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RESEARCH ARTICLE

Effects of packaging structure on optical performances of phosphor converted light emitting diodes

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Abstract Effects of tilt angles of reflective cup structure and phosphor surface geometries on light extraction efficiency and angular color uniformity (ACU) of phosphor converted light emitting diodes (pcLED) are investigated by Monte Carlo ray-tracing simulations. It is found that tilt angles of reflective cup and phosphor surface geometries affect the light extraction efficiency and the ACU distinctly. When the tilt angle varied from 60° to 15°, the light extraction efficiency of LED can achieve the improvements of 13.87%, 18.25% and 14.79% respectively, when the phosphor surface geometry is concave, flat and convex, respectively. It is also found the variety law of phosphor concentrations with the change of tilt angles and phosphor surface geometries to maintain a fixed correlated color temperature (CCT).

Keywords phosphor, packaging structure, reflective cup, light emitting diodes (LEDs)

1 Introduction

As the potential next generation light source, white light emitting diodes (LEDs) can achieve high luminous efficiency and good light performances [1]. Phosphor converted LED (pcLED) which combines a blue LED chip and yellow emitting phosphor is the most common approach to accomplish white light emission through LED packaging. In LED packaging, reflective cup structure is very popular because of lots of advantages, such as easy fabrication, being favorable for packaging, and so on. Some works about the effect of phosphor-in-cup packaging on LED performances have been done. Yu et al. [2] presented the effect of the phosphor geometries on the luminous flux of phosphor-in-cup pcLED and found the curvature of the convex surface is important. Lin et al. [3] studied the influence of phosphor concentration and configure on optical power, luminous efficiency, correlated color temperature (CCT), chromaticity coordinate and color-rendering index (CRI). Shuai et al. [4] demonstrated the effect of different packaging parameters on the angular homogeneity of CCT in phosphor-in-cup LED packages. Masui et al. [5] fabricated white light-emitting diode lamps with three types of commercial yellow-emitting phosphors and studied the effects of phosphor application geometry. Liu et al. [6] showed the effects of variations of phosphor thickness and concentration on optical consistency of LED. They compared five packaging methods, including phosphor in-cup packaging, with different phosphor locations, and it was found the hemispherical remoter phosphor is the best choice. Just as mentioned above, most of the existing works about phosphor-in-cup LED packages focus on the phosphor geometry, concentration and thickness, while few of them are done to investigate how the reflective cup affects the performance of LED.

In this work, the influence of tilt angles of reflective cup and phosphor surface geometries on light extraction efficiency and angular color uniformity (ACU) of LED with a fixed CCT was studied.

2 Analysis model

The optical models were built as shown in Fig. 1. The tilt angle of the reflective cup θ varies. In this works, θ is 15°, 30°, 45° and 60°, respectively. The reflective cup is 1 mm in height and the diameter at the bottom is 2 mm. The geometry of the top phosphor surface is concave, flat, convex, respectively. The height between the bottom point of the concave surface and top surface of the reflective cup

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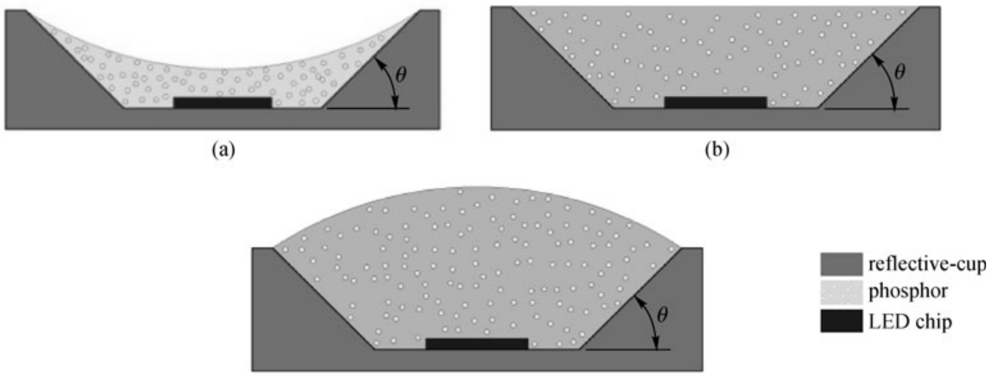

Fig. 1 Schematics of the phosphor in-cup packages with (a) concave surface, (b) flat surface and (c) convex surface

is equal to the height between the top point of the convex surface and top surface of the reflective-cup, and they are 0.6 mm. The LED chip is the conventional chip, and its size is 1 mm × 1 mm. The thicknesses of the various layers, such as N-GaN, MQW, P-GaN and Si are 4 μm, 100 nm, 300 nm, and 100 μm, respectively.

In our simulations, Monte Carlo ray tracing is employed. The absorption coefficients and refractive indices for N-GaN, MQW, and PGaN are 5, 8, and 5 mm^{-1} and 2.42, 2.54, and 2.45, respectively [7,8]. The absorption, scattering and emission of the phosphor gel, with a variable concentration, are simulated with Mie Theory [9]. The reflectance and absorption of the surface on the reflective cup is 80% and 20%, respectively. Blue light (460 nm) isotropically emits from the MQW with a uniform distribution, and phosphor absorbing the blue light emits yellow light (560 nm) with a quantum efficient 0f of 0.8. The optical models have been validated and were used to simulate the LEDs chips accurately in our previous studies [7,9–12]. The number of rays traced is 2000000 and the threshold of flux is 0.1%, then the simulation error can be neglect.

