High Breakdown AlGaN/GaN HEMTs Employing Nickel Oxide Floating Metal Ring

Young-Shil Kim[1], Min-Woo Ha[2], O-Gyun Seok[1], Woo-Jin Ann[1] and Min-Koo Han[1]

[1]School of Electrical Engineering, Seoul National University, Seoul, Korea
[2]Korea Electronics Technology Institute, Seongnam, Gyeonggi do, Korea

Corresponding author. Tel: +82-2-880-7254; Fax: +82-2-875-7254
E-mail address: mkh@snu.ac.kr

Keywords: AlGaN, GaN, Breakdown, NiO_X, FMR

Abstract

We proposed and fabricated AlGaN/GaN HEMT employing a Nickel oxide based floating metal ring which showed a highly stable reverse blocking capability. The leakage current of the proposed device was decreased by three orders of magnitude. Measured leakage current of the device using a NiO_X (oxidized at 400℃)-Ni/Au contact as a FMR was 1.1 nA at room temperature while that of the conventional one was 1.06 uA. We also have obtained a high breakdown voltage of 930 V. The highly stable blocking characteristic of the proposed device was attributed to the field distribution due to the extra depletion region introduced by NiO_X FMR between gate and drain electrode.

INTRODUCTION

AlGaN/GaN HEMT have been a subject for intensive investigation and emerged as an attractive candidate for a high power and high frequency applications due to its excellent material properties such as high density two dimensional electron gas (2DEG), high electron mobility, high critical electric field and low intrinsic carrier concentration [1]. It is known that leakage current and breakdown voltage of power device are the most critical factors to limit the performance of high power application [2]. The leakage current and premature-breakdown deteriorate blocking capability of the device by causing power loss during off-state operation [3]. The leakage current is mostly dominated by two components such as bulk and Schottky-gate reverse bias tunneling leakage current rather than bulk leakage current [4]. The Schottky-gate tunneling leakage depends on the magnitude and the special distribution of the electric field peak under at the drain side of the gate [5] In order to suppress the leakage current and improve the breakdown voltage, edge termination methods should be employed. It has been reported that FMR can be fabricated simply due to its synchronous fabrication of the main schottky gate and it effectively reduce the field peak of the main Schottky junction [6][7].

The purpose of our work is to report the NiO_X-based FMR as a method to improve reverse blocking capability of the AlGaN/GaN HEMT by increasing breakdown voltage and suppressing leakage current. We also investigated the effect of the NiO_X-based FMR on the electrical property of the device.

EXPERIMENTAL RESULT

AlGaN/GaN heterostructure was grown on SiC substrate by MOCVP. A 30 nm-thick unintentionally doped $Al_{0.3}Ga_{0.7}N$ and n 3 ㎛-thick GaN buffer formed 2DEG channel of AlGaN/GaN HEMT then undoped 3nm-thick GaN capping layer was grown. The mesa structure was formed for device isolation by ICP-RIE. For source and drain electrode, Ti/Al/Ni/Au (20/80/20/100 nm) based ohmic contact was e-gun evaporated then annealed at 880 ℃ for 30 s under N_2 ambient. For the NiO_X film, 20-nm thick Ni film was e-gun evaporated and thermally oxidized in the furnace at 400℃ under O_2 ambient. The flow rate of oxygen was 4.5 SLPM (standard litters per minute). Ni/Au (30/150 nm) over layer was e-gun evaporated to lower the contact resistance. A standard lift off method was used to define these metallization patterns. After every patterning for metal deposition, surface treatment using $HCl:H_2O_2$:DI (1:1:6) solution was performed to remove native oxide and contaminant at the surface

The change of the depletion contour due to the FMR structure was confirmed by measured off-state gate-drain capacitance (Fig. 1). When the gate bias is decreased below the pinch-off voltage (reverse bias condition), the channel capacitance was changed into the depletion capacitance. Two depletion capacitance components occurred. One was by the main Schottky contact (C_{dep1}) and the other was by the NiO_X contact (C_{dep2}). Off-state Gate-drain capacitance (C_{GD}) of the proposed device can be expressed as

$$C_{GD} = C_B \| [C_{dep1}C_B/(C_{dep1}+C_B) + C_{dep2}C_B/(C_{dep2}+C_B)]$$
$$\text{where, } C_B(C_{Barrier}) = C_{GaN}C_{AlGaN}/(C_{GaN}+C_{AlGaN}) \quad (1)$$

