Real-Time Process Monitoring by kSA ICE for GaN and AlGaN on Si

kSA ICE Metrology for development of GaN and AlGaN devices on Si substrates

Introduction and Motivation

Epitaxial growth of GaN-based alloys on Si (111) have been studied using the kSA Integrated Control for Epitaxy tool, kSA ICE. kSA ICE is a multi-function tool capable of measuring film reflectivity, growth rate, curvature, and emissivity-corrected temperature, all from one viewport. The real-time temperature, reflectivity and curvature monitoring of GaN and AlGaN layers on Si (111) allows efficient engineering of the epitaxial growth and resultant thin-film strain, and thus optimization of the MOCVD process.

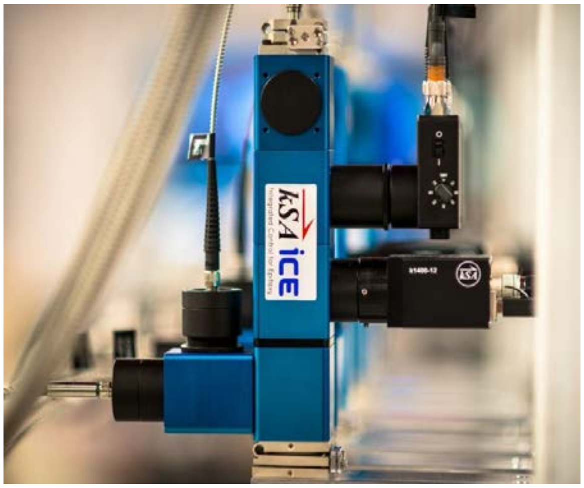

Figure 1: kSA ICE tool configured to measure Reflectivity, Wafer Curvature, and wafer temperature via ECP.

The epitaxial integration of GaN and Si is actively being pursued both in academics and industry to reduce the production cost of GaN-based LEDs and electronic devices. The lattice and thermal mismatch between GaN and Si induce significant tensile strain in the epilayer, often leading to cracking. Various techniques are used to engineer strain in the epitaxial structure wherein real-time metrology plays an important role in efficiently optimizing the epitaxy process. Since kSA ICE integrates various measurement modules into a single optical head, it is an ideal *in-situ* metrology tool for epitaxy monitoring and process optimization. The growth of GaN and AlN epitaxial layers can be studied in detail and compared from wafer-to-wafer and run to run. To this end, Prof. Shahedipour-Sandvik and her team at SUNY Polytechnic Institute are successfully utilizing kSA ICE on their Veeco D-180 reactor for MOCVD process and device quality improvement.

GaN on Si Temperature

Figure 2 shows a comparison of the emissivity corrected pyrometry (ECP) temperature and the uncorrected pyrometer temperature of GaN grown on an AlN/Si (111) template. The variations in ECP temperature are ± 1.5 ˚C whereas the uncorrected pyrometer shows temperature swings of over 20 °C. This is because the straight (uncorrected) pyrometer temperature cannot account for the change in emissivity that results from a growing GaN epilayer on a substrate with different optical properties (Si).

To correct for the changing optical properties of the growing film, the emissivity must be measured in real-time, and this measured value is used for proper temperature measurement. Using a wavelength collection region centered at 960 nm and a corresponding LED emitting at this wavelength, the kSA ECP module generally operates over a temperature range of 450 - 1250 °C. (Note that the kSA ECP range is configurable: for the SUNY group, the range is configured to 500 - 1250 ˚C, per their request). It achieves ± 0.1 °C resolution at 700 °C and ± 1 °C at 500 °C under constant temperature conditions. Measurement and control of actual wafer temperature is critical in film strain engineering as well as in enhancing the uniformity of LED wavelengths on large diameter Si substrates.

