



# Effect of Green-emitting $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$ Phosphor Concentration on the Correlated Color Temperature Deviation and the Lumen Output of the 7700 K Conformal Packaging WLEDs

Phu Tran Tin<sup>1</sup>, Tran Hoang Quang Minh<sup>2\*</sup>, Nguyen Huu Khanh Nhan<sup>2</sup>, and Tran Thanh Trang<sup>3</sup>

<sup>1</sup>Faculty of Electronics Technology, Industrial University of Ho Chi Minh City, Ho Chi Minh City, Vietnam.

<sup>2</sup>Optoelectronics Research Group, Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.

<sup>3</sup>Faculty of Electrical and Electronics Engineering, Ho Chi Minh City University of Food Industry, 140 Le Trong Tan, Ho Chi Minh City, Vietnam.

(Received 27 May 2017; Accepted 14 June 2017; Published on line 1 September 2018)

\*Corresponding author: [tranhoangquangminh@tdt.edu.vn](mailto:tranhoangquangminh@tdt.edu.vn)

DOI: [10.5875/ausmt.v8i3.1457](https://doi.org/10.5875/ausmt.v8i3.1457)

**Abstract:** In this manuscript, we propose a recommendation for improving the correlated color temperature deviation (D-CCT) and the lumen output of 7700 K WLEDs by adding the green-emitting  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  phosphor into the yellow-emitting YAG:Ce phosphor compounding. From the research results, the D-CCT could decrease more than 4 times, and the lumen output increased more than 1.5 times in comparison with the non-green-emitting  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  phosphor case. The results show that green-emitting  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  phosphor could become a new recommendation for enhancing the D-CCT and the lumen output of WLEDs.

**Keywords:** WLEDs, conformal packaging; green-emitting  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  phosphor ; D-CCT; lumen output

## Introduction

With excellence advantages (high efficiency, long lifetime, low cost, reliability, high color quality, and compactness), the white LED lamps (WLEDs) have considered like main lighting applications shortly. From the beginning to date, several approaches are recommended for the production of WLEDs. Firstly, WLEDs can be obtained by a combination of blue, green and red light chips to emit a white light spectrum. However, the high manufacturing cost and the required complicated electronics were disadvantages of this approach. Another method is a coating of yellow emitting phosphor like  $\text{Y}_3\text{Al}_5\text{O}_{12}:\text{Ce}^{3+}$  (YAG: Ce) on the blue LED with the result in white light emission. However YAG: Ce WLEDs have low color rendering index (CRI), a high correlated color temperature deviation (D-CCT) Then it is hard to use them for indoor lighting applications. The third approach

was the combination of multiple phosphors materials coated on the LED chip known as pc-LEDs. The luminescence of pc-LEDs significantly influenced by packing, assembly of phosphors and strong re-absorption of blue light by green and red phosphors. The third approach is popularly used in research and manufacturing WLEDs [1,15,16]. In recent years, many studies focused on enhancement lighting performance of W-LEDs package with the third approach. In [1,2], Quoc Anh et al. 2015, Lai et al. 2016 added  $\text{SiO}_2$  to YAG: Ce phosphor compound to enhance the color quantity of WLEDs. Seong, K. K., et al., 2012 improved D-CCT, CRI of WLEDs by doping  $\text{Y}_2\text{O}_3:\text{Eu}^{3+}$  to YAG:Ce phosphor compound [3]. Quang Minh et al. 2016 and Quoc Anh et al. 2016 on another way improved color uniformity of WLEDs with  $\text{Y}_2\text{O}_3:\text{Eu}^{3+}$  phosphor and green Ce,Tb phosphor [4,5]. However, these research only focus on increasing color uniformity and did not pay much attention to enhancing all luminous flux and color uniformity of WLEDs with high CCT (7700 K). It is the



remaining gap, which could be filled by this research work.

