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Power Schottky Barrier Diodes with Improved Schottky Contacts on AlGaN/GaN Heterostructures

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1. Introduction

Passivation is a conventionally well-known method to improve the GaN heterostructure device performance. Early passivation before the gate metallization can lead to a further improvement in device performance, such as increase of a breakdown voltage by a slanted gate [1]. Passivation even before an ohmic formation was proposed to protect a GaN surface which can be damaged by an annealing process with temperature above 600 °C [2]. Because currents are flowing through the Schottky interface in Schottky barrier diodes (SBD), quality of the Schottky contact is important. Thus, low damage etching of a passivation layer for an anode window opening is needed.

In this study, we proposed wet etching as a low damage etching method. Differences between wet etching and dry etching of SiN_x for an anode window opening were clarified in terms of GaN Schottky contacts. Furthermore, we will check the effects of a chemical treatment just prior to the Schottky metal deposition on electrical characteristics of GaN SBDs.

2. Anode window opening methods

The epi-layer structure consisted of an 18-nm undoped-$Al_{0.3}Ga_{0.7}N$ barrier, a 1-nm AlN spacer, a 2.8-μm undoped-GaN buffer layer on a sapphire substrate was used in this experiment. Organic residues on samples were cleaned with boiled solvent and piranha. Surface native oxides were removed by dipping in diluted HF (1:10) for 10 min. Next, 30-nm-thick SiN_x layer was deposited on the AlGaN surface using inductively coupled plasma chemical vapor deposition (ICP-CVD) at 350 °C. Ohmic contact metals of Si/Ti/Al/Mo/Au (5/20/80/35/50 nm) were deposited by e-beam evaporation and annealed at 800 °C for 30 s in N_2 ambient. The measured contact resistance and sheet resistance were 0.35 Ω-mm and 400 Ω/sq, respectively. SiN_x layer was etched away to form an anode window. Two etch methods, dry and wet etching; for anode window opening were compared in terms of Schottky contacts. The next patterning process defined the anode and anode field plates. Finally, Ni/Au (20/230 nm) was deposited as a Schottky metal.

A schematic cross-sectional view of the fabricated circular GaN SBD is shown in Fig. 1. The anode diameter (D_A) and field plate length were 100 μm and 2 μm, respectively. The anode-to-cathode distance (L_{AC}) was 5, 10, 15, and 20 μm. Figure 2 shows the C-V curve of the fabricated GaN SBD. Hysteresis phenomenon depending on DC voltage sweep direction was not observed. Figure 3 shows carrier concentration profile depending on penetration depth of epi-layer extracted from the C-V curve in Fig. 2. Detailed extraction procedures are explained in [3]. The peak in the carrier density at 18 nm below the surface corresponds to the location of the 2DEG channel.

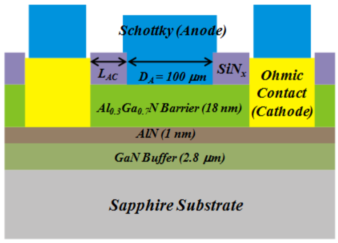

Fig. 1. Schematic cross-sectional view of the fabricated circular GaN SBDs

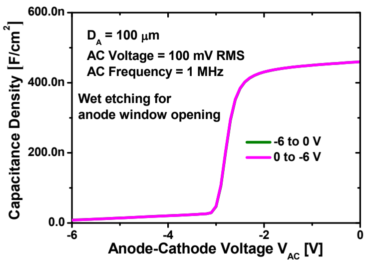

Fig 2. Measured C-V curve of GaN SBD (Green line and pink line are overlapped)

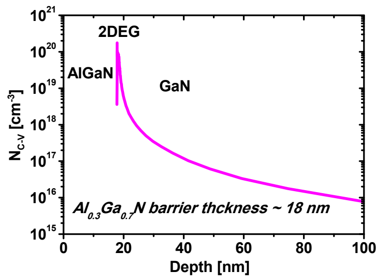

Fig. 3. Carrier concentration profile N_{C-V} vs. penetration depth of epi-layer

Opening of an anode window in SiN_x is typically performed with a fluorine based dry etch process. It is well known that fluorine is incorporated in the AlGaN barrier [4]. Those of incorporated fluorine can deplete the 2DEG channel. Because currents are flowing from a Schottky metal to a 2DEG channel, forward currents of the SBDs may be impeded by incorporated fluorine. A low-power and an isotropic dry etch condition was used in this experiment. The dry etch conditions were gas flows of SF_6, 100 sccm; a chamber pressure of 0.1 Torr, and an RF power of 10 W in a CCP etcher. The self DC bias was 5 V and etch rate was 10 nm/min. BOE (7:1) wet etchant was used for an opening of SiN_x in an anode window. Wet etch rate was 2 nm/min and SiN_x layer was intentionally over-etched by 15 % in all samples.