In this simulation, the phosphor concentration was adjusted to keep the ratio of yellow light power and blue light power (YBR) stabilizing at the value of 1.8, and the error of YBR was controlled less than 1%, then we can ensure the CCT is maintained at the same level for all simulations.

3 Results and discussion

Figure 2 shows the dependence of light extraction efficiency on tilted angles of reflective cup and phosphor surface geometries. It is found that the light extraction efficiency decreases when the tilt angle of reflective cup increases no matter what the phosphor surface geometry is. As the tilted angle varies from 60° to 15°, the light extraction efficiency can achieve the improvements of 13.87%, 18.25% and 14.79% when the phosphor surface geometry is concave, flat and convex, respectively. The reason is that more light is repetitively reflected between the sidewalls of the reflective cup when the tilt angle increases, which leads more power loss and decreases the light extraction efficiency. Therefore, the dependence of light extraction efficiency on the tilted angles of reflective cups is remarkable. It is also found from Fig. 2 that the connection between the light extraction efficiency and phosphor surface geometry is not clear.

Figure 3 shows the influence of tilt angles of reflective cup and phosphor surface geometries on ACU. It is found that the ACU becomes bigger when the phosphor geometry is concave at the tilt angle of 15° or 30°. While at the tilt angle of 45° or 60°, the bigger ACU appears when the geometry is flat. This phenomenon is related to light escape cone. In this works, the light escape cone is near 40°. When the tilt angle is 15° or 30°, which is less than the light escape cone, blue light without scattering will not go to the phosphor at the edge, then less yellow light will emit. When the phosphor surface geometry is

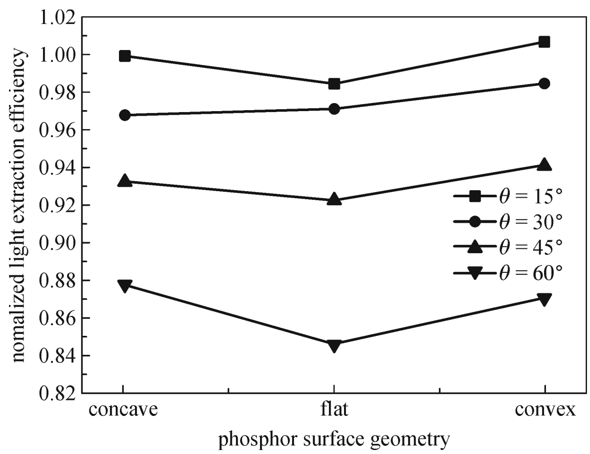

Fig. 2 Dependence of light extraction efficiency on the tilt angle of reflective cup and phosphor surface geometry

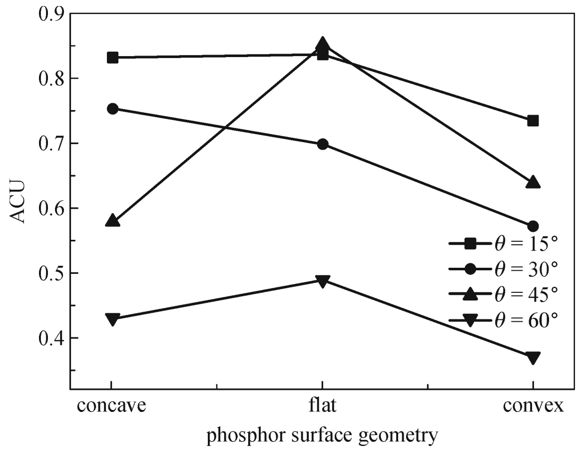

Fig. 3 Dependence of the ACU on the tilt angle of reflective cup and the phosphor surface geometry

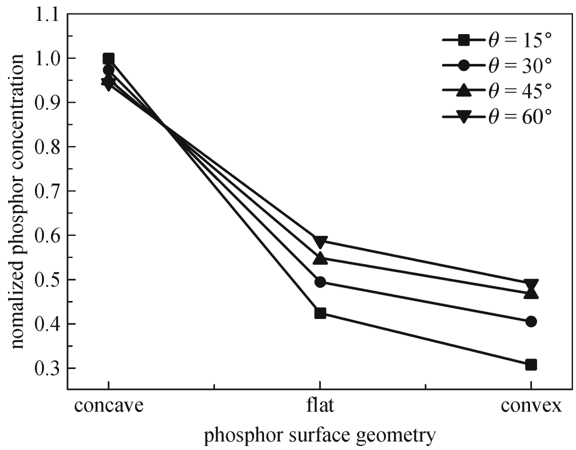

Fig. 4 Variety laws of phosphor concentrations with the change of tilt angles of reflective cup and phosphor surface geometries for a fixed CCT

concave, owing to the total internal reflection (TIR), there is also less blue light escape. As a result, the YBR is more uniform. When the tilt angle is 45° or 60°, which is more than the light escape cone, blue light without scattering is reflected by the wall of the reflective cup. When the phosphor surface geometry is concave, there is yellow light emitted by phosphor at the edge, while there is less blue light owing to the TIR. When the phosphor surface geometry is convex, there is more yellow light at the edge because of yellow light emitted by phosphor at the middle place will go to the edge. When the phosphor surface geometry is flat, the YBR is more uniform, so the ACU is bigger.

