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Investigation of fluorine-based plasma for Atomic Layer Etching of GaN

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1. Introduction

Atomic Layer Etching (ALE) is a cyclic etching process, aiming to remove one monolayer by cycle, and opens a new path to overcome the challenging issues of GaN etching [1]. Most of the reported plasma assisted ALE of GaN rely on chlorination of GaN surfaces to form $GaCl_x$ products for the adsorption step and Ar ions irradiation for the activation step. [2-3]. Fluorination of GaN leads to the formation of non-volatile GaF_x by-products (boiling point close to 950°C) which could re-inforce the required self-limited feature of the adsorption step. In this work, we propose to investigate the use of CF_4/O_2/Ar plasma to achieve fluorination of GaN as the adsorption step, combined with Ar ions irradiation as an activation step.

2. Experiment

A SiO_2 hardmask was deposited and patterned by photolithography into an array of 3 µm-diameter holes on top of un-doped *c*-axis oriented GaN grown on a sapphire substrate. ALE processes were developed in an Inductively Coupled Plasma (ICP) etcher (RIE-200iP from SAMCO). For the adsorption step, the feeding gas consisted in CF_4/O_2/Ar gas mixture. The ICP source power (RF_{source}) and pressure were set at 100 W and 5 mTorr, respectively. No ICP bias power (RF_{bias}) was applied during the adsorption step. The activation step relied on a Ar plasma at 5 mTorr. The self-bias voltage (DC bias) during activation was varied in the 12—39 V range by tuning RF_{bias} power. For each condition, Etching rate Per Cycle (EPC) was estimated from the etched depth of GaN submitted to 200 ALE cycles, measured from Scanning Electron Microscopy (SEM) images.

3. Results and Discussion

In Figure 1, in the case of O_2 flow rate set at 10 sccm, two distinct regimes are clearly identified. In regime I (DC bias < 26V), EPC decreases with the DC bias voltage. In regime II (DC bias > 26V), EPC increases with DC bias. For a O_2 flow rate of 20sccm, GaN is not etched for low DC bias (DC bias ≤ 15 V), By increasing DC bias above 15 V, EPC slightly increases and seems to plateau in the 0.34-0.55 nm range. XPS shows the presence of C and F atoms on surface in the case of 10 sccm O_2, but O and F are detected in the case of 20 sccm O_2. We assume that weakly dissociated CF_4/O_2/Ar plasma leads to the deposition of thin C_xF_y oligomers similarly to the polymer layers formed during the steady-state of Reactive Ion Etching of Si [4-5]. Low energetic Ar ions (regime I) induce de-fluorination of the C_xF_y oligomers by fragmentation, releasing additional F species readily available for the fluorination of GaN. Subsequent incoming Ar ions either degrade the oligomer layers and activate the underneath GaF_x, or activate GaF_x back diffusion back through the thin oligomer. As DC bias further increases, Ar ions degrades the C_xF_y, released F species recombine with sputtered CF_x to form volatile CF_4, reducing the available amount of F species for GaN fluorination, leading to a decrease of EPC. At DC bias higher than 26 V (regime II), Ar ions sputter both the oligomers and GaN.

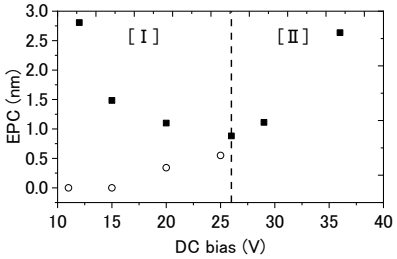

Figure 1. EPC as function of the DC bias during activation step for a CF_4/O_2/Ar plasma at adsorption with a O_2 flow rate of 10 sccm (back) and 20 sccm (white).

By increasing O_2 flow rate to 20 sccm, drastic change for the EPC is observed. Formation of C_xF_y is inhibited by the higher concentration of reactive O radicals in the plasma phase favoring the formation of CO and CO_2, reducing the C_xF_y ions concentration required for polymerization. The presence of O species in the fluorinated GaN surface leads to a shift in the threshold energy required for efficient Ar ions activation.

4. Conclusion

We have investigated the use of CF_4/O_2/Ar plasma for the surface modification step in the ALE of GaN. The de-fluorination of a C_xF_y layer, formed during adsorption, upon low energetic Ar ions is believed to be responsible for the high observed EPC. We also demonstrate that the O_2 flow rate is a critical parameter to control the fluorination of GaN during adsorption.

References

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