Extraction Efficiency of Three-Striped LED

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Abstract. In a typical GaN based LED structure, the extraction efficiency is about 37.3% when Fresnel reflection is the only mechanism to prevent out-coupling of light. But if the electrode absorption is assumed as 100%, the extraction efficiency is about 26.8%. In a three-striped LED, the extraction efficiency is about 40.7% when Fresnel reflection is the only mechanism to prevent out-coupling of light. But if the electrode absorption is assumed as 100%, the extraction efficiency is about 23.5%.

Keywords: LED · Extraction efficiency

1 Introduction

Light Emitting Diodes (LEDs) are widely used in many commercial products. As a lighting source, LED has some advantages in comparison with incandescent lamps; longer operational lifetime, improved color purity, higher electro-optic efficiency, particularly for colored light, etc.

In the field of general LED application, devices should have the following properties (i) high efficiency and (ii) high power capability. Therefore internal quantum efficiency and light extraction efficiency should be maximized. But owing to the high refractive index of semiconductors, the total internal reflection is occurred on a planar semiconductor-air interface if the angle of incidence is sufficiently large. As a result of total internal reflection, light can be trapped inside the LED die. Light trapped in the die will eventually be reabsorbed by the substrate, active layer, cladding layer, or by a metal electrode.

One of new technologies in high power LEDs is thin-film flip-chip technology [1]. Roughened n-GaN surface improves out-coupling of light. Also photonic crystal in the surface of LED chip enables light extraction through scattering of wave-guided light into radiation modes [2]. And die geometry has a large impact upon extraction efficiency. To date, the most efficient geometry is the truncated inverted pyramid [3].

In this paper, in order to study the effect of tapered three-striped LED structure on the extraction efficiency, the three-striped LED has been compared with a typical LED structure. Also the effect of metal electrode absorption on the extraction efficiency has been compared in these two LEDs.

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2 Simulation Model

2.1 Ray Tracing

The external quantum efficiency of an LED, η_{ext}, is the product of the carrier injection efficiency, η_{inj}, and the internal quantum efficiency, η_{int}, and the extraction efficiency, η_{extrac}, that is,

$$\eta_{ext} = \eta_{inj} \times \eta_{int} \times \eta_{extrac}. \tag{1}$$

Extraction efficiency depends on absorption within the substrate material, chip geometry, and relative refractive indices of the die, optical coupling material and transparent package. A unique feature of their ray tracing technique is the geometrical treatment combined with a wave optics approach, taking into account refraction, reflection, absorption and interference effects. Snell's law is applied at the boundary between two dielectric materials with different refractive indices n_i and n_t, as in (2). The angles θ_i and θ_t used in (2) are measured with respect to the surface normal, shown in Fig. 1.

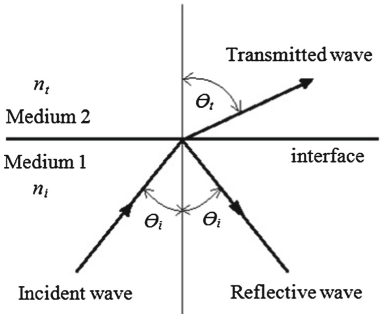

Fig. 1. Reflected and refracted light ray at the boundary between two media with refractive indices n_i and n_t, where $n_i > n_t$.

$$n_i \sin\theta_i = n_t \sin\theta_t. \tag{2}$$

The critical angle θ_c for total internal reflection is obtained using $\theta_t = 90°$, that is,

$$\theta_c = \sin^{-1}(n_t/n_i.) \tag{3}$$

For all angles of incidence $\theta_i > \theta_c$, total internal reflection occurs. Photons are generated in the active layer within the die and propagate in all directions. However, only a small fraction of them is able to pass through the boundary within the small cone. The remainder is reflected from the surface. Outside of the critical cone angle, photons experience total internal reflection and do not contribute to useful light. The light is still subject to Fresnel reflection at the semiconductor-air interface. The Fresnel equations determine the reflection and transmission of light incident on an interface of

two media with different indices of refraction. The reflection coefficient for perpendicularly polarized light is given by

$$R- = [n_i \cos\theta_i - n_t \cos\theta_t]/[n_i \cos\theta_i + n_t \cos\theta_t]. \quad (4)$$

The transmission coefficient for perpendicularly polarized light is as follows.

$$T- = 2n_i \cos\theta_i/[n_i \cos\theta_i + n_t \cos\theta_t]. \quad (5)$$

The reflection coefficient for parallel polarized light is given by

$$R_{||} = [n_t \cos\theta_i - n_i \cos\theta_t]/[n_i \cos\theta_t + n_t \cos\theta_i]. \quad (6)$$

The transmission coefficient for parallel polarized light is given by

$$T_{||} = 2n_i \cos\theta_i/[n_i \cos\theta_t + n_t \cos\theta_i]. \quad (7)$$

3 Results

In order to study the effect of tapered stripe structure on the extraction efficiency, the three-striped LED has been compared with a typical LED structure.