Figure 4 shows the variation of phosphor concentrations with the change of tilt angles of reflective cup and phosphor surface geometries to maintain the CCT. It can be seen that the phosphor concentration decreases with the increase of the tilt angle of reflective cup when the geometry of phosphor surface is concave, while it increases with the increase of the tilt angle of reflective cup when the geometry of phosphor surface is flat or convex. It is mainly because the TIR loss of blue light is the main factor to affect the CCT when the geometry of phosphor surface is concave. When the tilt angle of reflective cup increases with a fixed height, the curvature of the concave surface increases, then the injection angle of surface increases for the same blue light, so more TIR loss happens, leading less blue light escaping from the phosphor layer. At the same time, more blue light is absorbed by the phosphor and it emits more yellow light. In order to get the same CCT, it is necessary to decrease the phosphor concentration. When the geometry of the phosphor surface is flat or convex, the mean free path (MFP) of blue light replaces the TIR to be the main factor affecting the CCT. It is found that the MFP of blue light decreases as the tilt angle of reflective cup increases. On the one hand, the absorption from the phosphor layer decreases, which leads increase of blue light extraction. On the other hand, less absorption of blue light means less yellow light emitting. To maintain the same CCT, the phosphor concentration must be increased.

It also can be known the phosphor concentration decreases when the phosphor surface geometry varies from concave to flat then to convex when the tilt angle of reflective cup is fixed. The reason is less blue light escapes and the yellow light emitting increases if the concentration does not change, so it is necessary to decrease the phosphor concentration to maintain the same CCT.

4 Conclusions

It's presented that the tilt angles of reflective cup and phosphor surface geometries affect the light extraction efficiency and the ACU distinctly. The light extraction efficiency decreases with the tilt angle increasing, achieving an improvement as high as 18.25% in this work. And the ACU is also strongly relative with phosphor geometry and the tilt angles of reflective cup. It's also found that the phosphor concentration should be decreased with the tilt angle increasing when the phosphor surface geometry is concave to maintain a fixed CCT, while it should be increased when the phosphor surface geometry is flat or convex.

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References

1. Liu S, Luo X B. LED Packaging for Lighting Applications: Design, Manufacturing, and Testing. New York: John Wiley Press, 2011

2. Yu R Y, Jin S Z, Cen S Y, Liang P. Effect of the phosphor geometry on the luminous flux of phosphor-converted light-emitting diodes. IEEE Photonics Technology Letters, 2010, 22(23): 1765–1767
3. Lin Y C, You J P, Tran N T, He Y Z, Shi F G.Packaging of phosphor based high power white LEDs: Effects of phosphor concentration and packaging configuration. Journal of Electronic Packaging, 2011, 133(1): 011009–011014
4. Shuai Y, He Y, Tran N T, Shi F G. Angular CCT uniformity of phosphor converted white LEDs: Effects of phosphor materials and packaging structures. IEEE Photonics Technology Letters, 2011, 23 (3): 137–139
5. Masui H, Nakamura S, Denbaars S P. Effects of phosphor application geometry on white light-emitting diodes. Japanese Journal of Applied Physics, 2006, 45(34): L910–L912
6. Liu Z Y, Liu S, Wang K, Luo X B. Studies on optical consistency of white LEDs affected by phosphor thickness and concentration using optical simulation. IEEE Transactions on Components and Packaging Technologies, 2010, 33(4): 680–687
7. Wang K, Wu D, Chen F, Liu Z Y, Luo X B, Liu S. Angular color uniformity enhancement of white light-emitting diodes integrated with freeform lenses. Optics Letters, 2010, 35(11): 1860–1862
8. Lee T X, Gao K F, Chien W T, Sun C C. Light extraction analysis for GaN-based LEDs with pyramid array. Optics Letters, 2007, 15: 6670–6675
9. Liu Z Y, Wang K, Luo X B, Liu S. Precise optical modeling of blue light-emitting diodes by Monte Carlo ray-tracing. Optics Express, 2010, 18(9): 9398–9412
10. Liu Z Y, Liu S, Wang K, Luo X B. Optical analysis of color distribution in white LEDs with various packaging methods. IEEE Photonics Technology Letters, 2008, 20(24): 2027–2029
11. Liu Z Y, Liu S, Wang K, Luo X B. Measurement and numerical studies of optical properties of YAG:Ce phosphor for white light-emitting diode packaging. Applied Optics, 2010, 49(2): 247–257
12. Hu R, Luo X B, Liu S. Study on the optical properties of conformal coating light-emitting diodes by Monte Carlo simulation. IEEE Photonics Technology Letters, 2011, 23(22): 1673–1675