IMPROVING THE OPTICAL PROPERTIES OF RP-WLEDs BY Co-DOPING α-$SrO·3B_2O_3:Sm^{2+}$ CONVERSION PHOSPHOR INTO YELLOW-EMITTING PHOSPHOR PACKAGING

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In this paper, we investigate the optical properties in term of the correlated color temperature deviation (CCT-D), color rendering index (CRI) and lumen output (LO) of the 8500 K remote-packaging white LEDs (RP-WLEDs), while we vary the size of the red-emitting α-$SrO·3B_2O_3:Sm^{2+}$ conversion phosphor particles. By co-dopping the red α-$SrO·3B_2O_3:Sm^{2+}$ phosphor to the phosphor layer with using the Light Tool software, the CCT-D, CRI and LO of the 8500 K RP-WLEDs is investigated. Moreover, the effect of the red phosphor on the scattering process in the phosphor layer is analyzed by Mat Lab software based on the Mie Theory. The results show that the optical properties of the 8500K RP-LEDs are significantly affected by the size of the red phosphor particles. It can be lead to the novel recommendation for improving the color quality of the RP-LEDs.

(Received October 10, 2018; Accepted January 21, 2019)

Keywords: Remote packaging, α-$SrO·3B_2O_3:Sm^{2+}$, CCT Deviation, Lumen output, Color rendering index, RP-WLEDs

1. Introduction

White light-emitting diodes (wLEDs), the new-generation illumination light source replacing the conventional incandescent and fluorescent lamp, have attracted huge attention from researchers, merchants and customers because of low energy consumption, high efficiency, long lifetime, environmental friendliness and so on [1-3]. In the common LEDs industry, there are commonly three kinds of processes to fabricate wLEDs. In the first phase, single-phased yellow or mixed green and red phosphors are excited by a blue LED chip to realize white light. The near ultraviolet (n-UV) LED chips are used to excite the red, green, and blue phosphors to produce white light in a second way, and the combination of red, green, and blue three individual monochromatic LED chips forms white light in the third one. Because the third approach encounters lots of troubles, such as complicated electrics, high cost and mismatched aging properties (different thermal and driving behaviors), etc., then the former two fabrication schemes making use of phosphors have become the primary trend in the academic researches and practical applications. Since the first commercially available wLEDs came into being in Nichia Corporation, wLEDs have made fantastic and exciting progress in the last years. At present, the luminous efficiency of commercially available phosphor-converted wLEDs devices is raised to 200 lm/W [1-7].

Phosphors, namely luminescence materials, consisting of a crystalline host and an activator, are essential components of LEDs devices and play a crucial role in determining the color quality of wLEDs [3-5]. There are so many researches, which focus on improving the color

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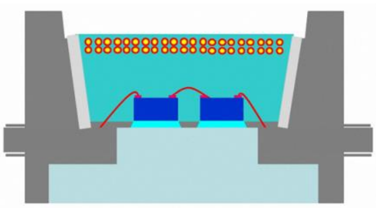
quality and lighting performance of the wLEDs in connection with phosphors. Authors in [8-9] study the influence and optimizing of the phosphor particle on the color quality of wLEDs. On the same way, authors in [10-11] investigate the wLEDs by optimizing the thickness of the phosphor layer and in [12] by optimizing the location of the phosphor layer. In [13-14], authors stated that the material and method packaging are playing an essential role in wLEDs and are necessary to investigate more and more. From this point of view, improving the optical properties of w-LEDs by adding diffusers into the phosphor layer is still necessary to investigate. In this research, we try to fill the remaining gap.

Red-emitting α-$SrO·3B_2O_3:Sm^{2+}$ phosphor having a peak wavelength of 680 nm, which is one of the red polycrystalline phosphors, is manufactured from three oxides including strontium oxide (SrO), samarium oxide Sm_2O_3, and orthoboric acid (H_3BO_3). Sm^{2+} ions are added to the polycrystalline phosphor for enhancing its absorbability at the excitation spectrum region from 420 nm to 502 nm, resulting in higher luminous efficiency. Besides, with the advantages of excellent thermal and chemical stability, α-$SrO·3B_2O_3:Sm^{2+}$ can be used for compensation red-light, resulting in the increasing of the color quality of LED lamps.However, until now, there have been too few studies which employ α-$SrO·3B_2O_3:Sm^{2+}$ for RP-WLEDs [15-16]. In the trend of these researches, we investigate the influence of the size of the red-emitting α-SrO·3B2O3:Sm2+ conversion phosphor particles on the optical properties (in term of the collated color temperature deviation (CCT-D), color rendering index (CRI) and lumen output (LO)) of the 8500 K remote-packaging white LEDs (RP-WLEDs). By co-doping the red α-SrO·3B2O3:Sm2+ to the phosphor layer using the Light Tool software, the CCT-D, CRI and LO of the 8500 K RP-WLEDs is investigated. Moreover, the effect of the red phosphor on the scattering process in the phosphor layer is analyzed by Mat Lab software based on the Mie Theory. The results show that the optical properties of the 8500K RP-LEDs are affected by the size of the red phosphor particles. It can be lead to the novel recommendation for improving the color quality of the RP-LEDs.

