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High-Breakdown Voltage Low-leakage Current AlGaN GaN HEMT with Peridodically C-doped GaN Buffer and AlGaN Back Barrier

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Abstract

In this study, we investigated characteristics of AlGaN/GaN HEMTs with high resistive buffer structure consisted of periodically carbon-doped (PCD) GaN buffer layer and AlGaN back barrier layer. The PCD structure was proposed for reducing undesirable trapping effects, which resulted in effective suppression of the current collapse compared to that in conventional carbon buffer structure. To further improve the dynamic performances of the device and to increase the electron confinement of the two dimensional electron gas (2-DEG) channel, AlGaN back barrier was inserted between the GaN channel and the PCD buffer layer, which results in greatly improved current collapse with slightly improved 2-DEG mobility and density, compared to those of the device without back barrier. The OFF-state leakage current of the device with back-barrier is about 2 orders lower in magnitude than that of device without back barrier, which leads to the breakdown voltage of 1.9 kV and figure of merit of 1.9 GV^{2}Ω^{-1}cm^{-2} for the device with L_{GD} of 10 µm, one of the highest values ever reported for the GaN-based high-electron mobility transistors (HEMTs).

1. Introduction

AlGaN/GaN-based high-electron mobility transistors (HEMTs) are attractive for high power electronics applications due to superior material properties of the III-nitride semiconductors such as large energy band-gap, high breakdown electrical field, and high saturation velocity [1]. In addition, high-resistivity (HR) buffer layer is required to fully utilize the material advantages of the HEMTs. The unintentionally doped (UID) GaN buffer layer has an insufficient resistivity due to inevitably introduced background n-type dopants, such as nitrogen vacancy and oxygen impurity, which can induce parasitic leakage paths increasing the OFF-state leakage current. The HR or semi-insulating (S.I.) GaN buffer layers can be achieved by introducing acceptors-like defects or dislocations and doping of deep acceptor impurities (such as Fe or C atoms), which compensates the background donors [2–5]. These approaches to obtain the S.I. buffer layer, however, occasionally suffer from a severe current collapse due to undesirable trapping effects related to the deep acceptors [6-11]. In our previous work, the novel periodically carbon-doped (PCD) GaN buffer structures was proposed instead of conventional thick carbon-doped GaN (C-GaN) buffer structure in order to suppress the undesirable effects related to the deep acceptors. However, the suppression of the trapping effect was not so satisfactory to achieve a reliable dynamic device operation [6]. In this work, simulation was first performed to obtain the optimized PCD GaN buffer structure with inserting an additional AlGaN back barrier between the GaN channel layer and the PCD buffer, which convince the improved electrical characteristics of the device. The HEMTs fabricated with optimized PCD GaN buffer and AlGaN back barrier exhibited not only an extremely low OFF-state leakage current, but also a greatly reduced current collapse phenomenon.

2. Results and Discusstion

The epitaxial structure for the propose AlGaN/GaN HEMT consists of 30 nm-thick low-temperature GaN layer, 2 µm-thick PCD buffer layer with carbon doping concentration of and 1 × 10^{18}/cm^3, 30 nm-thick $Al_{0.08}Ga_{0.92}N$ back barrier, 100 nm-thick GaN channel layer, 1 nm-thick AlN layer, and 25 nm-thick $Al_{0.21}Ga_{0.79}N$ layers, subsequently grown by using metal organic chemical vapor deposition (MOCVD) on the sapphire substrate. For comparison, two different reference HEMT structures were also grown with; 1) conventional S.I. UID-GaN buffer layer without both the PCD layer and AlGaN back barrier, 2) PCD buffer layer without the AlGaN back barrier. The schematic of the fabricated AlGaN/GaN-based HEMTs with three different S.I. GaN buffer layers are shown in Figure 1.

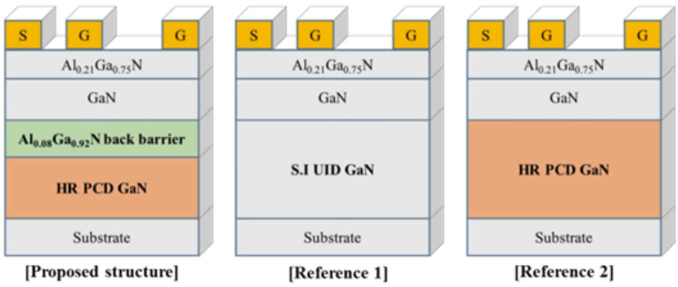

Figure 1 Schematic cross-sectional structures of fabricated HEMTs with various buffer structures.

For the device fabrication, the isolation process was carried out by using inductively coupled plasma-reactive ion etching (ICP-RIE). Then source and drain contacts were formed by Si/Ti/Al/Ni/Au metal scheme, and followed by rapid thermal annealing (RTA) at 850 °C for 30 sec in nitrogen ambient. Finally, Ni/Au metal was deposited for gate electrode.

The DC characteristics of the fabricated devices are measured by using an Agilent 4156 C semiconductor parameter analyzer at room temperature. Figure 2 shows the transfer characteristics at saturation region (V_{ds}: 10 V) of the fabricated AlGaN/GaN HEMTs with three different buffer structures. The proposed device with both PCD buffer and AlGaN back barrier shows an very low OFF-state leakage current of ~ 2×10^{-9} A/mm, which is much lower compared to the values of two reference HEMTs; ~ 1×10^{-5} A/mm and ~ 2×10^{-7} A/mm for the HEMT with S.I UID GaN buffer and for the HEMTs with PCD buffer only, respectively. It is also noticed that the ON-current of the proposed HEMT is comparable to the currents of the reference HEMTs, which results in excellent ON/OFF current ratio of 1.7×10^{8}, even though the OFF-state leakage current of the proposed HEMT is two and four orders lower in magnitude than those of the reference HEMTs with S.I UID GaN buffer and the HEMT with PCD buffer only, respectively. This indicates that the PCD buffer layer eliminates parasitic leakage paths because the carbon-related deep acceptors compensate the back ground donors in the PCD layer and further the AlGaN back barrier enhances the electron confinement in the channel which effectively prevent electrons from flowing into the buffer layer.

