Surface Science Studies During Plasma-Assisted Atomic Layer Epitaxial Growth of InN on GaN Substrates

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III-N semiconductors such as GaN, AlN, and InN are the basis for creating many compound ternary and quaternary semiconductor materials well suited for applications in several important technological areas, including high current, normally-off power switches. [1-3] While atomic layer deposition (ALD) is a versatile technique and has gained wide use, it does not offer the required level of crystallinity and purity needed for high-performance III-N semiconductor devices. Therefore, we have developed a technique adapted from ALD, called low temperature plasma-assisted atomic layer epitaxy (ALEp). [2] Using surface science techniques we plan to develop a fundamental understanding of the ALEp growth process to further enable the method as a powerful new technique for growth of semiconductor materials.

Here we employ *in-situ* and *in-vacuo* surface studies of GaN substrate preparation and InN ALEp growth to advance fundamental understanding of the ALEp process as well as the effect of variation in nitrogen plasma pulse conditions on ALEp of InN. We conduct *in-situ* grazing incidence small angle x-ray scattering (GISAXS) experiments at the Cornell High Energy Synchrotron Source and The National Synchrotron Light Source-II at Brookhaven National Laboratory, utilizing morphological evolution monitoring to investigate the growth surface during sample preparation and film deposition, as well as using this technique to understand how the nitrogen plasma pulse affects nucleation and growth kinetics of InN on GaN substrate surfaces. GISAXS information is complemented with *in-vacuo* x-ray photoelectron spectroscopy and reflection high-energy electron diffraction studies conducted at the Palmstrøm Lab at UCSB, where we consider traditional molecular beam gallium flash-off [4] in contrast to our ALEp based gallium flash-off as ways to produce the most suitable GaN surface for our ALEp-based approach. We have been able to determine with GISAXS that ALEp based gallium-flash off experiments run at higher temperatures (500°C) produce a less roughened starting surface than lower temperatures. We have also determined with *in-vacuo* XPS that traditional molecular beam gallium flash-off greatly reduces the oxygen content at the GaN interface (<40% remaining), while our ALEp based approach does not reduce the oxygen as effectively.

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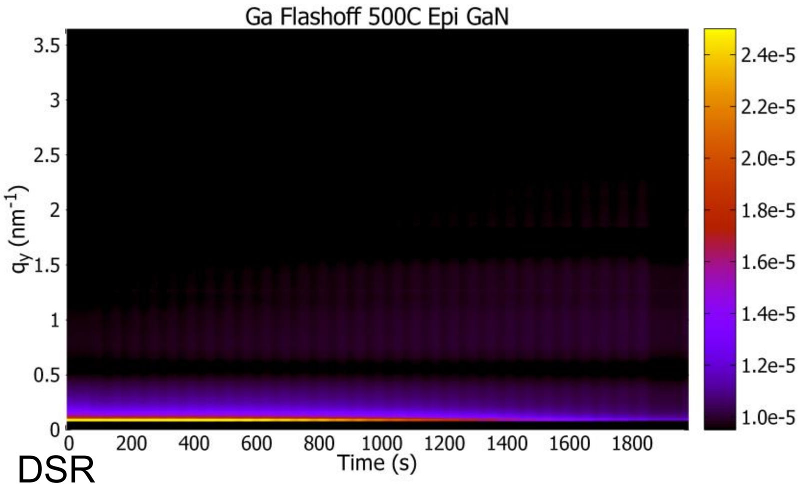
Supplementary Page

a) Epi GaN at 500C



b) Epi GaN at 400C

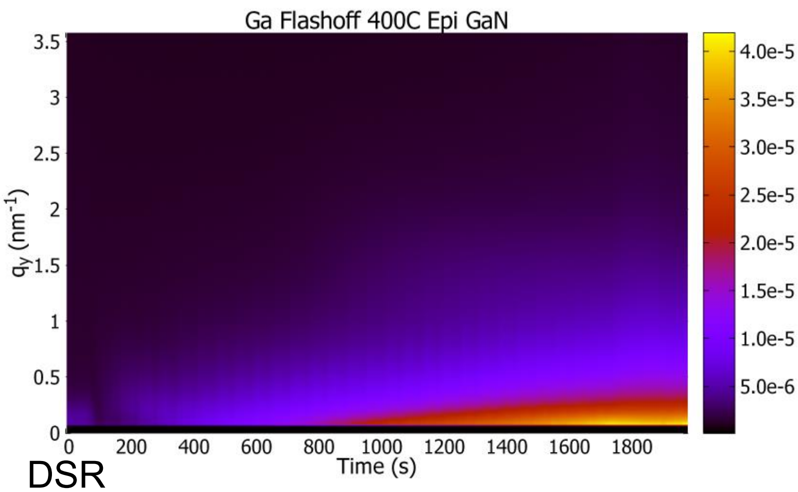


Figure 1: GISAXS monitoring of an ALEp gallium flash-off of a 2 µm thick GaN MOCVD homoepitaxial film a) at 500°C b) at 400°C. At 400°C increased scattering intensity indicates increased surface roughening, not seen at 500°C, indicating that ALEp gallium-flash off produces a smoother surface at higher temperatures.