Vertical GaN Power Device -Expectation and Challenges-

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Abstract

The development of vertical GaN devices is in the process development stage for practical use. This report summarizes the current state of development of process technology that enables stable device manufacturing. Examples of device prototypes are also presented.

1. Introduction

Vertical structure of the power device has advantages such as small chip size, easy wiring, and high breakdown voltage. Furthermore, wideband gap semiconductors have the greatest feature of low on-resistance. GaN is material having the ability to fully exhibit these properties and in recent years development of GaN vertical devices has been accelerated. For example, GaN vertical devices with over 1kV breakdown voltage have been reported recently[1-5]. Moreover, over 3kV pn diodes were also reported[6,7]. Therefore, ability of GaN for high voltage devices has been proven. Next issues are developments of fabrication process technologies which make devices stable operation. In this paper, we will report recent advances in process technologies for GaN vertical devices.

2. Fabrication process and devices

Some vertical structures have been reported. Among these structures, we select the trench MOSFET as the structure that makes the best use of the special feature of GaN, and aim to build the fabrication process. Figure 1 shows the main fabrication techniques. Below, the progress of these technologies and the results of trial manufacture of trench MOFETs will be explained.

Epitaxial growth -Low doping growth-

For high voltage power devices, the drift layer requires a low doping concentration lower than 1×10^{16}cm^{-3}. The required concentration is one or two order of magnitude lower than the optical device. Therefore, optimization of the growth

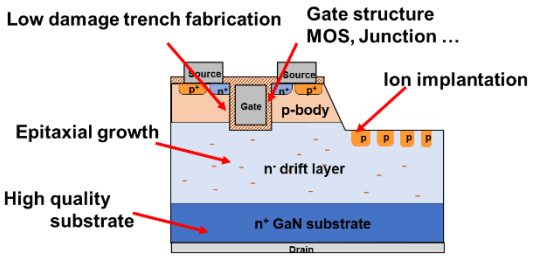

Fig. 1 Fabrication technologies of vertical GaN power devices.

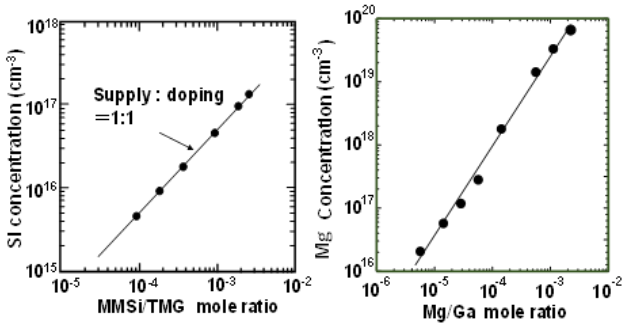

Fig. 2 Si and Mg doping concentrations vs. these source gases supply ratios. Modified from Narita et al. [8] © AIP Publishing.

equipment and conditions became necessary. We have improved the MOVPE equipment for low doping control by using dilution system for the Si and Mg supply lines. Figure 2 shows the high controllability of low concentrations of Si and Mg.[8] The quality of the growth layer also important. The electron maximum mobility at room temperature, for example, was 1200 cm^2/Vs for the $1\text{x}10^{16}$ cm^{-3} sample, which was very high quality[9].

Low damage trench fabrication

In trench MOSFET devices, trench formation is an important process because the sidewalls of the trench act as the gate channel. Therefore, the trench sidewalls must be highly vertical and highly flat. Furthermore, it is necessary to form rounded corners at the bottom of the trench to prevent the gate oxide film from being destroyed by the electric field concentration. In order to obtain high channel mobility, removal of processing damage on the trench sidewall surface is also an important issue.

