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Effect of red Y2O3:Eu3+ phosphor on the color quality and luminous efficacy of the 7000K IPW-LEDs

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Abstract

In this study, we investigate the effect of concentration of the red Y2O3:Eu3+ phosphor on the Color Rendering Index (CRI), Color Quality Scale (CQS) and Lumen Output (LO) of the 7000K in-cup packaging white LEDs (IPW-LEDs). The physical model of the 7000K IPW-LEDs is conducted by Light Tools software. By varying the concentration of the red phosphor from 0% to 0.36%, we use the Light Tools software to investigate the CRI, CQS, and LO of the 7000K IPW-LEDs. From the research results, it can be observed that the CRI and CQS can be increased to 85 and 71, respectively. However, the LO has a decrease in the increasing trend of the red phosphor concentration. This paper provides the new recommendation for the manufacturing of the IPW-LEDs.

Keywords: *CQS, CRI, IPW-LEDs, LO, red phosphor*

1. Introduction

In the history of human development, lighting sources have been changed from collecting natural fire sources from drilling wood to torch, oil lamp, to the candle, and later to the widely used kerosene lamp, and now to white LEDs (W-LEDs) [1]. Nowadays, W-LEDs is considered an essential solution for replacing traditional lighting sources based on excellent properties for display technology, including high brightness, low power consumption, long lifetime, fast response as well as climate impact resistance [2]. The main research direction in W-LEDs is improving their lighting performance in term of the CCT deviation (D-CCT), Color Rendering Index (CRI), Color Quality Scale (CQS) and Lumen Output (LO). Authors in [3] tried to enhancing the D-CCT of W-LEDs by adding SiO2 powder with suitable concentration to the phosphor layer, but the lumen output had a considerable decrease. On another way, the LO of the W_LEDs can be improved significantly by co-doping the green Ce0.67 Tb0.33 MgAl11 O19: Ce, Tb phosphor to the phosphor compounding as shown in [4]. For the purpose of improving the CRI of the W-LEDs, authors in [5, 6] proposed to mix the red phosphors to the high CRI multi-chip W-LEDs [7] used green (Ba, Sr) 2SiO4: Eu2+ and red CaAlSiN3: Eu2+ phosphors with various packages W-LEDs to enhance the CRI and [8] showed the missing red component in phosphor-converted W-LEDs for improving its optical properties.

In this research, we investigate the influence of the red Y2O3:Eu3+ phosphor particles' concentration on the optical properties in term of CRI, CQS, and LO of the 7000K in-cup packaging white LEDs (IPW-LEDs). The main contribution of the research paper can be summarized as the followings:

– The physical model of the 7000L IPW-LEDs based on the real W-LEDs is simulated by the Light Tools.
– The influence of the red phosphor particles' concentration on the CRI, CQS, and LO is investigated and derived by varying the red phosphor concentration from 0 to 0.36%.

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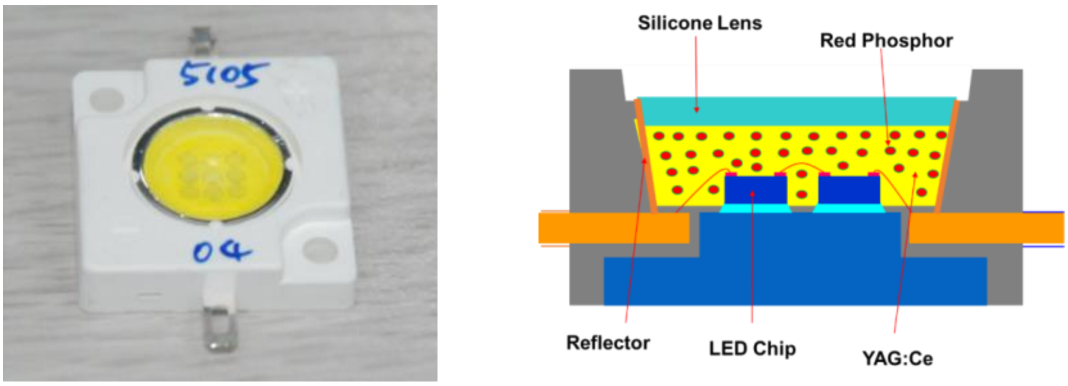
– The simulation result is confirmed by the analytical expression based on Mie-Theory and Beer-Lambert Law.

