Overcoming the efficiency droop in GaInN light-emitting diodes and novel technologies for c-plane GaInN polarized emitters

by

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ABSTRACT

Recent years have seen a tremendous surge in the number and diversity of applications for light-emitting diodes (LEDs). Increases in efficiency and light output have made LEDs increasingly viable for power-hungry applications. However, the ultimate goal of replacing fluorescent and incandescent lamps for general illumination remains elusive, as the GaInN LEDs which are most promising for solid-state lighting are plagued by decreasing efficiency once the drive current passes a low value – typically below 10 A cm^{-2} – where the efficiency peak occurs. This problem is known as the efficiency droop, and is the fundamental remaining obstacle to adoption of LEDs for general illumination.

In addition to simply higher power and efficiency, some emerging applications call for additional controllability of other light source properties. One such property is the polarization of emitted light; many applications including LCD backlighting, free-space optical communication, and illumination for computer vision benefit from light sources that directly emit polarized light.

This thesis will discuss both the efficiency droop and polarized light emission in detail. A series of experiments aimed at uncovering the physical origin of efficiency droop will be described; this fundamental question – what mechanism is actually responsible for droop – remains unresolved in the LED community, and seemingly conflicting data has been presented. Experimental and simulation results are described which indicate that electron leakage from the active region, enabled by sheet charges at heterointerfaces, may play a crucial role in the efficiency droop. Further, it is shown that LEDs with modified active region designs that reduce these sheet charges achieve lower efficiency droop together with higher efficiency at high currents.

This thesis will also describe novel concepts that enable polarized LED light sources based on conventional c-plane GaInN LEDs. These devices are shown to emit polarized light toward the sides; however, light is polarized in such a manner that conventionally packaged LEDs produce unpolarized light. A theoretical explanation for polarized emission is given. Further, it is shown that through a clever redesign of the secondary optics surrounding the LED, such as reflectors and encapsulation, polarized light can be extracted from conventional GaInN LEDs.