Cross section of a typical LED and its geometrical structure parameters used for computer simulation are shown in Fig. 2 and Table 1. Light is generated in the emitting layer of an LED and emitted into all directions. If the incidence angle of the ray is smaller than the critical angle of total internal reflection, then the light is coupled out. The extraction efficiency is about 37.3% when Fresnel reflection at the semiconductor-air interface is the only mechanism to prevent out-coupling of light, that is, there are no metal electrodes. But the p- and n-metal electrodes absorb photons and reduce the light extraction efficiency. If the electrode absorption is assumed as 100%, the calculated extraction efficiency of a typical LED structure is about 26.8%.

Cross section of the three-striped LED and its geometrical structure parameters used for computer simulation are shown in Fig. 3 and Table 2. The extraction efficiency of the three-striped LED is about 40.7% when Fresnel reflection at the semiconductor-air interface is the only mechanism to prevent out-coupling of light, that is, there are no electrodes. But the p- and n-metal electrodes absorb photons and reduce the light extraction efficiency. The effect of p- and n-metal electrode absorption on the light extraction efficiency has been studied. If the electrode absorption is assumed as 100%, the calculated extraction efficiency of the three-striped LED structure is about 23.5%.

If there are no metal electrodes absorbing the photons emitted from the active layer, the tapered striped structure enhances the light extraction. So the extraction efficiency of the three-striped LED is higher than that of a typical LED.

When a photon emission point is located under the p-electrode, the light extraction efficiency is decreased. Therefore when the p- and n-metal electrode absorption is

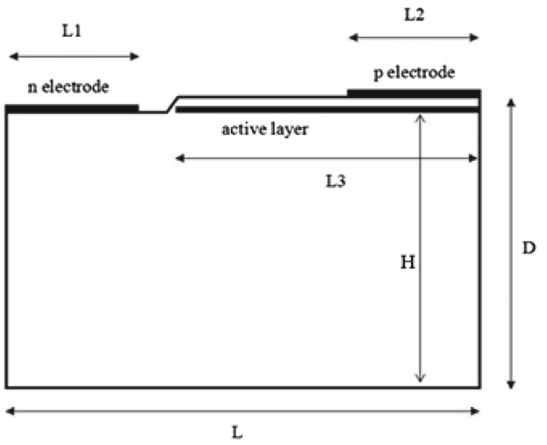

Fig. 2. Structure of a typical LED used for computer simulation with refractive indices n_i and n_o, where $n_i > n_o$.

Table 1. Structure parameters of an LED shown in Fig. 2.

Parameter	Value
n-electrode width, L1 [um]	90
p-electrode width, L2 [um]	90
Active Layer width, L3 [um]	200
Active layer height, H [um]	100
Die width, L [um]	310
Die height, D [um]	103
Inner refractive index, n_i	3.45
Outer refractive index, n_o	1.0

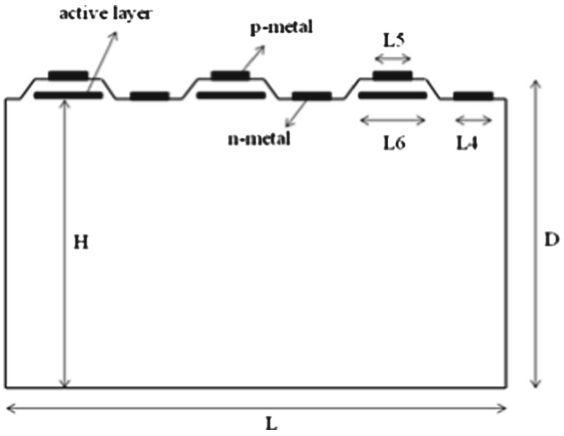

Fig. 3. Structure of the three-striped LED used for computer simulation.

Table 2. Structure parameters of an LED shown in Fig. 3.

Parameter	Value
n-electrode width, L4 [um]	30
p-electrode width, L5 [um]	30
Active layer width, L6 [um]	50
Active layer height, H [um]	100
Die width, L [um]	310
Die height, D [um]	103
Inner refractive index, n_i	3.45
Outer refractive index, n_o	1.0

assumed as 100%, the light extraction efficiency of the three-striped LED is lower than that of a typical LED.

4 Conclusion

In a typical GaN based LED structure, the extraction efficiency is about 37.3% when Fresnel reflection is the only mechanism to prevent out-coupling of light. But if the electrode absorption is assumed as 100%, the extraction efficiency is about 26.8%. In a three-striped LED, the extraction efficiency is about 40.7% when Fresnel reflection is the only mechanism to prevent out-coupling of light. But if the electrode absorption is assumed as 100%, the extraction efficiency is about 23.5%.

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