International Journal of Electrical and Computer Engineering (IJECE)
Vol. 9, No. 5, October 2019, pp. 3975~3980
ISSN: 2088-8708, DOI: 10.11591/ijece.v9i5.pp3975-3980

$K_2SiF_6:Mn^{4+}$ phosphor: recommendation for improving LO and D-CCT of the 7700K RPW-LEDs

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Article Info

Article history:

Received Jan 8, 2018
Revised Apr 23, 2019
Accepted Apr 30, 2019

Keywords:

CQS
CRI
D-CCT
LO
RPW-LEDs

ABSTRACT

In this paper, we propose a new recommendation for improving lumen output (LO) and CCT deviation (D-CCT) of the 7700 K RPW-LEDs by K2SiF6:Mn4+ red phosphor. Based on Light Tool and Mat Lab simulation software, we can see that the D-CCT and LO can be improved significantly, but the CQS and CRI have a slight decrease with increasing the concentration of the red phosphor. Besides, the analytical and simulation results agree well with each other.

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1. INTRODUCTION

In the last few years, LEDs can be considered as a potential replacement for the conventional light sources based on their advantages such as long lifetime, low electric consumption, fast switching, high brightness, robustness, small size, and environment-friendly characters [1-7]. Nowadays, packaging direction is the primary direction research on improving the optical performance of the LEDs. By controlling the thickness and concentration of phosphor, we can control the optical properties of LEDs in term of Color colerrated temperature deviation (D-CCT), Color rendering index (CRI), Color quality scale (CQS) and lumen output (LO). Authors in [8, 9] experimentally studied that higher luminous efficacy are taken with the lower phosphor concentration and higher phosphor thickness. [10] states that we can improve the spatial color uniformity of white LEDs by changing the phosphor concentration or thickness. In [11-14], authors investigate the effect of phosphor location on the spatial color distribution and derive that packaging elements should make the blue light and yellow light have a similar radiation pattern for obtaining high color uniformity. On the same direction, authors in [15-17] focus on improving the optical properties of multi-chip white LEDs (MCW-LEDs) by green or red phosphor [15-17].

In this paper, the red-emitting $K_2SiF_6{:}Mn^{4+}$ phosphor is proposed to improving the D-CCT, CRI, CQS, and LO of the 7700K remote packaging W-LEDs (RPW-LEDs). The main contribution of the paper can be formulated as the followings

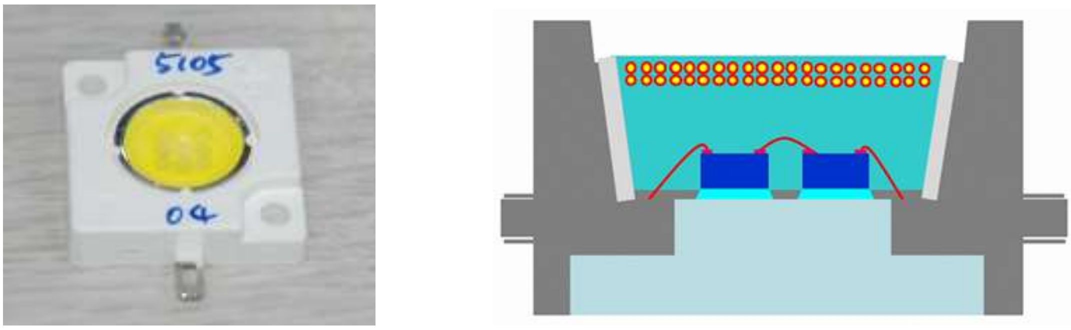
- Physical model of the 7700K RPW-LEDs is constructed by Ligh Tools. By varying the concentration of the red phosphor, we investigate the D-CCT, CQS, CRI, and LO of the 7700K RPW-LEDs.
- The analytical descriptions and simulation scattering process in phosphor layers of the 7700 K RPW-LEDs is built by Mat Lab software.
- The results derived the influence of the concentration red phosphor on the D-CCT, CQS, CRI, and O of the RPW-LEDs.

The rest of the paper can be organized as the followings. The research method is proposed in the second section. The third section provides the research results and discussions. Some conclusions are shown in the last section.