The rest of this work is drawn as below. The research method is drawn in the second section using Light Tools. The third section proposes the numerical results, analytical expression and some discussions. Finally, some conclusions is summarized in the last section.

2. Research Method

In this section, we use the real IPW-LEDs as shown in Figure 1 (a) for conducting the physical model of the 7000K IPW-LEDs by Light Tools as in Figure 1 (b). In this simulation stage, the depth, the inner and outer radius of the reflector are set to be 2.07 mm, 8 mm, and 9.85 mm, with the fixed thickness of 0.08 mm and 2.07 mm, respectively, cover nine chips. The blue LED chip has a dimension of 1.14 mm x 0.15 mm. The radiant flux of each blue chip is 1.16 W, and the peak wavelength is 453 nm. The phosphor layers consist of YAG: Ce, Y2O3:Eu3+ powders and the silicone matrix. Their refractive indexes are set to be 1.83, 1.93, and 1.50, respectively. Meanwhile, the mean radii of phosphor powders are 7.25 µm, same as real particle size [9-15].



(a) (b)

Figure 1. (a) CPW-LEDs (b) Physical model

3. Numerical Examples and Discussion

Figure 2 illustrates the influence of the concentration of the red phosphor particle on the CRI of the 7000K IPW-LEDs. In this Figure the concentration of the red phosphor particles varies continuously from 0% to 0.36%. From the results, we can see that the CRI increases crucially from 68 to near 85 when the concentration of the red phosphor varies from 0% to 0.28%. After that, the CRI falls with the concentration of the red phosphor from 0.28% to 0.36%. The maximal value of the CRI can be obtained at 85 with 0.28% to 0.30% concentration of the red phosphor particles. Moreover, the CQS of the 7000K IPW-LEDs versus the concentration of the red phosphor particles is plotted in Figure 3 with the concentration from 0% to 0.36%. Similar to the above case, the CQS rise from 66 to 71 with increasing the red phosphor concentration from 0% to 0.28% and then falls significantly when the red phosphor concentration increases further. The maximal value of the CQS is 71 with 0.28% to 0.30% red phosphor concentration. All these results can be achieved with increasing of the red phosphor concentration.

Figure 4 presents the effect of the red phosphor particles' concentration on the LO of the 7000K IPW-LEDs in the connection of increasing the red phosphor concentration from 0% to 0.36%. From Figure 4, it can be observed that the LO falls crucially with increasing the red phosphor concentration. We can justify these results based on the relationship between luminous output and the Y2O3:Eu3+ size according to Mie-scattering theory and the Beer-Lambert law [1, 12, 16-26].

