Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 972-973

E-10-2

Improvement of Breakdown Voltages in GaN Schottky Barrier Diodes by Pseudo-Superjunction Structures

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1. Introduction

GaN has been widely investigated for future high power switching devices owing to its high breakdown field with high electron mobility. Schottky barrier diodes (SBD) are indispensable in power switching systems, for which both high breakdown voltage and low on-state resistance are required to enable their low loss operation [1, 2]. Reducing the carrier concentration in the drift layer increases the breakdown voltage in the SBDs, however, the improvement is limited in case of GaN because of high residual carrier concentration in the order of 10^{16} cm^{-3}. Thus, a new technique to increase breakdown voltage with highly doped GaN has been strongly desired.

In this paper, we propose a novel technique to increase the breakdown voltage of vertical GaN SBDs utilizing so-called pseudo-superjunction (PSJ) structures. The PSJ structure consists of selectively ion-implanted insulating layer in the drift layer over which the Schottky metal is formed. The channel drift layers and insulating layers are alternately stacked as is demonstrated in Si-based superjunction structures [3]. The PSJ structure utilizes insulating layer instead of p-type layer in conventional Si-based superjunctions because selective formation of high concentration p-type GaN layer is a technical challenge. Detailed device simulation and device fabrication results are presented confirming the technical advantages of the PSJ-SBD.

2. Concept of PSJ-SBD

Figure 1 shows the schematic cross section of the PSJ-SBD structure. Since virtually no ionized donor to be neutralized exists in the Boron ion-implanted insulating layer, the depleted depth is deeper in the insulating region. The narrow channel region is depleted laterally from the insulating region as well as the vertical depletion. The resultant depleted depth in the channel of PSJ-SBD is deeper than that in the conventional SBD at a given reverse voltage. The deep depletion relieves the maximum electric field so that the breakdown voltage is increased. Figure 2 shows the simulated edge of the depletion layer for various reverse voltages comparing the proposed PSJ-SBD and the conventional one. Figure 3 shows the simulated depth profile of the electric field in the channel for both the PSJ-SBD and the conventional structure at the reverse voltage of 150 V. The maximum electric field at the surface is effectively reduced by the PSJ especially with deeper insulating layer. Since summation of the electric field at the entire depths is the applied reverse voltage, the applicable maximum reverse voltage is higher in the PSJ-SBD than in the conventional SBD utilizing the relieved electric field at the surface region. In addition to the depth of the insulating layer, other device dimensions such as the widths of channel and insulating region in the PSJ need to be optimized. Figure 4 shows simulated relaxation of electric field as a function of duty of channel opening over the stacking pitch which is represented as A/(A+B). The results indicate that the reduction of the duty at shorter pitch effectively reduces the maximum electric field. Low on-state voltage is another requirement for the low-loss operation, which in general has a trade-off relationship with the breakdown voltage. Figure 5 shows the simulated breakdown voltages and on-state voltage varying the carrier concentration of the drift layer. On-state voltage is defined at which the forward current is 100 A/cm^2. The results show that the breakdown voltages can be higher in the PSJ-SBD keeping low on-state voltages with the high carrier concentration in the order of 10^{17} cm^{-3}. Thus, the presented PSJ structure is advantageous for low-loss SBDs using highly doped GaN.

3. Fabrication and Performance of PSJ-SBD

The used epitaxial structure consists of 4 μm-thick n^--GaN drift layer with the carrier concentration of 2.5×10^{17} cm^{-3}, n^+-GaN layer on sapphire grown by metalorganic chemical vapor deposition (MOCVD). The selective insulated layer with the depth of 2 μm was formed by ion-implantation of Boron. The Ti/Al Ohmic electrode is formed on the n^+-GaN, and Pd Schottky gate electrode is formed on the epitaxial surface.

Figure 6 shows the experimentally obtained breakdown voltages as a function of duty of channel opening (A/(A+B)). The breakdown voltages are increased by the reduction of the duty, where the simulated enhancement of the breakdown voltage well agrees with the experimental results. The breakdown voltage in the SBD without PSJ is still far lower than the ideal value probably because the breakdown field in the vertical structure is low due to the epitaxial dislocations. Further improvement of crystal quality would increase the breakdown voltages in the PSJ-SBDs. Table I summarizes the typical characteristics of the fabricated SBDs comparing them with and without PSJ structure. The breakdown voltage is increased in the PSJ-SBD keeping low on-state voltage demonstrating the advantages of the presented structure.

4. Conclusion

We demonstrate a novel vertical pseudo-superjunction SBD, in which narrow channel and insulating region is alternately stacked. The proposed PSJ structure helps to reduce the maximum electric field with deep depletion layers. The fabricated PSJ-SBDs exhibit higher breakdown voltages keeping the low on-state voltage. The proposed PSJ-SBD is promising as a future power switching device with low-loss operation.

