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IMPROVING COLOR QUALITY SCALE OF CONFORMAL-PACKAGING MCW-LEDs BY RED-EMITTING $Y_2O_3:Eu^{3+}$ PHOSPHOR

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In this paper, an innovative solution of using the deep red Y2O3:Eu3+ phosphor for enhancing the Color Quality Scale (CQS) of the multi-chip white LEDs (MCW-LEDs) to more than 80 are proposed and investigated. For this purpose, the effect of the Y2O3:Eu3+ phosphor particles' concentration on the CQS is simulated, analyzed and demonstrated by Mat lab and Light Tools software. The research results show that the CQS can be enhanced to near 80, but the luminous efficacy is slightly decreased due to the enhancement extinction coefficient, scattering, reduced scattering process in the phosphor layer. All the research results are confirmed by Mie Theory and Monter Carlo simulation.

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Keywords: CQS, Color Quality Scale, Conformal Packaging, Red-emitting.

1. Introduction

From the time, when Holonyak and Bevacqua invented the first red LEDs in 1962 [1-2], LEDs has made remarkable progress in the past four decades with the huge trend of compound semiconductor technology. Moreover, LEDs with the excellent properties such as low power consumption, fast response, high brightness, a long lifetime as well as climate impact resistance have been proposed as a future source to replace traditional light source [2-5]. With the development of lighting technology, the technique based on blue LED chip and yellow phosphor (YAG: Ce3 +) is the most popular way, and phosphor converted WLEDs (pc-WLEDs) are widely used for mass production. For pc-WLED, the white light is received from mixing phosphor-converted yellow rays in phosphor coating layer and the transmitted chip-emitted blue rays. From that point of view, phosphor coating structure has an important role in illumination quality of pc-WLEDs [6]. Many researchers have been studied the phosphor coating structure, which has been thought of as an essential factor to influence the optical properties of MCW-LEDs [7-9]. The results show that packing and coating methods play an essential role in the optical properties of MCW-LEDs. Moreover, some researchers tried to investigate the influence of the phosphors' particle on lighting performance of MCW-LEDs [10-12]. Furthermore, research direction of packaging and phosphor material is still hot at this time.

In this manuscript, we propose and investigate the effect of the red-emitting $Y_2O_3:Eu^{3+}$ phosphor particles' concentration on the color quality scale (CQS) of the conformal-packaging MCW-LEDs with high CCT. By using simulation package program Light Tool and Mat Lab based on the Lambert-Beer law and Mie theory, we can see that concentration of $Y_2O_3:Eu^{3+}$ had a significant impact on CQS of conformal package MCW-LEDs. The main contributions of this paper can be considered as bellows:

1) By adding the red-emitting $Y_2O_3:Eu^{3+}$ phosphor particle into the phosphor layer, the CQS of the MCW-LEDs can be enhanced to near 80.

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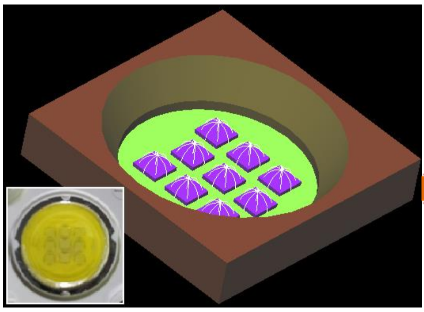
2) By control the concentration of the red-emitting$Y_2O_3:Eu^{3+}$ phosphor particle, we can obtain the optimal values of CQS and luminous efficacy of MCW-LEDs.

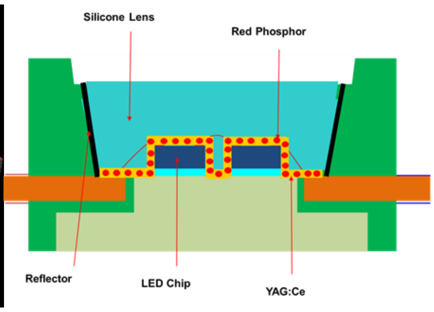
The rest of paper can be formulated as the following. Section 2 proposed the research method. The physical model and the mathematical model of MCW-LEDs is formulated in this section. Some results and discussions are proposed in section 3. Finally, section 4 concludes the paper.

2. Research method

In this results, we simulate the physical model of the high CCT conformal-packaging MCW-LEDs by the commercial software Light Tools based on Monter Carlo simulation. For thí step, we use the paremeters the real model of MCW-LEDs in the market as presented in Fig. 1a. With this model, the depth, the inner and outer radius of the reflector are 2.07 mm, 8 mm and 9.85 mm. LED chips are covered with a fixed thickness of 0.08 mm and 2.07 mm. Each blue chip has a dimension of 1.14 mm by 0.15mm, the radiant flux of 1.16 W, and the peak wavelength of 453 nm [12]. Fig. 1(b) shows that the conformal-packaging phosphor layer is coated conformally on LEDs chip. In the phosphor layer, YAG:Ce and $Y_2O_3:Eu^{3+}$ and silicone glue have the refractive indices of 1.83, 1.93 and 1.50 [10-12, 17].