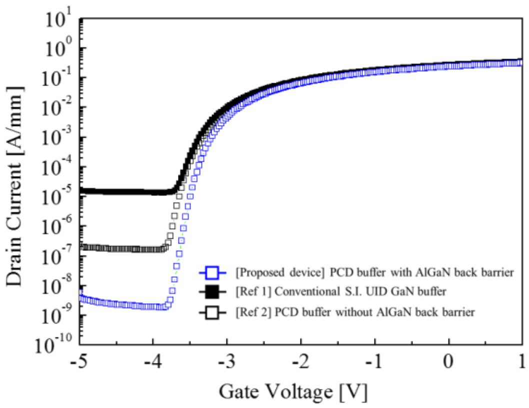

Figure 2 Comparisons of measured ID-VGS characteristics of fabricated HEMTs with different buffer structures.

The OFF-state breakdown characteristics of the fabricated HEMTs with a gate-to-drain distance (L_{GD}) of 5 and 10 µm were measured by using Curve Tracers 370A as shown in Figure 3. The breakdown voltage (V_{br}) is defined as the drain voltage when the drain current reaches to 1 mA/mm. For device with L_{GD} of 5 µm, the HEMTs with S.I. UID GaN buffer, with PCD GaN buffer, and with PCD GaN buffer and AlGaN back barrier exhibit V_{br} of 461 V, 1180 V, and 1291 V, respectively. High V_{br} for the HEMTs with the PCD buffer layer is believed to be due to the spatial compensation between the UID and C-doped GaN layer [6]. The compensation makes the UID layer fully depleted to greatly increase the resistance of the layer, which causes the PCD buffer layer to be semi-insulating. The proposed HEMT exhibited even higher V_{br} because the AlGaN back barrier effectively blocks electrons flowing to buffer layer, as discussed above. The extremely high V_{br} of 1918 V was achieved from the proposed HEMT with L_{GD} of 10 µm. The extracted R_{on} of the proposed HEMT in this work is 1.9 mΩ·cm^2 with the device active area including the channel regions as well as transfer region from the source and drain contact pads. A very high FOM of 1.9 GV^{2}Ω^{-1}cm^{-2} has been achieved for the proposed device with L_{GD} of 10 µm, one of the highest values ever reported for the GaN-based high-electron mobility transistors (HEMTs), even though the proposed HEMT investigated in this work does not have other approaches like field-plated structures.

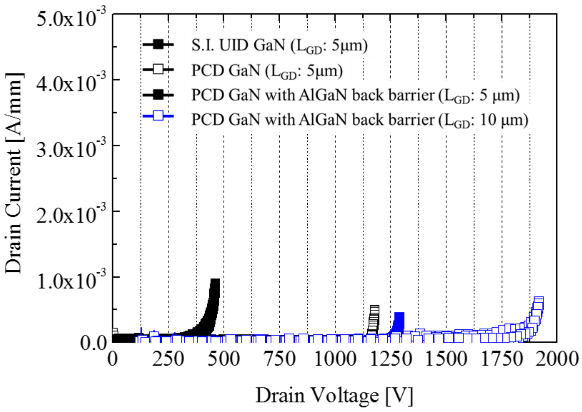

Figure 3 Measured OFF-state breakdown characteristics of fabricated HEMTs with different buffer structures by using curve tracer 370A.

3. Conclusions

Characteristics of high-performance AlGaN/GaN HETMs with high resistive GaN buffer consisted of PCD buffer and AlGaN back-barrier were investigated. The proposed device with both PCD buffer and AlGaN back barrier shows the very low OFF-state leakage current of ~ 2×10^{-9} A/mm, and the excellent breakdown voltage of 1918 V. A very high FOM of 1.9 GV^{2}Ω^{-1}cm^{-2} has been achieved for this device. This indicates that the proposed buffer structure consisted of PCD buffer and AlGaN back-barrier is promising for high power device applications.

Acknowledgements

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References

[1] Y. F. Wu *et al.*, Appl. Phys. Lett., 69, 1438 (1996).
[2] S. M. Hubbard *et al.*, J. Cryst. Growth 284, 297 (2005).
[3] S. Heikman *et al.*, Appl. Phys. Lett. 81, 439 (2002).
[4] S. Kato *et al.*, J. Cryst. Growth 284, 831 (2007).
[5] Poblenz *et al.*, J. Vac. Sci. Technol. B 22, 1145 (2004).
[6] H.-S. Kang *et al.*, Phys. Status Solidi A-Appl. Mat., 212, 1116 (2015).
[7] S.A. Chevtchenko, *et al.*, Appl. Phys. Lett, 100, 223502 (2012).
[8] S. C. Binari *et al.*, IEEE Trans. Electron Devices 48, 465 (2001).
[9] M. J. Uren *et al.*, IEEE Trans. Electron Devices 59, 3327 (2012).
[10] P. B. Klein *et al.*, Appl. Phys. Lett. 79, 3527 (2001).
[11] P.G. Whiting *et al.*, TMS 2015 144th Annual Meeting&Exhibition, 553 (2016).