Plasma Science and Technology
Room 201 ABCD W - Session PS1-WeA

Plasmas for Emerging Device Technologies

Moderators: Michael Gordon, University of California at Santa Barbara, **Scott Walton**, Naval Research Laboratory

2:15pm **PS1-WeA-1 Main Etch Challenges in the GaN-based Devices***,* ***Patricia Pimenta Barros****, Simon RUEL,* Univ. Grenoble Alpes, CEA, LETI, France*; David CASCALES,* Univ. Grenoble Alpes, CEA, Leti and CNRS, LTM, France*; Nicolas Posseme,* Univ. Grenoble Alpes, CEA, LETI, France*; Thoueille Philippe,* Lam Research, France*; Eugénie MARTINEZ,* Univ. Grenoble Alpes, CEA, LETI, France*; Bassem SALEM,* Univ. Grenoble Alpes, CNRS, LTM, France*; Maxime PEZERIL, Khatia BENOTMANE,* Univ. Grenoble Alpes, CEA, LETI, France*; François GAUCHER,* Lam Research, France*; Laura VAUCHE, Yveline GOBIL,* Univ. Grenoble Alpes, CEA, LETI, France **INVITED**

Thanks to the inherent properties of Gallium Nitride, the semiconductor industry envisages the introduction of GaN in a wide range of applications. For instance, GaN-based high electron-mobility transistors (HEMTs) have been adopted in power devices thanks to their high breakdown electric field and electron mobility[1]. Also, GaN's direct wide-band gap (3.4eV) is exploited into LED, microLED and displays for better photon emission.

Among the manufacturing steps of GaN-based devices, the plasma etching steps are part of the most critical ones as they have to satisfy morphological requirements without damaging the GaN material. Indeed, when patterning the GaN-based HEMTs, the electrical performances are directly linked to the damage induced by plasma etching at the gate bottom [2]. Depending on the architectures, the GaN etching step has to comply with different morphological criteria: i) high pGaN etching selectivity over AlGaN in pGaN gate transistors, ii) vertical profiles with bottom rounded corners in recessed-gate transistors.

This talk will focus on the main etching challenges that occur during the gate patterning of GaN-based HEMTs, and will give an overview of our recent outcomes. First, a GaN etching mechanism with a resist and SiN hardmask will be proposed based on morphological studies and the chemical analysis of the remaining byproducts on GaN sidewalls analyzed. The best etch parameters leading to vertical GaN sidewalls and bottom rounded corners with an etched-depth of 1µm will be shared.

In the case of pGaN gate structure, $Cl_2/N_2/O_2$ and BCl_3/SF_6 based chemistries will be compared in terms of selectivity and profile. Secondly, the damage induced by plasma etching on the GaN surface was investigated. Thus, electrical characterizations have been conducted using either sheet resistance (R_{sheet}) or C-V measurements in order to simulate the pGaN and recessed-gate MOS transistors' behavior, respectively. The goal will be to compare the benefits and drawbacks of different Cl_2-based etching processes, and to identify the main degradation mechanisms.

In conventional etching processes, it has been shown that passivating chemistries like $SiCl_4$-based processes could be an alternative solution for improving recessed gate-MOS transistors [3]. In addition, we demonstrated that Atomic Layer Etching (ALE) reduces the damage induced by conventional etching [4]. Finally, this paper will compare ALE and bias pulsed processes.

[1] Musumeci and Barba, Energies, 16, 3894 (2023)

[2] P. F. P. Pinto Rocha et al., Energies. **16(7)**, 2978 (2023)

[3] D. Cascales et al., Semicond. Sci. Technol. 39, 115026 (2024)

[4] S. Ruel et al., J. Vac. Sci. Technol. A **39**, 022601 (2021)

2:45pm **PS1-WeA-3 Study of N-Polar GaN Etching by a CH4/H2/Ar Plasma for µLED Applications***,* ***Sandra Kozuch****, Simon Ruel, David Vaufrey, Olivier Renault,* CEA-Leti, France

The ability of Gallium Nitride (GaN) to form ternary alloys with Al or In for emission wavelength modulation makes it a material of choice for µLED (micro-Light Emitting Diodes) applications. The µLED studied structures are VTF (Vertical Thin Film) type implying the report of the GaN stack on a backplane resulting in a N-polar GaN exposed. The pixel fabrication involves a plasma etching step (mostly with a Cl_2-based chemistry), known to damage the material mostly at mesa sidewalls [1]. For instance, defects like lattice amorphization, nitrogen depletion, implantation or deposition of etching by-products can be responsible for non-radiative recombinations of electron-hole pairs. This phenomenon is heightened for smaller pixels and results in an efficiency loss for the devices with miniaturization.

To address these issues and improve device performances, there is a need to develop less damaging etch processes. A change of etching chemistry for CH_4/H_2 mix, and avoid using Cl_2, can be an interesting and still poorly investigated strategy: by-products formed by CH_4 and GaN are very volatile, preventing them from redepositing on the etched surface [2]. Moreover, H atoms can passivate donor states near the surface [3].

In this study, we propose to etch N-polar GaN with $CH_4/H_2/Ar$ plasma in an ICP chamber, with the goal of understanding its etch mechanisms and impact on material degradation. Different etch parameters are studied as DC bias voltage, source power, pressure or gas ratio to found a maximum ER of 50 nm/min and 85° profile, as vertical sidewalls as for a chlorine-base etching.

Scanning Electron Microscopy (SEM) measurements enabled measuring N-polar GaN etching rate, carbon-containing by-products deposition rate and sidewalls verticality. The surface etched using the best conditions were first studied by X-Ray Photoelectron Spectroscopy to obtain N/Ga stoichiometry and study valence and core-level states to retrieve band bending and chemical bonding states. Secondly, cathodoluminescence was performed on the same samples to study the GaN Yellow Band emission (between 500 and 700 nm) linked to radiative defects emissions. Then, the results were compared with those of a Cl_2-based etch of reference. These characterizations aim to determine if the developed etching process is less invasive or not to the material.

[1] R.J.Shul et al., J. Vac. Sci. Technol.A, vol. 18, no 4, p. 1139–1143, juill. 2000, doi: 10.1116/1.582313.

[2] S. J. Pearton, J. C. Zolper, R. J. Shul, et F. Ren, *J. Appl. Phys.*, vol. 86, n° 1, p. 1–78, juill. 1999, doi: 10.1063/1.371145.

[3] S. Wolter *et al.*, *J. Appl. Phys.*, vol. 136, n° 24, p. 245703, déc. 2024, doi: 10.1063/5.0243841.

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