Optical Polarization Study and Dislocation Reduction in GaN-based Light-Emitting Diodes

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ABSTRACT

Great improvements of GaN-based light emitting diodes (LEDs) have been made in the last decade, and have led to the first wave of solid-state lighting by replacing light bulbs with high efficiency LEDs. Smart Lighting technology is the second wave of solid-state lighting that lets people use the artificial light in their environment in radically new ways. This requires the further control of light properties from LED sources, including color, intensity, polarization and efficiency. In this doctoral thesis, I would like to present several works associated with the sources aspect of smart lighting: Optical polarization control from non-polar and semi-polar LEDs, and dislocation reduction techniques to achieve highly efficient green LEDs.

Polarized spontaneous emission from non-polar and semi-polar LEDs covering the blue to green spectral range is analyzed. Highly polarized light emission was observed in *m*-plane GaInN/GaN-based LEDs in both, photoluminescence and electroluminescence. Such a device should allow up to 50% power savings compared to non-polarized *c*-plane LEDs combined with a polarizing filter, as commonly used in LED-backlit liquid crystal displays. Analysis of semi-polar LEDs also shows the optical polarization anisotropy. Strong polarized light emission was found in cyan $(20\bar{2}\bar{1})$ LEDs, while polarization switching with emission wavelength was confirmed in $(10\bar{1}1)$ LEDs. Further analysis of the dependence of polarization properties on temperature and excitation power reveals its mechanism as controlled by the valence band structure of wurtzite GaN. The properties of polarized light propagation were also analyzed in bulk GaN with different crystal orientation. It is found that the degree of polarization decreases with progressive light propagation along the sample. This could indicate that any imperfections of the sample induce a light scattering towards the stronger polarization direction.

Several approaches to reduce the threading dislocation density in green LEDs were attempted and the structures were analyzed by cross-section and plane-view TEM. By using micro-patterned sapphire substrate, the dislocation density initiated at the interface of GaN and sapphire can be greatly reduced (30 %) compared to the planar sapphire. Such reduction of threading dislocation density is determined to be the consequence of dislocation bending at the interface of GaN and micro-patterned sapphire. By using nano-patterned sapphire substrate, the voids between the protruding patterns due to the

lateral overgrowth of GaN can also reduce the dislocation density in this material and hence dramatically increase its crystal quality.