International Journal of Database Theory and Application
Vol.9, No.4 (2016), pp.259-266
http://dx.doi.org/10.14257/ijdta.2016.9.4.24

Influence of Red $Y_2O_3:Eu^{3+}$ Phosphor Concentration to the Multi-Chip White LEDs Color Rendering Ability

Nguyen Huu Khanh Nhan, Tran Hoang Quang Minh and Nguyen Doan Quoc Anh*

Faculty of Electrical and Electronics Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam
**Corresponding author*
nguyenhuukhanhnhan@tdt.edu.vn,tranhoangquangminh@tdt.edu.vn, nguyendoanquocanh@tdt.edu.vn

Abstract

In this paper, a novel solution and application of the red Y2O3:Eu3+ dopant phosphor for enhancing color rendering index to more 86 for multi-chip white LED lamps (MCW-LEDs), which have correlated color temperature (CCT) of 7700 K, 6600 K, 5600 K, are presented. Then the effect of the concentration of Y2O3:Eu3+ phosphor on the color rendering index (CRI) is simulated, analyzed and demonstrated. After that the lumen output of MCW-LEDs depended on concentration Y2O3:Eu3+ phosphor is discovered. The lumen output has a decrease tendency at large weight range due to the enhancement extinction coefficient, according to Mie-scattering theory. Simulation results provided important conclusions for selecting and developing the phosphor materials in MCW-LEDs manufacturing.

***Keywords**: Y2O3:Eu3+ phosphor, Beer-Lambert law, color rendering index, pc-WLEDs*

1. Introduction

In the history of human development, lighting sources have experienced numerous changes initially from collecting natural fire sources to making fire by drilling wood. The development of lighting has witnessed the progress of human history. Fire plays an important role in human history in that it provides humans with food, warmth, and brightness. The use of fire follows the tremendous progress of human civilization. Prior to the eighteenth century, fire had always been a lighting tool for humans, the form of which developed from torch, animal oil lamp, and vegetable oil lamp to the candle, and later to the widely used kerosene lamp. Humans have never stopped exploring new lighting methods [1]. Nowadays, MCW-LEDs have attracted great attention from both manufactures and consumers due to its great properties for display technology, including high brightness, low power consumption, long lifetime, fast response as well as climate impact resistance [2]. Consequently, MCW-LEDs are considered as key lighting devices to replace traditional light sources.

MCW-LEDs, because of their advantages in cost, efficiency, and stability, as well as extended lifetime, are considered as the best candidates to compete with traditional lights. Recently, several methods have been proposed for improving MCW-LED performance, relating to the Fresnel lenses, the chip arrays, and the patterned reflectors. However, the color uniformity and the luminous flux still need to be further improved for the MCW-LED to compete in the current lighting market. An MCW-LED consists of multiple blue chips inside, so the interaction process between the light and the LED structures is more complicated than that of the

ISSN: 2005-4270 IJDTA

conventional LED with a single chip. Red Y2O3:Eu3+ phosphor is one of cathodoluminescent phosphors, which is employed widely in color displays as a red-light-emitting component [1]. However, Y2O3:Eu3+ phosphor has not many applications for improving CRI as yet. In this paper, we introduce the impacts of Y2O3:Eu3+ phosphor particles in multi-chip white light LEDs with conformal phosphor packages to improve color rendering ability. It has been found that the participation of Y2O3:Eu3+ phosphor particles can dominate the red-light emitting event in pc-WLEDs, so that the LED light distribution can be free from the dispersion incurred by LED packages to yield higher color rendering index.