2. Model, simulation, and discussion

In this paper, we simulate the 8500K RP-WLEDs by Light Tools software based on the real parameters of the real wLEDs as shown in Fig. 1(a). The physical model of the 8500K RP-WLEDs is drawn in Fig. 1(b). The parameters of the RP-WLEDs as in our previous papers [15-16]. In this research, we vary the size of the red phosphor from 1µm to 8 µm for controlling and optimizing the optical properties of the 8500K RP-WLEDs. The mathematical description model of the scattering processes inner the phosphor layer can be formulated as the below section.

a)



b)

Fig. 1. (a) The white LED package without remote phosphor compound;
(b) Simulation of the RP-WLEDs.

In this research, we use the Mie-theory for calculating scattering processes of particles in the phosphor layer of RP-WLEDs as in [17-22]. Then the scattering coefficient $\mu_{scattering}(\lambda)$, anisotropy factor $g(\lambda)$, and reduced scattering coefficient $\delta_{sca}(\lambda)$ can be computed by the followings

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

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

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

Where r: the radius of particles (μm),

$C_{scattering}$: the scattering cross sections (mm^2),

λ: the light wavelength (nm),

$N(r)$: the distribution density of particles (mm^{-3}),

θ: the scattering angle,

$p(\theta,\lambda,r)$: the phase function,

and $f(r)$: the size distribution function of α-SrO·3B_2O_3:Sm^{2+} particles.

On another way, Mie-scattering theory could be applied to derive the relationship of luminous output and the Y2O3:Eu^{3+}. The transmitted light power can be formulated by using the Lambert-Beer law [17-22] as the following

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

Where I: the transmitted light power,

I_0: the incident light power,

$\mu_{ext} = N.C_{ext}$: the extinction coefficient,

L: the path length,

N: the number of particles per cubic millimeter.

The extinction cross section C_{ext} of phosphor particles can be calculated by the following equation:

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

Where x = 2πa/λ: the size parameter,

a_n and b_n: the expansion coefficients with even symmetry and odd symmetry, respectively as in[15-16].

3. Results and Discussions

In this section, the scattering coefficient versus the red phosphor size as shown in Fig. 2. In Fig. 2, the scattering coefficients (SC) increase up when the red phosphor particle increases and the SC at 453 are the highest, at 555 nm is lowest in comparison with another. It can be shown that the blue-light intensity becomes stronger than yellow-light, which can alleviate the deviation between the intensity distributions of blue-light and yellow-light. This can be caused by the involvement of the red phosphor in enhancing the absorption ability of blue-light. The influence of the red phosphor particles on the anisotropy coefficient (AC) is drawn in the Fig. 3. It is observed from the results that the anisotropy factor values at 680 nm are higher than those at 555 nm, which is an expected result. However, it is at 453nm that the maximum anisotropy factor value is obtained. This means that α-SrO·3B2O3:Sm2+ should display the strongest scattering event at 453 nm. In the same way, Fig. 4 illustrates the reduced scattering coefficients (RSC) versus the red phosphor particles. RSC is the same for 453 nm, 555 nm, and 680 nm wavelengths. From the results, it can be observed that the red phosphor is effected on the scattering process inner the phosphor layer of wLEDs.