(a)



(b)

Fig. 1. (a) The real MCW-LED (b), The conformal-packaging MCW-LEDs.

3. Results and discussion

In this section, the CQS performance and lumen output of the conformal-packaging MCW-LEDs are obtained and calculated by Light Tools software. We fixed the CCT of the conformal-packaging MCW-LED at 7000K, 6600K and 5600 K values and varied the concentration $Y_2O_3:Eu^{3+}$ phosphor weight from 0% to 15%. After that, CQS is calculated and presented in details in Fig. 2. We can see that CQS has a considerable increase while the concentration of the red-emitting phosphor rise from 0% to near 13%. After the optimal value, CQS decreases slightly with the concentration from 13% to 15%. The optimal value of CQS at near 80 can be received with near 13% of the red phosphor. From the research results, we can control CQS of the high CCT MCW-LEDs by adding $Y_2O_3:Eu^{3+}$ phosphor in phosphor compound and control its concentration. It can be explained by the scattering and reduced scattering process in the phosphor layer. Until now, Mie-theory has been considered as an excellent theory for calculating scattering properties of particles. In this work, the scattering properties of $Y_2O_3:Eu^{3+}$ phosphor particles including the scattering coefficient $\mu_{scattering}(\lambda)$, anisotropy factor $g(\lambda)$, and reduced scattering coefficient $\delta_{sca}(\lambda)$ can be computed by equations (1), (2), and (3):

$$\mu_{scattering}(\lambda) = \int N(r) C_{scattering}(\lambda, r) dr \quad (1)$$

$$g(\lambda) = 2\pi \int \int_{-1}^{1} p(\theta, \lambda, r) f(r) \cos\theta d(\cos\theta) dr \quad (2)$$

$$\delta_{scattering} = \mu_{scattering}(1-g). \quad (3)$$

In these equations, r is the radius of particles (µm), $C_{scattering}$ is the scattering cross sections (mm^2), λ is the light wavelength (nm), $N(r)$ indicates the distribution density of particles (mm^{-3}), θ is the scattering angle, $p(\theta,\lambda,r)$ is the phase function, and $f(r)$ is the size distribution function of α-$SrO{\cdot}3B_2O_3{:}Sm^{2+}$ particles [10-12, 17].

As presented in Fig. 2, the scattering coefficients grow with the red phosphor concentration. The scattering coefficients obtain higher values at 453 nm and lower ones at 555 nm. In this situation, the blue-light intensity becomes stronger than yellow-light, which can alleviate the deviation between the intensity distributions of blue-light and yellow-light. Moreover, the participation of red phosphor particles can enhance the absorption ability of blue light. The main contribution of phosphor particles is to increase red-light in WLEDs. From these reasons, phosphor should be considered for improving the optical performance of WLEDs. As illustrated in Fig. 4, the reduced scattering coefficients of the red phosphor at 453 nm, 555 nm, and 680 nm wavelengths grow with concentration. The deviations of the reduced scattering coefficients among three wavelengths are negligible. Correspondingly, the obtained results prove the stable scattering property of red phosphor for different wavelengths.

Furthermore, we calculate and display theeffect of $Y_2O_3{:}Eu^{3+}$ on the lumen output as shown in Fig. 6 when the concentration of the red phosphor varies from 0% to 15%. At low $Y_2O_3{:}Eu^{3+}$ concentration regime, the extinction coefficient tends to reduce, which results in the enhancement of luminous output. Meanwhile, the lumen output decreases with the $Y_2O_3{:}Eu^{3+}$ weight enhancement due to the increasing of extinction coefficient. Here, we can apply Mie-scattering theory [12] to derive the relationship of luminous output to the $Y_2O_3{:}Eu^{3+}$ weight rigorously. The transmitted light power can be calculated by the Lambert-Beer law [13-17]:

$$I = I_0 exp(-\mu_{ext} L) \quad (4)$$

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,

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 [17]:

$$C_{ext} = \frac{2\pi a^2}{x^2} \sum_{n=1}^{\infty} (2n+1) \mathrm{Re}(a_n + b_n) \quad (5)$$

