ENHANCED LUMINOUS FLUX OF WHITE LED USING FLAT DUAL-LAYER REMOTE PHOSPHOR CONFIGURATION

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(Received: 8-April-2019; accepted: 27-June-2019; published: 30-June-2019)
DOI: http://dx.doi.org/10.25073/jaec.201932.222

Abstract. *The luminous flux of two different dual-remote phosphor structures concluding flat dual-remote phosphor (FDRP) and concave dual-remote phosphor (CDRP) is compared in this paper. The outcomes demonstrate that the FDRP structure is more lucrative than the CDRP structure. The article additionally clears up that in CDRP structure, the distance between two phosphor layers (d_1) and the distance between the phosphor layer with the LED surface (d_2) enormously affect the optical properties. Moreover, the difference in d_1 and d_2 causes a dramatic variance in the scattering and absorption properties of the remote phosphor layer and hence hugely affects WLEDs' illumination ability and chromatic uniformity. In order to limit these problems, the correlated color temperature of WLEDs, which is essentially a gauge of how the chromaticity observed when a "black body" radiator is warmed to a foreordained temperature, should be balanced out at 8500K when d_1 and d_2 vary, requiring a suitable modification of the YAG:Ce^{3+} phosphor's concentration. When $d_1 = d_2 = 0$, the scattering and assimilation in the remote phosphor layer become lowermost, prompting the most reduced viability in both shading quality and iridescent transition, which is confirmed dependent on the unearthly impacts created when these two separations are not same. Then again, when d_1 and d_2 get bigger, so does the dispersing surface, and the mixing of the blue beams with yellow beams swings to be increasingly homogeneous. This gives the insignificant different white light yet can't achieve any enhancement for luminous flux. According to the researched results, the luminous flux reaches a peak at 1020 lm when $d_1 = 0.08$ mm or $d_2 = 0.63$ mm whereas the chromatic inhomogeneity hits the lowest point when $d_1 = 0.64$ mm or $d_2 = 1.35$ mm.*

Keywords

White LED, Lambert-Beer Law, Color Rendering Index, Luminous Efficacy.

1. INTRODUCTION

Solid-state lighting devices such as light-emitting diode (LED), organic light-emitting diode (OLED), quantum-dot light-emitting diode (QLED), carbon-dot light emitting diode (CLED) using eco-friendly technologies are considered as prospective energy efficient lighting sources for general lighting and display applications [1]. Recently, LEDs have developed from the research and are presently supplanting customary lights inferable from their incredible performance, energy savings, short response, and life span [2]. LEDs are currently expanding their application areas from outdoor to indoor lighting, from traffic lighting to electronic billboards, and many other situations [3]. However, in any case, there are still a few challenges limiting the advancement of LEDs, and accomplishing higher luminous flux is one of them.

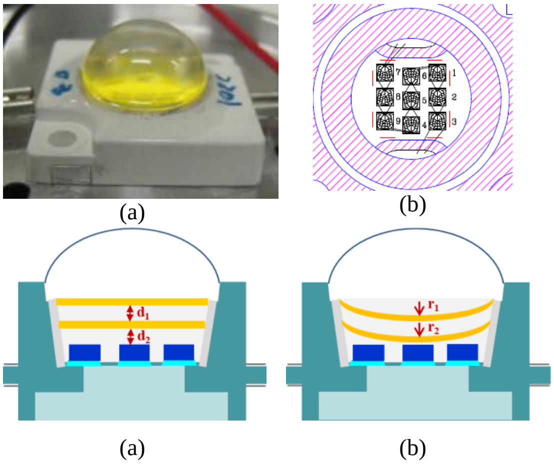
Remote phosphor LEDs, in which the phosphor layer is isolated from the blue-LED chips, have been affirmed to be a technique for improving the change productivity and lifetime of phosphor-changed over LEDs [4, 5] and in this way they are broadly used for general lighting applications. However, to make the phosphor design coordinate with the blue discharge example of the LED chip is a difficult issue which lessens brilliant adequacy. One of the conceivable ways to approach this issue is to advance the geometries or the molecule qualities of the remote phosphor to raise the glowing effectiveness utilizing patterned or shaped phosphor layers [6], multi-layer phosphor [7], nanoparticle-mixed phosphor [8], and new phosphor material [9]. The second way includes the blending of the LED discharges utilizing a focal point reflector to get the ascent of glowing adequacy [10]. The concept of separating the chip and the phosphor layer of remote phosphor structures are demonstrated in preceding researches [11, 12]. One solution of advancing extraction proficiency is the upgraded light extraction by inside reflection structure using a polymer hemispherical shell focal point with an inside phosphor covering. Besides, an air-hole installed structure can increase the luminescent effectiveness by reflecting descending light. It isn't just the structure of the bundle yet in addition the centralization of phosphor which expedites sensational impacts luminous efficiency. The re-absorption loss in the phosphor layer goes up when the phosphor concentration grows, resulting in a drop in devices' luminous efficacy, especially at lower correlated color temperature (CCT). Some investigations showed that the phenomenon of high scattering and reflecting additionally lessens the luminous performance. Therefore, it is vital to upgrade the outflow of the blue beams and yellow beams, and diminish the measure of light lost from backscattering and reflection.

