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Recent Advances on GaN Power Devices

Tetsu Kachi

[1]TOYOTA CENTRAL R&D LABS., INC, Nagakute-cho, Aichi 480-1192, JAPAN

Tel: +81-561-63-4721 Fax: +81-561-63-6927 E-mail: kachi@mosk.tytlabs.co.jp

Introduction

In recent years, saving of energy consumption and reduction of CO_2 emission are recognized as global targets. Power electronics is a key technology for the subjects and, especially, development of power devices is the most important issue. In the present time, silicon-based power devices are widely used. However, the limit of the Si-based devices becomes apparent. So that, wide band-gap semiconductors, such as SiC and GaN, have been recently studied as novel power devices which breakthrough the Si limit.

Thought GaN has some advantages over SiC such as wide band-gap, high electron mobility, hetero-junction, many of developed electronic devices based on GaN have been for high frequency devices. However, taking advantage of the impressive result of a lateral insulated-gate AlGaN/GaN HEMTs[1)], studies of GaN power devices has been increasing. In this presentation, recent progress in the development of high-voltage GaN power devices is reviwed.

Schottky rectifiers

Until recently, all the GaN Schottky diodes reported are either lateral or quasi-vertical in structure[2)] because of the lack of an electrically conducting GaN substrate. Though many dislocation of $\sim 10^9$ cm^{-2} is in the GaN epi-layer on sapphire substrates, high breakdown voltage as high as 9.7kV been reported[3)] with the lateral structure. In the lateral structure, direction of electric field is normal to the direction of the dislocation, which results in high breakdown voltage.

GaN substrates made with HVPE are recently supplied commercially. Using the GaN substrates, a pn diode has been fabricated on an n^+ GaN subsurate. Breakdown voltage over 900V has been obtained[4)]. The GaN substrate has still about 10^6 cm^{-2} dislocations. This result suggests that the dislocations don't seriously affect the breakdown voltage, but need to be done to ensure long-term reliability.

AlGaN/GaN HEMT power devices

First demonstration of an AlGaN/GaN HEMT for a switching application was the report by Zhang et al[1)]. The breakdown voltage of 1.3kV and on-resistance of 1.7mΩcm^2 have been reported using lateral insulated-gate structure. The insulated-gate structure is effective to obtain high breakdown voltage because of the reduction of gate leak current and electric field crowding at gate edge. However, the threshold voltage V_{th} shifts to negative direction because of insertion of the low series capacitance. Figure1 shows I_d-V_g characteristics of the Schotkky gate HEMT (SG-HEMT) and insulated gate HEMT (IG-HEMT). In this case, 50nm SiO_2 film shifts V_{th} from –4V to –25V[5)]. To suppress the shift of V_{th}, high-k materials such as HfO_2, TiO_2 and HfAlO, have been studied as the insulator. Breakdown voltage of 2kV has been reported using TiO_2/SiN insulaor[6)].

The other method for high breakdown voltage is field plate structure. The field plate structure shown in fig.2 suppresses the electric field crowding at the gate edge and current-collapse. However, the effect of the field plate is sensitive to the design[7)].

Recent trend

Until now, almost all developed GaN transistors are normally-on in the operation because the technology of GaN power devices was based on that of high frequency devices. Normally-off operation is more desirable for power switching applications. So that, studies on normally-off operation have been projected. To realize the normally-off operation based on HEMT structure, various methods have been proposed, for example, a recess gate structure, a p-type gate structure, F ion treatment, use of non-polar surface. However, though the expected V_{th} as a normally-off operation is above 5V, many of their V_{th} are near 0V.

Clear normally-off operation has been reported using conventional MOSFET structure[8)]. The V_{th} was 3.3V and the maximum channel mobility was 167cm^2/Vs, which is higher than that of SiC MOSFET.

As another structure, vertical device with normally-off operation using GaN substrate has been demonstrated. The device structure is shown in Fig.3. A vertical device has some advantage compared with a lateral device, such as easy wiring, small device size and collapse free. Development of large size GaN substrate is a key for the vertical devices.

Summary

History of GaN power devices is shorter than that of SiC power devices. Nevertheless, perfomance of the GaN power device has been progressing rapidly. To overtake SiC devices, total progress of technologies for GaN power devices, such as GaN substrates, processing and device design, is needed.

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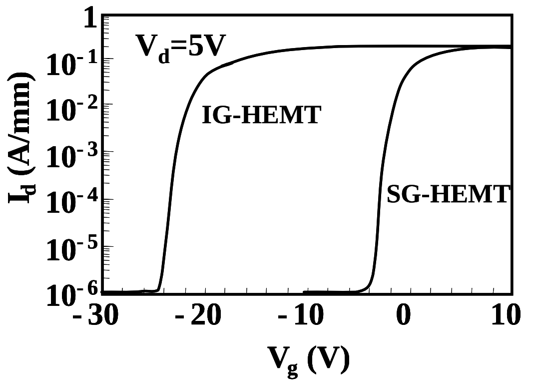

Fig.1 Comparison of Vth for SG-HEMT and IG-HEMT.

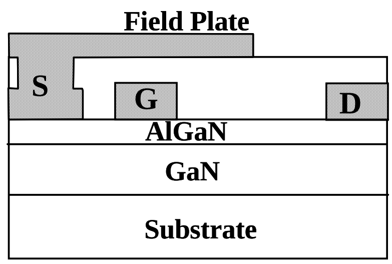

Fig.2 Field plate structure for high breakdown voltage.

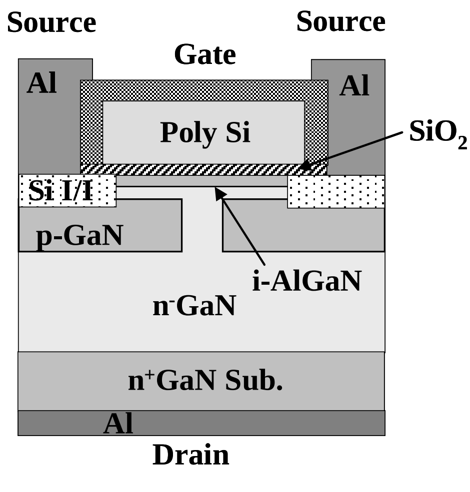

Fig.3 Vertical device using GaN substrate.