2. RESEARCH METHOD

In this research, we simulate the physical model of the 7700K RPW-LEDs as in Figure 1(b) based on the real model of the RPW-LED as in Figure 1(a). For this purpose, we set the main parameters of the RPW-LEDs as the followings:

- The depth, the inner and outer radius of the reflector to 2.07 mm, 8 mm and 9.85 mm, respectively.
- 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.
- The phosphor layer consists of the yellow-emitting YAG:Ce and the red-emitting $K_2SiF_6{:}Mn^{4+}$ conversion phosphors particles and the silicone glue, which respectively have the refractive indices of 1.85, 1.95 and 1.50. Also, the average radius of the yellow-emitting YAG:Ce phosphor particles are set to 7.25 µm like a value of real particle size [15-17].



(a) (b)

Figure 1. (a) The real RPW-LEDs, (b) Physical model of the 7700K RPW-LEDs

Here, we use the Mie-theory for investigating the influence of the concentration of the red phosphor on the optical performance of the RPW-LEDs [1, 3, 15-17]. The scattering process in the phosphor layers can be formulated via the coefficients. The scattering coefficient $\mu_{sca}(\lambda)$ (mm^{-1}), the absorption coefficient $\mu_{abs}(\lambda)$ (mm^{-1}), anisotropy factor $g(\lambda)$ (mm^{-1}), and reduced scattering coefficient $\delta_{sca}(\lambda)$ (mm^{-1}) can be computed by the below expressions (1), (2), (3), and (4):

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

$$\mu_{abs}(\lambda) = \int N(r) C_{abs}(\lambda, r) dr \quad (2)$$

$$g(\lambda) = 2\pi \int \int_{-1}^{1} p(\theta, \lambda, r) f(r) \cos\theta d \cos\theta dr \quad (3)$$

$$\delta_{sca} = \mu_{sca}(1 - g) \quad (4)$$

where $N(r)$ indicates the distribution density of diffusional particles (mm^3). C_{abs} and C_{sca} is the absorption and scattering cross sections (mm^2), $p(\theta,\lambda,r)$ is the phase function, λ is the light wavelength (nm), r is the radius of diffusional particles (µm), and θ is the scattering angle (°), and $f(r))$ is the size distribution function of the diffuser in the phosphorous layer. Moreover, $f(r)$ and $N(r)$ can be calculated by:

$$f(r) = f_{dif}(r) + f_{phos}(r) \quad (5)$$

$$N(r) = N_{dif}(r) + N_{phos}(r) = K_N.[f_{dif}(r) + f_{phos}(r)] \quad (6)$$

$N(r)$ is composed of the diffusive particle number density $N_{dif}(r)$ and the phosphor particle number density $N_{phos}(r)$. In these equations, $f_{dif}(r)$ and $f_{phos}(r)$ are the size distribution function data of the diffusor and phosphor particle. Here K_N is the number of the unit diffusor for one diffuser concentration and can be calculated by the following equation:

$$c = K_N \int M(r)dr \quad (7)$$

where $M(r)$ *is* the mass distribution of the unit diffuser and can be proposed by the below equation:

$$M(r) = \frac{4}{3}\pi r^3[\rho_{dif} f_{dif}(r) + \rho_{phos} f_{phos}(r)] \quad (8)$$

Here $\rho_{diff}(r)$ and $\rho_{phos}(r)$ are the density of diffuser and phosphor crystal [18-26].

3. RESULTS AND DISCUSSION

Figure 3 plots the influence of the red phosphor concentration on the scattering coefficient with the wavelengths 453nm, 555nm, and 680nm. From the results, it can be seen that the scattering coefficient increases with increasing the red phosphor concentration. The highest scattering coefficient is the 555nm wavelength, and the lowest is the 680nm one. It can be observed that the white-light quality can be enhanced by controlling red phosphor concentration. The reduced scattering coefficient of the RPW-LEDs phosphor layer versus the red phosphor concentration is presented in Figure 4. We can see that the reduced scattering coefficients of wavelengths 453nm, 555nm, and 680nm significantly rise up while red phosphor concentration from 0 to 30%. All reduced scattering coefficients of wavelengths 453nm, 555nm and 680nm are the same with each other.

