D-2-02 Extended Abstracts of the 2020 International Conference on Solid State Devices and Materials, VIRTUAL conference, 2020, pp193-194

Improvement of Channel Property of GaN Vertical Trench MOSFET by Compensating Nitrogen Vacancies with Nitrogen Plasma Treatment

Takashi Ishida[1,2], Nam Kyung Pil[1], Maciej Matys[1], Tsutomu Uesugi[1], Jun Suda[1] and Tetsu Kachi[1]

[1] Nagoya University
Furo-cho, Chikusa-ku, Nagoya, Aichi 464-8601, Japan
Phone: +81-52-559-9675 E-mail: ishida.takashi@a.mbox.nagoya-u.ac.jp
[2] MIRISE Technologies Corporation
543, Kirigahora, Nishihirose-cho, Toyota, Aichi 470-0309, Japan
Phone: +81-565-46-6793

Abstract

The electrical properties of vertical GaN trench MOSFETs without drift layers were evaluated to investigate the effect of nitrogen plasma treatment on the trench sidewalls. It is demonstrated that nitrogen plasma treatment improves the field-effect mobility of the vertical GaN trench MOSFET. The possible mechanism of this improvement is the supply of nitrogen atoms from nitrogen plasma treatment to the trench surfaces, and the compensation of the nitrogen vacancies near the trench surfaces by the nitrogen atoms during the gate oxide annealing.

1. Introduction

GaN-based vertical MOSFETs are promising as high-power devices for in-vehicle applications [1]. The trench gate structure has the potential to achieve lower RonA than the planar one because of its narrower cell pitch. To utilize the merit, the trench sidewalls achieving a high channel mobility is crucial. One of the factors limiting the channel mobility is the defects near channel surface introduced by ICP-RIE forming trench structures. Previous studies reported that ICP-RIE introduced donor-like defects near the etched surface and the origin of the defects was considered to be nitrogen vacancies (V_N) [2]. Petravic *et al.* reported that sputtering with nitrogen ions may drastically suppress the reduction in nitrogen concentration at the GaN surface as the nitrogen from the ion beam replaces the preferentially removed nitrogen and restores the N-Ga bonds [3]. Therefore, the nitrogen plasma treatment to the trench sidewalls can be effective in reducing the defects related to V_N and improve the channel properties.

In this study, we clarify the effect of the nitrogen plasma treatment by comparing the channel properties of the MOSFETs with different treatments on the trench sidewalls.

2. Device Fabrication

Fig. 1 shows a schematic cross-section of the fabricated GaN vertical trench MOSFET. The layered structure on the n+GaN substrate was composed of a 2-µm-thick p-type body layer and a 100-nm-thick p-type contact layer grown by MOCVD, where the doping concentrations were 5×10^{17} cm^{-3}, and 5×10^{19} cm^{-3}, respectively. To analyze the channel property clearly, a drift layer was not grown in the layered structure to exclude the drift resistance. The activation annealing for p-type layers was performed at 850 °C in an N_2 ambient atmosphere for 5 min. With hydrogen-free sputtering method [4], a 200-nm-thick source n-type layer was selectively formed on the body layer where the p-type contact layer was etched. The Si concentration of a source n-type layer was 3×10^{20} cm^{-3}. The trench structure was formed using multi-step bias etching to reduce the defects caused by ICP-RIE [5]. Considering the existence of the residual defects related to V_N even after multi-step bias etching, the nitrogen plasma treatment was performed in the ALD chamber for 30 min. A 35-nm-thick $Al_{0.78}Si_{0.22}O$ film was deposited as a gate oxide by ALD and annealed at 950 °C in an N_2 ambient atmosphere for 10 min. A p-type poly-Si was deposited as a gate electrode using LPCVD. Ti/Al, Ti/Al/Ni/Au and Ni/Au were deposited by electron-beam evaporation as the source, drain, and p-type body contact electrodes, respectively.

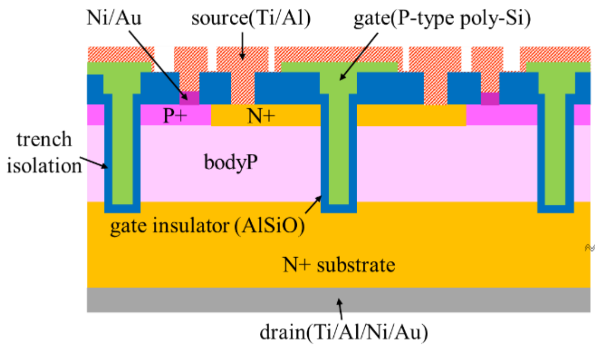

Fig. 1 Schematic cross-section of the fabricated GaN vertical trench MOSFET.

3. Results and Discussion

To calculate the field-effect mobility, the I_d-V_g characteristics of the fabricated MOSFETs were measured under the following conditions: $V_d = 1$ V, $V_s = 0$ V, and $V_g = 0$ to 20 V at 300 K. The trench length of the measured MOSFET was 25 µm, which corresponds to half of the channel width. Fig. 2 shows the I_d-V_g transfer characteristics. The threshold voltages of the MOSFETs with and without nitrogen plasma treatment defined as the gate voltages when the drain currents reach 1 µA were 4.2 and 4.4 V, respectively. These values are consistent with the calculated value (4.1 V).