Improving luminous flux has become a central focus for some specialists and utilizing double layer remote phosphor designs is a successful technique for this issue as proposed in ongoing examinations. Nonetheless, it is uneasy to choose a reasonable setup among the previously mentioned ones for optimal luminescent performance because each structure has its own advantages and disadvantages. This article gets two average setups named flat dual-layer remote phosphor configuration and concave dual-layer remote phosphor configuration to present and validate. After broad research and examination endeavors, the outcomes demonstrate that the FDRP arrangement produces huge dispersing varieties when the separation between the two phosphor layers (d_1) and the separation between the phosphor layer with the LED surface (d_2) are balanced in an unexpected way. In particular, the YAG:Ce^{3+} fixation will fluctuate on the grounds that the modification of d_1 and d_2 and this change can likewise control the luminous flux. Unlike the FDRP configuration, the scattering of the CDRP structure deviates only slightly while adjusting the bended surface sweep of the phosphor layer and henceforth the glowing motion control is also a challenging mission. Besides, the manufacture of the CDRP structure isn't absolutely basic. Consequently, this examination suggests the FDRP setup with a suitable YAG:Ce^{3+} focus to achieve higher luminous flux.

2. COMPUTATIONAL SIMULATION

2.1. Constructing the WLEDs configuration

In this section, a 3-D ray tracing simulation with LightTools software is utilized to exhibit the two phosphor layers' effect on performing pc-LEDs at the corresponded temperature of 8500 K. A real WLED structure includes blue LED chips, two phosphor layers, a reflector cup, and a silicone layer. A model WLED with a dome-lens used for simulation from the real one is shown in Fig. 1 (a) and Fig. 1 (d). Flat dual-layer remote phosphor configuration (FDRP) and concave dual-layer remote phosphor configuration (CDRP) are proposed and compared to each other for lighting performance. The separation between the two phosphor layers and between the phosphor layer with the LED surface of the FDRP structure are separately called d_1 and d_2, as appeared in Fig. 1 (c). Meanwhile, r_1 and r_2, respectively, are the curved surface radius of the upper and lower phosphor layers of the CDRP structure, see Fig. 1 (d).


(a) (b)

(a) (b)

Fig. 1: Photograph of WLEDs structure: (a) Actual WLEDs, (b) Bonding diagram, (c) Illustration of FDRP, (d) Illustration of CDRP

Each LED chip is bonded with a 2.07 mm high and 8 mm bottom-long reflector. What's more, the parameters of the blue chips are structured fastidiously to guarantee the most noteworthy exactness. In particular, its measurement, brilliant power, and a pinnacle wavelength are individually 1.14 mm x 0.15 mm, 1.16 W, and 453 nm, as appeared in Fig. 1 (b). These chips are secured with a 0.08 mm thick phosphor layer whose work is cleared up by the optical recreation process directed with the variety of separation among phosphor layers and the LED. The phosphor molecule is round molded with a normal distance across of 14.5 μm.

Two phosphor layers are separated by an air gap called d_1 and the distance from the LED surface to the lower phosphor layer is called d_2 as illustrated in Fig. 1 (c), where d_1 is modified from 0 to 0.64 mm and d_2 is varied from 0 to 1.43 mm. When d_1 and d_2 are such modified, both the luminous flux and the chromatic uniformity will achieve the most astounding point. To consistent the shading temperature of LED at 8500 K, the phosphor fixation should be shifted from 14%-26% wt. Relating to the separation of phosphor layers. For the CDRP structure, r_1 is fixed at 16 mm while r_2 ranges from 16 mm to 17 mm. As can be seen from Fig. 2 (c) that when r_2 differed from 16.1 mm to 16.6 mm, the YAG:Ce^{3+} focus dropped forcefully from 16.9% to about 16.6%, at that point bounced to almost 17% as r_2 expanded from 16.6 mm to 16.9 mm. At this time the average CCT is kept intact. It can be concluded from Fig. 2 that the YAG:Ce^{3+} concentration of the CDRP structure varies less than the FDRP structure so the scattering change is negligible, resulting in no significant difference in the emission of luminous flux. Additionally, the process of fabricating the FDRP structure is much simpler than the CDRP structure. Thus, the FDRP structure has numerous preferences over the CDRP one. This model enables us to change the phosphor position to an ideal separation between phosphor layers that can decide the optical properties of LEDs.