With significant advantages, green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> phosphor could be considered as a prospective approach in WLEDs lighting [6-8]. Nevertheless, there is not much research, which demonstrated green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> phosphor for enhancing the luminous flux and color quantity of the conformal phosphor packaging WLEDs (RP-WLEDs) as yet. In this research, a new approach by mixing green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> particles into the YAG:Ce phosphor compounding of conformal phosphor geometry (CPG) white LED lamps to improve their luminous flux, and color uniformity (D-CCT) was proposed and demonstrated. In this work, the influence of both size and concentration of green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> particles to lighting performance was analyzed and investigated. This manuscript can be divided into three sections. In the first section, a physical simulation model of 7000 K W-LEDs by the LightTools software was presented. After that influence of both size and concentration of green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> particles was calculated and analyzed by the commercial LightTools software and Mat lab. In this sections, the size of green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> particles was changed from 3 μm to 9 μm, and its concentration was varied from 0% for non-green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> particles to 28%. Finally, some results and some discussion were demonstrated and convinced totally. From the research results, the luminous flux increased more than 1,5 times, and D-CCT could decrease more than 4 times in comparison with the non-green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> phosphor case. From that point of view, green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> phosphor could become a new recommendation for enhancing the lumen output and D-CCT of WLEDs.

**PHU Tran Tin** received the Bachelor degree (2002) and Master degree (2008) from Ho Chi Minh City University of Science. In 2007, he was lecturer at the Faculty of Electronics Technology (FET), Industrial University of Ho Chi Minh City. His major research interests are wireless communication in 5G, energy harvesting, performance of cognitive radio, physical layer security, and optoelectronics.

**TRAN Hoang Quang Minh** (Corresponding Author) received his Ph.D. from Tomsk Polytechnic University, Tomsk, Russian Federation. His research interests include high-voltage power systems, relay protections and optoelectronics. He serves as Lecturer in the Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.

**NGUYEN Huu Khanh Nhan** obtained his Ph.D. from the Institute of Research and Experiments for Electrical and Electronic Equipment, Moscow. He serves as Lecturer in Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam. His research interests include VLSI, MEMS and LED driver chips.

**TRAN Thanh Trang** was born in Vietnam in 1979. He received the B.E and M.E degrees in electronics engineering from Ho Chi Minh city University of Technology, National University Ho Chi Minh city, Vietnam, in 2001 and 2004, respectively, and the Ph.D degree in electronics engineering from Yeungnam University, South Korea in 2012. His research interests include modeling and simulation of micro-nano electron devices, display engineering, photovoltaic systems, and power electronics.

## Physical and mathematical model

The real 7000 K WLEDs was simulated with physical model by the commercial LightTools software (Fig. 1). The LightTools software based on the Monte Carlo ray-tracing method. The real WLEDs has:

- 1) Each LED chip with a 1.14 mm square base and a 0.15 mm height is bonded in the reflector. The power of each blue chip is 1.16 W.
  - 2) reflector has a bottom length of 8 mm, a height of 2.07 mm and a length of 9.85 mm.
  - 3) The conformal phosphor compounding has the fixed thickness 0.08 mm, which covers the nine chips [16,17].
- The refractive indexes of the green-emitting CaF<sub>2</sub>:Ce<sup>3+</sup>,Tb<sup>3+</sup> and YAG:Ce phosphors and its silicone glue are 1.52 and 1.83, respectively. The refractive index of the silicone glue is 1.5.

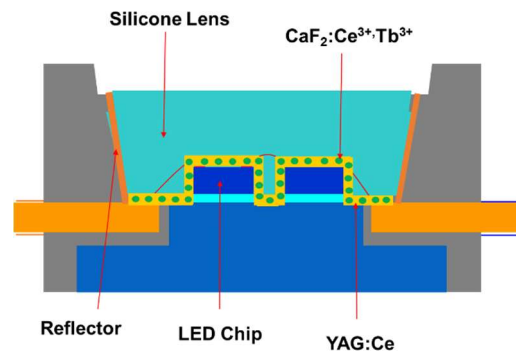


Fig. 1. The physical structure of conformal phosphor geometry (CPG) WLEDs.

In this section, we demonstrate the scattering process inside the phosphor compounding by Matlab software using Mie-scattering theory [9,15,16]. In common, the scattering coefficient  $\mu_{sca}(\lambda)$ , anisotropy factor  $g(\lambda)$ , and reduced scattering coefficient  $\delta_{sca}(\lambda)$  are calculated by expression (1), (2), and (3):

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

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

$$\delta_{sca} = \mu_{sca}(1-g), \quad (3)$$

where  $N(r)$  is the density distribution of diffusional particles,

$C_{sca}$  is the scattering cross sections,

$p(\vartheta, \lambda, r)$  is the phase function,

$\lambda$  is the wavelength of the incident light,

$r$  is the radius of particles,

$\vartheta$  is the scattering angle,

$f(r)$  is the size distribution function of the diffusers

in the phosphor layer.