The parameters a_n and b_n are defined as:

$$a_n(x,m) = \frac{\psi_n^{'}(mx)\psi_n(x) - m\psi_n(mx)\psi_n^{'}(x)}{\psi_n^{'}(mx)\xi_n(x) - m\psi_n(mx)\xi_n^{'}(x)} \quad (6)$$

$$b_n(x,m) = \frac{m\psi_n^{'}(mx)\psi_n(x) - \psi_n(mx)\psi_n^{'}(x)}{m\psi_n^{'}(mx)\xi_n(x) - \psi_n(mx)\xi_n^{'}(x)} \quad (7)$$

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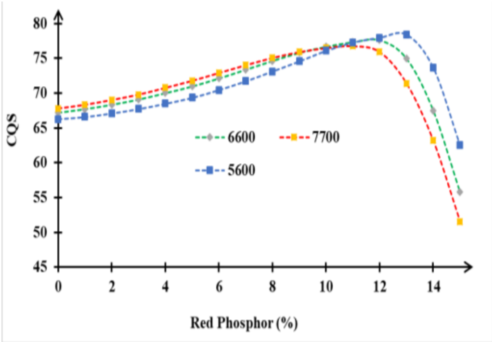

Fig. 2. The color quality scale (CQS).

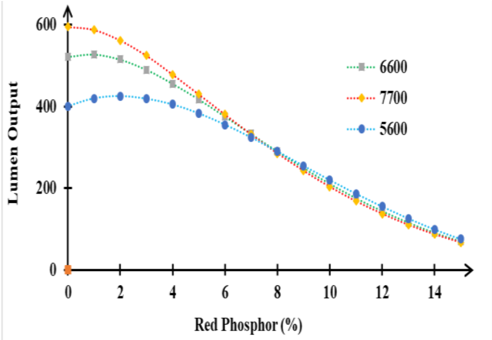

Fig. 3. Lumen Output.

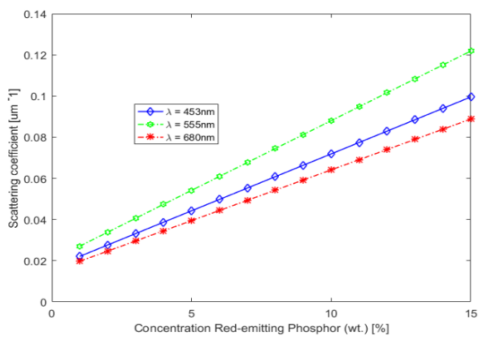

Fig. 4. Scattering coefficient.

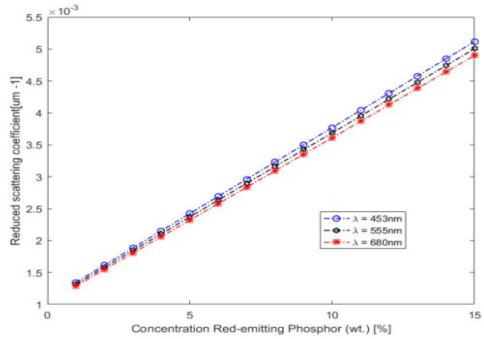

Fig. 5. Reduce scattering coefficient.

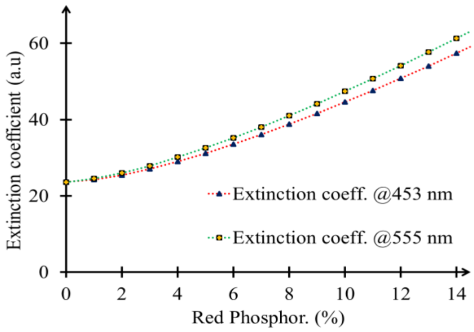

Fig. 6. Extinction coefficient.

The extinction coefficient values of the red $Y_2O_3:Eu^{3+}$ phosphor are verified for two distinct wavelengths, 555 nm, and 453 nm, which are the emission peaks of the YAG:Ce phosphor and the LED chips, respectively. The variation of the mentioned parameters concerning the $Y_2O_3:Eu^{3+}$ concentration according to the above equations are displayed in Fig.6 for 7700K, 6600 K and 5600 K respectively. It is indicated that the higher lumen output should occur at the lower $Y_2O_3:Eu^{3+}$ concentration, which corresponds to the lower extinction coefficient values. These results can be employed to estimate the influence of the concentration of $Y_2O_3:Eu^{3+}$ on the lumen output produced by the pc-WLEDs [17].

4. Conclusion

From the research results, there are some conclusions:

1) The concentration of the red phosphor affected on the lumen output and CQS of the MCW-LEDs. Moreover, the CQS can be improved more than 80.

2) The lumen output has a decreased tendency at vast weight range due to the enhancement extinction coefficient. However, it is noticeable that the lumen output can be grown after adding $Y_2O_3:Eu^{3+}$ with low weight range.

The paper proves the implications of $Y_2O_3:Eu^{3+}$ phosphor for developing MCW-LEDs manufacturing.

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