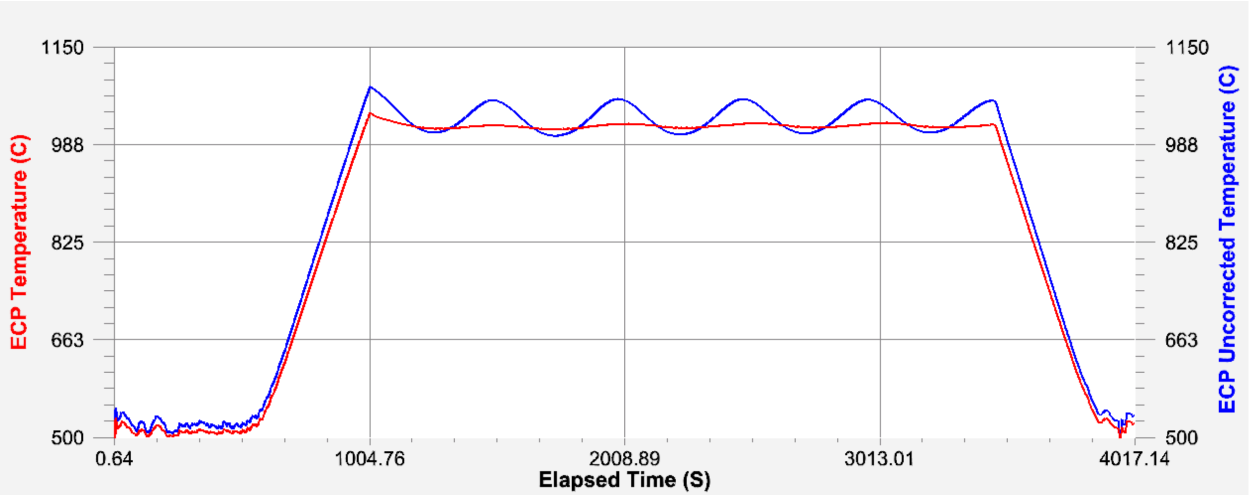

Figure 2: Emissivity corrected temperature and uncorrected temperature of GaN on Si (111). Courtesy of SUNY Polytechnic Institute.

GaN on Si Wafer Curvature

Real-time substrate curvature and film stress measured with the kSA ICE curvature module monitors the stress induced during each step of the growth process and gives important insight into its dynamic behavior. Jeff Leathersich *et al.* of SUNY Polytechnic Institute investigated three different AlN buffer layer designs with comparable total thickness (~115nm) grown on Si (111).[1] The three different buffer designs consisted of, A) an AlN layer grown with simultaneous flow of Al and NH_3 precursors, B) a pulsed AlN buffer that consisted of an AlN layer grown by a pulsing Al source gas and a constant NH_3 flow, and C) an AlN buffer with a low temperature AlN nucleation layer followed by a pulsed AlN layer. Figure 3 shows a comparison of the substrate curvature measured by the kSA ICE tool during the simultaneous deposition of 1 µm GaN grown on these three different AlN/Si(111) buffers. The tensile stress as GaN was grown on buffers A and B began increasing and continued to increase linearly during the layer growth; this is indicated by increasing positive curvature values. Buffer C, which included the low temperature nucleation layer, resulted in a stress beginning with a compressive region before becoming tensile, as indicated by decreasing curvature values (negative) before the curvature begins to increase again. This curvature data suggests that the AlN buffer with low temperature nucleation layer may be used to compensate for the epitaxial tensile strain for GaN growth on Si, resulting in GaN device layers with reduced stress. The selective real-time wafer monitoring of curvature allowed reproducible growth conditions for testing these different AlN buffers, thus reducing the number of runs required for process optimization.

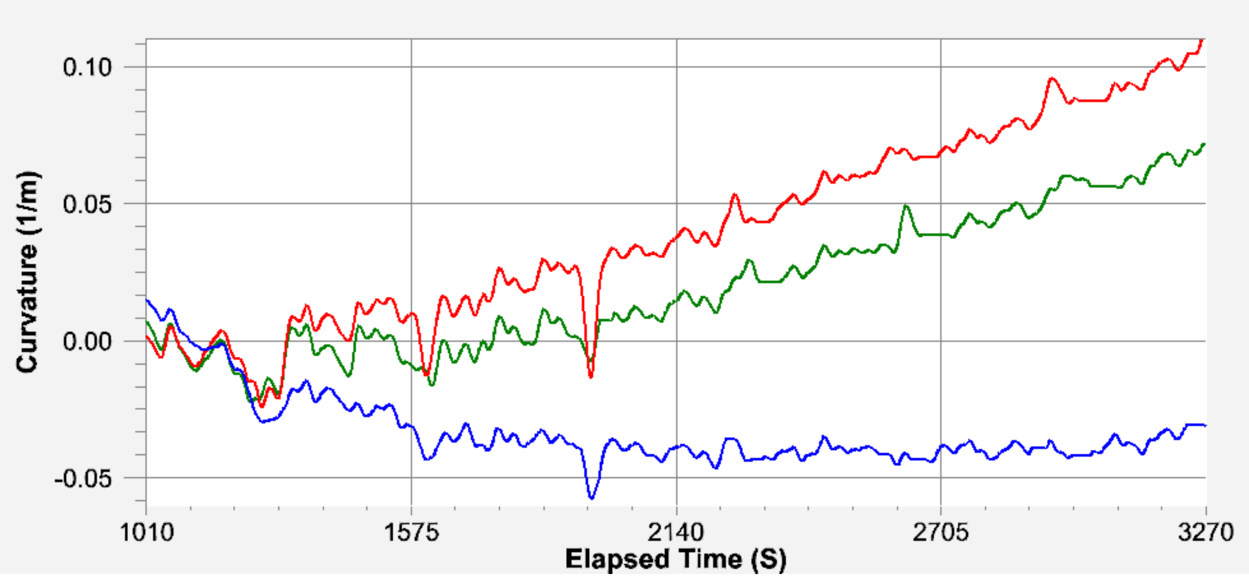

Figure 3: Curvature versus time during the growth of a 1 µm GaN overlayer on different AlN/Si (111) buffers. Courtesy of SUNY Polytechnic Institute.

