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Removal of reactive-ion-etching damage from n-GaN surface using a photoelectrochemical process

Satoru Matsumoto, Masachika Toguchi, Taketomo Sato

Research Center for Integrated Quantum Electronics, Hokkaido Univ.
North 13, West- 8, Kita-ku, Sapporo, 060-8628, Japan
Phone: +81-11-706-7174, E-mail: matsumoto@rciqe.hokudai.ac.jp

Abstract

The low-damage etching of GaN surface was demonstrated utilizing a photoelectrochemical (PEC) oxidation and a subsequent alkali-treatment. The PEC-process was very useful to remove the damage layer induced by a plasma-assisted reactive-ion-etching.

1. Introduction

GaN and related materials are promising for high-power electronic devices achieving high blocking voltage and yet low on-resistance. One of the key technologies for GaN-device is the low-damage-etching process with a high controllability. The etching process for GaN is commonly carried out in high-energy environments utilizing accelerated ions or plasma-assisted species. However, such high-energy processing tends to generate surface damage and defects, leading to degradation of device performance [1,2].

In this study, we demonstrated that the photo-electrochemical (PEC) process was useful to remove the damage layer induced by plasma-assisted etching process such as reactive-ion-etching (RIE) and reactive-ion-beam-etching (RIBE). The experimental results showed no additional damage induced on GaN surface after the PEC process.

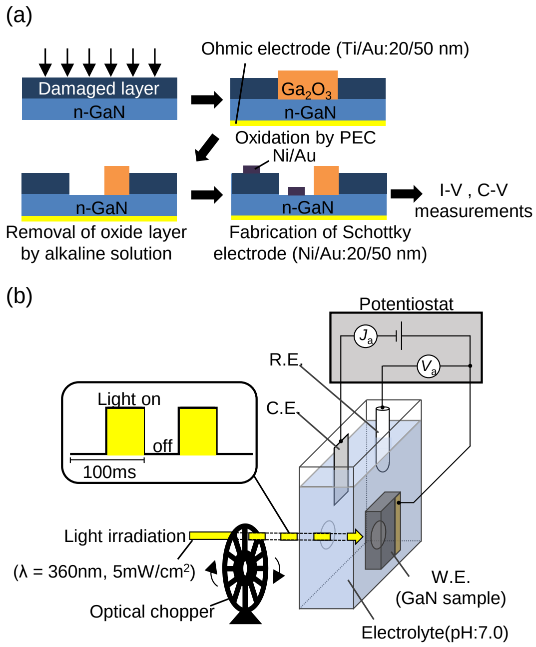

Fig. 1 Schematic illustration of (a) experimental procedure and (b) setup of photoelectrochemical (PEC) process.

2. Experimental

The schematics of experimental procedure and PEC setup are shown in **Figs. 1(a) and (b)**, respectively. An n-type GaN layer grown on a free-standing GaN substrate with a thickness of 3 µm and a carrier density of 5×10^{16} cm^{-3} was used as a starting "as-grown" sample. The RIBE process was conducted using an electron-cyclotron-resonance (ECR) plasma with a microwave power of 250W under a bias voltage of 150 V. After RIBE process, an ohmic contact was formed on the back surface of GaN substrate. Then, the GaN surface was oxidized by a PEC reaction in an electrolyte. As shown in **Fig. 1 (a)**, the UV light with a wavelength of 360 nm was periodically irradiated on the GaN surface through an optical chopper. The anodic voltage, V_a, of 4 V was applied to the GaN surface with respect to a reference electrode (R.E.) using a potentiostat. After PEC process, the oxide films formed on GaN surface were removed by an alkali-treatment [3]. Finally, Schottky barrier diodes (SBDs) were formed both on RIBE-processed- and PEC-processed-surface to compare the electrical properties.

3. Results and Discussion

The oxide thickness formed by the PEC process was plotted in **Fig. 2** as a function of charge density estimated from anodic-reaction currents, J_a. The linear relationship indicates that the oxide thickness was well controlled by the PEC process. **Figure 3** shows the current-voltage (I-V) characteristics of SBDs formed on Sample A and B after the removal of oxide films using an alkali-treatment. The extremely-large leakage currents were observed on the RIBE-processed surface where the apparent barrier height lowered. A possible reason for this is that highly active-plasma species react with the GaN surface, inducing shallow-donorlike defects due to the nitrogen vacancy and so on [1]. On the other hand, the leakage currents drastically decreased with the PEC

