the depth and gap-distance of the deep P+ layer.

From Figure 4, the simulation results show that the proposed structure improves the breakdown voltage compared to the conventional TIGBT without changing the threshold voltage and the on-state voltage drop. Also, the distribution effect of the electric field is changed by the depth of the deep P+ layer, as shown in Figure 4. The effect of the electric field distribution is related to the depletion balance. When the depth of the trench gate corner and the deep P+ layer are the same, the breakdown voltage is at the highest point.



(a)



(b)

Fig. 5. Change of breakdown voltage depending on the design parameters
(a) change of breakdown voltage depending on the deep P+ layer depth and the gap distance between the trench gate corner and the deep P+ layer,
(b) change of breakdown voltage depending on the deep P+ layer concentration.

From Figure 5 (a) shows that the breakdown voltage is higher when there is a shorter the gap distance between the trench gate corner and the deep P+ layer. The shorter gap distance has a large distribution effect on the electric field.

Also, the electric field distribution is affected when the doping level of the deep P+ layer exceeds the appropriate value, as shown in Figure 5 (b).

Equation (2) determines the length of depletion layer that expands into the deep P+ layer in the PN junction that consists of the N-drift region and the deep P+ layer[1].

$$W_{deepP+} = \sqrt{\frac{2\varepsilon_s (V_{bi} + V_{Breakdown})}{qN_{deep\,P+}} \left(1 + \frac{1}{N_{n-drift}}\right)^{-1}} \quad - (2)$$

If the doping level of the deep P+ layer($N_{deep\ P+}$) is below the doping level that the length of the depletion layer from expanding into the metal trench electrode by Equation (2), then punch-through occurs, so the effect of the electric field distribution is not present in this case.

3. CONCLUSION

We proposed a new TIGBT structure that has a deep P+ layer beneath the trench emitter. The deep P+ layer is formed by ion-implantation at the bottom of the trench emitter after partial etching of the P-base region. We analyzed this structure by device simulation. From the simulation results, the proposed structure lets the TIGBT obtain a higher breakdown voltage than conventional TIGBTs without changing the threshold voltage and the on-state voltage drop. The deep P+ layer can distribute the concentrated electric field at the trench gate corner when its concentration exceeds the appropriate value. Also, when the deep P+ layer has the same depth as the trench gate corner, the breakdown voltage is the highest. As the gap-distance between the trench gate corner and the deep P+ layer gets shorter, the breakdown voltage gets higher.

The new structure is expected to be incorporated into the next generation of high voltage IGBTs with the additions of simple processes.

ACKNOWLEDGMENT

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REFERENCES

[1] B.Jayant Baliga, “Power semiconductor devices”, PWS, 1996

[2] J. S. Lee, E. G. Kang, M. Y. Sung, "Improvement of Electrical Characteristics of Vertical NPT Trench gate IGBT Using Trench Emitter Electrode", J. KIEEME, Vol. 19, No. 10, p. 912, 2006

[3] H. H. Shin, H. S. Lee, M. Y. Sung, “A Study on the Breakdown Voltage Characteristics with Process and Design Parameters in Trench Gate IGBT”, J. KIEEME, Vol. 20, No. 5, p403, 2007

[4] E. G. Kang, M. Y. Sung, "A Novel Trench electrode BRT with the intrinsic Region for Superior Electrical Characteristics", J. KIEEME, Vol. 15, No. 3, p. 201, Mar. 2002

[5] C. M. Yun, D, Y, Kim, M. K. Han, Y. I. Choi, " A Self-Aligned Trench Body IGBT Structure with Low Concentration Source ", J. KIEE, Vol. 45, No. 2, p. 249, 1996

[6] E. G. Kang, D. S. Oh, D. W. Kim, D. J. Kim, M. Y. Sung, "A Novel Lateral Trench electrode IGBT for Superior Electrical Characteristics", J. KIEEME, Vol. 15, No. 9, p. 758, Sep. 2002

[7] E. G. Kang, S. H. Moon, M. Y. Sung, "A new trench electrode IGBT having superior electrical characteristics for power IC systems", Microelectronics J. Vol. 32, p. 641, 2001

[8] E. G. Kang, M. Y. Sung, "A small sized lateral trench electrode IGBT for improving latch-up and breakdown characteristics", Solid State Electronics, Vol. 46, p. 295, 2002

[9] B. Smith, “An approach to graphs of linear forms (Unpublished work style),” unpublished.

[10] X. Yuan, T. Trajkovic, F. Udreak, J. Thomson, P. R. Waind, P, Taylor, et al, “Suppression of parasitic JFET effect in trench IGBTs by using a self-aligned p base process,” Solid-State Electronics, vol. 46, p1907-1912, 2002.