Due to the large capacitance of the series connection (C_B) of the GaN capping layer and the AlGaN layer, C_{GD} is dominated by two depletion capacitance components.

$$C_{GD} \approx C_{dep1} + C_{dep2} \quad (2)$$

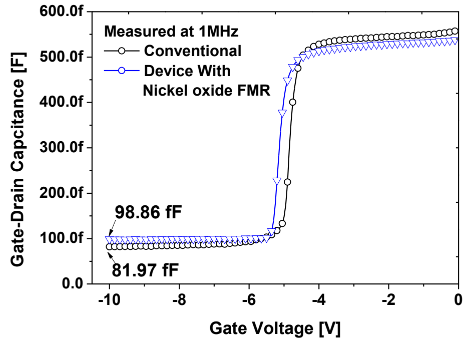

Fig. 1. Measured gate-drain capacitance of the device with FMR

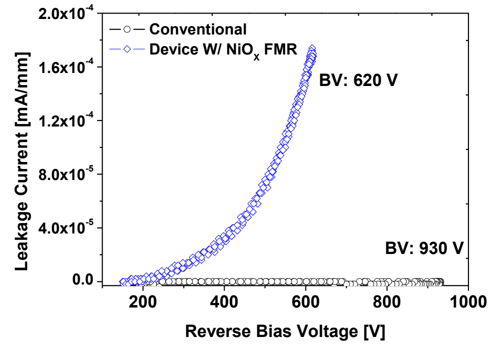

Fig. 4. Measured Breakdown voltage of the device with FMR

Because depletion capacitance by main Schottky contact was fixed, the difference between two capacitances at the -10V indicated the extra depletion was introduced by the FMR. The specific contour of the extra depletion due to FMR had area of 1.56 μm^2 and depth of 0.7 µm. By the introduction of extra depletion region, electric field concentrated at the drain-side gate edge was distributed field more uniformly under reverse bias condition.

The leakage current under the reverse bias condition, where the gate and drain voltage was -10 V and 50 V respectively, was decreased by three orders of magnitude. Measured leakage current of the conventional and proposed device at room temperature was 1.6 µA to 1.11 nA and those measured at 200 ℃ was 8.75 µA and 36 nA respectively (Fig. 2).

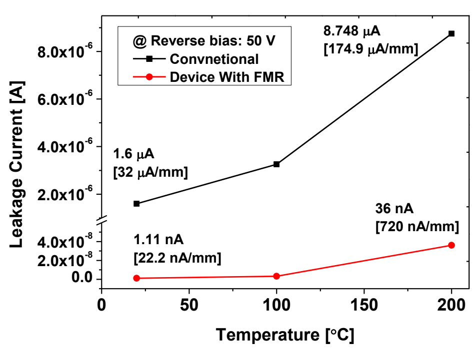

Fig. 2. Measured leakage current of the device with FMR

The Breakdown voltage of the AlGaN/GaN HEMT with FMR was increased by 50%. Measured breakdown voltage of the conventional device and proposed one was 620 V and 930 V (Fig. 3). Proposed device showed higher breakdown voltage as well as complete leakage suppression characteristic. Both the decrease in leakage current and the improvement of breakdown voltage reflected that the extra depletion region induced by FMR dropped the peak electric field at gate edge and reduced the surface potential which was dumped into the main Schottky contact.

CONCLUSIONS

We proposed NiO_X-based FMR as an edge termination technique for high breakdown voltage AlGaN/GaN HEMT. NiO_X floating metal ring introduced an extra depletion region laterally. This decreased a peak of the electric field concentrated at the drain-side gate edge by distributing field more uniformly. By this mechanism, AlGaN/GaN HEMT with FMR achieved high breakdown voltage and low leakage current. Measured breakdown voltage of the proposed device was 930 V. It was higher than that of the conventional device by 50%.

ACKNOWLEDGEMENTS

This work was supported by the ‘Power Generation & Electricity Delivery’ of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea Government Ministry of Knowledge Economy.

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ACRONYMS

HEMT: High Electron Mobility Transistor