Comprehensive Characterization of InGaN-Based LED Structures

PH Clifton[1], TJ Prosa[1], D Olson[1], DA Reinhard[1] and DJ Larson[1]

1. Cameca Instruments Inc., 5500 Nobel Drive, Madison, WI USA 53711

Peter.clifton@ametek.com
Keywords: atom probe tomography, mass spectrometry, microscopy

Light-emitting diodes based on InGaN quantum well (QW) structures are of significant technological importance and have been making important commercial advances in recent years. The continued growth of this technology may depend on an ability to characterize and understand nanoscale structure-property-performance relationships. At the nanometer-scale, the interplay between structure, defect density, bulk and local compositional variations and their effect on device performance is not well understood. The challenges imposed by nanometer-scale characterization of structure and composition have been well discussed, but simple solutions have been slow to develop. Because no single technique can provide all the information necessary to understand the structure-property relationships, multiple techniques need to be utilized. This paper provides an example of complementary methods now available to comprehensively understand structure at the nanoscale.

GaN-based devices are particularly important given their capability to provide blue, green or white light emission by tuning bandgaps within the GaN/$In_xGa_{1-x}N$/GaN QW structure [1,2]. A key issue related to ultra-efficient emission from these materials is compositional homogeneity. Distribution of indium within the QWs is central to understanding carrier localization and recombination properties affecting device performance; however, the measurement of QW compositional homogeneity is an on-going challenge. Transmission electron microscopy (TEM) and atom probe tomography (APT) [3] are well suited for measuring In-composition distributions at the nanometer-scale, but each method has inherent limitations.

Atom probe tomography has been demonstrated on to work on these structures and with development of the needed protocols, site-specific specimen preparation is now routine [4].

This paper details a study where complementary techniques are combined to characterize a real device structure. An off-the-shelf LED is deprocessed (Fig. 1A) and the critical InGaN regions are identified using EDAX in a dual-beam focused ion beam (FIB) environment (Fig. 1B). Conversion of the device region-of-interest (ROI) into a format suitable for APT analysis is illustrated in Fig. 2. First a section of the ROI is removed in the FIB and transplanted onto a silicon specimen carrier array (Fig. 2A and 2B). The transplanted material is then milled to the shape of a sharp needle (apex diameter ~50 nm as shown in Fig. 2C). Subsequent analysis reveals compositional information at a sub-nm scale with a typical analytical volume illustrated in Fig. 2D. Here the many In QWs are visible within the GaN matrix. The detection of dilute species such as those used as dopants will also be discussed.

[1] J Wu *et al*, Appl. Phys. Lett. **80** (2002) p.3967.
[2] W Walukiewicz *et al*, J. Phys. D-Appl. Phys. **39** (2006) p. R83.
[3] T Bartel *et al*, Phys. Stat. Sol. A **203** (2006) p.167.
[4] DJ Larson *et al*, “Atom Probe Tomography for Microelectronics”; in *Handbook of Instrumentation and Techniques for Semiconductor Nanostructure Characterization*, eds. R. Haight, F. Ross and J. Hannon, World Scientific Publishing, (2011) p.407

