

# High Breakdown Voltage AlGaIn/GaN HEMTs Employing Recessed Gate Edge Structure

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## Abstract

We have proposed and fabricated a new AlGaIn/GaN high electron mobility transistor (HEMT) employing the recessed gate edge structure. The breakdown voltage and the leakage current of the new AlGaIn/GaN HEMT was improved due to reduced electric field concentration at the gate edge. The breakdown voltage of the proposed device was 1160 V while that of the conventional device was 962 V. The leakage current of the proposed device was 1 order less than that of conventional device. The forward characteristic of proposed device is slightly degraded due to the decrease of 2DEG density.

## INTRODUCTION

AlGaIn/GaN HEMT has considerable attention for power application because of the high critical electric field and the low intrinsic carrier density [1,2]. The breakdown voltage is one of the most important parameters in high power device.

The breakdown voltage is controlled by potential distribution between gate and drain in AlGaIn/GaN HEMTs [3]. When the negative bias applied to the gate of the AlGaIn/GaN HEMT, depletion curvature was formed roundly under the gate edge which causes electric field concentration. The electric field concentration on the gate edge decreases breakdown voltage. In order to improve breakdown voltage, considerable amount of works have been reported such as SiO<sub>2</sub> passivation, floating metal ring, Ni/Au oxidation and As<sup>+</sup> ion implantation into SiO<sub>2</sub> passivation layer. [4-7].

The purpose of this work is to report a new AlGaIn/GaN HEMT employing recessed gate edge structure. We have fabricated the recessed gate edge structure as a new type of edge termination to increase the breakdown voltage. Recently, many groups reported recess gate structure for normally-off operation such as recessed slanted gate HEMT [8] and recess MIS-HEMT [9], but recessed gate edge structure for edge termination has been reported scarcely.

Fig.2 shows the depletion region and electric field concentration under the negative bias. The depletion region curvature of proposed device was distributed more uniformly and electric field concentration near the gate edge was decreased than that of conventional device. Because the

electric field concentration at the edge of gate was reduced, the maximum electric field was decreased so that the breakdown voltage was increased. The breakdown voltage of the proposed device was 1160 V while that of the conventional device was 962 V.

## DEVICE FABRICATION

The cross-sectional view of the fabricated AlGaIn/GaN HEMT is shown in Fig. 2. AlGaIn/GaN heterostructure was grown on semi-insulating 4H-SiC substrate by MOCVD. The 270 nm mesa structure for isolation was formed by ICP-RIE. Ohmic metal for the source/drain electrodes, Ti/Al/Ni/Au (20/80/20/100 nm) were formed with an e-gun evaporator and defined by a liftoff technique and annealed at 870 °C for 30 sec under N<sub>2</sub> ambient. Schottky metal for the gate electrode Ni/Au/Ni (30/150/30 nm) was formed with an e-gun evaporator and defined by a lift-off technique. The recessed gate edge structure was formed 22 nm depth and 2 μm length by inductively coupled plasma etching. The oxygen annealing was performed at 300 °C for 5 min. Fig.1 shows SEM image of the etched AlGaIn/GaN surface. We etched AlGaIn/GaN surface about 22 nm depth by inductively coupled plasma etching using BCl<sub>3</sub>/Cl<sub>2</sub> gas at the KANC (Korea Advanced Nano fab. Center).

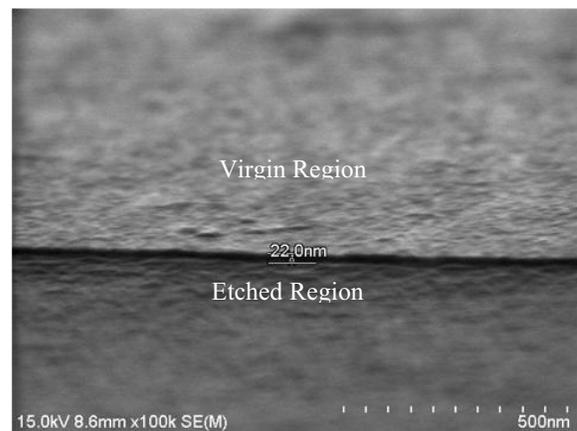
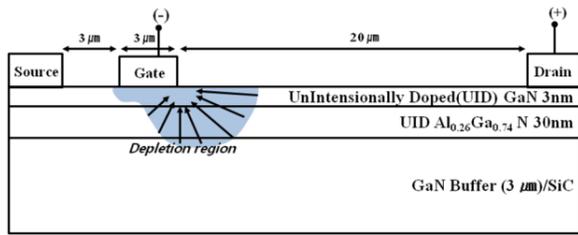
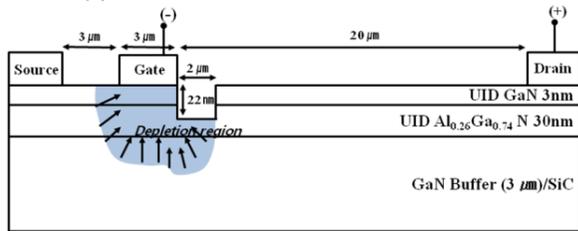