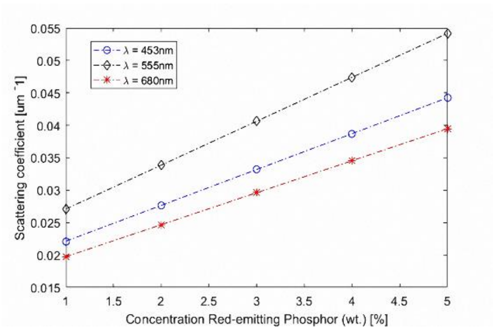


Fig. 2. Scattering coefficients

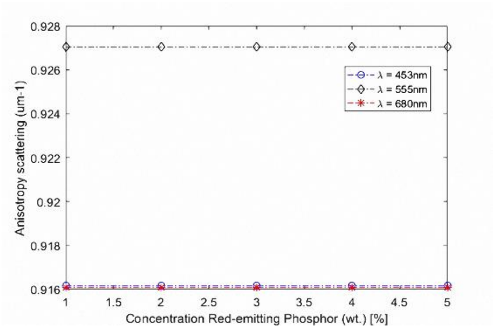


Fig. 3. Anisotropy scattering coefficients

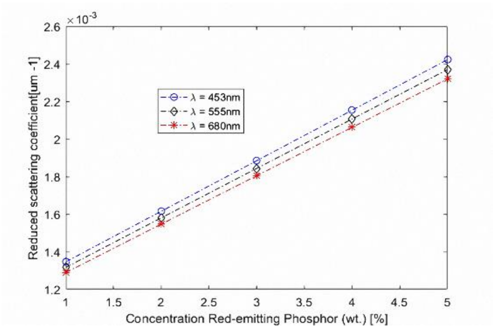


Fig. 4. Reduced scattering coefficients

Moreover, the effect of the red α-SrO·$3B_2O_3$:Sm^{2+} phosphor particles' size on the CRI of the 8500K RP-WLEDs is presented in Fig. 5. In this analysis, the size of the red phosphor is varied from 1µm to 8µm. The results show that CRI decreases from 76 to 71 by increasing the size of the red phosphor. In the beginning, the CRI falls significantly and is more stable in the end interval increasing of the red phosphor size. Fig. 6 illustrates the LO of the 8500K RP-WLEDs versus the red phosphor particles 'size. Firstly, LO rises from 710 lm to 740 lm and then falls to 680 lm. Finally, the influence of the red phosphor particles' size on the CCT-D of the 8500K RP-WLEDs is proposed in Fig. 7. The results show that the CCT-D has a considerable decrease from 8502K to 8499K with rising the size of the red phosphor from 1µm to 8µm. From all the results, we can see that the size of the red phosphor particles has a massive effect on the optical properties of the RP-WLEDs. This is in connection with the scattering process in the phosphor layer.

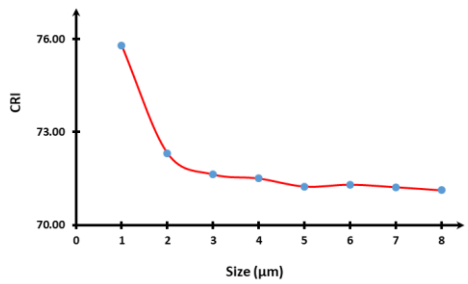


Fig. 5. CRI versus red phosphor particle's size of RP-WLEDs

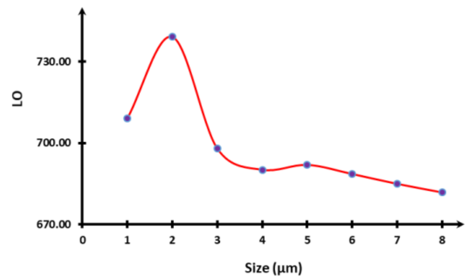


Fig. 6. Luminous flux versus red phosphor particle's size of RP-WLEDs

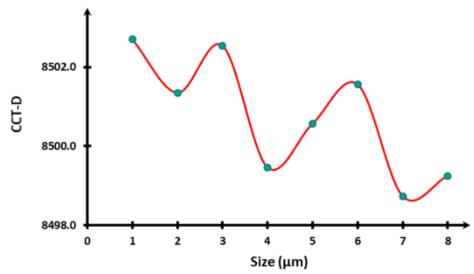


Fig. 7. D-CCT red phosphor particle's size of RP-WLEDs

4. Conclusions

In this paper, we investigate the influence of the size of the red-emitting α-SrO·3B2O3:Sm2+ conversion phosphor particles on the optical properties (in term of the collated color temperature deviation (CCT-D), color rendering index (CRI) and lumen output (LO)) of the 8500 K remote-packaging white LEDs (RP-WLEDs). The results show that the optical properties of the 8500K RP-LEDs are affected by the size of the red phosphor particles. It can be lead to the novel recommendation for improving the color quality of the RP-LEDs.

Acknowledgments

The authors appreciate the support of Professor Hsiao-Yi Lee, Department of Electrical Engineering, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan.

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