High Growth Rate Plasma
Considerations for Indium-Rich III-Nitrides

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A high nitrogen flow rate Veeco plasma source has been employed to achieve GaN growth rates above 10 µm/hr utilizing the metal modulated epitaxy (MME) growth technique in a plasma-assisted molecular beam epitaxy (PAMBE) reactor. High growth rates enable thick buffer layers which can lower threading dislocation densities, essential for III-nitride optoelectronic devices such as solar cells and green light emitting diodes (LEDs). Additionally, PAMBE is capable of growing single phase $In_xGa_{1-x}N$ films for all indium compositions ($0 \leq x \leq 1$). It is shown that as the indium content increases and the bandgap of the material decreases, the surface becomes more sensitive to plasma-induced damage, as observed via atomic force microscopy (AFM) and reflection high energy electron diffraction (RHEED). Thus, in order to grow thick $In_xGa_{1-x}N$ films with fast growth rates, the plasma induced crystal damage must be minimized by optimizing the nitrogen plasma discharge. *In-situ* plasma discharge monitoring and optimization can be accomplished with a combination of optical emission spectroscopy (OES) as well as utilizing a flux gauge collector pin as a Langmuir probe. OES determines a plasma's molecular and atomic content, while the Langmuir probe current-voltage characteristics can determine the plasma discharge floating acceleration voltage and ion densities. In this work, correlations between plasma conditions and crystal quality are established. It is shown that by increasing the nitrogen flow the positive ion content increases, however, the acceleration voltage reduces. Additionally, a higher applied plasma power results in a negligible increase in positive ion content. In particular, AFM results demonstrate that the surface pit density of MME grown InN films dramatically reduces with reduced ion content. Finally, a roadmap will be presented to minimize damage in high indium content III-nitride devices.

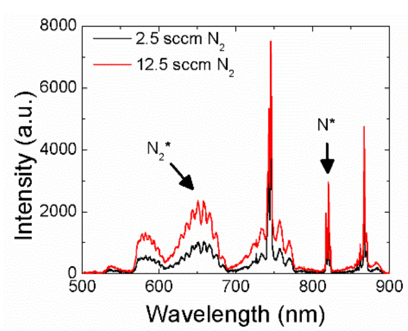

Figure 1. OES of a plasma discharge with low and high flow rates of N_2.

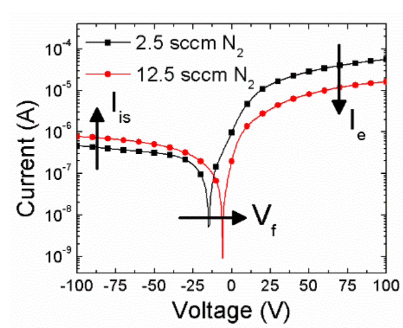

Figure 2. Langmuir probe current-voltage characteristics of a plasma with low and high flow rates of N_2.

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Supplementary information:

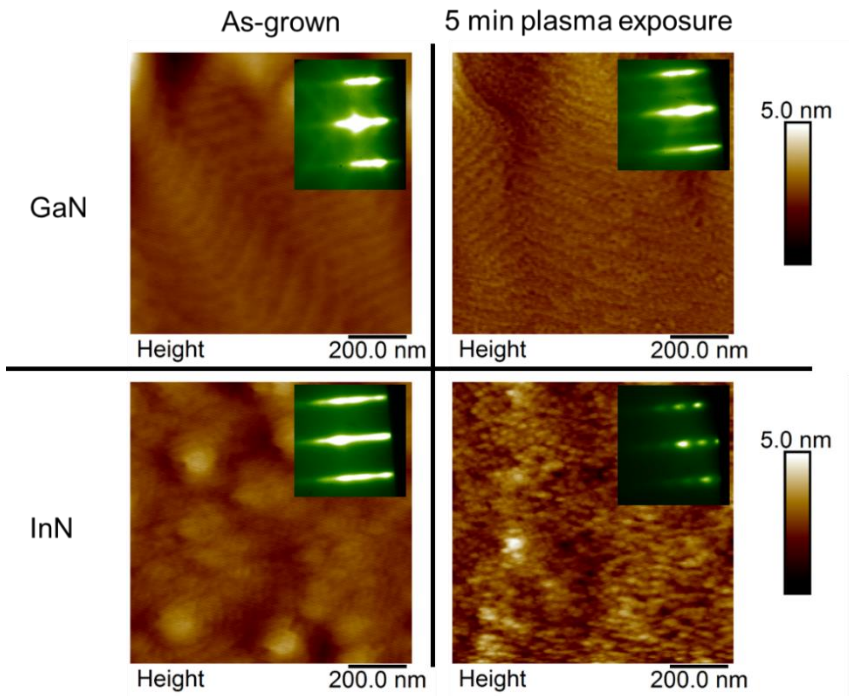

Figure 3. AFM and RHEED insets of GaN and InN surfaces as-grown and after 5 minutes of plasma exposure. InN films are more sensitive to plasma exposure and exhibit rougher surfaces compared to the GaN films.

