Electroemission Spectroscopy of GaN-Based Diodes – Revealing the Inner Working of LEDs and More!

James S. Speck
Materials Department
University of California, Santa Barbara CA 93106

In this talk, we introduce the technique of electroemission spectroscopy (EES) and its application to GaN-based LEDs. The technique is based on electron emission from p-GaN surfaces that have been cessiated to realize negative electron affinity (NEA). For LEDs the p-GaN surface is exposed through open apertures in a grid metal contact. We have developed this technique to measure electron emission into vacuum that are the result of (i) three-body Auger nonradiative recombination (n^2p process (assuming $n \approx p$, scaling as n^3)), trap-assisted Auger recombination (TAAR, n^2 process); and electron overflow.

In this talk we review the evolution of the EES technique as applied to LEDs and reference p-n and p-i-n diodes. We review four different techniques that have identified the first conduction band upper valley (UV1) at 0.9 eV above the CBM. We show evidence for the next upper valley (UV2) at 1.7 eV above the CBM. Additionally, we review systematic measurements to assure that the emitted electrons from the p-GaN surface are indeed a result of processes occurring at the internal diode junction.

Recently we have performed EES measurement on electrically driven InGaN/GaN commercial blue c-plane (peak wavelengths λ = 465 nm) light emitting diode (LED) with 60 nm of p-GaN on top of the active region (this is relatively thin p-GaN). The signal-to-noise ratio of semiconductor peaks is improved on the thin p-GaN LED due to reduced loss of electrons en route to emission into vacuum during transit through the thin p-GaN. This further proves that hot electrons are generated in the bulk region and not by light or other hot electron generation mechanisms at the surface. Using square root of the light output power as a proxy for the active region carrier density, n, the hot electron integrated peak intensity is shown to be proportional to n^3 and, thus, is directly attributed to a 3-body Auger process. Since there are significant Auger recombination currents even at low injection current densities, it is expected that Auger recombination current will dominate over radiation recombination and Shockley–Read–Hall (SRH) currents at higher current densities.