Influence of $Ca[Mg_3SiN_4]Ce^{3+}$ phosphor's concentration on optical properties of the 5600K RP-WLEDs

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ABSTRACT

In this paper, we propose $Ca[Mg_3SiN_4]Ce^{3+}$ Phosphor as a new material solution for improving the optical properties in terms of CRI, CQS. D-CCT, LO of the 5600K remote-packaging white LEDs (RP-WLEDs). In the first stage, we built and investigated the 5600K RP-WLEDs by adding the red phosphor to the phosphor layer. Then, the scattering processes inside the phosphor layer are investigated by Mat Lab software. From the research results, we discovered that the concentration of the adding phosphor significantly improved the optical properties of the 5600K RP-WLEDs. All the results are convinced by Light Tools and Mat Lab software.

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1. INTRODUCTION

In comparison with incandescent and fluorescent lamps, the InGaN-based white-light-emitting diodes (LEDs) have many advantages in energy efficiency, long lifetime, compactness, and environment-friendly and designable features. Phosphor converted LEDs (pcLED), which combines a blue LED chip and the yellow emitting phosphor, is the most common way to conduct the white light emission through LEDs packaging [1-5]. Thickness and concentration of phosphor are considered as the main factors in the white LEDs packaging because the luminous flux and color of LEDs are adjusted mainly through changing the phosphor thickness and concentration after the phosphor converters are chosen. The influence of phosphor thickness and concentration on LEDs luminous flux and CCT is studied in [6, 7] by experiment. Authors in [8] investigated the effects of phosphor thickness, concentration, and size on the spatial color distribution of white LEDs. In [9-12], the effect of phosphor location on the spatial color distribution was investigated. Moreover, some researchers were concentrated on enhancing the optical performance of multi-chip white LEDs (MCW-LEDs) by adding green or red phosphor into the phosphor layer [13-17].

The optical properties of the 5600K RP-WLEDs is considered as a novel method. From the research, results we can state that the CCT Deviation (D-CCT), CRI, CQS, and lumen output may be significantly increased by varying the concentration of α $Ca[Mg_3SiN_4]Ce^{3+}$ phosphor particles from 10% to 30%. In this paper, we focus on the main contributions as follows:

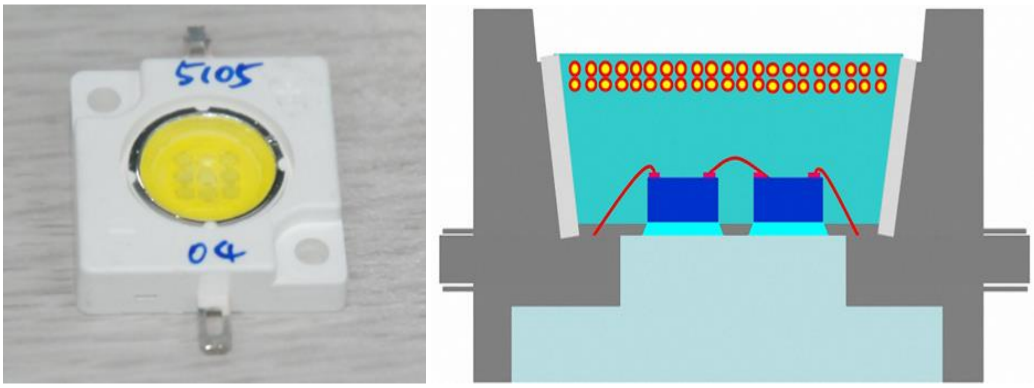
a. We conduct the RP-WLEDs model by Light Tools software.
b. The scattering process in the phosphor layer of the RP-WLEDs is investigated with Mat Lab software.

c. The influence of the red phosphor on the optical properties in terms of CRI, CQS, D-CCT, and LO is analyzed.

The structure of the rest of the paper can be drawn as follows. The research method is proposed in the second section. Section 3 presents the research results and makes some discussions. Some conclusions are drawn in the last section.

2. RESEARCH METHOD

In this section, the 5600K RP-WLEDs are employed. Figure 1(a) presents a real WLEDs package. Based on this package, the remote phosphor compound should be simulated by the Light Tools software, as shown in Figure 1(b). In this model, RP-WLEDs have been c configured as in previous studies. The main parameters of the 5600K RP-WLEDs can be conducted as in [13].



