Shaping InGaN Light-emitting Diodes at the Micrometer, Nanometer and Millimeter Scales

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Although present-day white-light InGaN light-emitting diodes (LEDs) can be twice as energy efficient as fluorescent lamps, LEDs promise a lot more given their high internal quantum efficiencies. Nevertheless, with a large refractive index, the escape cone from a typical nitride LED is restrictively narrow, so that light extraction efficiencies rarely exceed 20%. Being able to release the remaining 80% is the key towards realizing the ideal light source.

Micro-structured LEDs, consisting of interconnected arrays of micrometer scale light-emitting pixels, is our first approach towards enhancing light extraction by providing additional photon escape pathways. Through our extensive studies on effects of dimensions and geometry, it became apparent that an increase in surface-area-to-volume-ratio promotes light extraction, prompting further dimension downscaling.

Nanosphere lithography (NSL) is our adopted approach for patterning large-area ordered periodic nanostructures, with distinct advantages over conventional nano-patterning techniques. The incorporation of NSL-patterned photonic crystals into LEDs has been successfully demonstrated. Such ordered periodic nanostructures, with the ability of manipulating spontaneous emission, can be extremely useful for extracting guided modes to air.

To further release more photons, our chips are completely re-designed geometrically, taking on the shapes of polygons, circles, and even 3D pyramidal and conical structures; the enabling technology for realizing LEDs of unconventional geometries is laser micromachining.

Apart from the various device structuring and shaping techniques, our vision on LED chip packaging, particularly for lamps and LCD backlights, will also be discussed.