Fig. 1. The SEM image of etched AlGaIn/GaN layer



(a) Conventional AlGaIn/GaN HEMT



(b) Proposed AlGaIn/GaN HEMT

Fig. 2. Cross-sectional view of AlGaIn/GaN HEMT and depletion region distribution under the negative bias. (a) Conventional device (b) Proposed device

EXPERIMENT RESULT

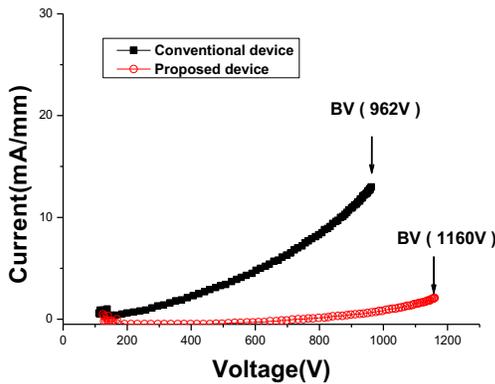


Fig. 3. Measured blocking characteristics

Fig. 3 shows the breakdown voltage of AlGaIn/GaN HEMT before and after gate edge recess. After etching of the 20 nm depth and 2 μm length at the gate edge, the breakdown voltage increased to 1160 V from 962 V due to the edge termination by recessed gate edge structure. Depletion curvature of gate edge in proposed AlGaIn/GaN HEMT was distributed more uniformly comparing with conventional AlGaIn/GaN HEMT as shown Fig.2, which decreased electric field concentration of the proposed device. Because the electric field concentration at the edge of gate was reduced, the maximum electric field was decreased and the breakdown voltage was increased.

At the reverse bias condition, the electron trapping to the AlGaIn surface-state from the gate of the conventional device caused virtual-gate effect. Virtual-gate effect degraded the blocking characteristics such as breakdown voltage and leakage current. Since the gate edge of the proposed device was removed, the electron trapping to the surface-state from the gate was decreased which solved the virtual-gate effect. It is another reason that the breakdown voltage was increased.

Because the AlGaIn thickness was partially thinned, polarization field under the etched region also was relaxed and electron trapping to 2DEG from surface-state was reduced which decreased the reverse leakage current. When the blocking voltage is 850 V, the reverse leakage current of the proposed device is 1 mA/mm while that of the conventional device is 10 mA/mm.

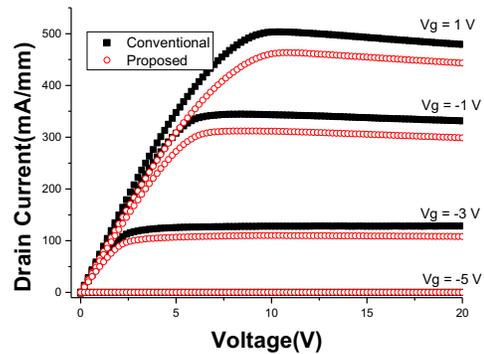


Fig. 4. Measured forward I-V characteristics

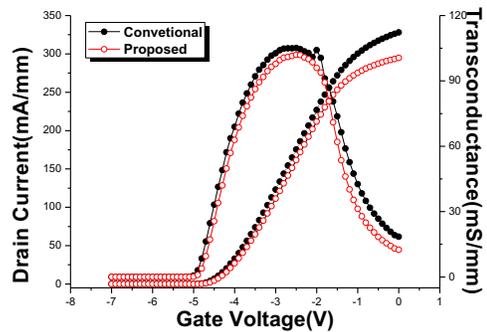


Fig. 5. Measured Transfer I-V characteristics

Fig.4 shows output characteristics of the AlGaIn/GaN HEMTs before and after gate edge recess. When the gate bias was 1 V, maximum drain current of the proposed device was 463.17 mA/mm while that of conventional device was 503.37 mA/mm. Drain current of the proposed device was decreased about 90% than that of conventional device due to partially etched AlGaIn layer. Reduced AlGaIn thickness

caused decrease of the 2DEG density and it improved the reverse leakage current.

