Omnidirectional Reflectors with Novel Low-Refractive-Index Material for Light-Emitting Diodes

by

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ABSTRACT

Solid state lighting technology requires high brightness light-emitting diodes (LEDs) with high light-extraction efficiency. A very promising approach to improve the light-extraction efficiency of devices is to integrate a high reflectivity omnidirectional reflector (ODR) with low-refractive-index (low-*n*) material onto LED chips. ODRs are defined as reflectors with reflectivity close to 100% at any incident angle for both polarizations. Low-*n* material is a new class of optical thin film material, which has great potential in application of not only ODRs but also other optical filters.

In this dissertation, internal ODRs with low-*n* material are discussed. Two kinds of ODRs are reviewed. One is a triple-layer ODR, which consists of a semiconductor, a quarter-wavelength thick low-*n* layer, and a reflective metal layer such as Ag or Al. The other one is a dielectric-multilayer ODR, which consists of a thick low-*n* material and a one-dimensional photonic crystal. Both reflectors have high reflectivity at any incident angle in the semiconductor ambient. Low-*n* material is the key component for the ODRs.

A novel low-*n* material with refractive index as low as $n = 1.05$, has been demonstrated to have advantages over conventional optical thin films. A single-pair distributed Bragg reflector using such low-*n* material is demonstrated to have enhanced reflectivity in the visible spectrum. A graded-index anti-reflection coating with index matching condition enabled by the low-*n* material is demonstrated to have reflectivity lower than 0.3% over wide spectrum range and angle of incidence.

A *conductive* low-*n* material is obtained by oblique-angle deposition of indium-tin oxide (ITO). Such material has a much lower refractive index than conventional transparent dense ITO material while still having good conductivity. A GaInN with triple-layer ODR using a conductive low-*n* material is successfully fabricated and incorporated into an LED that is shown to have enhanced light-output.

Finally, a new type of 3-dimensional reflector, a pyramid reflector, is demonstrated to provide an additional light-escape cone to the LED die so that the light-extraction efficiency can be significantly enhanced. GaN-based LED with pyramid reflector is

demonstrated to have 13.9% enhancement of light output compared with the conventional LEDs.