Highly efficient package configurations for white-light-emitting diode lamps with novel remote phosphor distribution and electrostatic discharge protection

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ABSTRACT

In this dissertation, the electrical-to-optical conversion efficiency and electrostatic-discharge reliability of light sources based on light-emitting diodes (LEDs) are discussed. Firstly, surface-patterned reflectors, namely diffuse reflectors and pyramid reflectors, are employed in GaInN LEDs to enhance the light extraction from the LED chip. The optical properties of these patterned reflectors are analyzed and discussed. The analysis shows that reflections on the patterned reflector can redirect the trapped optical modes in the high-index semiconductor into an additional extraction cone. In addition, three-dimensional ray tracing simulations are performed and they show that the light-extraction efficiency of GaInN LEDs is enhanced up to 40.7% by employing these patterned reflectors.

Secondly, a strong improvement in the efficiency of white LED lamps is achieved by LED package structures that employ a novel remote phosphor distribution. It is demonstrated by ray tracing simulations that the remote phosphor arrangement can reduce the probability for the phosphorescence to be absorbed by the LED chip and thus enhance η_{ex}. In addition, a diffuse reflector cup can randomize and extract out the trapped whispering-gallery optical modes in the LED packages to free space. By optimizing the LED package, η_{ex} is enhanced by 50% over conventional proximate phosphor packages based on ray-tracing simulations. Furthermore, di-chromatic LED lamps with remote phosphor and diffuse reflector cup are fabricated and measured. The phosphor conversion efficiency shows an enhancement up to 27% over that of conventional proximate-phosphor-in-specular-cup packages.

Thirdly, a novel electrostatic discharge (ESD) protection, supplemental current path (SCP), for GaN-based LEDs is demonstrated. The SCP is a thin ZnO film, which connects the cathode and anode of the device, providing an additional current path during the reverse electrostatic discharge. The experimental results show that that the electrical and optical characteristics of the devices are not influenced by the SCP at normal operation condition. The ESD stability of the LEDs with SCP films is measured by a self-built ESD simulator that is based on the human body model. The experimental results show that the mean ESD-voltage-to-failure is increased by more than 4-fold by employing the novel SCP protection.