Epitaxy and Structural Characterizations of Green and Deep Green GaInN/GaN Light-Emitting Diodes

by

Mingwei Zhu

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Examining Committee:

Christian Wetzel, Thesis Adviser

E. Fred Schubert, Member

Peter D. Persans, Member

Ishwara B. Bhat, Member

Theeradetch Detchprohm, Member

Rensselaer Polytechnic Institute
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ABSTRACT

Green light-emitting diode (LED) is an essential component in energy-efficient solid-state white lighting with good color rendering. Its efficiency, however, falls far behind the AlGaInP-based red LEDs and AlGaInN-based blue LEDs. The propensity of defect generation and large polarization field across the *c*-axis grown GaInN/GaN active region limit the performance of green LEDs.

This thesis studied the epitaxial growth and structural properties of polar and non-polar green GaInN/GaN LEDs. LEDs were grown by metalorganic vapor phase epitaxy and their optical properties and structural perfection were evaluated at different development stages by means of optical spectroscopy, transmission electron microscopy (TEM), atomic force microscopy, and X-ray diffraction techniques.

V-defects triggered by edge-type misfit dislocations (MDs) were observed and analyzed in the *c*-plane green QWs on sapphire. Epitaxy processes were developed to suppress V-defect and MD initiation in LEDs up to the yellow wavelength range, resulting in light output power (LOP) enhancement by a factor of two compared to same-wavelength defective light emitters. The V-defect-free green LED also shows improvement of reliability.

A reduction of dislocation density by a factor of 30 was achieved by homoepitaxy for *c*-plane blue LED on bulk GaN and lead to a power enhancement by an order of magnitude at 20 mA compared to the simultaneously grown blue LED on sapphire. In green LEDs on *c*-plane bulk GaN, a unique type of defect – an inclined dislocation pair (IDP) was found in the active region. A model was proposed to quantitatively explain the formation of IDPs by the stepwise removal of lattice points between the separating dislocations lined up along opposing <1-100> directions. A high density of MD generation was found in the active region of a *c*-plane yellow LED on bulk GaN that leads to a strain relaxation of the QW. Higher efficiency at low current (< 50 mA) but larger efficiency droop at higher current was found for both homoepitaxial green and yellow LEDs when compared with their counterparts on sapphire. Linewidths of electroluminescence spectra were also found to be closely related to the dislocation density in the QWs.

Non-polar *a*-plane green LEDs were grown on bulk GaN and their dislocation-free active region lead to a LOP enhancement by a factor of 3 compared to *a*-plane green LEDs on *r*-plane sapphire, which contains a high density of threading dislocations and stacking faults. A good power cyan LED (481 nm, 2.8 mW at 100 mA) was achieved on *m*-plane bulk GaN but LEDs show a significant power drop as the wavelength is extended to the green range (> 510 nm). This is attributed to the formation of MDs in the active region. We find that twice the InN fraction is needed in the *a*-plane and *m*-LEDs to reach the same green wavelength emission as the *c*-plane LEDs. We attribute this to the absence of the piezoelectric field in the non-polar growth directions. *a*-Plane and *m*-plane green LEDs show a minimal wavelength shift over a wide range of current. This result is highly relevant for the realization of color-stable energy-efficient solid-state lighting.