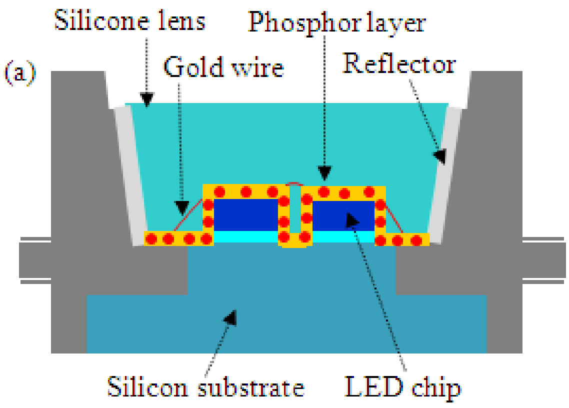
In this paper, firstly the MCW-LEDs physical model having average CCT of 7700 K, 6600 K and 5600 K is conducted by Light Tools software at first. Secondly, the transmission of light can be decreased after mixing Y2O3:Eu3+ particles, which demonstrated by the Beer-Lambert law. Finally, we have investigated the effects of Y2O3:Eu3+ phosphor particles on the color rendering ability of MCW-LEDs according to the simulation results. Thus, the proposed method, doping certain amounts of Y2O3:Eu3+ in the LED packages, can improve their CRI significantly. The lumen output has a decrease tendency at large weight range due to the enhancement extinction coefficient. However, it is noticeable that the lumen output can be grown after adding Y2O3:Eu3+ with low weight range.

2. Main Part

2.1. MCW-LEDs Physical Model

Based on Light Tools 8.1.0 program, the MCW-LEDs which is covered by flat silicone is employed (Figure 1). The MCW-LED products and their manufacture information are supported by the Silicon ware Precision Industries Co., Ltd., Taiwan [12]. The key work consists of pc-WLEDs construction and phosphor concentration adjustment. Firstly, the structures of pc-WLEDs such as the conformal phosphor package (CPP) are introduced with CCT of 7700 K, 6600K and 5600 K. Secondly, it is necessary to keep the MCW-LEDs work at the mean CCT for achieving the LED product specification. If the weight percentage of the red Y2O3:Eu3+ phosphor increases, that of yellow YAG:Ce phosphor needs to be decrease to maintain the mean CCT values. The depth, inner, and outer radius of the reflector are 2.07 mm, 8 mm and 9.85 mm, respectively. The CPP, with the fixed thickness of 0.08 mm and 2.07 mm in turn, cover the nine chips. The blue Led chip has a dimension of 1.14 mm x 0.15 mm. The radiant flux of each blue chip is 1.16 W, and the peak wavelength is 453 nm. In Figure 1 (b), its phosphor layer is coated conformally on nine LEDs.

The absorption, emission and scattering of both YAG:Ce and Y2O3:Eu3+ phosphor particles, with the peak wavelengths including blue of 453 nm and yellow of 555 nm, can be computed by Mie-scattering theory [2-3]. The phosphor layers consist of YAG:Ce and Y2O3:Eu3+ powders and the silicone matrix. Their refractive indexes are 1.83, 1.93 and 1.50, respectively. Meanwhile, the mean radius of the phosphor powders are 7.25 μm, which like the real particle size.



(a) (b)

Figure1. (a) The MCW-LED and Its Manufacture Information as a Product of the Silicon Ware Precision Industries Co., Ltd., Taiwan, (b), Illustration of MCW-LEDs with the Conformal Phosphor Package

2.2. Simulation Results and Discussion

In this section, the CRI performance of MCW-LED is obtained by simulation with Light Tools program. In order to verify the CRI improvement of MCW-LED quality by using Y2O3:Eu3+ phosphor, we switch the CCT of 7700 K, 6600K and 5600 K respectively and vary Y2O3:Eu3+ weight from 0% to 14%. The corresponding values of CRI are then calculated and displayed on Figure 2 for each option. It can be observed that the CRI grows with the weight percentage of Y2O3:Eu3+ phosphor in the continuous range from 0 % to nearly 10 %. The highest color rendering ability is obtained with the Y2O3:Eu3+ weight range from 8 % to 12 %. In particular, optimal color rendering index that can be achieved exceeds 86 in these case.

The effect of Y2O3:Eu3+ concentration in phosphor compound on the lumen output is also verified together with the CRI, as shown in Figure 3. The weight percentage of phosphor compound was varied continuously from 0 % to 14 %. At low Y2O3:Eu3+ concentration regime, the extinction coefficient tends to reduce, which results in the enhancement of luminous output. Meanwhile, the lumen output decreases with the Y2O3:Eu3+ weight enhancement due to the increasing of extinction coefficient.