AlGaN Growth Rate

Real-time reflectivity and curvature measurements of GaN and $Al_xGa_{1-x}N$ on Si using kSA ICE allows the study of the evolution of growth rate and curvature as a function of $Al_xGa_{1-x}N$ composition. Figure 4 shows 660nm reflectance and curvature measurements of varying $Al_xGa_{1-x}N$ compositions grown sequentially on AlN/Si(111). Table 1 highlights the real-time growth rate and total layer thickness measured by kSA ICE.

Layer	Growth Rate (nm/s)	Thickness (nm)
$Al_{0.6}Ga_{0.4}N$	0.096	211
$Al_{0.4}Ga_{0.6}N$	0.126	411
$Al_{0.15}Ga_{0.75}N$	0.293	937

Table 1: Growth rate measured by kSA ICE reflectivity module for $Al_xGa_{1-x}N$ layers. Note an increase in growth rate with increasing Ga concentration.

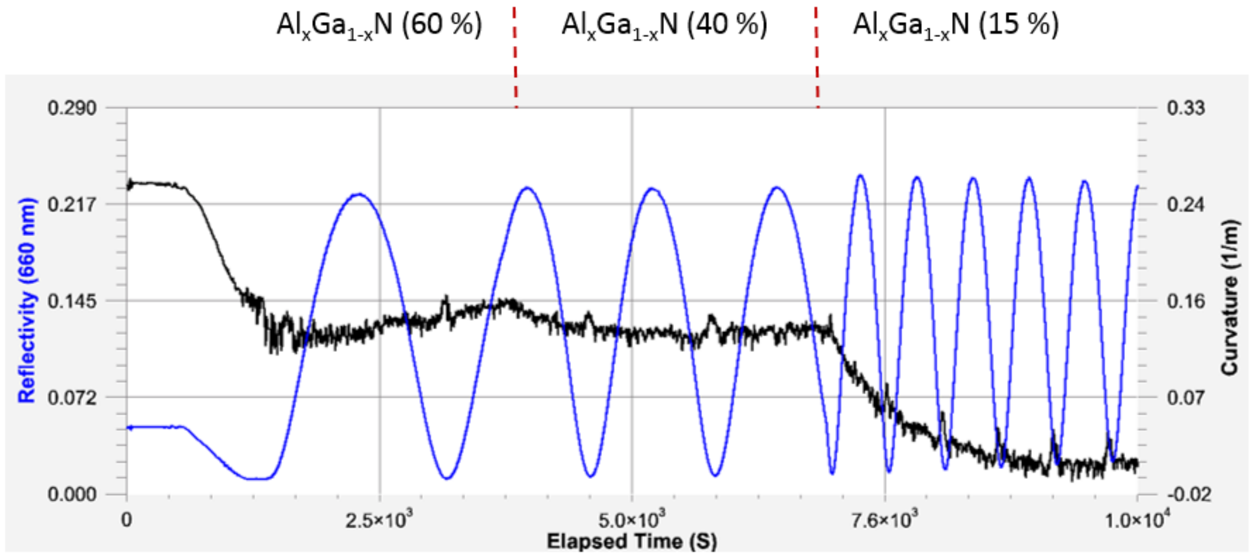

Figure 4: Curvature and reflectivity profiles of varying composition $Al_xGa_{1-x}N$ on AlN/Si (111). Courtesy of SUNY Polytechnic Institute.

Conclusions

In summary, the kSA ICE metrology tool is small, compact, modular, and easy to use. It offers *in situ*, real-time wafer temperature, film thickness, and wafer curvature measurement. It has been shown to be useful in the development of low stress GaN layers on Si (111) substrates and for the development of optimum buffer layer design to mitigate the film stress. The full suite of technologies integrated into the kSA ICE system makes it a powerful and comprehensive *in situ* metrology tool for both R&D and Production MOCVD process optimization.

1] J. Leathersich, P. Suvarna, J. Marini, I. Mahaboob, J. Bulmer, N. Newman, S. Shahedipour-Sandvik, *"Investigations into Stress Development in $Al_xGa_{1-x}N$ Heterostructures"*, presented at the 57th Electronics Materials Conference (Columbus, OH, 2015).

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