$$f(r) = f_{dif}(r) + f_{phos}(r), \quad (4)$$

$$N(r) = N_{dif}(r) + N_{phos}(r) = K_N \cdot [f_{dif}(r) + f_{phos}(r)] \quad (5)$$

Where  $f_{dif}(r)$  and  $f_{phos}(r)$  are the size distribution function,  $K_N$  is the number of the unit diffusor and is calculated as follows:

$$c = K_N \int M(r) dr. \quad (6)$$

Here the mass distribution  $M(r)$  (milligrams) of the unit diffusor can calculate  $M(r)$  by the below equation:

$$M(r) = \frac{4}{3} \pi r^3 [\rho_{dif} f_{dif}(r) + \rho_{phos} f_{phos}(r)], \quad (7)$$

where  $\rho_{dif}(r)$  and  $\rho_{phos}(r)$  are the density of diffuser and phosphor crystal.

In Mie theory,  $C_{sca}$  can be presented as:

$$C_{sca} = \frac{2\pi}{k^2} \sum_0^\infty (2n-1) (|a_n|^2 + |b_n|^2), \quad (8)$$

Where  $k$  is the wavenumber ( $2\pi/\lambda$ ), and  $a_n$  and  $b_n$  are the expansion coefficients with even symmetry and odd symmetry, respectively. These coefficients can be calculated by equations below:

$$a_n(x, m) = \frac{\psi'_n(mx)\psi_n(x) - m\psi_n(mx)\psi'_n(x)}{\psi'_n(mx)\xi'_n(x) - m\psi_n(mx)\xi'_n(x)}, \quad (9)$$

$$b_n(x, m) = \frac{m\psi'_n(mx)\psi_n(x) - \psi_n(mx)\psi'_n(x)}{m\psi'_n(mx)\xi'_n(x) - \psi_n(mx)\xi'_n(x)}, \quad (10)$$

where  $x$  is the size parameter ( $= k.r$ ),  $m$  is the refractive index of the diffusive scattering particles, and  $\psi_n(x)$ ,  $\xi_n(x)$  are the Riccati - Bessel function [11].

For small spheres, the phase function  $p(\theta, \lambda, r)$  can be calculated according to the following equation:

$$p(\theta, \lambda, r) = \frac{4\pi\beta(\theta, \lambda, r)}{k^2 C_{sca}(\lambda, r)}, \quad (11)$$

where  $\beta(\theta, \lambda, r)$  is the dimensionless scattering function, which is obtained by the scattering amplitude functions  $S_1$  and  $S_2$ :

$$\beta(\theta, \lambda, r) = \frac{1}{2} [ |S_1(\theta)|^2 + |S_2(\theta)|^2 ], \quad (12)$$

$$S_1 = \sum_{n=1}^\infty \frac{2n+1}{n(n+1)} \left[ \begin{matrix} a_n(x, m)\tau_n(\cos\theta) \\ + b_n(x, m)\tau_n(\cos\theta) \end{matrix} \right], \quad (13)$$

$$S_2 = \sum_{n=1}^\infty \frac{2n+1}{n(n+1)} \left[ \begin{matrix} a_n(x, m)\tau_n(\cos\theta) \\ + b_n(x, m)\pi_n(\cos\theta) \end{matrix} \right]. \quad (14)$$

In equations (13) and (14), the angular dependent

functions  $\pi_n(\cos\theta)$  and  $\tau_n(\cos\theta)$  are expressed in the angular scattering patterns of the spherical harmonics [16,17].

## Results and Discussion

In this research, the coefficients were calculated by Mat lab software using Mie theory. In the Mie-scattering computing, the concentration of  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  particles is varied from 0 % to 28%, continually. As presented in Fig. 2, the scattering coefficients grow with the growing  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  concentration. In this situation, the yellow-light intensity becomes stronger in comparison with blue-light intensity. From that point of view,  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  could be used to improve the D-CCT and the lumen output of WLEDs. Moreover, the reduced coefficient is the same for the cases 555 nm, and 453 nm wavelengths (Fig. 3). The reduced scattering coefficients of  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  among 453 nm, 555 nm wavelengths grow with  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  concentration. The results showed that  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  had a significant influence on all scattering and reduced coefficients (Fig. 4).

