

GaN Wet Etching Process for Power and RF Devices

Fumimasa Horikiri¹, Noboru Fukuhara¹, Hiroshi Ohta², Naomi Asai², Yoshinobu Narita¹, Takehiro Yoshida¹, Tomoyoshi Mishima², Masachika Toguchi³, Kazuki Miwa³ and Taketomo Sato³

¹ SCIOCS Co., Ltd.,

880 Isagozawa-cho, Hitachi-shi, Ibaraki 318-1418, Japan

Phone: +81-294-42-5025 E-mail: horikirif@sc.sumitomo-chem.co.jp

² Research Center of Ion Beam Technology, Hosei Univ.

3-11-15 Midori-cho, Koganei, Tokyo 184-8584, Japan

³ Research Center for Integrated Quantum Electronics (RCIQE), Hokkaido Univ.
North13, West8, Sapporo, Hokkaido 060-0813, Japan

Abstract

An etching process is essential for fabricating the structures of GaN power and RF devices, e.g., isolations, mesas, trenches, and gate-recesses. Photoelectrochemical etching of GaN, which is based on photo-assisted anodic oxidation, is preferred for these GaN device fabrication process. Photoelectrochemical etching has good controllability of the etching depth owing to Faraday's laws of electrolysis and has a high etching selectivity against etching masks. The etched surface has exhibits little damage; this was confirmed by photoluminescence and by a low interface state of the metal-oxide-semiconductor structure. An experimental setup for simple contactless photoelectrochemical etching was also constructed, wherein the sample was dipped into the electrolyte under UV irradiation. These results indicate that photoelectrochemical etching is a preferable low-damage wet etching process for GaN power and RF devices.

1. Introduction

Gallium nitride (GaN) is widely used in electronic RF devices for mobile base stations to reduce energy consumption and meet 4–5G application demands [1]. In addition, GaN power devices have recently attracted considerable research attention as energy-saving solutions because of their low specific on-resistance coupled with a high breakdown voltage [2–4].

An etching process is essential for fabricating GaN RF and power device structures, e.g., isolations, mesas, trenches, and gate-recesses. Generally, GaN is etched by inductively coupled plasma reactive-ion etching [5,6]. However, plasma can easily damage the GaN surfaces. Although GaN has a good chemical stability, photoelectrochemical reactions have been reported for the wet etching process [7–10], which has the feature of plasma damage-free. In this paper, we review recent progress in the development of a damage-free GaN wet etching process by means of a PEC reaction [11–16].

2. Experimental method and results

Photo-assisted anodic oxidation is the basis of PEC etching of GaN [7–16]. GaN dissolves as Ga^{3+} ions owing to the holes excited by UV irradiation at the anode of the GaN/electrolyte interface. The Ga^{3+} ions react with hydroxide ions (OH^-) in the electrolyte, resulting in the formation of Ga_2O_3 .

Ga_2O_3 dissolves in acid or base; thus, this is the basis of PEC etching of GaN as shown in Eq. (1) and (2).

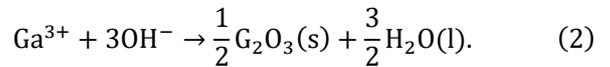
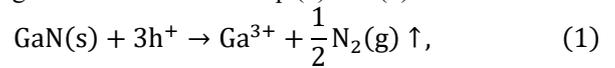


Figure 1 shows a schematic representation of typical PEC etching of GaN [12]. n-GaN and AlGaIn/GaN HEMT epitaxial wafers were used as etching samples, which were grown by metal-organic vapor-phase epitaxy (MOVPE) [12–14]. Typical electrolytes that are used are NaOH aqueous solutions or a mixture of H_2SO_4 and H_3PO_4 . A Pt counter electrode (CE) was used as the cathode. The anode was GaN or AlGaIn epi surface with ohmic contact to the CE via an external circuit. UV irradiation and etching voltage were applied simultaneously for anodic oxidation.

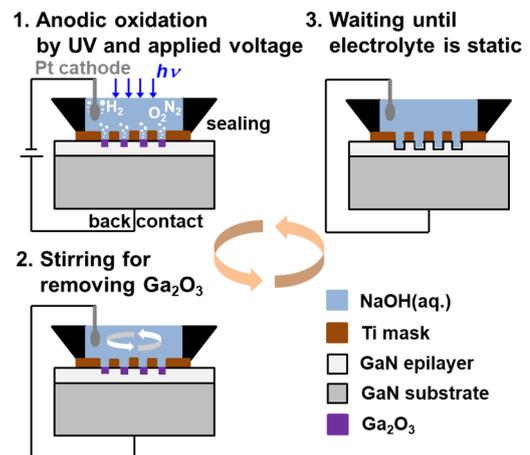


Fig. 1 Schematic representation of typical photoelectrochemical etching of GaN [12].

Figure 2 shows typical PEC etching results of fabricating deep trenches of a n-GaN epilayer on a n-GaN substrate. It has a high aspect ratio and the estimated etching selectivity against a Ti etching mask was >400 ($\sim 20 \mu\text{m}/50 \text{nm}$); these are excellent features of PEC etching. The photoluminescence intensity, as shown in Fig. 3, was almost the same value for both the non-etched and etched surfaces, which indicates that PEC etching is a low-damage GaN etching process [11].

