JUNCTION-BARRIER SCHOTTKY DIODES FABRICATED WITH VERY THIN HIGHLY MG-DOPED P^+-GAN(20 NM)/N-GAN LAYERS GROWN ON GAN SUBSTRATES

Hayashi, Kentarou / Mishima, Tomoyoshi / Nakamura, Tohru / Ohta, Hiroshi

(出版者 / Publisher)
法政大学イオンビーム工学研究所

(雑誌名 / Journal or Publication Title)
PROCEEDINGS OF THE 36th SYMPOSIUM ON MATERIALS SCIENCE AND ENGINEERING RESEARCH CENTER OF ION BEAM TECHNOLOGY HOSEI UNIVERSITY (December 13, 2017)

(巻 / Volume)
36

(開始ページ / Start Page)
29

(終了ページ / End Page)
32

(発行年 / Year)
2018-02

(URL)
https://doi.org/10.15002/00030356

JUNCTION-BARRIER SCHOTTKY DIODES FABRICATED WITH VERY THIN HIGHLY MG-DOPED P$^+$-GAN(20 NM)/N-GAN LAYERS GROWN ON GAN SUBSTRATES

Kentarou Hayashi*, Hiroshi Ohta, Tohru Nakamura and Tomoyoshi Mishima
Department of Electrical and Electronics Engineering, Hosei University, Koganei, Tokyo 1840003, Japan

This paper presents Low turn-on voltage junction barrier Schottky (JBS) diodes were fabricated using very thin (20 nm) and extremely highly Mg doped ($2x10^{20}$ cm^{-3}) p$^+$-GaN layer placed on top of n$^-$-GaN epitaxial layers grown on n-GaN substrates. By omitting p-GaN layers in conventional p$^+$-GaN/p-GaN/n$^-$-GaN vertical p-n junction diodes, device processing has been eased and low specific on-resistances (R_{on}<0.3 mΩcm^2) have been obtained.

I. Introduction

Recent improvements in crystalline quality and productive technologies of free-standing GaN substrates have accelerated developments of the vertical structure GaN power devices, which can extract the GaN's full potentials for the power-conversion applications. GaN p-n junction diodes with high breakdown voltages around 3 kV showed the larger Baliga's figure of merits (FOM) than those of SiC Schottky-barrier diodes [1]-[3].

We have reported GaN p-n junction diodes with field-plate (FP) electrodes by low-damage processing which enabled low on-resistance (R_{on}) and high breakdown voltages [2], [4]-[5]. Remaining subject for the p-n diode is to lower its turn-on voltage which is now about 3 V. Here we report the decreased turn voltage by applying the JBS structures to the p$^+$-n junction GaN wafer whose p-type layer is very thin and highly Mg-doped p$^+$-GaN. This layer structure is also effective for further reduction of R_{on}, because high resistance moderately Mg-doped p-GaN layer in typical p-n junction diode [1]-[5] is omitted.

II. Experimental

The free-standing GaN substrates used in this sturdy were produced by SCIOCS through their void-assisted separation (VAS) method. [6-7] The VAS GaN substrate has a low density of dislocations uniformly spread out over the surface, which can provide much convenience in producing high performance and large power devices. The schematic structure of the p$^+$-n diode is shown in Fig.1. The layer structures were grown by metal-organic vapor phase epitaxy (MOVPE). After formation of mesa structure by conventional ICP dry etching, shallow trenches of concentric circles were dug by low power dry etching. The width and the depth of the trench were 10 μm and 60 nm, respectively. Pd anode electrode was formed by vacuum evaporation method. Ti/Al cathode ohmic electrodes were formed on the back side of the GaN substrate. The Ti/Al electrode was partially removed in case of observing p-n junction area emitting light under forward biased conditions. For comparison of the JBS diode characteristics, p-n

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* Corresponding author: e-mail kentaro.hayashi.3r@stu.hosei.ac.jp

junction diodes (PND) without the trench etching and Schottky barrier diodes (SBD) by the total removal of the p^+-GaN layer were simultaneously fabricated on the same chip.

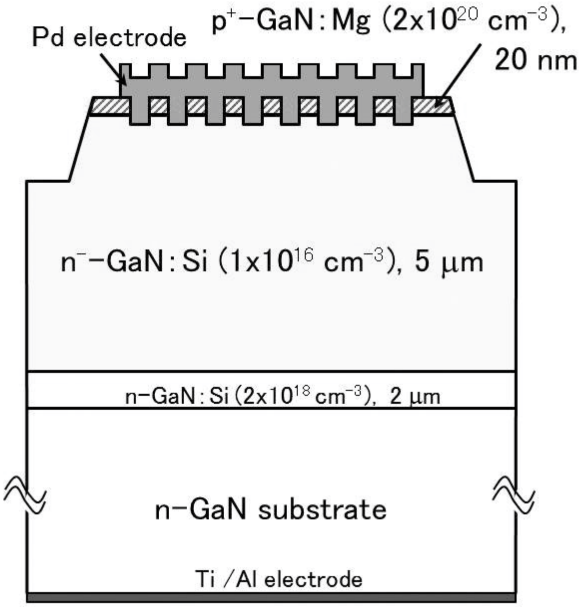

Figure 1. Schematic structure of the fabricated JBS diode.

III. Results and Discussions

Figure 2 shows the optical microscopic image of the JBS diode with the anode electrode of 200 μm in diameter. Figure 3 shows the image of the JBS diode under forward-biased condition of 4 V. The image was captured through a hole opened on the Ti/Al electrode. Strong light emissions matching with the p-n junction areas of the concentric circles were observed. The electroluminescence showed ultra-violet and blue spectra, which indicated the existence of high quality p-n junctions. I-V characteristics of the JBS diode are shown in Fig. 4 comparing with those of PND and SBD. The turn-on voltage of the JBS diode was about 1.0 V as that of SBD. Over 4 V, the current of the JBS diode increased rapidly as that of the PND; hence the expected JBS nature was realized. The slightly larger current in the JBS diode around 4 V than those of the PND and SBD were reproducible but the reason for this characteristic is not clear yet. Very small R_{on}'s of about 0.3 mΩcm^2 at 6 V were obtained by the JBS diode.