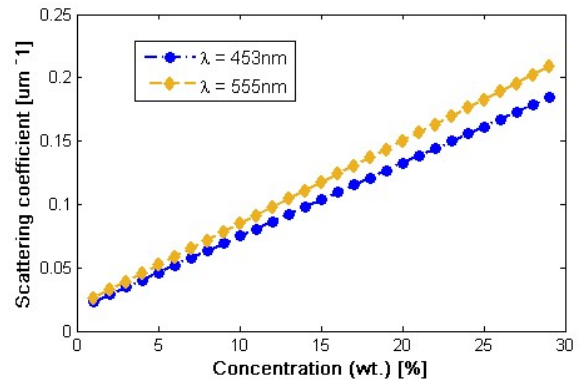


Fig. 2. Scattering coefficients of  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  in proportion to wavelengths of 453nm, 555nm.

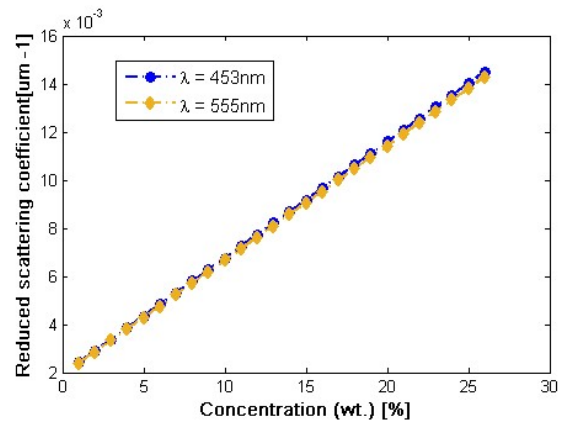


Fig. 3. Reduced scattering coefficient of  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  in proportion to wavelengths of 453nm, 555nm.

The D-CCT and lumen output of WLEDs with  $\text{CaF}_2:\text{Ce}^{3+}, \text{Tb}^{3+}$  particles were calculated by the commercial



Light Tool software. As illustrated in Fig. 5, D-CCT of the 7000 K conformal packaging WLEDs decreased more than 4 times. These results could be explained by compensating blue-light in pc-LED as employing  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  particles phosphor. The minimum D-CCT could be obtained with the  $1\ \mu\text{m}$  size and 12% concentration of  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  particles. The higher concentration and less size, the smaller D-CCT can be obtained. Furthermore, the lumen output of the 7000 K WLEDs increased remarkably by increasing concentration and decreasing size of  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  particles. The lumen output could be increased more than 1,5 times (Fig. 6). The maximum value of luminous flux is near 950 lm with  $\mu\text{m}$  size and 12% concentration of  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  particles. From those results, the optimal size and concentration of  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  particles was around  $1\ \mu\text{m}$  in size and 12% in concentration. Finally, the results showed that both the size and concentration of  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  particles significant effect on D-CCT and lumen output of the 7000K conformal packaging WLEDs.

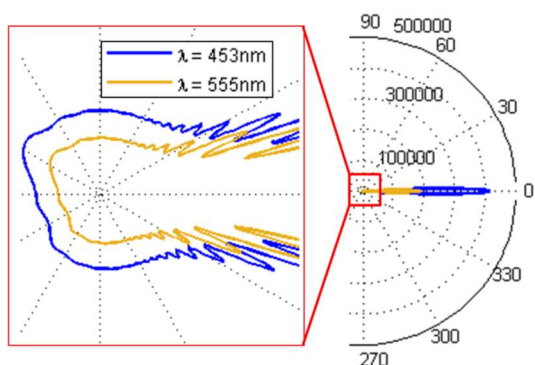


Fig. 4. The angular scattering amplitudes of  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  in proportion to wavelengths of 453nm, 555nm.

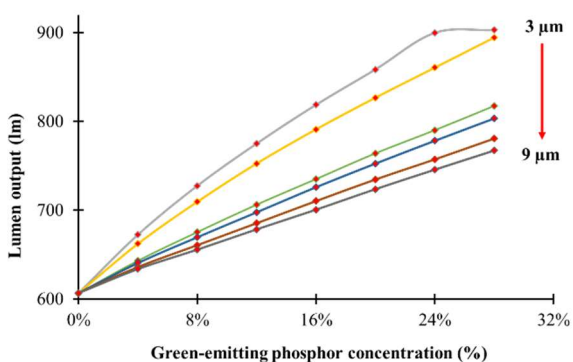


Fig. 5. The  $\Delta\text{CCT}$  deviation of W-LEDs 7000 K by adding the green-emitting  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  phosphor particles.