2.2. Computing the transmission of light

This portion will present and demonstrate the numerical model of the transmitted blue light and converted yellow light in the dual-layer phosphor structure to achieve the enhancement of LED viability. The transmitted blue light and converted yellow light for single layer remote phosphor bundle with a 2h thick phosphor layer are displayed as follows [13-16]:

$$PB_1 = PB_0 \times e^{-2\alpha_{B1}h} \quad (1)$$

$$PY_1 = \frac{1}{2}\frac{\beta_1 \times PB_0}{\alpha_{B1} - \alpha_{Y1}}(e^{-2\alpha_{Y1}h} - e^{-2\alpha_{B1}h}) \quad (2)$$

The transmitted blue light and converted yellow light for double layer remote phosphor package with the phosphor layer thickness of h are defined as:

$$PB_2 = PB_0 \times e^{-2\alpha_{B2}h} \quad (3)$$

$$PY_2 = \frac{1}{2}\frac{\beta_2 \times PB_0}{\alpha_{B2} - \alpha_{Y2}}(e^{-2\alpha_{Y2}h} - e^{-2\alpha_{B2}h}) \quad (4)$$

Where h is the thickness of each phosphor layer. The subscript "1" and "2" are used to describe single layer and double-layer remote phosphor package. β presents the conversion coefficient for blue light converting to yellow light. γ is the reflection coefficient of the yellow light. The intensities of blue light (PB) and yellow light (PY) are the light intensity from blue LED, indicated by PB_0. α_B; α_Y are parameters describing the fractions of the energy loss of blue and yellow lights during their propagation in the phosphor layer respectively. The lighting efficiency of pc-LEDs with the double-layer phosphor structure enhances considerably compared to a single layer structure:

$$\frac{(PB_2 + PY_2) - (PB_1 + PY_1)}{PB_1 + PY_1} > 0 \quad (5)$$

To verify the increase of the flux, Figure 3 depicts the emission spectrum of the dual-layer phosphor. For d_1, the emitted spectral intensity when $d_1 = 0$ is smaller than which in the cases $d_1 > 0$ at the two wavelength ranges of 380 to 480 nm and 480 to 580 nm. For d_2, the blue LED surface is at least 0.23 mm from the lower phosphor layer resulting in the lowest flux compared to the case $d_2 > 0.23$ mm. Thus, the photon emitted in dual-layer phosphor structure is larger than that of the single layer phosphor structure.