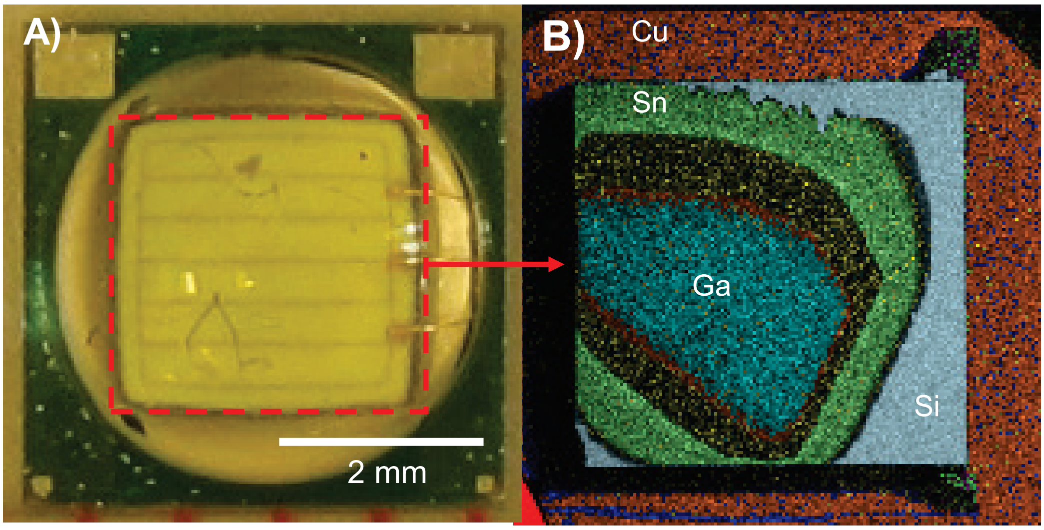

Figure 1. *A) LED device as received viewing emitting region though the optic that is part of the device. B) EDAX measurement of the device after it has been asymmetrically polished to remove varying amounts of material from the surface.*

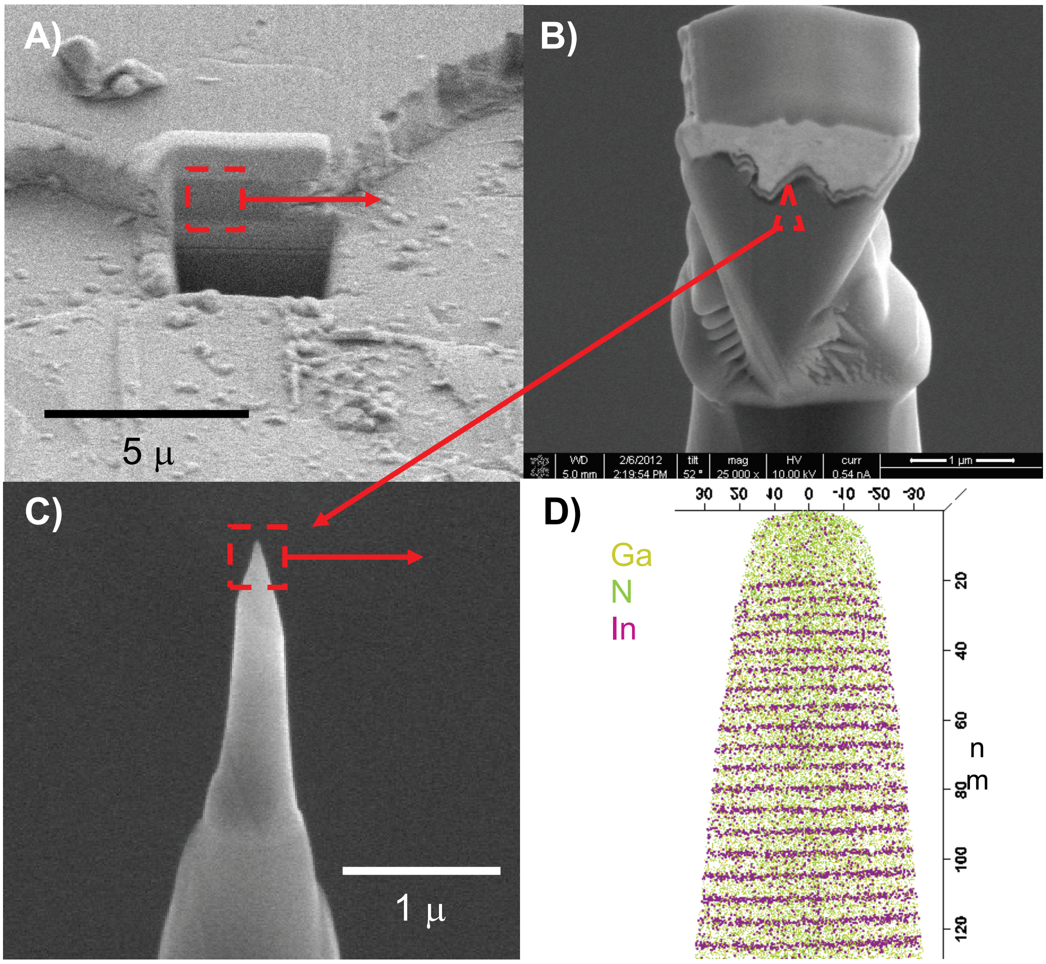

Figure 2. *A) Target region of interest transferred to B) silicon array of specimen carrier tips and C) sharpened into a shape suitable for atom probe analysis. D) Reconstructed atom map shows the locations of the gallium, nitrogen, and indium atoms (not all atoms are shown for clarity).*