Novel AlN Growth Processes for High Performance Deep UV Optoelectronics

by **A. A. Allerman, M. H. Crawford, K. H. A. Bogart, S. R. Lee, D. M. Follstaedt, N. A. Missert, and P. P. Provencio**

Motivation—AlGaN semiconductors have emerged as materials of great technological importance. With direct energy bandgaps that are tunable throughout much of the ultraviolet (UV) region of the spectrum (200-365 nm), these alloys have recently enabled compact, solid-state, solar-blind detectors as well as UV light emitting diodes (LEDs) and laser diodes. Relevant applications for these devices include flame and missile plume detection, fluorescence-based biological agent detection, non-line-of-sight communication, and portable water purification.

A major challenge of achieving high performance AlGaN optoelectronic devices is the lack of commercially available native substrates. Growth of AlGaN alloys is typically performed on lattice-mismatched sapphire or SiC substrates, resulting in high (> 10^{10} cm^{-2}) densities of threading dislocations. Our previous research has shown that the electrical and optical performance of deep UV emitters is critically limited by threading dislocations. Therefore, a major emphasis of our research has been to investigate methods to lower the dislocation density of AlGaN device structures by controlling the AlGaN growth process on lattice-mismatched substrates.

Accomplishment—To date, our best AlGaN device structures have been nucleated on AlN epilayers grown on sapphire substrates. Our studies have revealed that the crystal quality of AlGaN-based device layers is largely determined by the nucleation and growth conditions of the AlN epilayer. We have developed a growth process for AlN epilayers that utilizes a morphologically complex "transitional" AlN layer between the sapphire or SiC substrate and the conventionally grown AlN epilayer. This transitional layer consists of a self-organized, denticulated surface structure that is revealed by the atomic force microscopy image in Fig. 1. The structure is created by the application of lower growth temperatures and careful selection of the partial pressures of hydrogen, ammonia and trimethylaluminum.

The overgrowth of a high temperature AlN layer on an AlN surface similar to Fig. 1 enables the recovery of a smooth surface morphology suitable for device structures and results in a significant reduction of dislocation density. The full width half max (FWHM) of two complementary x-ray diffraction (XRD) measurements of AlN epilayers with and without the transitional layer is shown in Fig. 2. Improved crystal quality is indicated by narrower FWHM of the x-ray linewidths. The application of this denticulated layer has specifically enabled dislocation densities of < $1x10^9$ cm^{-2}, compared to densities of 2-5 x 10^{10} cm^{-2} achieved without this transitional layer. This novel AlN growth process and its application to improved AlGaN devices is the subject of a patent application that has recently been filed by the Sandia team.

Significance—The reduction of dislocation density in AlN films is expected to improve the performance of UV emitters and detectors by improving the electrical and optical properties of the overlying AlGaN device layers. With improved performance, AlGaN optoelectronic devices will replace photomultiplier tubes, mercury lamps and/or large frame lasers and enable a new generation of compact, robust and portable systems for sensing, communications and water purification.

Sponsors for various phases of this work include: Defense Advanced Research Projects Agency/Semiconductor Ultraviolet Optical Sources, Laboratory Directed Research & Development, and Nuclear Weapons/Science & Technology

Contact: Andrew A. Allerman, Advanced Materials Sciences, Dept. 1126
Phone: (505) 845-3697, Fax: (505) 844-3211, E-mail: aaaller@sandia.gov

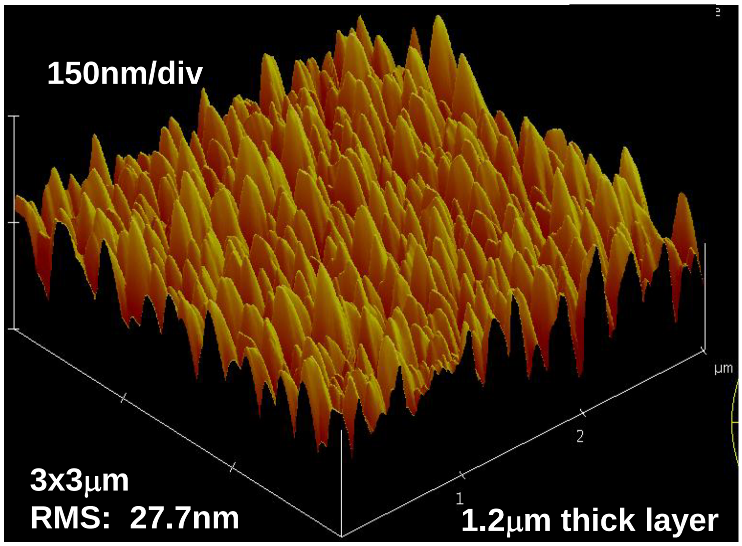

Figure 1. An atomic force microscopy image of the surface of an AlN transitional layer showing the self-organized, denticulated structure formed under specific growth conditions. This structure is responsible for the reduction in the density of threading dislocations of the overgrown, high temperature AlN layer.

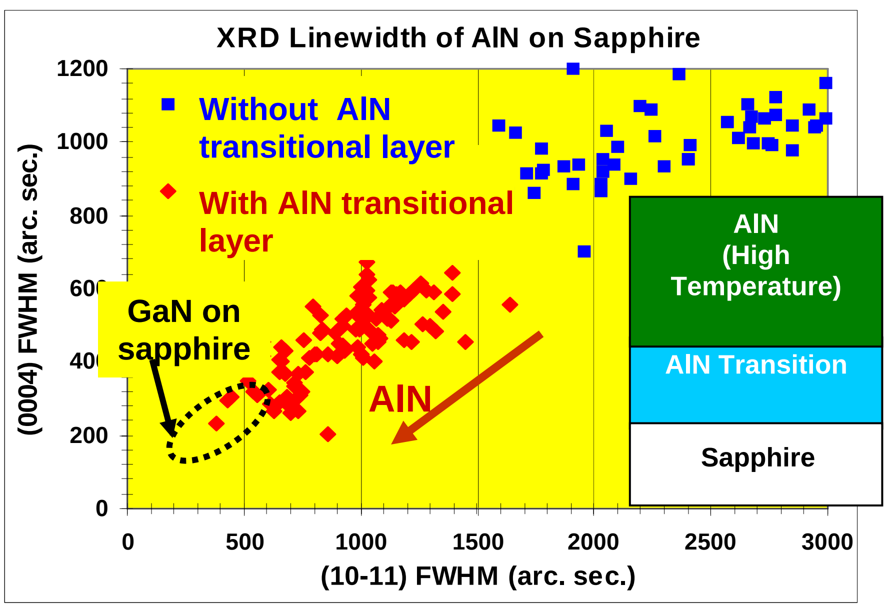

Figure 2. A significant reduction in the full width half max (FWHM) of the x-ray diffraction (XRD) linewidths of the high temperature AlN layer is achieved when an AlN transitional layer, similar to Fig. 1, is grown before the high temperature AlN layer. The smaller FWHM linewidth indicates improved crystalline quality. Through application of this transition layer, the quality of AlN films on sapphire is approaching that of GaN epilayers that are commonly used in commercial blue LEDs.