XeF_2 – A new MOCVD source for removal of surface Si contamination and *in-situ* etching of GaN for epitaxial regrowth

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Epitaxial regrowth is being developed for fabricating advanced power and RF devices in III-Nitride semiconductor materials. For example, epitaxial regrowth of p-GaN on a lightly doped, thick (> 100 um) n-GaN drift layer grown by MOCVD or HVPE would enable MPS diodes and JFETs with breakdown voltages exceeding 10 kV. The development of regrown PN junctions has been frustrated by the presence of Si contamination at the regrowth surface from atmospheric sources and residual crystalline damage from *ex-situ* etch or CMP processes which results in excessive leakage current. Additionally, Si functions as an effective micro-mask, on air-exposed GaN surfaces resulting in rough surfaces following *in-situ* etching using common bromine and chlorine -based precursors. *Ex-situ* processes such as Ozone oxidation followed by HF can remove surface Si contamination. However, the surface is still exposed to the atmosphere prior to loading the MOCVD system, risking re-contamination by an unknow quantity of Si. *Ex-situ* Si removal processes thus appear challenging to implement in high yield, commercial production unless re-contamination of Si can be prevented.

We present the novel use of XeF_2 for *in-situ* removal of surface Si contamination and subsequent etching of GaN in the MOCVD chamber. While XeF_2 is ubiquitous in the processing of Si devices, we are not aware of the source being used in MOCVD growth systems. Unlike chlorine (TBCl and CCl_4) and bromine (CBr_4) -based precursors we have studied; we obtained a smooth surface following *in-situ* fluorine etching of air-exposed GaN.

We also report that *in-situ* fluorine etching of ICP etched n-GaN Schottky barrier diodes (SBDs) formed by shadow mask evaporation results in reverse leakage currents more than 3 orders of magnitude lower than those formed on n-GaN layers that have only experienced ICP etching. Additionally, *in-situ* fluorine treated, ICP etched SBDs show reverse leakage currents equal to those of SBDs formed on as-grown n-GaN layers. This suggests that the *in-situ* fluorine etching is effective at removing the residual damage from the ICP etch process.

Next, this *in-situ* fluorine etch lowered the peak density of surface Si from an unusually high level of 1-2 x 10^{19} cm^{-3} to the detection level (2-4 x 10^{15} cm^{-3}) of the SIMS measurement prior to the regrowth of uid-GaN. Finally, PN diodes with a regrown p-GaN anode on a blanket etched n-GaN drift layer following *in-situ* fluorine etching exhibit reverse leakage current of ~ 1 x 10^{-8} A/cm^2 to -1000V, matching reverse leakage current measured in continuously grown PN diodes of similar structure. Optimization of the XeF_2 process is expected to reduce the ideality factor from 2.0 to the 1.5-1.6 typically measured in our continuously grown PN diodes. The similar reverse and forward current characteristics of these *in*-situ XeF_2 etched and regrown PN diodes and continuously grown PN diodes indicates that a device quality PN junction can be formed by epitaxial regrowth on *ex-situ* etched GaN. The use of *in-situ* XeF_2 etching for the first time overcomes two critical obstacles preventing the formation of more advanced PN junction devices such as MPS diodes and JFETs in GaN by epitaxial regrowth and demonstrates the utility of XeF_2 as a precursor for MOCVD processes.

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