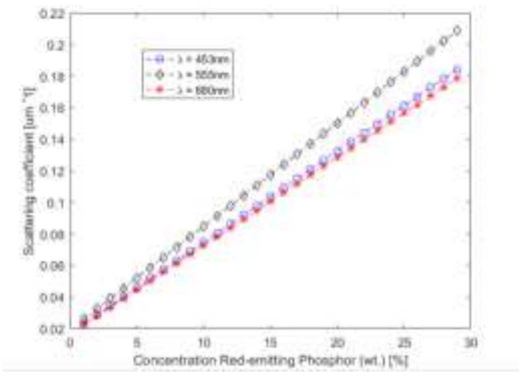


Figure 3. Scattering coefficients

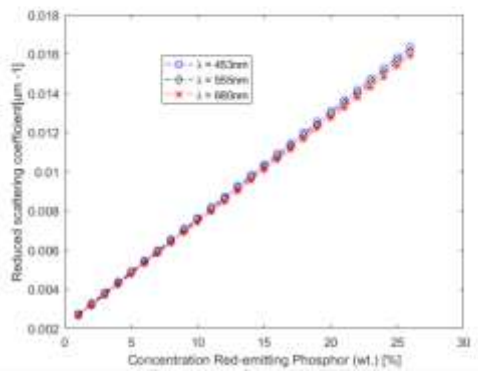


Figure 4. Reduced scattering coefficient

Anisotropy coefficients of wavelengths 453nm, 555nm, and 680nm versus the red phosphor concentration are illustrated in Figure 5. From Figure 5, we can see that all anisotropy coefficients of wavelengths 453nm, 555nm and 680nm do not change with increasing the red phosphor concentration from 0 to 30 %. The anisotropy coefficients of wavelengths 555nm are higher than the other ones. The anisotropy coefficients of wavelengths 453nm and 680nm are the same. Besides, the scattering amplitude of wavelengths 453nm, 555nm and 680nm are shown in Figure 6. It can be observed that green light has the highest amplitude.

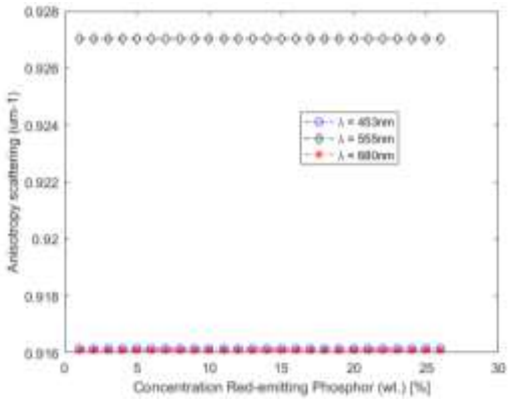


Figure 5. Anisotropy coefficient

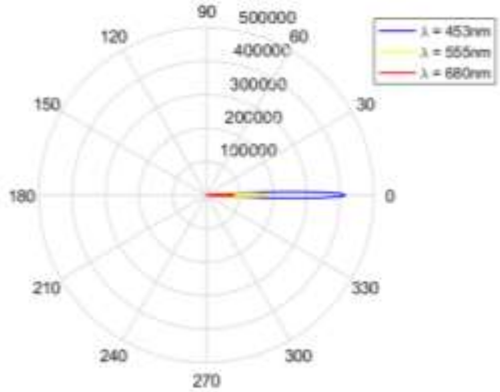


Figure 6. The scattering amplitude

The influence of the red phosphor concentration on the CQS and CRI is plotted in Figure 7 and Figure 8. In these figure, the red phosphor concentration varies from 3% to 26%. From Figure 7, we can say that CQS has a slight increase when the concentration of red phosphor varies from 3% to 18%, then significantly falls up with 18% to 26% concentration of red phosphor. On another hand, CRI decreases crucially from 68 to 63 while red phosphor concentration increases from 3 to 26% as shown in Figure 8.

