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Fully Recessed Schottky Barrier Diodes with a Digital Etching on AlGaN/GaN Heterostructures

Namcheol Jeon[1], Woojin Choi[1], Hojin Ryu[1], Ho-Young Cha[2], and Kwang-Seok Seo[1]

[1] Department of Electrical Engineering and Computer Science and Inter-university Semiconductor Research Center, Seoul National University
599 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea, E-mail: ksseo@snu.ac.kr
[2] School of Electronic and Electrical Engineering, Hongik University, Seoul 121-791, Korea

Abstract

An effective digital etching technique and its application on fully recessed Schottky barrier diode (SBD) are described in this paper. Etch rate and roughness of the digitally etched $Al_{0.25}GaN$ surface were 0.6 nm/cycle and 0.58-nm which is almost identical with a non-recessed surface. Hall-effect measurement revealed a negligible damage on GaN surface was generated after digital etching. Fabricated SBD with a digital etching showed an improved Schottky contact which has ideality factor of 1.19 and Schottky barrier height of 0.73 eV, respectively. The on-resistance and reverse breakdown voltage were 1.13 mΩ-cm^2 and 566 V, respectively.

1. Introduction

Recessed gate is a well-known method to implement SBDs with a low turn-on voltage and normally-off HEMTs which have received great attentions for power electronics applications [1], [2]. Wet recess etching was a conventional process in AlGaAs/GaAs heterostructures, because of moderate etch rate and etch stop layer. On the other hand, GaN is hard to etch away by wet etchants, thus dry recess etching is a favorable process in AlGaN/GaN heterostructures [3]. However, GaN surface is prone to be damaged by dry recess etching. Several groups suggested a so-called digital etching as a low damage recess etching technique [4], [5]. Digital recess etching is consecutive repetitions of an epitaxial layer oxidation and formed oxide removal process.

In this study, we investigated the influence of digital etching on electrical characteristics of fully recessed SBDs.

2. Digital recess etching

The epi-layer structure consisted of a 30-nm undoped-$Al_{0.25}GaN$ barrier, a 5.6-µm GaN buffer layer on a Si substrate was used in this experiment. The oxidation conditions using N_2O plasma were a gas flow rate of 40 sccm, a chamber pressure of 200 mTorr, a RF power of 20 W, and a time of 180 sec. N_2O plasma was preferred for surface oxidation, because O_2 plasma may create deep level traps which is related with a nitrogen deficiencies [6]. The formed oxide removal was carried out by dipping samples in diluted HCl (1:1) solution for 60 sec.

Figure 1 shows the AFM image of a digitally etched $Al_{0.25}GaN$ surface. The etch rate was measured using AFM as a function of number of digital recess cycles, i.e., 3, 6, 10 cycles as shown in Fig. 2. Figure 3 shows the roughness of the AlGaN surface before and after recess etching. The measured RMS roughness after recess was in the range of 0.58 – 0.61-nm which is almost identical with a non-recessed surface.

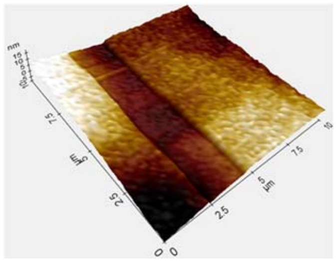

Fig. 1. AFM image of digitally etched $Al_{0.25}GaN$ surface (Recess width = 2 µm, depth = 4.3 nm)

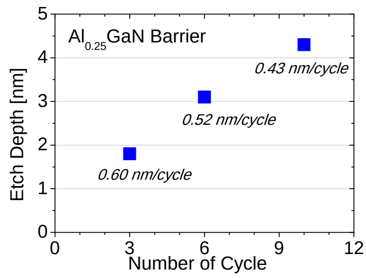

Fig. 2. Etched depth vs. number of cycles

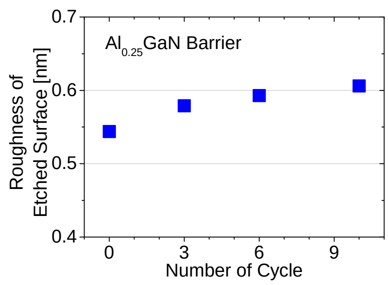

Fig. 3. RMS Roughness (R_q) vs. number of cycles

3. Hall-effect measurement

The epitaxial wafer structure used for Hall-effect measurement consisted of a 4-nm un-doped-GaN capping layer, a 20-nm undoped-$Al_{0.23}GaN$ barrier, a 1.7-µm undoped-GaN buffer on an N-type Si (111) substrate. Mesa isolation was defined using inductively coupled plasma reactive ion etching (ICP-RIE) with BCl_3/Cl_2 gas mixture. A Si/Ti/Al/Mo/Au (=5/20/80/35/50 nm) metal stack was evaporated and annealed at 820 °C for 30 s in N_2 ambient for the ohmic contact. In order to investigate the digital etching induced damage, the active area was exposed to the

N_2O plasma and diluted HCl. Measured 2DEG carrier concentration and hall mobility are show in Fig. 4. It was observed that GaN surface and 2DEG was not deteriorated after digital etching. Buffer leakage current was also decreased after digital etching as shown in Fig. 5.