For the trench etching, etching gases (Cl_2, BCl_3, $SiCl_4$) and their mixed gas were appropriately selected according to the etching process of the trench using ICP-RIE. And we realized

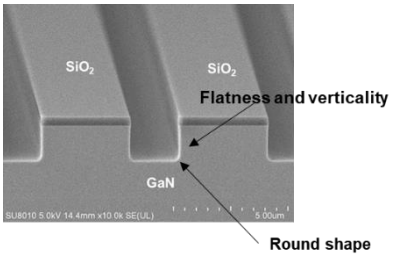

Fig. 3 SEM image of fabricated trench shape by ICP-RIE.

the expected trench shape as shown Fig.3. In addition, to reduce the etching damage, we have developed novel etching technology called the multi-step-bias etching method and conformed the effect of reducing the etching damage.[10)]

Mg ion implantation and activation

Ion implantation is a standard technology for device fabrications of Si and SiC power devices. However, for GaN, ion implantation and activation of Mg for p-GaN has been very difficult until now because there is no high-performance cap layer to protect the GaN surface during high-temperature annealing. To solve the problem, we have tried Mg activation under ultra-high pressure N_2 and high temperature with no protection cap. The pressure and the temperatures were 1GPa and from 1300℃ to 1480℃, respectively. Cathode luminescence measurements of the annealed sample revealed that the green luminescence due to nitrogen vacancies was very low and donor-acceptor pair luminescence was very high, which was the same order of that from epitaxial p-GaN. These results indicate that the recover of the crystal quality and Mg activation were successful. Hall measurements was made to characterize electrical properties of the activated layer. Figure 4 shows the temperature dependence of the hole concentration of the sample of activation temperature of 1400℃.[11)] This shows that the activation under ultra-high pressure N_2 was very effective for forming p-GaN with ion implantation.

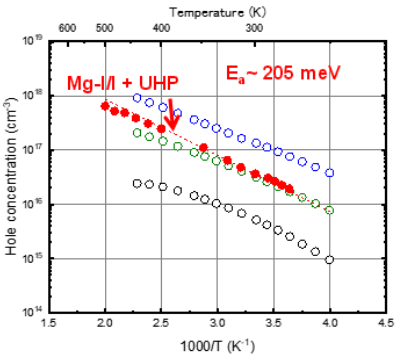

Fig. 4 SEM image of fabricated trench shape by ICP-RIE. Sakurai et al. [10] ©AIP Publishing.

Trench MOSFET fabrication

A trench MOSFET was prototyped using the developed fabrication technologies. As a first step, we adopted a structure without a drift layer as shown in Fig.5 to evaluate the gate channel characteristics. In this structure, the source n-GaN and p-body contact layers have high doping concentration of 3×10^{20} cm^{-3} and 5×10^{19} cm^{-3}, which reduces the contact resistance. The gate length was about 2 microns. The gate

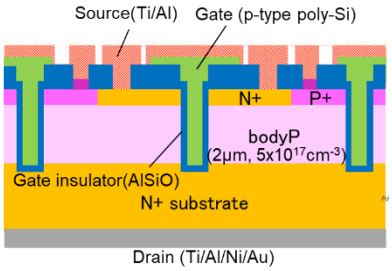

Fig. 5 Cross section of the fabricated trench MOSFET.

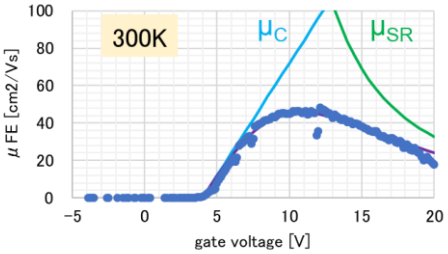

Fig. 6 Channel mobility at 300K. Main limiting factors of the mobility were Coulomb scattering and surface roughness.

insulator film was AlSiO (Al: 78%, Si: 22%), of which thickness was 30 nm. Obtained threshold voltage was 4.2 V, which was consistent with the calculated value. Figure 6 shows the channel mobility vs Vg. The maximum value was 47 cm^2/Vs. The channel mobility limiting factors were analyzed. As shown in Fig.6, Coulomb scattering and surface roughness scattering were the main limiting factors for channel mobility. The results indicate that the channel mobility will be improved by reducing the interface state density of the gate and forming sidewalls with higher planarity.

Applications of vertical GaN power devices

A feature of the vertical GaN device is very low on-resistance. This feature makes it possible to construct a new system, which has been difficult with conventional power devices. For example, air cooling, downsizing, and high current applications as shown in Fig.7.

Fig. 7 Suitable applications of vertical GaN power decies.

Summary

In the research on GaN high voltage devices, the stage of demonstrating high breakdown voltage has already been completed. Development of process technology, which is the next challenge, is currently progressing steadily.

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