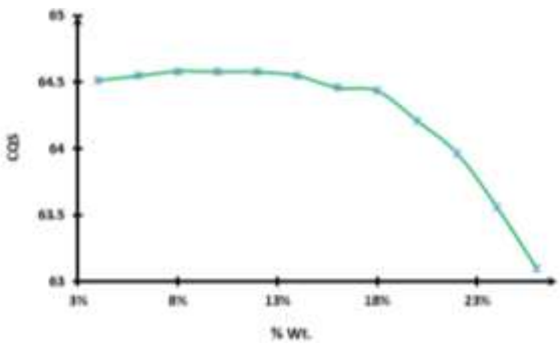


Figure 7. CQS

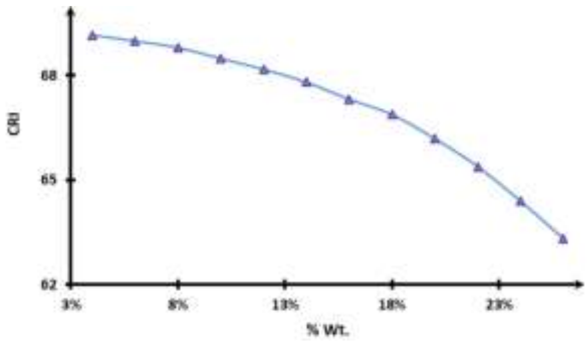


Figure 8. CRI

However, LO of the 7700K RPW-LEDs versus the red phosphor concentration is presented in Figure 9. It is observed that LO rises from 620 lm. To near 1500 lm when the red phosphor concentration varies from 3 to 26%. Also, the D-CCT has a massive decrease from 7200 to 3200 with increasing the concentration of the red phosphor as shown in Figure 10. The results show that we can control the LO and D-CTT by varying the concentration of the red phosphor. All the simulation and numerical results agree well with each other.

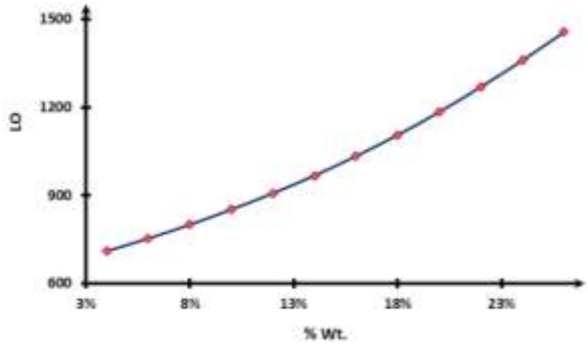


Figure 9. LO

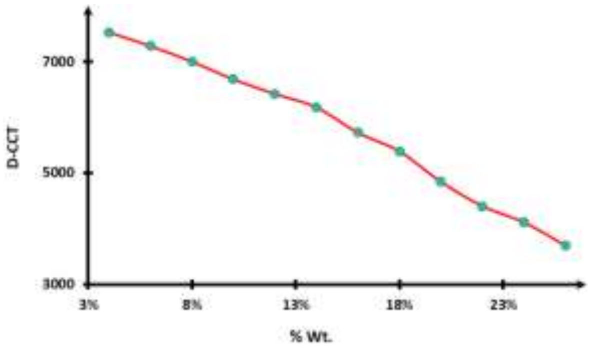


Figure 10. D-CCT

4. CONCLUSION

In this paper, we propose a new recommendation for improving lumen output (LO) and CCT deviation (D-CCT) of the 7700 K RPW-LEDs by K2SiF6:Mn4+ red phosphor. Based on Light Tool and Mat Lab simulation software, we can see that the D-CCT and LO can be improved significantly, but the CQS and CRI have a slight decrease with increasing the concentration of the red phosphor. In addition, the analytical and simulation results agree well with each other.