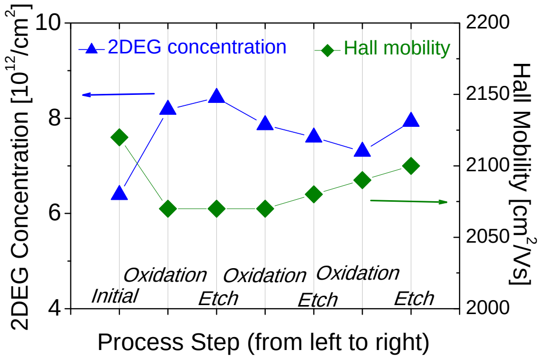

Fig. 4. n_s and μ_e after digital etch

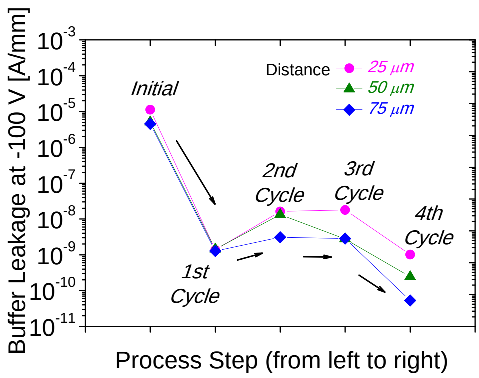

Fig. 5. Buffer leakage current

4. Fully recessed SBDs with a digital etching

Ohmic contact was first formed and mesa isolation was followed. Next, anode region was fully recessed under the 2DEG channel to define a recessed Schottky contact. 34-nm was etched which is 10-nm deeper than a channel depth. Anode recess was carried out using BCl_3/Cl_2 (=2/18 sccm) gas mixture with a DC self-bias of 25 V. Additional digital etching was performed on the recessed area to decrease the dry etching damage. Then, a non-recessed Schottky metal was evaporated. Finally, a 200-nm-thick SiN_x film was deposited at 250 °C for surface passivation. A schematic cross-sectional view of the fabricated SBD is shown in Fig. 6.

Figure 7 and 8 show the typical forward and reverse characteristics of the fabricated SBDs. The ideality factor and Schottky barrier height were 1.35 and 0.60 eV in a reference SBD and 1.19 and 0.73 eV in a digitally etched SBD, respectively. The specific on-resistance was also decreased slightly from 1.28 to 1.13 mΩ-cm^2. The reverse current at -100 V of recessed, and recessed with a digital etching SBDs were 100 and 36 μA/mm, respectively. These results reveal the digital etching can relieve the dry etching induced damage. Reverse breakdown voltage of the fabricated SBD with an anode-to-cathode distance (L_{AC}) of 10 μm was 566 V.

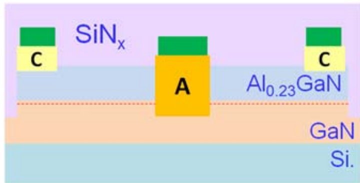

Fig. 6. Schematic cross-sectional view of the fully recessed SBD

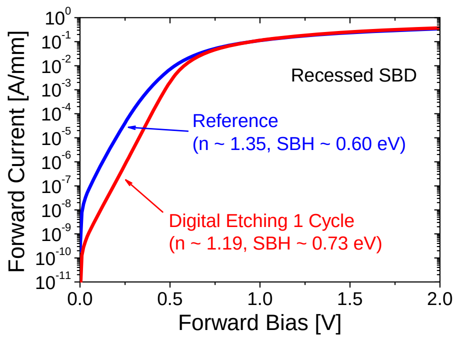

Fig. 7. Forward characteristics of recessed SBDs (Anode length = 10 μm, L_{AC} = 10 μm)

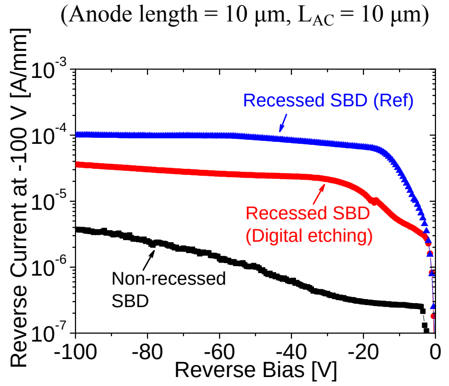

Fig. 8. Reverse characteristics

5. Conclusion

The fully recessed SBDs with a digital etching were fabricated. GaN surface was oxidized with a N_2O gas and a RF power of 20 W to achieve a low damage digital etching. We found that deteriorated GaN surface by dry etching can be recovered by digital etching. Thus, better Schottky contact was demonstrated. Forward and reverse characteristics were also improved by digital etching. Described technique could be applicable to the GaN recess etching, which is widely used in the GaN device process.

Acknowledgement

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