As a second example, Fig. 4 shows the relationship between the etching depth and etching time in a AlGaIn/GaN HEMT sample on a SiC substrate [13]. The etching depth was proportional with respect to the etching time. In addition, PEC etching for a Al_{0.25}Ga_{0.75}N(25 nm)/GaN HEMT structure exhibits the self-termination feature owing to the limitation of photo-hole generation in the AlGaIn-layer. The etching depth was controlled by the light intensity. These features indicate that PEC etching is preferable for fabricating recessed-gate structures. The PEC-etched recessed-Al₂O₃/AlGaIn metal-oxide-semiconductor (MOS) also shows a low interface state [14]. Furthermore, successful simple contactless PEC etching was also achieved, wherein the sample was dipped into the electrolyte under UV irradiation [16].

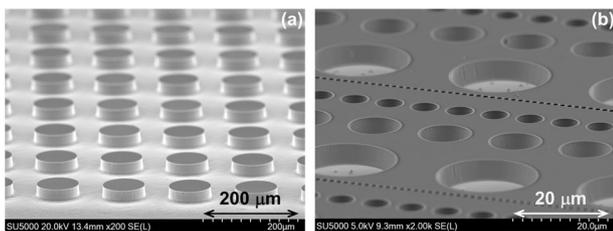


Fig. 2 SEM images of PEC-etched cylinder-shaped (a) and cavity-shaped GaN patterns (b) [12].

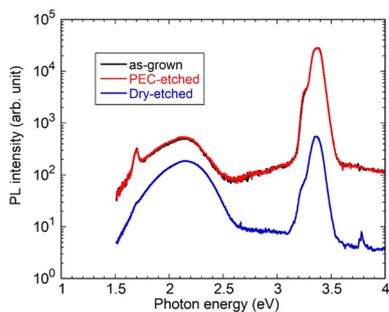


Fig. 3 PL spectra of non-etched and etched surface of n-GaN epilayer on n-GaN substrate [11].

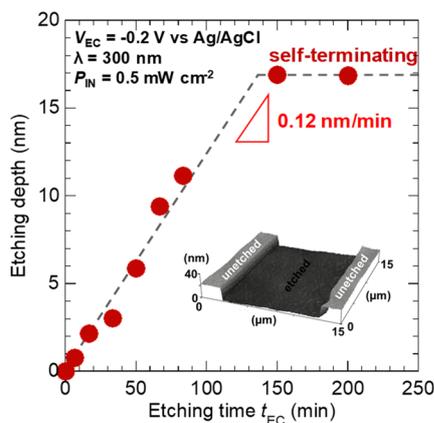


Fig. 4 Relationship between the etching depth and etching time in the AlGaIn layer of Al_{0.25}Ga_{0.75}N(25 nm)/GaN HEMT structures [13].

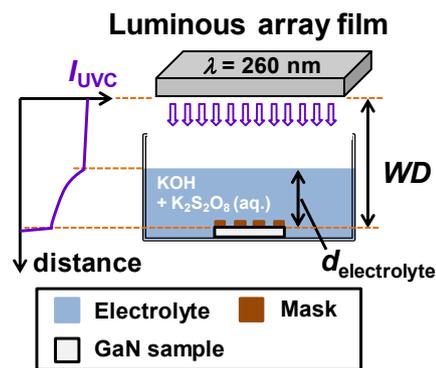


Fig. 5 Schematic representation of simple contactless photoelectrochemical etching of GaN [15].

3. Conclusions

PEC etching of GaN, which is based on photo-assisted anodic oxidation, has good controllability of the etching depth owing to Faraday's laws. Further, it has a high etching selectivity against etching masks. The etched surface also exhibited little damage, which was confirmed by photoluminescence and by a low interface state of the MOS structure. Simple contactless PEC etching was successfully achieved, wherein the sample was dipped into the electrolyte under UV irradiation. These results indicate that PEC etching is a preferable low-damage wet etching process for GaN power and RF devices.

Acknowledgements

The authors would like to thank the Japan Ministry of the Environment for their support. This research was partially supported by JSPS KAKENHI (Grant Numbers JP16H06421 and JP17H03224).

References

- [1] F. Yamaki and S. Sano, *Proceedings of CS ManTech* (2018) 004-5.
- [2] H. Amano *et al.*, *J. Phys. D: Appl. Phys.* **51** (2018) 163001.
- [3] W. Saito *et al.*, *Solid-State Electron.* **48** (2004) 1555.
- [4] H. Ohta *et al.*, *Jpn. J. Appl. Phys.* **57** (2018) 04FG09.
- [5] R. J. Shul *et al.*, *Appl. Phys. Lett.* **69** (1996) 1119.
- [6] N. Medelci *et al.*, *J. Electron. Mater.* **29** (2000) 1079.
- [7] M. K. Minsky *et al.*, *Appl. Phys. Lett.* **68** (1996) 1531.
- [8] C. Youtsey *et al.*, *Appl. Phys. Lett.* **71** (1997) 2151.
- [9] J. A. Bardwell *et al.*, *J. Appl. Phys.* **89** (2001) 4142.
- [10] D. H. van Dorp *et al.*, *J. Electrochem. Soc.* **156** (2009) D371.
- [11] F. Horikiri *et al.*, *Jpn. J. Appl. Phys.* **57** (2018) 086502.
- [12] F. Horikiri *et al.*, *Appl. Phys. Express.* **11** (2018) 091001.
- [13] Y. Kumazaki *et al.*, *J. Appl. Phys.* **121** (2017) 184501.
- [14] S. Matsumoto *et al.*, *Jpn. J. Appl. Phys.* **57** (2018) 121001.
- [15] N. Asai *et al.*, *Jpn. J. Appl. Phys.* **58** (2019) SCCD05.
- [16] F. Horikiri *et al.*, *Appl. Phys. Express.* **12** (2019) 031003.