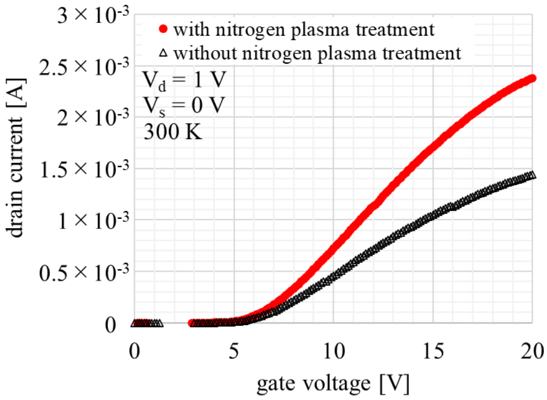

Fig. 2 I_d-V_g transfer characteristics with and without nitrogen plasma treatment.

Fig. 3 shows the field-effect mobility (μ_{FE}) curves calculated from the I_d-V_g transfer characteristics. The MOSFET with the nitrogen plasma treatment exhibited a higher peak value of the field-effect mobility (47 cm^2/Vs) than that without the nitrogen plasma treatment (30 cm^2/Vs). This result strongly indicates that the nitrogen plasma treatment is effective in improving the channel properties of GaN vertical trench MOSFETs.

The limiting factors of the field-effect mobility were also analyzed using the limiting factors of Coulomb scattering (μ_C), phonon scattering (μ_{PH}), and surface roughness scattering (μ_{SR}) [6]. The fitting curve of the field-effect mobility of the MOSFET with the nitrogen plasma treatment is also shown in Fig. 3. This result indicates that the limiting factors of the field effect mobility are Coulomb scattering and surface roughness scattering. Coulomb scattering can be suppressed by optimizing the conditions of the nitrogen plasma treatment. The surface roughness scattering can also be suppressed by TMAH treatment [7] to the trench sidewalls.

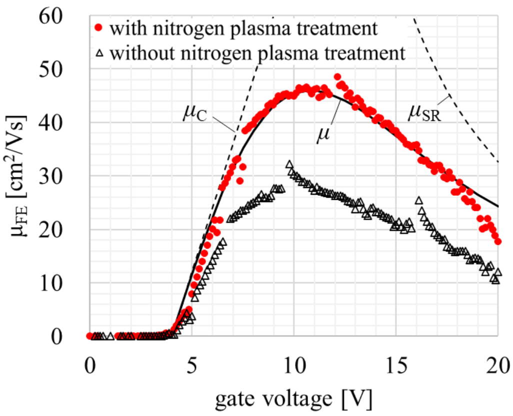

Fig. 3 Field-effect mobility (μ_{FE}) curves with and without nitrogen plasma treatment. The fitting curve of the field-effect mobility (μ_{FE}) with nitrogen plasma treatment is also shown. The dots, dashed lines, and solid line represent the experimental data, Coulomb scattering (μ_C) and surface roughness scattering (μ_{SR}), and fitting field-effect mobility (μ), respectively.

The possible mechanism of this improvement is as below; (1) The defects related to V_N remained near the trench sidewalls after forming trench structures. (2) The nitrogen plasma treatment supplied nitrogen atoms, and the surface of the trench sidewalls became nitrogen-rich. (3) The nitrogen atoms diffused into the GaN bulk during the subsequent gate oxide annealing at 950 °C. (4) The diffusing nitrogen atoms compensated for the defects related to V_N.

4. Conclusions

In summary, the effect of the nitrogen plasma treatment to channel surfaces to improve the channel property of a GaN vertical trench MOSFET was demonstrated. To analyze the channel property clearly, a drift layer was not grown in the layered structure to exclude the drift resistance. MOSFETs with and without nitrogen plasma treatment were fabricated for comparison to confirm the effect of the nitrogen plasma treatment. The MOSFET with the nitrogen plasma treatment exhibited a higher peak value of the field-effect mobility (47 cm^2/Vs) than that without the nitrogen plasma treatment (30 cm^2/Vs). The limiting factors of the field-effect mobility are Coulomb scattering and surface roughness scattering. These scattering factors can be suppressed by optimizing the conditions of the nitrogen plasma treatment and TMAH treatment to the trench sidewalls. These results strongly suggest that nitrogen plasma treatment is effective in improving the channel properties of GaN vertical trench MOSFETs.

Acknowledgements

This work was supported by the MEXT "Research and development of next-generation semiconductor to realize energy-saving society" Program Grant Number JPJ005357. The layered epitaxial structures were grown by Dr. Narita in Toyota Central R&D Labs. Inc. The n-type source layers were sputtered using QAM-4-STS at ULVAC Inc. The nitrogen plasma treatment, deposition, and annealing of the gate oxide were processed by Dr. Kikuta in Toyota Central R&D Labs. Inc. The other fabrication processes were conducted at the CIRFE Transformative Electronics Facilities (C-TEFs) at Nagoya University.

References

[1] T. Kachi, Jpn. J. Appl. Phys. **53** (2014) 100210.
[2] T. Maeda *et al.*, IEEE Electron Device Lett. **40** (2019) 941.
[3] M. Petravic *et al.*, J. Vac. Sci. Technol. A **23** (2005) 1340.
[4] A. Saito *et al.*, ISPlasma2015 (2015) B1-P-01.
[5] S. Yamada *et al.*, Appl. Phys. Express **13** (2020) 016505.
[6] S. Takagi *et al.*, IEEE Trans. Electron Devices **41** (1994) 2357.
[7] M. Kodama *et al.*, Appl. Phys. Express **1** (2008) 021104.