Transfer I-V characteristics of AlGaIn/GaN HEMT before and after gate edge recess is shown Fig.5. Maximum transconductance of the proposed device was 101.93 mS/mm while that of conventional device was 105.1 mS/mm. Threshold voltage of the proposed device was -4.1 V while that of conventional device was -3.9 V which was calculated by the  $g_m$  max method. Threshold voltage of the proposed device was shifted to positive about 0.2 V while that of conventional device. Due to the etched region, depletion area of the proposed device can easily approach to 2DEG under the same gate bias.

#### SIMULATION RESULT

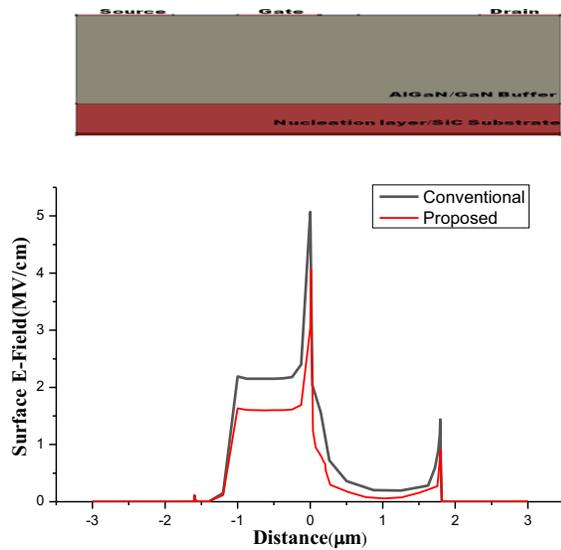


Fig. 6. Surface electrical field of Proposed and Conventional AlGaIn/GaN HEMT at  $V_d = 100$  V

We verified the the electric field relaxation through 2D simulation using ISE-TCAD software. The structure of simulated AlGaIn/GaN HEMTs and surface electric field are shown in Fig.6 . The simulation parameter values are shown in Table.I.

TABLE I. Simulation Parameter Values

|   | AlGaIn            | GaN               |
|---|-------------------|-------------------|
| Electron mobility ( $\text{cm}^2\text{V}^{-1}\text{s}^{-1}$ ) | 550               | 1100              |
| Electron saturation velocity ( $\text{cm s}^{-1}$ )           | $1.5 \times 10^7$ | $2.1 \times 10^7$ |
| Dielectric constant   | 9.55              | 9.5               |
| Bandgap(eV)   | 4.152             | 3.47              |

The simulated epi structure was the same as fabricated AlGaIn/GaN HEMT. For describing recessed AlGaIn region, we grooved 20nm depth of the AlGaIn layer and groove length was 10% of the gate-drain length. We changed the

density of 2DEG under the grooved region which was considered polarization effect. After 10nm depth of the gate edge groove, the electric field under the reverse biased condition became moderate and the maximum electric field strength was decreased as shown in Fig. 6.

#### CONCLUSIONS

We have fabricated AlGaIn/GaN HEMT with recessed gate edge structure and etched region was 22 nm depth and 2  $\mu\text{m}$  length. The maximum forward current of the proposed device is decreased about 10 % than that of conventional device due to partially the recessed active layer. The breakdown voltage was increased 20 % more than that of conventional device and the leakage current of the proposed device was 1 order than that of conventional device. The breakdown voltage of the proposed device was 1160 V while that of the conventional device was 962 V and the leakage current of the proposed device was 1 mA/mm when the drain bias was 850 V while that of conventional device was 10 mA/mm at the same condition. The recessed gate edge structure may be effective edge termination method for improving the breakdown voltage as well as the leakage current of AlGaIn/GaN HEMT.

#### ACKNOWLEDGEMENTS

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## ACRONYMS

HEMT: High Electron Mobility Transistor  
2DEG: 2(Two)-Dimensional Electron Gas  
MOCVD: Metal Organic Chemical Vapor Deposition  
ICP-RIE: Inductively Coupled Plasma Reactive Ion Etch  
SEM: Scanning Electron Microscopy