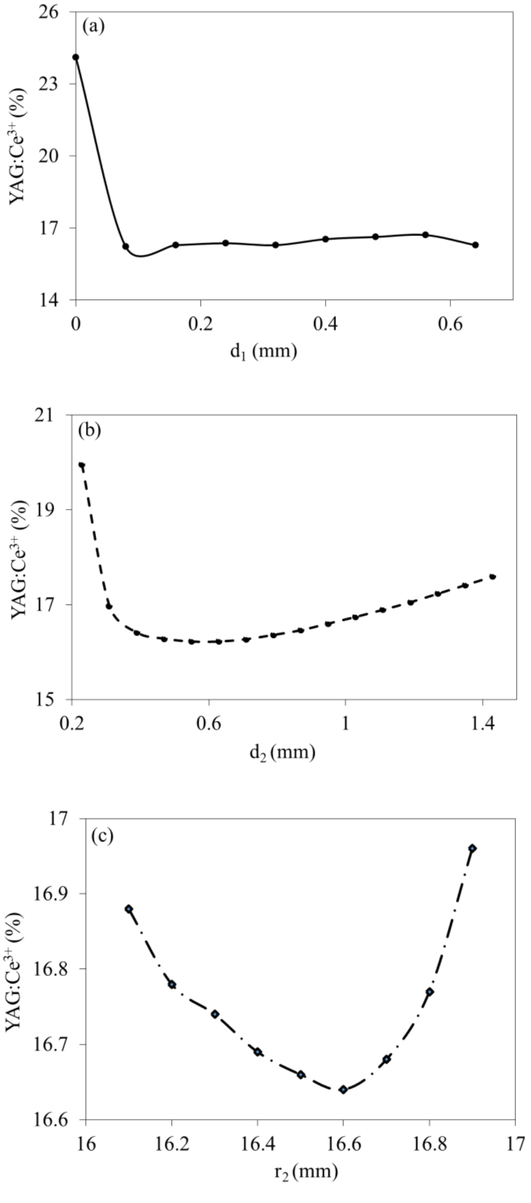


Fig. 2: The concentration of yellow phosphor in case of d_1 (a); d_2 (b) and r_2 (c)

3. RESULTS AND DISCUSSION

Fig. 4 illustrated the influence of the gaps among the phosphor layers and the LED chip of inaccessible phosphor bundle on the transmitted luminous flux. Firstly, the luminous flux in Fig. 4 (a) relating to d_1 and in Fig. 4 (b) relating to d_2 which tends to emphatically increase and reach the peak in the ranges of 0 to 0.08 mm and 0.23 mm to 0.63 mm respectively. For FDRP configuration, the luminous flux is maximum at 1020 lm when $d_1 = 0.08$ mm or $d_2 =$

0.63 mm. Meanwhile, the luminous flux hits the largest at 894 lm when $r_2 = 16$ mm and $r_2 = 16.6$ mm in term of CDRP configuration. Conversely, the luminous flux features a slight descending tendency when the distance between the phosphor layers becomes larger. The blue light from LED chip will encounter the first phosphor layer and be converted to the yellow light. Still, several parcels of the light are misplaced inside the LEDs due to the back-scattering, absorption, and reflection while other parcels are converted to yellow light and transmitted throughout the second phosphor layer. The enlargement of the crevice helps to reduce the distance from the phosphor layer to the LED chips, and hence much light retained and reflected inside the gap between the first phosphor layer with the LED chips. This can be why when the temperature of the intersection between phosphor layers and the LED chips increases, the conversion efficiency diminishs markedly. Consequently, the variation of the distance is proved to have a dramatic impact on light extraction.

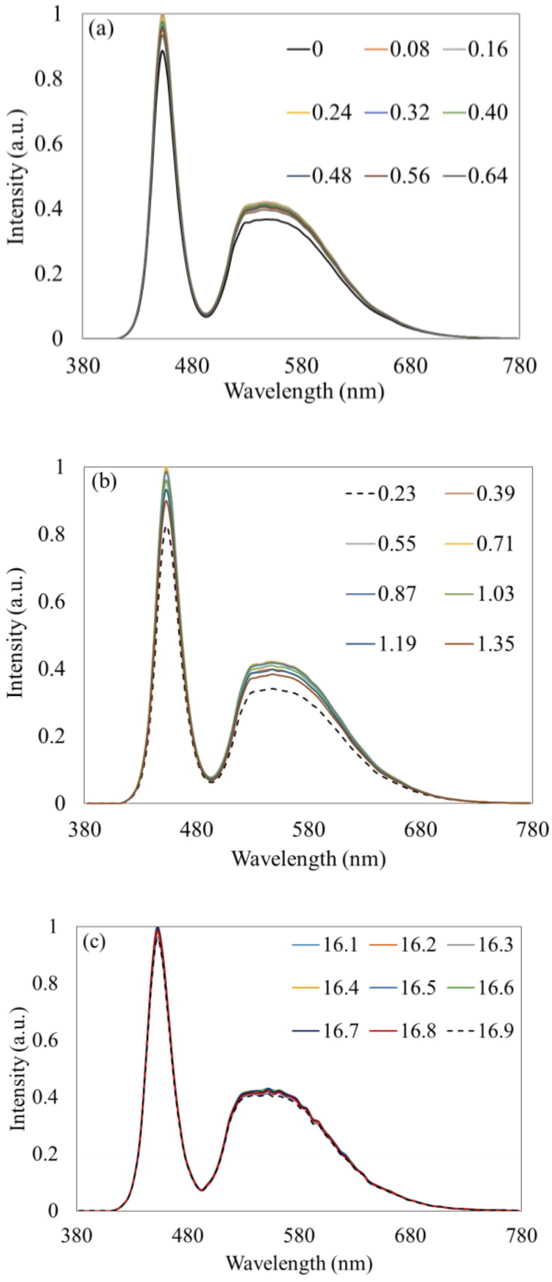


Fig. 3: Emission spectra of dual-layer phosphors: (a) case of d_1; (b) case of d_2 and (c) case of r_2