## Conclusion

In this paper, we investigate the effect of the green-emitting  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  phosphor on the lumen output and D-CCT of the 7000 K white LED lamps with conformal

phosphor packaging. From research results and theory analysis, some conclusions are proposed:

1) The lumen output of WLEDs lamps was influenced by the size and concentration of the green-emitting  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  phosphor. From the research results, lumen output increased about 1,5 times when adding the green-emitting  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  phosphor to the phosphor compounding.

2) Furthermore, D-CCT decreased more than 4 times with varying concentration and size of the green-emitting  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  phosphor.

In the further works, the influence of the green-emitting  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  phosphor on optical properties of the in-cup and the remote packaging WLEDs is necessary to present, analyze and demonstrate.

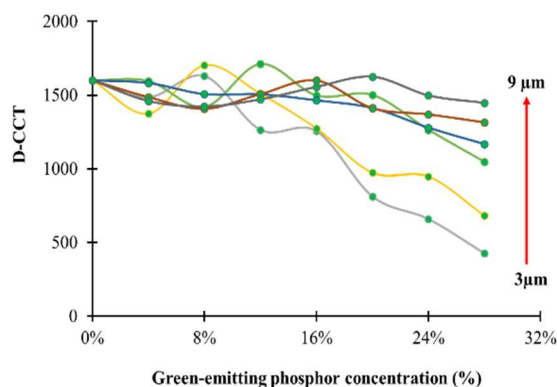


Fig. 6. The luminous flux of W-LEDs 7000 K by adding the green-emitting  $\text{CaF}_2:\text{Ce}^{3+},\text{Tb}^{3+}$  phosphor particles.

## Acknowledgements

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

## References

- [1] J. Chao and E. F. Schubert, "Light Emitting Diodes," *Encyclopedia of Optical and Photonic Engineering*, Second Edition, Feb. 2016.
- [2] N. D. Quoc Anh, M.-F. Lai, H.-Y. Ma, and H.-Y. Lee, "Enhancing of correlated color temperature uniformity for multi-chip white-light LEDs by adding  $\text{SiO}_2$  to phosphor layer," *Journal of the Chinese Institute of Engineers*, vol. 38, no. 3, pp. 297-303, Dec. 2014. doi: [10.1080/02533839.2014.981214](https://doi.org/10.1080/02533839.2014.981214)
- [3] M.-F. Lai, N. D. Quoc Anh, H.-Y. Ma, and H.-Y. Lee, "Scattering effect of  $\text{SiO}_2$  particles on correlated color temperature uniformity of multi-chip white light LEDs," *Journal of the Chinese Institute of*