Figure 4 shows the measured anode current at forward bias with respect to anode window opening methods. The ideality factor and Schottky barrier height were 2.24 and 0.72 eV in dry etch process and 1.72 and 0.79 eV in wet etch process, respectively. These results reveal the wet chemical can etch SiN_x with low damage on AlGaN surface than fluorine plasma.

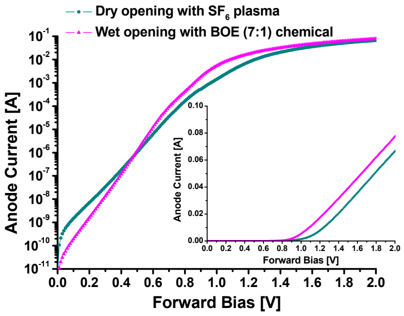

Fig. 4. Comparison of dry opening and wet opening: anode current vs. forward bias

3. Pre-Schottky wet chemical treatment

There are many researches on effect of the wet chemical such as HF, HCl, NH_4OH, and KOH treatment on AlGaN surface [5], [6]. However, many papers about wet chemical treatments are focuses on cleaning of an AlGaN surface as a first step of a device fabrication. Effect of chemical treatments just prior to the Schottky metal deposition was studied in terms of electrical characteristics of GaN SBDs.

All samples were wet etched to open the anode window as explained in §2. We tried BOE (7:1) and HCl (1:3) chemical treatment. Wet chemicals are treated at room temperature, because PR was patterned on samples. Fig. 5 shows the ideality factor and Schottky barrier height of the fabricated SBDs. BOE (7:1) treatment for 3 min just prior to the Schottky metal deposition showed best results. Anode leakage currents were increased over 10 times when treatment time is over 5 min both in BOE and HCl treatment. This phenomenon attribute to lowered Schottky barrier height caused by excessive chemical treatment. Forward current at 1.5 V are affected little by chemical treatment time. Figure 6 and 7 shows the forward current and breakdown voltage of the fabricated SBDs with pre-Schottky treatment of BOE (7:1) for 3 min.

4. Conclusion

Influences of the anode window opening methods on SBD performance were investigated. Low damage etching of SiN_x was achieved by the HF based wet etching. Thus, good Schottky contact was possible in SBD with wet opening. On the other hand, SBD with dry opening shows poor Schottky contact and smaller forward current. The reason for these results is incorporation of fluorine in AlGaN barrier and damage at the AlGaN surface during dry etching of SiN_x for the anode window opening.

Wet chemical treatment just prior to the Schottky metal deposition also influences the Schottky contact. Optimum treatment condition was 3 min treatments of BOE (7:1) in our experiments. Excessive chemical treatment causes increase of the anode leakage current. Further studies of physical analysis on surface states in an AlGaN surface are needed.

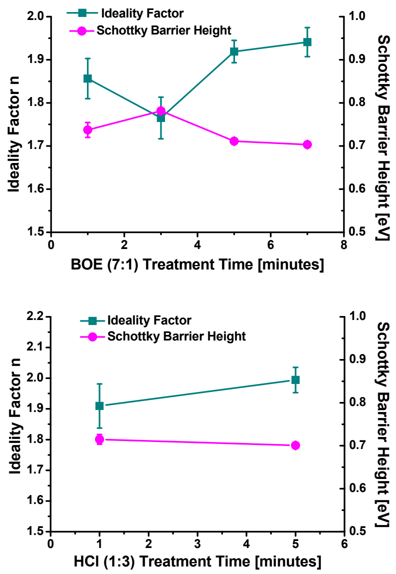

Fig. 5. n and SBH vs. chemical treatment time just prior to the Schottky metal deposition

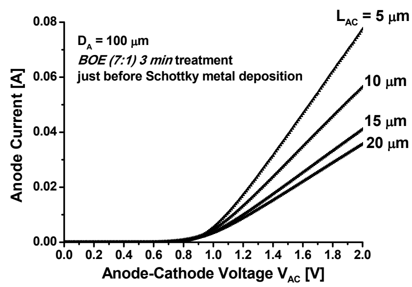

Fig. 6. Forward current vs. V_{AC} of GaN SBD

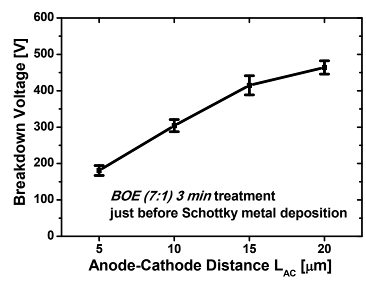

Fig. 7. Breakdown voltage vs. L_{AC} of GaN SBD

Acknowledgement

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References

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