(a) (b)

Figure 1. (a) The real white LED package; (b) Physical model of the RP-WLEDs package.

3. RESULTS AND ANALYSIS

In this simulation, the concentration of $Ca[Mg_3SiN_4]Ce^{3+}$ should be varied continuously from 10% to 30% for selecting a proper concentration. The optical properties of $Ca[Mg_3SiN_4]Ce^{3+}$ particles are configured by using the Light Tools software based on Mie-theory as in [13, 18-25]. The scattering coefficient $\mu_{scattering}(\lambda)$, anisotropy factor $g(\lambda)$, and reduced scattering coefficient $\delta_{sca}(\lambda)$ can be formulated as:

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

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

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

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 $Ca[Mg_3SiN_4]Ce^{3+}$ particles.

The scattering coefficients increase significantly with the rising $Ca[Mg_3SiN_4]Ce^{3+}$ concentration from 0% to 30%, as plotted in Figure 2. The scattering coefficients at 453 nm get the highest values and the lowest ones at 555 nm. Figure 3 shows the anisotropy factors of $Ca[Mg_3SiN_4]Ce^{3+}$ particles at the wavelengths of 453 nm, 555 nm, and 680 nm, respectively. It is observed from the results that the anisotropy factor values at 680 nm are higher than at 555 nm. However, it is at 453 nm that the maximum anisotropy factor value is obtained. From simulation results, the anisotropy factors have a slight deviation approximately between 0.978 and 0.982. The concentration of $Ca[Mg_3SiN_4]Ce^{3+}$ particles is varied from 0% to 30%, continuously. The reduced scattering coefficients of $Ca[Mg_3SiN_4]Ce^{3+}$ at 453 nm, 555 nm, and 680 nm wavelengths grow with $Ca[Mg_3SiN_4]Ce^{3+}$ concentration, as shown in Figure 4. The deviations of the reduced scattering coefficients among three wavelengths are the same values [13, 18-22].

