Nitride Semiconductor Materials Research in Sandia's Physical, Chemical, & Nano Sciences Center: Overview

by **J. Y. Tsao**

Motivation—III-V compound semiconductor materials in which nitrogen occupies the column V position have been of intense interest over the past decade and a half. They promise unique performance: in electronic devices (particularly those driven at high frequencies and high powers); in optoelectronic devices (particularly those spanning the visible and ultraviolet wavelengths); and in micro-optoelectro-mechanical systems (particularly those that require high mechanical strength).

Many aspects of these materials are now understood well enough for active devices to be fabricated and used in commercial and national security applications. However, many aspects are only now being explored, with the expectation that the span of usefulness for these materials will be expanded significantly: into microwave communications, into solid-state lighting, and into ultra-miniature and ultra-reliable opto-mechanical components.

Accomplishment—Exploration of nitride semiconductor materials is a challenge that requires sophisticated capabilities and expertise in semiconductor epitaxy, nano- and micro-fabrication, materials characterization, optical physics, and device modeling and design. A critical mass of these capabilities and expertise has been developed within Sandia's Physical, Chemical, & Nano Sciences Center, in collaboration with other Sandia organizations.

This critical mass of capabilities and expertise has enabled a number of advances in recent years, the sum of which have led to widespread recognition of Sandia as one of the world's premier laboratories for one of the most important applications for nitride semiconductor materials: solid-state lighting. Indeed, Sandia was recently named the lead laboratory for the National Center for Solid-State Lighting, as detailed in the Brief by Mike Coltrin and Jerry Simmons.

Many examples of nitride semiconductor materials research could be given. Some are illustrated in Figure 1; two we report on as Briefs for this year.

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Dave Follstaedt and co-workers report on the mechanisms underlying a synthesis technique in which AlGaN epitaxy occurs on lithographically pre-patterned GaN material. This technique has the potential to reduce the density of extended defects, a huge current problem with AlGaN materials and their application to ultraviolet light emitters. The work made use of semiconductor epitaxy by metal-organic chemical vapor deposition (MOCVD), and materials analysis at the nanoscale through focused ion beam (FIB) sample preparation and transmission electron microscopy (TEM).

George Wang and co-workers report on the mechanisms underlying a synthesis technique in which GaN epitaxy occurs in a dense array of nanowires. This technique has the potential to eliminate extended defects entirely, and to provide novel one-dimensional geometries for transport and confinement of electrons/holes and for emission of photons. The work makes use of vapor-solid-liquid (VLS) synthesis of epitaxial nanowires, Monte Carlo simulations, and scanning electron microscopy.

Sponsors for various phases of this work include: Laboratory Directed Research & Development, Office of Energy Efficiency & Renewable Energy (EERE), and DOE Office of Basic Energy Sciences

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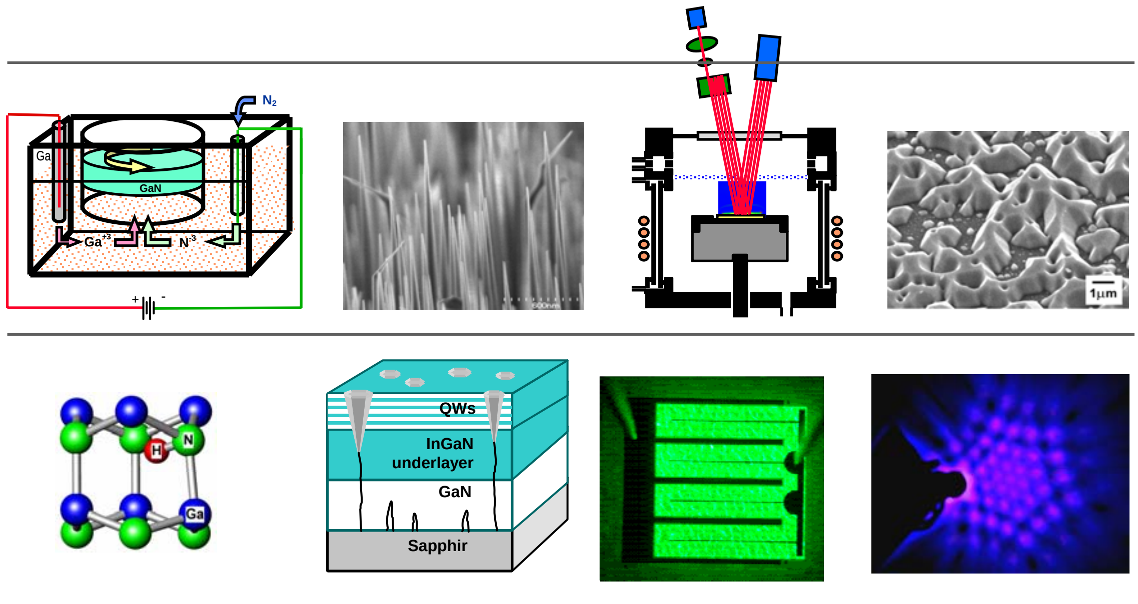

Figure 1. Vignettes of research in nitride semiconductor materials at Sandia National Laboratories and in the Physical, Chemical, & Nano Sciences Center. Clockwise from upper left: bulk nitride growth using electrochemical methods; epitaxial nitride nanowires; nitride metal-organic chemical vapor deposition reactor with advanced in-situ optical diagnostics; nanostructurally engineered nitride nucleation layers; photonic lattice light-emitting diode; green light-emitting diode; defect formation during GaN and InGaN epitaxy; and atomic model for H in GaN.