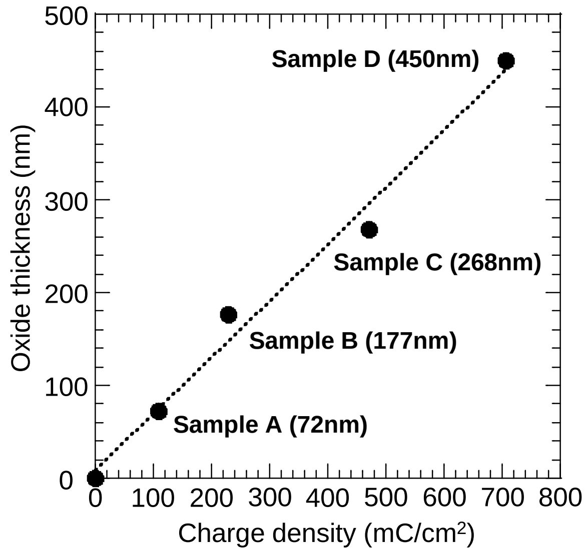

Fig. 2 Correlation between oxide thickness formed by PEC process and charge density estimated from current density.

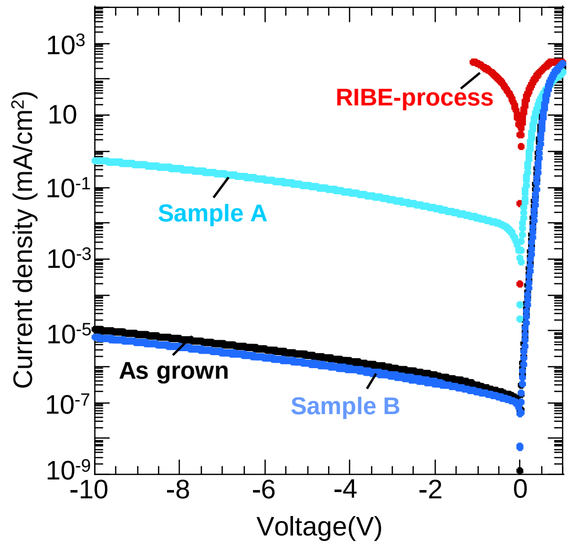

Fig. 3 *I-V* characteristics of SBDs formed on as-grown surface, RIBE-processed surface and PEC-processed surface with an alkali treatment.

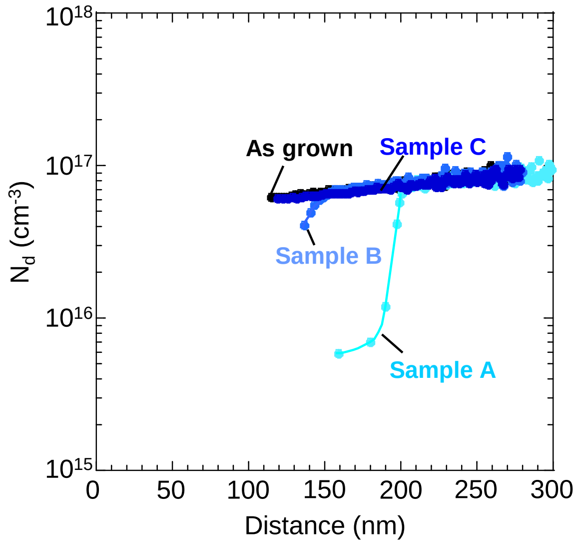

Fig. 4 Carrier profiles obtained from *C-V* measurements on as-grown sample and PEC-processed samples with an alkali treatment.

process. The *I-V* characteristics recovered to the as-grown level on Sample B after the removal of 177 nm-thick oxide formed by the PEC process.

Figure 4 compares the carrier profiles obtained by capacitance-voltage (*C-V*) measurements on various SBD samples. The C-V characteristic was unmeasurable on the RIBE-processed sample due to the large-leakage currents, as seen in **Fig.3**. As shown in **Fig. 4**, the carrier density of Sample A and B reduced from that of as-grown sample within 200 nm and 145 nm in depth bellow the surface, respectively. This result suggests that the RIBE-process induced the defects that deactivate or compensate Si donors in sub-micron distance below the surface, and they were gradually removed by the PEC process. This kind of deep-level defect has been reported by the previous work [4], where the bombardment of ions accelerated by the high-electric field induced damage into GaN in sub-micron range. As for Sample C after the removal of 268 nm-thick oxide formed by the PEC process, the carrier profile was comparable to that of as grown sample in the analyzable range.

These results indicate that the present PEC process is useful to remove the surface layer without any additional damage induced on GaN.

4. Conclusion

The oxide thickness formed on the GaN surface was well controlled by the total electric charge during the PEC process. From the *I-V* and *C-V* measurements on SBDs, the RIBE-process induced the various defects, such as that increase the leakage currents of SBDs or decrease the carrier density in sub-micron distance below the surface. The damage layer including these kinds of defects was effectively removed by the PEC process without any additional damage induced on GaN.

Acknowledgements

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