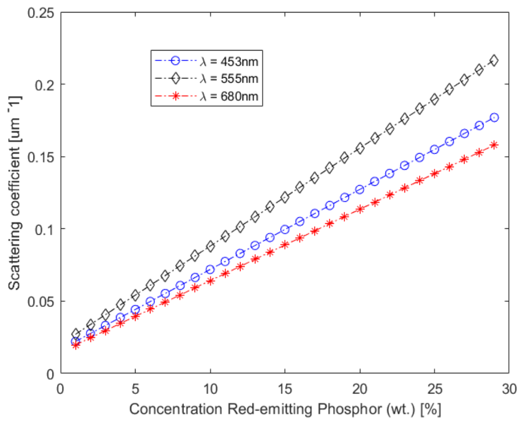


Figure 2. Scattering coefficients

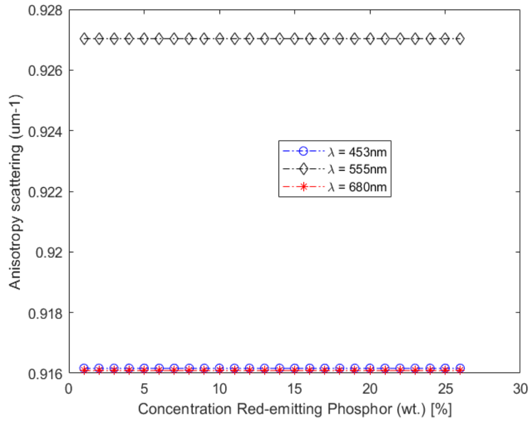


Figure 3. Anisotropy scattering

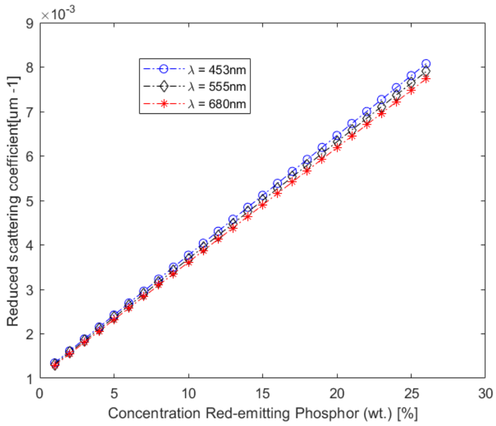


Figure 4. Reduced scattering coefficients

From Figure 5, we can state that the CRI rises from 64 to 74, while the concentration of the phosphor varies from 10 to 30%. In the same way, the CQS increases from 63.5 to 69.5 while the concentration of the phosphor varies from 10 to 30% are plotted in Figure 6. From these results, we can say that the concentration of the red phosphor significantly influences on the color quality of the 5600K RP-WLEDs. Furthermore, the influence of the red phosphor concentration on the LO and D-CCT of the 5600K RP-WLEDs is illustrated in Figure 7 and 8. As shown in Figure 7, LO increases with 10% to 25% concentration of the red phosphor and then has a huge decrease with 25% to 30% concentration of the red phosphor. Moreover, D-CCT has a slight decrease when the concentration of the red phosphor varies from 10% to 30%.

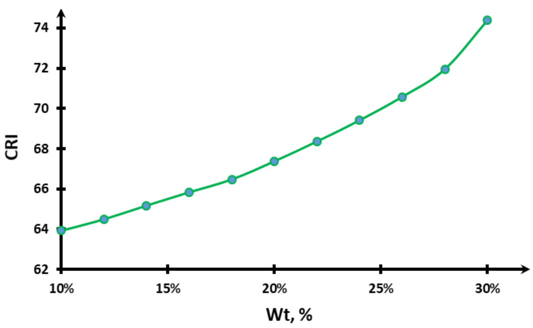


Figure 5. CRI

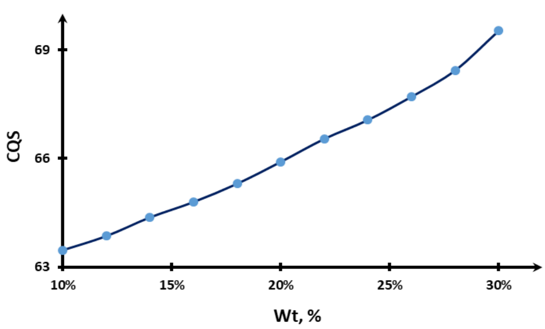


Figure 6. CQS

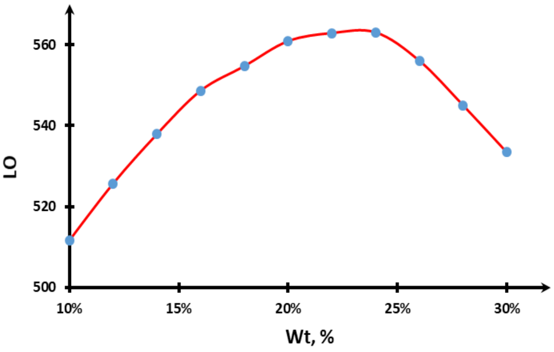


Figure 7. Luminous flux

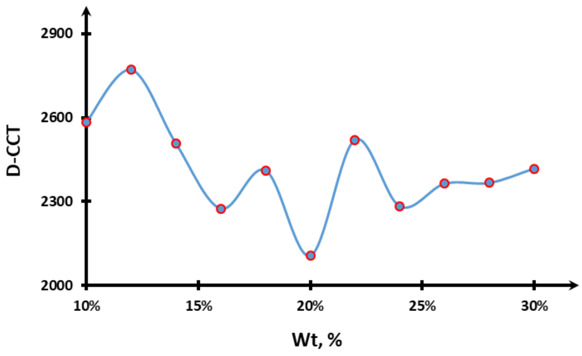


Figure 8. D-CCT

4. CONCLUSION

In this paper, we propose Ca[Mg3SiN4]Ce3+ Phosphor as a novel recommendation for improving the optical properties in terms of CRI, CQS, D-CCT, and LO of the 5600K RP-WLEDs. From the research results, we discovered that the concentration of the adding phosphor significantly improved the optical properties of the 5600K RP-WLEDs. All the results are convinced by Light Tools and Mat Lab software. The CRI can be increased from 74 to 85, and CQS from 64 to 70, respectively. This research can provide a novel recommendation for improving the optical properties of the RP-WLEDs.

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