- Engineers*, vol. 39, no. 4, pp. 468-472, Jan. 2016.  
doi: [10.1080/02533839.2015.1117950](https://doi.org/10.1080/02533839.2015.1117950)
- [4] T. H. Q. Minh, N. H. K. Nhan, T. P. Vo, and N. D. Quoc Anh, "Enhancement of Color Rendering Index for White Light LED Lamps by Red Y2O3:Eu3+ Phosphor," *Advances in Electrical and Electronic Engineering*, vol. 14, no. 3, pp. 340-344, Sep. 2016, doi: [10.15598/aeec.v14i3.1642](https://doi.org/10.15598/aeec.v14i3.1642)
- [5] J. Vitasek, J. Jargus, S. Hejduk, T. Stratil, J. Latal, and V. Vasinek, "Phosphor decay measurement and its influence on communication properties," in proceeding of 2017 19<sup>th</sup> International Conference on Transparent Optical Networks (ICTON), Girona, Catalonia, Spain, July 2-6, 2017.  
doi: [10.1109/ICTON.2017.8024951](https://doi.org/10.1109/ICTON.2017.8024951)
- [6] N. D. Quoc Anh and H.-Y. Lee, "Improving the angular color uniformity and the lumen output for white LED lamps by green Ce<sub>0.67</sub>Tb<sub>0.33</sub>MgAl<sub>11</sub>O<sub>19</sub>:Ce,Tb phosphor," *Journal of the Chinese Institute of Engineers*, vol. 39, no. 7, pp. 871-875, July 2016.  
doi: [10.1080/02533839.2016.1208062](https://doi.org/10.1080/02533839.2016.1208062)
- [7] J. Kwak, J. Lim, M. Park, S. Lee, K. Char, and C. Lee, "High-power genuine ultraviolet light-emitting diodes based on colloidal nanocrystal quantum dots," *Nano Letters*, vol. 15, no. 6, pp.3793-3799, May 2015.  
doi: [10.1021/acs.nanolett.5b00392](https://doi.org/10.1021/acs.nanolett.5b00392)
- [8] V. K. B. Adusumalli, H. Koppiseti, and V. Mahalingam, "Ce<sup>3+</sup> sensitized bright white light emission from colloidal Ln<sup>3+</sup> doped CaF<sub>2</sub> nanocrystals for developing transparent nanocomposites," *J. Mater. Chem. C*, vol. 4, no. 12, pp. 2289-2294, 2016.  
doi: [10.1039/C6TC00756B](https://doi.org/10.1039/C6TC00756B)
- [9] C. Zhang, C. Li, C. Peng, R. Chai, S. Huang, D. Yang, Z. Cheng, and J. Lin, "Facile and Controllable Synthesis of Monodisperse CaF<sub>2</sub> and CaF<sub>2</sub>:Ce<sup>3+</sup>/Tb<sup>3+</sup>+Hollow Spheres as Efficient Luminescent Materials and Smart Drug Carriers," *Chemistry*, vol. 16, no. 19, pp. 5672-5680, May 2010.  
doi: [10.1002/chem.200903137](https://doi.org/10.1002/chem.200903137)
- [10] J. Zhong, M. Xie, Z. Ou, R. Zhang, M. Huang, and F. Zhao, "Mie Theory Simulation of the Effect on Light Extraction by 2-D Nanostructure Fabrication," in the proceeding of 2011 Symposium on Photonics and Optoelectronics (SOPO), Wuhan, China, May 16-18, 2011.  
doi: [10.1109/SOPO.2011.5780566](https://doi.org/10.1109/SOPO.2011.5780566)
- [11] S. Liu and X.-B.Luo, *LED Packaging for Lighting Applications: Design, Manufacturing and Testing*, Beijing: Chemical Industry Press, 2011.  
doi: [10.1002/9780470827857](https://doi.org/10.1002/9780470827857)
- [12] Z. Liu, S. Liu, K. Wang, and X. Luo, "Optical Analysis of Color Distribution in White LEDs with Various Packaging Methods," *IEEE Photonics Technology Letters*, vol. 20, no. 24, pp. 2027-2029, Dec. 2008.  
doi: [10.1109/LPT.2008.2005998](https://doi.org/10.1109/LPT.2008.2005998)
- [13] M. Jonasz and G. R. Fournier, *Light Scattering by Particles in Water*, Elsevier, 2007, pp. 87-130.  
doi: [10.1016/B978-0-12-388751-1.X5000-5](https://doi.org/10.1016/B978-0-12-388751-1.X5000-5)
- [14] M. I. Mishchenko, L. D. Travis, and A. A. Lacis, *Scattering, Absorption, and Emission of Light by Small Particles*, 2<sup>nd</sup> electronic ed., Cambridge: Cambridge U. Press, 2004.
- [15] M. Schratz, C. Gupta, T. J. Struhs, and K. Gray, "Reducing Energy and Maintenance Costs while Improving Light Quality and Reliability with Led Lighting Technology," in the proceeding of International Conference on Pulp and Paper Industry Technical, Charlotte, NC, USA, June 23-27, 2013, pp. 43-49.  
doi: [10.1109/PPIC.2013.6656043](https://doi.org/10.1109/PPIC.2013.6656043)
- [16] T. H. Q. Minh, N. H. K. Nhan, N. D. Q. Anh, and H.-Y. Lee, "Red-Emitting  $\alpha$ -SrO·3B<sub>2</sub>O<sub>3</sub>:Sm<sup>2+</sup> 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, no. 4, pp. 313-317, Apr. 2017.  
doi: [10.1080/02533839.2017.1318720](https://doi.org/10.1080/02533839.2017.1318720)
- [17] T. H. Q. Minh, N. H. K. Nhan, and N. D. Q. Anh, "Influence of CaCO<sub>3</sub>, CaF<sub>2</sub>, SiO<sub>2</sub>, and TiO<sub>2</sub> Scattering Particles' Concentration on Color Rendering Index and Color Quality Scale of the Conformal Packaging Multi-Chip White LEDs," *International Journal on Electrical Engineering and Informatics*, vol. 9, no. 1, pp. 139-145, Mar. 2017.  
doi: [10.15676/ijeei.2017.9.1.9](https://doi.org/10.15676/ijeei.2017.9.1.9)