REFERENCES

[1] "Design of LED Packaging Applications," *LED Packaging for Lighting Applications*, pp. 215-315, 2011.
[2] E. Gibney, "Nobel for Blue LED That Revolutionized Lighting," *Nature*, vol. 514, pp. 152-153, 2014.
[3] H. Winkler, et al., "LED Lighting:Technology and Perception," Weinheim, Wiley-VCH, 2015.
[4] X. Luo, et al., "Heat and Fluid Flow in High-Power LED Packaging and Applications," *Progress in Energy and Combustion Science*, vol. 56, pp. 1-32, 2016.
[5] H. F. Sijbom, et al., "K_2SiF_6:Mn^4 as a red phosphor for displays and warm-white LEDs: A review of properties and perspectives," *Optical Materials Express*, vol. 7, pp. 3332, 2017.
[6] P. F. Smet, et al., "Selecting Conversion Phosphors for White Light-Emitting Diodes," *Journal of the Electrochemical Society*, vol. 158, 2011.
[7] Y. Wang, et al., "Investigations on the luminescence of emission-tunable Ca10K(PO4)7:Eu2 , Sr2 , Mg2 phosphors for white LEDs," *RSC Adv.*, vol. 5, pp. 2689-2693, 2015.
[8] N. T. Tran and F. G. Shi, "Studies of Phosphor Concentration and Thickness for Phosphor-Based White Light-Emitting-Diodes," *Journal of Lightwave Technology*, vol. 26, pp. 3556-3559, 2008.
[9] Y. Shuai, et al., "Angular CCT uniformity of phosphor-converted white LEDs: effects of phosphor materials and packaging structures," *IEEE Photonics Technology Letters*, vol. 23, pp. 137-139, 2011.
[10] C. Sommer, et al., "Tailoring of the Color Conversion Elements in Phosphor-Converted High-Power LEDs by Optical Simulations," *IEEE Photonics Technology Letters*, vol. 20, pp. 739-741, 2008.
[11] S. Li, et al., "Angular Color Uniformity Enhancement of Phosphor Converted White LEDs Integrated with Compact Modified Freeform TIR Components," *2012 13thInternational Conference on Electronic Packaging Technology&High Density Packaging*, 2012.
[12] Z. Liu, et al., "Analysis of Factors Affecting Color Distribution of White LEDs," *2008 International Conference on Electronic Packaging Technology & High Density Packaging*, 2008.
[13] Z. Liu, et al., "Optical Analysis of Color Distribution in White LEDs with Various Packaging Methods," *IEEE Photonics Technology Letters*, vol. 20, pp. 2027-2029, 2008.
[14] Z. Liu, et al., "Effects of Phosphor's Location on LED Packaging Performance," *2008 International Conference on Electronic Packaging Technology & High Density Packaging*, 2008.
[15] T. H. Q. Minh, et al., "Red-Emitting α-SrO·3B2O3:Sm2 Phosphor: an Innovative Application for Increasing Color Quality and Luminous Flux of Remote Phosphor White LEDs," *Journal of the Chinese Institute of Engineers*, vol. 40, pp. 313-317, 2017.
[16] N. D. Q. Anh, et al., "Y2O3:Eu3 Phosphor: a Novel Solution for an Increase in Color Rendering Index of Multi-Chip White LED Packages," *Journal of the Chinese Institute of Engineers*, vol. 40, pp. 228-234, 2017.
[17] N. D. Q. Anh and H. Y. Lee, "Improving the Angular Color Uniformity and the Lumen Output for Multi-Chip White LED Lamps by Green Ce0.67Tb0.33MgAl11O19: Ce,Tb Phosphor," *Journal of the Chinese Institute of Engineers*, vol. 39, pp. 871-875, 2016.
[18] "Beyond Mie's Theory II - The Generalized Mie Theory," *Optical Properties of Nanoparticle Systems*, pp.317-339, 2011.
[19] J. R. Frisvad, et al., "Predicting the Appearance of Materials Using Lorenz–Mie Theory," *The Mie Theory Springer Series in Optical Sciences*, pp. 101-133, 2012.

[20] D. Mackowski, “The Extension of Mie Theory to Multiple Spheres,” *The Mie Theory Springer Series in Optical Sciences*, pp. 223-256, 2012.
[21] T. Wriedt, “Mie Theory: A Review,” *The Mie Theory Springer Series in Optical Sciences*, pp. 53-71, 2012.
[22] X. Luo and R. Hu, “Chip packaging: Encapsulation of nitride LEDs,” *Nitride Semiconductor Light-Emitting Diodes (LEDs)*, pp. 441-481, 2014.
[23] M. I. Mishchenko, et al., “Scattering, Absorption, and Emission of Light by Small Particles,” Cambridge, Cambridge University Press, 2002.
[24] J. Zhong, et al., “Mie Theory Simulation of the Effect on Light Extraction by 2-D Nanostructure Fabrication,” *2011 Symposium on Photonics and Optoelectronics (SOPO)*, 2011.
[25] C. Sommer, et al., “The Impact of Light Scattering on the Radiant Flux of Phosphor-Converted High Power White Light-Emitting Diodes,” *Journal of Lightwave Technology*, vol. 29, pp. 2285-2291, 2011.
[26] M. Jonasz and G. R. Fournier, “General Features of Scattering of Light by Particles in Water,” *Light Scattering by Particles in Water*, pp. 87-143, 2007.