In other words, the lumen output grows with the $Y_2O_3{:}Eu^{3+}$ size due to the decreaseing of extinction coefficient values. To justify these results, the relationship between luminous output and the $Y_2O_3{:}Eu^{3+}$ size can be formulated according to Mie-scattering theory [1, 12]. The depletion of light is calculated by the Beer – Lambert law:

$$I = I_0 exp(-\mu_{ext} L) \qquad (1)$$

Where I is the transmitted light power, I0 is the incident light power, $\mu_{ext} = N.C_{ext}$ is the extinction coefficient, L is the path length and 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:

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

Here, x = 2πa/λ is the size parameter; a_n and b_n are the expansion coefficients with even symmetry and odd symmetry, respectively. The parameters a_n and b_n are defined as:

$$a_n(x,m) = \frac{\psi_n'(mx)\psi_n(x) - m\psi_n(mx)\psi_n'(x)}{\psi_n'(mx)\xi_n(x) - m\psi_n(mx)\xi_n'(x)} \quad (3)$$

$$b_n(x,m) = \frac{m\psi_n'(mx)\psi_n(x) - \psi_n(mx)\psi_n'(x)}{m\psi_n'(mx)\xi_n(x) - \psi_n(mx)\xi_n'(x)} \quad (4)$$

Where a is the spherical particle radius, λ is the relative scattering wavelength, m is the refractive index of scattering particles, $\psi_n(x)$ and $\xi_n(x)$ are the Riccati-Bessel functions.

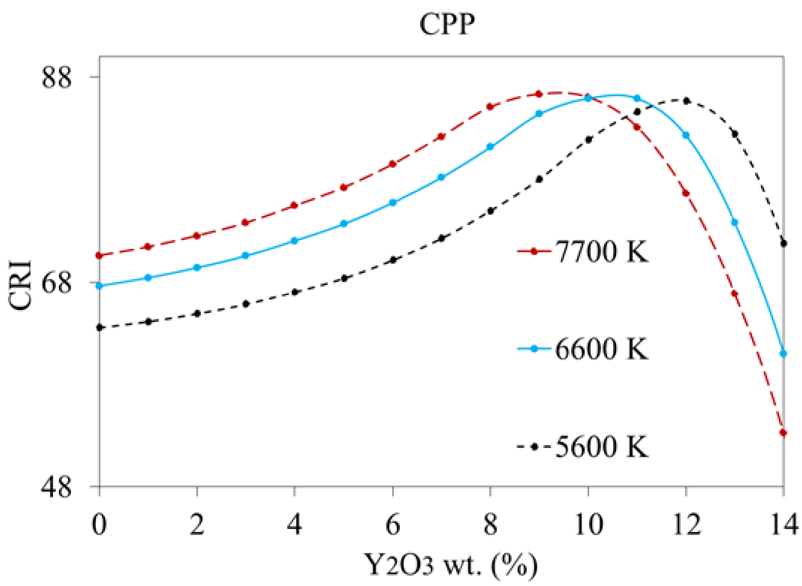
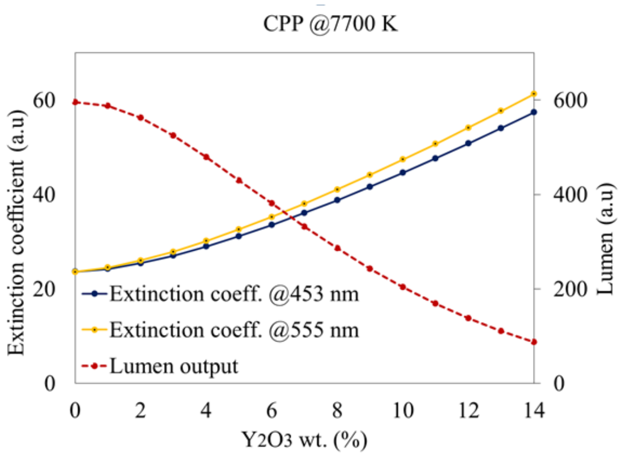
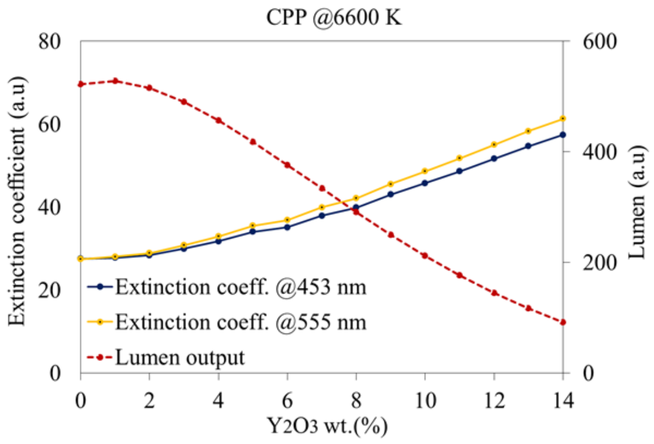