Reverse breakdown voltage of the JBS diode with another trench dimensions with 2.5 μm pitch showed over 600 V.

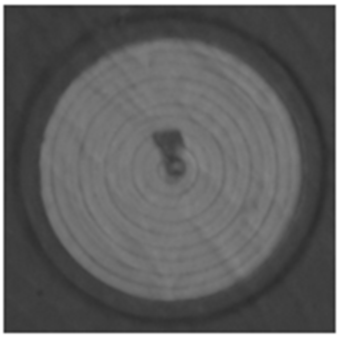

Figure 2. Optical microscopic image of the JBS diode.

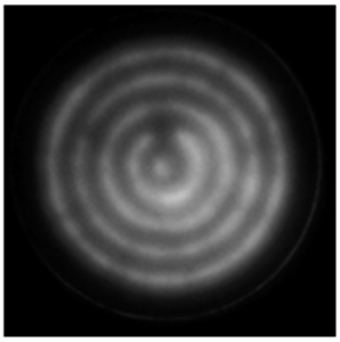

Figure 3. Optical microscopic image of the light-emitting JBS diode

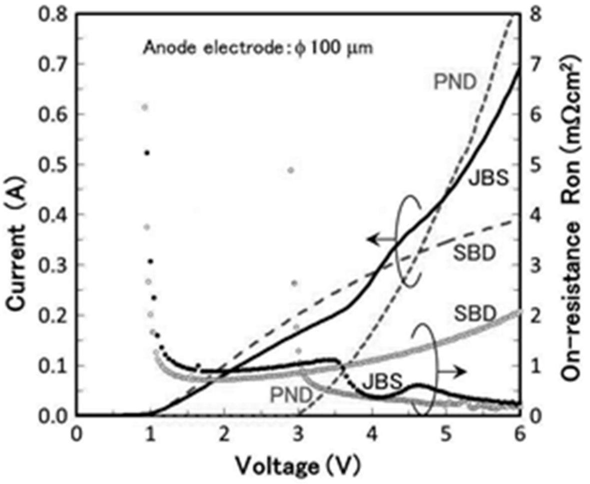

Figure 4. Forward I-V characteristics of the JBS diode, PND and SBD.

IV. Conclusions

GaN JBS diodes were fabricated using very thin (20 nm) and extremely highly Mg doped ($2x10^{20}$ cm^{-3}) p^+-GaN layer as the p-type layer of p-n junction. By omitting p-GaN layers in conventional p^+-GaN/p-GaN/n^--GaN vertical p-n junction diodes, device processing has been eased because of shallow dry etching and a series resistance by the p-GaN was neglected. Expected JBS nature with low turn-on voltages and low specific on-resistances (R_{on}<0.3 mΩcm^2) have been obtained. These results are helpful for improving vertical structure GaN power devices.

Acknowledgement

The authors thank the Japan Ministry of the Environment for giving us the opportunity of this sturdy.

References

[1] I. C. Kizilyalli, A. P. Edwards, H.Nie, D. Disney, and D. Bour, "High voltage vertical GaN p-n diodes with avalanche capability," *IEEE Trans. Electron Devices,* vol.60, no.10, pp. 3067-3070, Oct. 2013.

[2] Y. Hatakeyama, K. Nomoto, A. Terano, N. Kaneda, T. Tsuchiya, T. Mishima, and T. Nakamura, "High-breakdown-voltage and low-specific-on-resistance GaN p-n Junction diodes on free-standing GaN substrates fabricated through low-damage field-plate process," *Jpn. J. Appl. Phys.* vol.52, pp.028007-1-3, Jan. 2013.

[3] I. C. Kizilyalli, A. P. Edwards, H.Nie, D. Bour, T. Prunty, and D. Disney, "3.7 kV vertical GaN pn diodes," *IEEE Electron Devices Letters,* vol.35, no.2, pp.247-249, Feb. 2014.

[4] K. Nomoto, Y. Hatakeyama, H. Katayose, N. Kaneda, T. Mishima, and T. Nakamura, "Over 1.0 kV GaN p-n junction diodes on free-standing GaN substrates," *Phys. Stat. Sol. (A),* vol. 208, no. 7, pp. 1535-1537, Jul. 2011.

[5] Y. Hatakeyama, K. Nomoto, N. Kaneda, T. Mishima, and T. Nakamura, "Over 3.0 GW/cm^2 figure-of-merit GaN p-n junction diodes on free-standing GaN substrates," *IEEE Electron Device Lett.* vol.32, no.12, pp.1674-1676, Dec. 2011.

[6] Y. Oshima, T. Eri, M. Shibata, H. Sunakawa, K. Kobayashi, T. Ichihashi, and A. Usui, “Preparation of freestanding GaN wafers by hydride vapor phase epitaxy with void-assisted separation,” *Jpn. J. Appl. Phys.*, vol. 42, no. 1A/B, pp. L1-L3, Jan. 2003.

[7] T. Yoshida, Y. Oshima, T. Eri, K. Ikeda, S. Yamamoto, K. Watanabe, M. Shibata, and T. Mishima, “Fabrication of 3-in GaN substrates by hydride vapor phase epitaxy using void-assisted separation method,” *J. Cryst. Growth*, vol. 310, no. 1, pp. 5-7, Jan. 2008.