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Invited Oral Contribution

Atom Probe Tomography of InGaN Quantum Wells in Planar and Non-Planar (Nanowire) Heterostructures

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$In_xGa_{1-x}N$ is a promising material for visible light-emitting diodes (LEDs) due to its high light-emission efficiency and tunable bandgap. However, quantum wells (QWs) grown on polar (0001) GaN exhibit the quantum-confined Stark effect (QCSE), in which separation of the electron and hole wave functions decreases light-emission efficiency. The effect is enhanced at high In concentrations, as are fluctuations in In concentration. QWs grown on nonpolar and semipolar surfaces exhibit a reduced QCSE and enable improved performance at longer wavelengths. As In content is increased, however, threading dislocations increase, degrading efficiency. Nanowires etched from polar GaN grown on inexpensive substrates allow for the growth of radial nonpolar and semipolar QWs with high In content and low defect density. We will describe atom probe tomography (APT) analysis of InGaN QWs grown on GaN nanowire arrays and on planar substrates for comparison.

APT is a destructive analysis technique that generates a 3-D reconstruction of the distribution of atoms in a small needle-shaped specimen with nanoscale resolution. In pulsed laser atom probe, individual ions are removed from the specimen by thermally assisted field evaporation upon laser pulsing, and time of flight mass spectroscopy is used to identify the charge to mass ratio. The recent development of pulsed laser APT with UV lasers has enabled the analysis of wide bandgap semiconductors and oxides. APT has many unique attributes that are highly relevant to the development of structure property relationships in InGaN QWs. First, one can examine the roughness and diffuseness of buried interfaces independently, whereas transmission electron microscope-based imaging may convolve these two factors. In contrast to x-ray diffraction, APT provides local rather than averaged information about interfaces. Second, one can analyze alloy decomposition without concern that the technique itself (such as the electron beam in STEM imaging) influences the measurement. Finally, APT detects all elements with equal sensitivity, providing unique ability to analyze doping gradients in three dimensions.

We have performed APT on two types of InGaN QW light emitting diode (LED) devices. We have characterized nonplanar InGaN QWs grown on GaN nanowire arrays by the G. Wang group at Sandia National Laboratory. We characterized planar InGaN QWs grown on (0001) polar, (10-10) nonpolar, and (20-2-1) semipolar surfaces by the Wetzel group at Rensselaer Polytechnic Institute. In this invited presentation, I will relate (1) sample preparation methods needed to extract a select region of interest from an LED device structure for atom probe analysis; (2) optimization of run conditions to enable reliable analysis of the indium distribution within the quantum wells; (3) our analysis of QW compositional uniformity, width, and abruptness. The presentation will highlight the unique and complementary capabilities of APT that can provide greater understanding of the performance characteristics of current LEDs and provide new insights into how the performance of future generations of LEDs might be improved.