Efficiency study and device optimization of GaInN-based green light-emitting devices

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ABSTRACT

Energy efficient solid state lighting relies on light-emitting diodes and laser diodes prepared in wide bandgap group-III nitride semiconductors, in particular GaInN alloys. This thesis concerns the development of green and deep green light-emitting diodes and laser diodes and the analysis of preeminent efficiency limitations under high injection current densities.

In the first chapter, a new device fabrication process was developed for deep green light-emitting diode epitaxial wafers on *c*-plane sapphire. Characteristics of the process are a reduced number of photolithography steps by self-alignment of the *p*-metal and the avoidance of *n*-metal annealing by an oxygen plasma pretreatment. These steps resulted in a better ohmic behavior and over 40% lower *p*-contact resistance. 555 nm deep green light-emitting diodes were fully fabricated and a partial external quantum efficiency as high as 16% was achieved under pulsed operation conditions, a significant increase over the 5% achieved in DC operation. Also, a reduced blue shift of the emission wavelength over DC current operation was observed. Both aspects suggest that carrier heating may actually contribute in the particular performance limitations.

To study efficiency limitations under high photon flux, fabrication steps for green emitting laser diodes were developed. To overcome the problem of *p*-AlGaN cracking that is common to large area growth, a selective regrowth method was developed for ridge-type *p*-layers. By growth optimization an AlN content up to 13% in the AlGaN ridge-type *p*-cladding layer was achieved without structural cracking. As a result, a super-linear increase of the light output power was achieved up to 230 A/cm^2 in the new laser diode structures. Under optical excitation, superluminescence at 465 nm was achieved at a threshold of 1.2 MW/cm^2.

In the third aspect of this work, the commonly observed efficiency droop at high injection current density was analyzed. In order to correlate such observation in the light output power with any other directly observable features, the optical absorption within light-emitting diode structures was measured by the transmission of light from an external light source. Under variation of the external irradiance, a strong nonlinear optical absorption was observed with an onset under conditions similar to those of the onset of droop. We developed a model that can explain the observed nonlinear

absorption by means of a mixture of excited state absorption and free carrier absorption. In an actual light-emitting diode structure the same transmission reduction could be achieved under electrical injection suggesting that efficiency droop may actually originate in the here quantified nonlinear optical absorption.