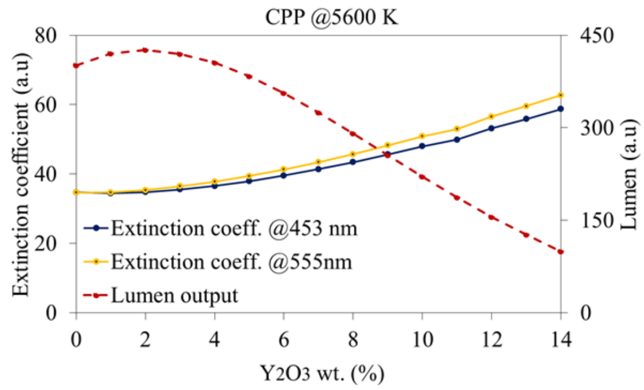
Figure 2. The Color Rendering Index at Average CCTs of 7000K and 8500 K with Various Y2O3:Eu3+ Weight with Two Phosphor Geometries: (Top) CPP and (Bottom) IPP



(a)



(b)



(c)

Figure 3. Luminous Flux According to Computed Extinction Coefficient with 7700K (A), 6600K (B), 5600K (C)

The extinction coefficient values of the red Y2O3:Eu3+ 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 with respect to the Y2O3:Eu3+ concentration according to the above equations are displayed in Figure 3 (a)-(c) for 7700K, 6600 K and 5600 K respectively. It is indicated that the higher lumen output should occur at the lower Y2O3:Eu3+ concentration, which corresponds to the lower extinction coefficient values. These results can be employed to estimate the influence of the concentration of Y2O3:Eu3+ on the lumen output produced by the pc-WLEDs

3. Conclusion

In this paper, some conclusions are proposed:

1) Both the CRI and the lumen output of MCW-LEDs depend on the red Y2O3:Eu3+ phosphor concentration.

2) It is noted that the CRI can be enhanced more 86 regardless of the mean CCTs and the phosphor geometries.

3) The lumen output has a decrease tendency at large weight range due to the enhancement extinction coefficient. However, it is noticeable that the lumen output can be grown after adding Y2O3:Eu3+ with low weight range.

4) The paper proves the implications of Y2O3:Eu3+ phosphor application for developing the pc-WLEDs of MCW-LEDs manufacturing.

Acknowledgment

This paper was supported by professor Hsiao-Yi Lee, Department of Electrical Engineering, National Kaohsiung University of Applied Sciences, Kaohsiung, Taiwan.