For the CDRP structure, the concave surface favorably backscatters light on the surface of the LED chip, so there is more misplaced radiated light energy. This clarifies for the diminishing of luminous flux when r_2 goes up. When r_2 increases to 16.9 mm, the gap between the phosphor surface and the LED chip surface is smallest leading to produce the largest amount of light backscattered. This backscattering event occurs not only at the LED surface of the lower phosphor layer but also at the upper phosphor layer on the CDRP structure. Especially, as r_2 increases from 16.1 mm to 16.6 mm, the scrambling energy decreases due to the rise of two phosphor layers' distance. This facilitates the direct transmission of light rays, leading to increased luminosity. On the other hand, as r_2 increases, the distance between the lower phosphor layer and the phosphor surface gets shorter which causes the enhancement of this lower phosphor layer's diffusing and the reduced luminosity.

4. CONCLUSION

In conclusion, this inquiry has specifically analyzed and demonstrated the significance of the distance between dual-phosphor layers and the phosphor layer with the LED surface to the optical properties of the remote phosphor bundle. Therefore, photon emanation firmly depends on the different phosphor coatings of the two structures FDRP and CDRP. The capacity to transmit light in a straight line through two phosphor layers of the FDRP structure is much more favorable than that of the CDRP structure. According to this article, the choice of an appropriate position of the phosphor layer in the remote phosphor bundle will significantly raise the WLEDs' luminous flux. Concretely, the luminous flux notably rises and hits the peak value when $d_1 = 0.08$ mm or $d_2 = 0.63$ mm while the color consistency value reduces in both cases. On the contrary, if $d_1 > 0.08$ mm or $d_2 > 0.63$ mm, the luminous flux has a tendency to fall down but the chromatic homogeneity is improved sharply due to the impact of the expanded retention, the light backscattering in LED package, and the chemical transformation of the heated phosphor layer. Consequently, in order to produce high-efficiency pc-LEDs, studying an appropriate gap between phosphor layers in remote phosphor bundle is a must-focused concern for numerous analysts.

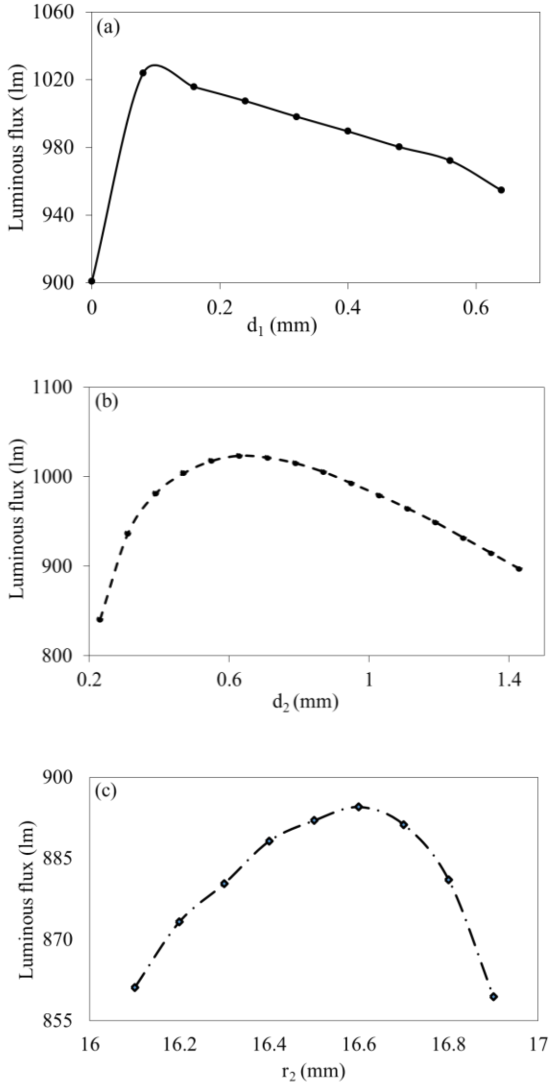


Fig. 4: The luminous output of WLEDs at the same CCT in cases of d_1 (a), d_2 (b) and r_2 (c)

ACKNOWLEDGEMENT

This research was supported by National Key Labrolatory of Digital Control and System Engineering (DCSELAB), HCMUT, VNU-HCM.

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