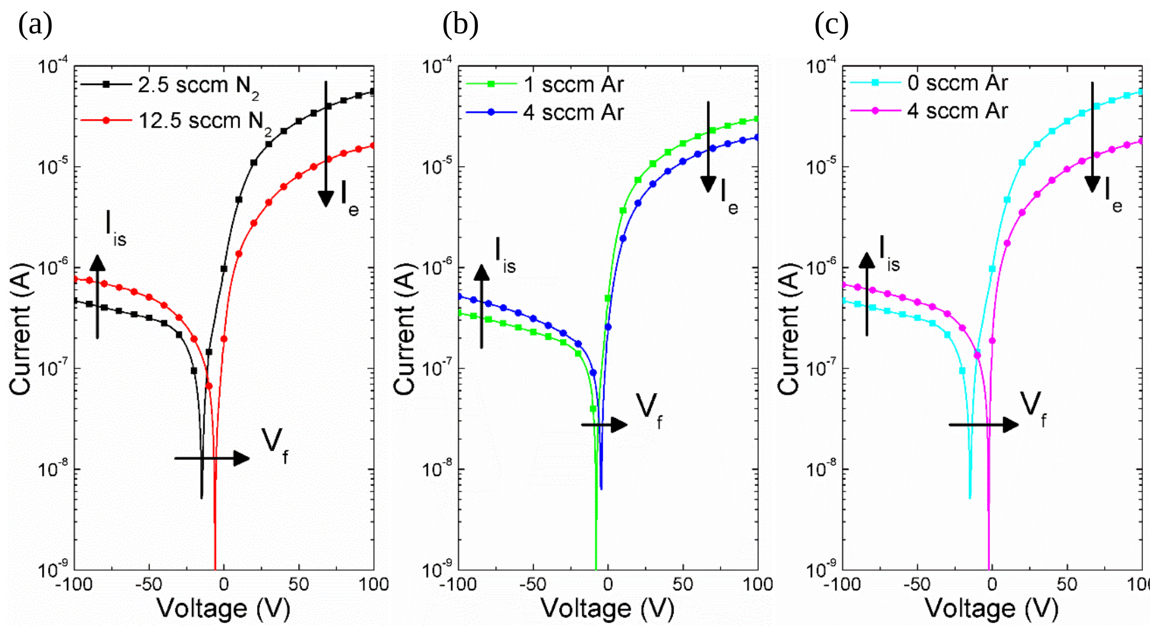

Figure 4. Langmuir probe current-voltage characteristics of a plasma operated at 350 W: (a) pure nitrogen flows, (b) pure argon flows, and (c) mixed chemistry of argon flows with a constant 2.5 sccm nitrogen flow.

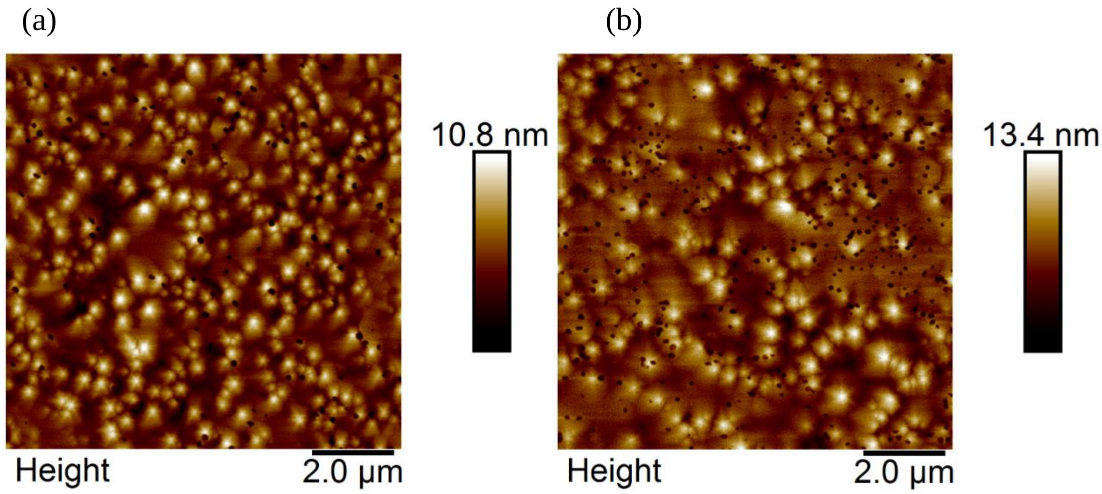

Figure 5. 10×10 μm^2 AFM images of 1 μm-thick InN surfaces grown via MME with a plasma power of (a) 350 W and (b) 550 W. Pit density is increased at higher plasma powers.