References

[1]. V. V. Bakhmetyev, M. M. Sychov, L. A. Lebedev, A. B. Vlasenko, S. P. Bogdanov, E. P. Sheshin, H. Kominami, "Synthesis and characterization of finely dispersed Y2O3:Eu cathodoluminescent phosphors", In Proceedings of International Conference on Vacuum Electron Sources Conference, **(2014)**, pp. 1-2.
[2]. S. Liu and X. B. Luo, "LED Packaging for Lighting Applications: Design, Manufacturing and Testing", Chemical Industry Press and John Wiley & Sons, Beijing, **(2011)**.
[3]. Z. Y. Liu, S. Liu, K. Wang and X. B. Luo, "Optical analysis of color distribution in white LEDs with various packaging methods", IEEE Photon. Technol. Lett., vol. 20, no. 24, **(2008)**, pp. 2027–2029.
[4]. N. D. Q. 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 SiO2 to phosphor layer", Journal Chin. Inst. Eng. vol. 38, **(2015)**, pp. 297-303.
[5]. M. F. Lai, N. D. Q. Anh, H. Y. Ma and H. Y. Lee, "Scattering effect of SiO2 particles on correlated color temperature uniformity of multi-chip white light LEDs", Journal Chin. Inst. Eng., vol. 39, **(2016)**, pp. 1-5.
[6]. M. F. Lai, N. D. Q. Anh, H. Y. Ma and H. Y. Lee, "Effects of Ce0.67 Tb0.33 MgAl11 O19:Ce, Tb phosphor on optical performance of multi-chip white LEDs", in Proceedings of Optics & Photonics of Taiwan International Conference (OPTIC), **(2014)**.
[7]. L. Lohaus, E. Leicht, S. Dietrich, R. Wunderlich and S. Heinen, "Advanced color control for multicolor LED illumination systems with parametric optimization", In Proceedings of International Conference on Industrial Electronics Society (IEEE), **(2013)**.
[8]. M. Zheng, W. Ding, F. Yun, D. Y. Xia, Y. P. Huang, Y. K. Zhao, W. H. Zhang, M. Y. Zhang, M. F. Guo and Y. Zhang, "Study of High CRI White Light-emitting Diode Devices with Multi-chromatic Phosphor", In Proceedings of International Conference on Electronic Components & Technology (IEEE), **(2014)**.
[9]. Y. H. Won, H. S. Jang, K. W. Cho, Y. S. Song, D. Y. Jeon and H. K. Kwon, "Effect of phosphor geometry on the luminous efficiency of high-power white light-emitting diodes with excellent color rendering property", Opt. Lett., vol. 34, no. 1-3, **(2009)**.
[10]. K. J. Chen, C. C. Lin, H. V. Han, C. Y. Lee, S. H. Chien, K. Y. Wang, S. H Chiu, Z. Y. Tu, J. R. Li, T. M Chen, X. Li, M. H. Shi and H. C. Kuo, "Wide-Range Correlated Color Temperature Light Generation From Resonant Cavity Hybrid Quantum Dot Light-Emitting Diodes", IEEE J. Sel. Top. Quantum Electron. 21: 1900407, **(2015)**.
[11]. M. Zhang, X. H. Li, Z. X. Wang, Q. Y. Hu and H. J. Guo, "Synthesis of Y2O3:Eu3+ phosphors by surface diffusion and their photoluminescence properties", Trans. Nonferrous Met. Soc. China, vol. 20, **(2010)**, pp. 115-118.
[12]. Siliconware Precision Industries Co., Ltd., http://www.spil.com.tw
[13]. Y. Shuai, N. T. Tran, J. P. You and F. G. Shi, "Phosphor size dependence of lumen efficiency and spatial CCT uniformity for typical white LED emitters", In Proceedings of International Conference on Electronic Components and Technology Conference (IEEE), **(2012)**.

Authors

Nguyen Huu Khanh Nhan, received his B. Eng. degrees in Electrical and Electronic Engineering from University of Technical education Ho Chi Minh City, Vietnam in 1991-1996, and received his M. Eng. degrees in Nano materials and electronic devices from Ho Chi Minh City National University, Vietnam in 2005 – 2007, and Studied PhD. degree at Institute of research and experiments for electrical and electronic equipments, Mosscow – Russia in 2012. Now, He is teaching at Department 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 Hoang Quang Minh, defended his PhD thesis at Tomsk Polytechnic University, Tomsk City, Russian Federation. The author's major fields of study are High-voltage Power System, Relay Protections and LED Technology. He is working as Lecturer in Faculty of Electrical and Electronic Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.

Nguyen Doan Quoc Anh, defended his PhD thesis at National Kaohsiung University of Applied Sciences**,** Kaohsiung, Taiwan. The author's major fields of study are LED Technology and Power System. He is working as Lecturer in Faculty of Electrical and Electronic Engineering, Ton Duc Thang University, Ho Chi Minh City, Vietnam.