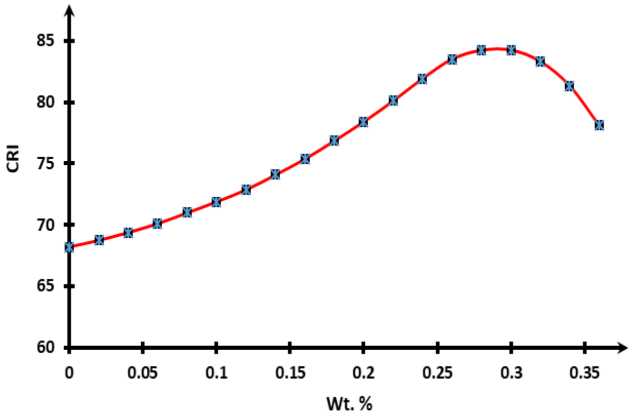


Figure 2. CRI

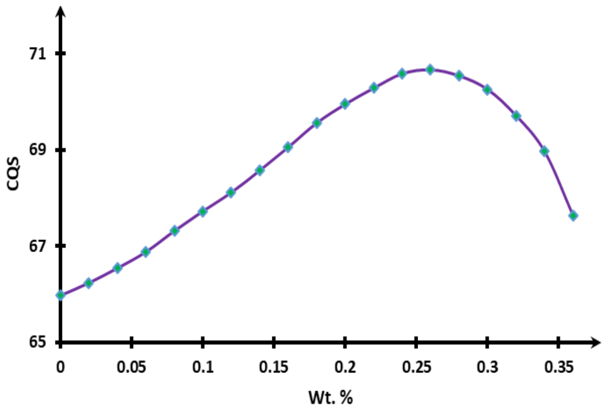


Figure 3. CQS

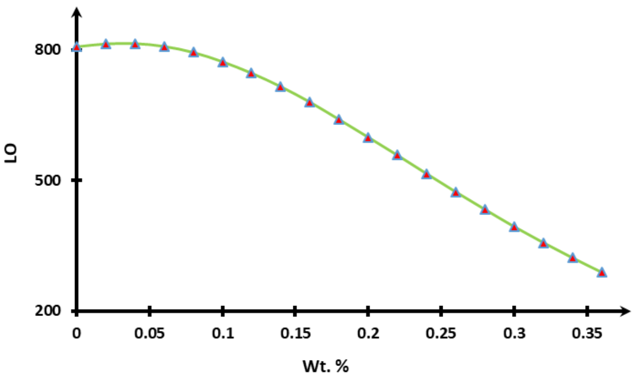


Figure 4. LO

$$I = I_0 exp(-\mu_{ext} L) \quad (1)$$

where I is the transmitted light power, I_0 is the incident light power, $\mu_{ext} = N.C_{ext}$ is the extinction coefficient, L is the path length, and N is the number of particles per cubic millimeter. According to Mie-scattering theory, the extinction cross section C_{ext} of phosphor particles can be characterized by the following equation:

$$C_{ext} = \frac{2\pi a^2}{x^2}\sum_{n=1}^{\infty}(2n+1)\,\mathrm{Re}(a_n + b_n) \quad (2)$$

Here, x=2πa/λ is the size parameter; an and bn are the expansion coefficients with even symmetry and odd symmetry, respectively.The parameters a_n and b_n are defined as:

$$a_n(x,m) = \frac{\psi_n^{'}(mx)\psi_n(x) - m\psi_n(mx)\psi_n^{'}(x)}{\psi_n^{'}(mx)\xi_n(x) - m\psi_n(mx)\xi_n^{'}(x)} \quad (3)$$

$$b_n(x,m) = \frac{m\psi_n^{'}(mx)\psi_n(x) - \psi_n(mx)\psi_n^{'}(x)}{m\psi_n^{'}(mx)\xi_n(x) - \psi_n(mx)\xi_n^{'}(x)} \quad (4)$$

where a is the spherical particle radius, λ is the relative scattering wavelength, m is the refractive index of scattering particles, and $\psi_n(x)$, $\xi_n(x)$ are the Riccati-Bessel functions [16-22].

4. Conclusion

In this study, we investigate the effect of concentration of the red Y2O3:Eu3+ phosphor on the color rendering index (CRI), Color Quality Scale (CQS) and Lumen Output (LO) of the 7000K in-cup packaging white LEDs (IPW-LEDs). The physical model of the 7000K IPW-LEDs is conducted by Light Tools software. By varying the concentration of the red phosphor from 0% to 0.36%, we use the Light Tools software to investigate the CRI, CQS, and LO of the 7000K IPW-LEDs. From the research results, it can be observed that the CRI and CQS can be increased to 85 and 71, respectively. However, the LO has a decrease in the increasing trend of the red phosphor concentration. This paper provides the new recommendation for the manufacturing of the IPW-LEDs.

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