Acknowledgment

The authors would like to express sincere thank to Dr. Daisuke Ueda for his technical advice and continuing support for this work. The authors are also grateful to Masahiro Hikita for his great technical advice on processing.

References

[1] A. P. Zhang, G. Dang, F. Ren, J. Han, A. Y. Polyakov, N. B. Smirnov, A. V. Govorkov, J. M. Redwing, X. A. Cao and S. J. Pearton, Appl. Phys. Lett. **76** (2000) 1767.

[2] S. Yoshida, J. Li, N. Ikeda, and K. Hataya, Phys. Status Solidi C **2** (2005) 2602.

[3] T. Fujihira, Jpn. J. Appl. Phys. **36** (1997) 6254.

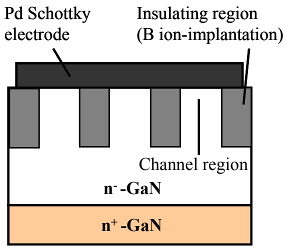

Fig. 1 Schematic cross section of the fabricated PSJ-SBD structure.

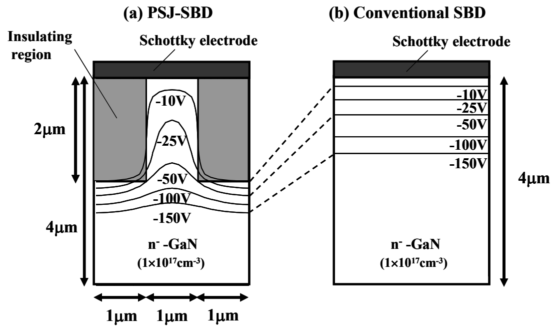

Fig. 2 Simulated edge of depletion layer for various reverse bias in (a) PSJ-SBD (channel width = 1 μm, insulating region width = 2 μm) and (b) conventional SBD.

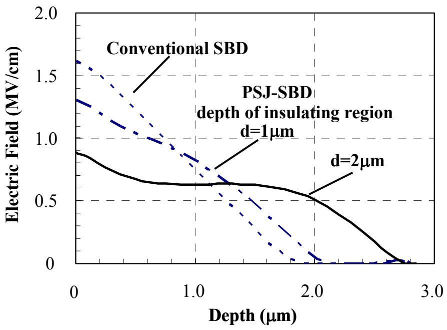

Fig. 3 Depth profile of the electric field in the channel for both PSJ-SBD (channel width = 1 μm, insulating region width = 2 μm) and conventional SBD at the reverse voltage of 150 V.

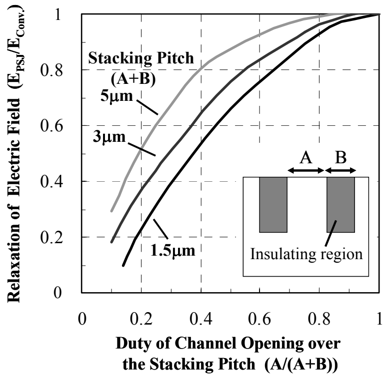

Fig. 4 Simulated relaxation of electric field as a function of duty of channel opening over the stacking pitch.

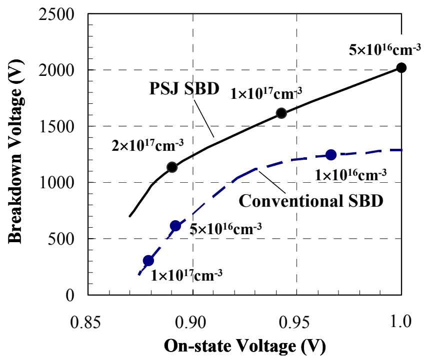

Fig. 5 Simulated breakdown voltages and on-state voltages varying the carrier concentrations (inserted values). The channel and insulating region widths of the PSJ-SBD are 0.5 μm and 1 μm, respectively.

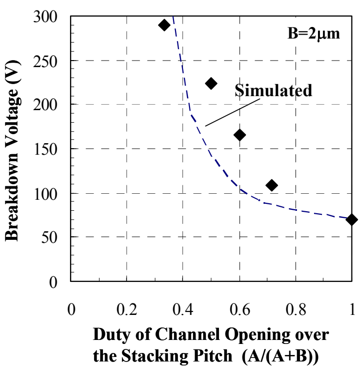

Fig. 6 Breakdown voltages of the fabricated PSJ-SBDs as a function of duty of channel opening over the stacking pitch.

Table I Typical on-state and breakdown voltages of fabricated PSJ-SBD and conventional SBD.

	PSJ-SBD Channel Width=3μm Insulating Region Width=2μm	Conventional SBD without PSJ
On-state Voltage (V)	0.93	0.87
Breakdown Voltage (V)	165	70